Our Ref: NIN. 05. 469
Your Ref: Letter dated 31 July 2006

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14 November 2006

Ninham Shand (Pty) Ltd
P.O. Box 509
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Attention: Messrs. Kamal Govender and Brett Lawson

PROPOSED POWER STATION AND ASSOCIATED INFRASTRUCTURE
WITBANK GEOGRAPHICAL AREA
HYDROGEOLOGICAL INVESTIGATION

Dear Sir

With reference to our proposal (GCS ref. NIN.05/469, dated 17 November 2005) please find our hydrogeological report detailing the necessary groundwater resource and candidate site assessments for the Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP) for the proposed coal-fired power station in the Witbank area.

A site suitability assessment, from a groundwater perspective, was carried out for each of the candidate sites.

The possible impacts of the proposed power station and associated infrastructure, FGD technology, and ash disposal, on the groundwater regime have been assessed and mitigation or risk reduction management options have been compiled.

Should you require any additional information please contact our Rivonia office, 011 – 8035726.

Yours faithfully,

Mark Stewart Pr.Sci.Nat
Senior Hydrogeologist
GCS (Pty) Ltd

Kobus Troskie Pr.Sci.Nat
Project Hydrogeologist

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EXECUTIVE SUMMARY

GCS were appointed by Ninham Shand (Pty) Ltd to compile a hydrogeological report detailing the necessary groundwater resource and candidate site assessments for the Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP) for the proposed coal-fired power station in the Witbank area.

The hydrogeological assessment included the determination of the aquifers, quantity and quality, present on the candidate sites. The possible impact of the proposed power station and ancillary infrastructure, possible use of flue gas desulphurization technology, and ash disposal, on the groundwater regime was assessed.

The geology underlying the study area comprises Karoo Sequence and Pretoria Group sediments. The rocks the Pretoria Group have been altered due to the intrusive Rashoop Granophyre Suite. The Karoo sediments, comprising glacial tillite and shale, are largely unaltered except for several intrusive diabase sills.

Borehole census records indicate that the study area, underlain by Karoo shale and tillite, have limited groundwater potential due to low permeabilities, limited effective storage, and have low yielding boreholes (± 1 m^3/hr). These areas can be classified as a non-aquifer system, with minor aquifers developed in areas of enhanced groundwater potential along discrete zones of secondary processes, such as faulting or fracturing.

The altered Pretoria Group rocks have enhanced groundwater potential due to fractures and diabase intrusions. High yielding boreholes, yields > 10 l/s, are located within these rocks.

Site selection, from a groundwater perspective, indicates that the power station and ancillary infrastructures should be located on areas of limited groundwater use, low sustainable borehole yields, and areas of limited groundwater potential.

It is envisaged that the proposed power station will receive water, via a pipeline from the existing Kendal power station, from the Vaal River Eastern Sub-system. For a dry-cooled power station the envisaged water demand is ± 3.3 million m^3 per year. The Department of Water Affairs and Forestry will make water available from the Vaal River Eastern Sub-system augmentation project. This augmentation of surface water will allow for an assurance of supply.

Groundwater monitoring at other Eskom operating power stations indicates that the groundwater quality deteriorates with time and that artificial recharge can occur in localised areas. If the power station and associated infrastructure are constructed on poorly developed aquifers then the impacts, from persistent contaminant sources such as ash dumps, will be limited.

A site suitability assessment of the each of the candidate sites indicates that the most suitable farms, from a groundwater perspective, for the construction of a new power station and infrastructure is the majority of Site X.

A broad based risk assessment regarding the groundwater resources was compiled to assess the potential impacts of the power station and ancillary infrastructure, FGD technology, and ash disposal. Based on the risk assessment, the following hazards were identified: -

Power station and ancillary infrastructure

- Poor quality water stored on site recharging the groundwater
- Artificial recharge impacting on groundwater
- Solid waste site
- Seepage below the ash dump
- Poor quality surface water on site
- Sewage facilities
- Fuel (bunker) oil
- Surface water supply
- Coal stockyard
- Chemical conveyance and storage

FGD Technology

- Increased water demand
- Poor quality water stored on site recharging the groundwater
- Wet waste disposal
- Removal of surface water from catchment
- Gypsum temporary stockpile

Ash disposal

- Above ground - Seepage below ash dump
- Back-ashing – Persistent contamination
- In-pit ashing – Mobilisation of contaminants

Risk reduction and threat mitigation recommendations have been compiled for each of the threats. The correct site selection, construction and management of the new power station and infrastructure will ensure that the overall risk to the groundwater resources is acceptable.

1 INTRODUCTION AND TERMS OF REFERENCE

Mr. Ashwin West of Ninham Shand (Pty) Ltd contacted GCS (Pty) Ltd for a proposal and budget to undertake the necessary groundwater studies for the proposed power stations, one in Kendal North and one in Vaal South.

GCS proposal (GCS ref. NIN.05.469, dated 17 November 2006) was accepted. GCS received a letter of appointment, dated 31 July 2006, to conduct the necessary groundwater resource and candidate site assessments for the Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP) for the proposed coal-fired power station in the Witbank geographic area.

An initial site inspection was conducted on 09 March 2006, a second site inspection was held on the 10 July 2006. A workshop was held, on 11 July 2006, to discuss and screen each of the nine proposed candidate sites. The sites were reviewed and reduced to two sites, site 6 and site 4 and 5 combined. These two candidate sites, labeled X and Y, were selected for assessment in the EIA process.

2 SCOPE OF WORK

The scope of work for the study was to undertake the groundwater impact assessment of the two candidate sites, which included (as set out in the scoping report): -

- Participate in the site selection process
- Undertake a baseline review, including a literature review, to establish the status quo of the quality and quantity of groundwater resources on the two alternative sites
- Evaluate the data, and if necessary, undertake fieldwork to address any shortfalls in the existing data
- Undertake an assessment to predict potential impacts, as well as their significance, of the proposed power station and associated infrastructure on groundwater
- Assess in detail the groundwater impacts of the three proposed means of ash disposal:
    - Above ground dumping;
    - Back ashing; and
    - In-pt ashing.
- Assess in detail the potential groundwater impacts of other activities associated with the power station , including fuel and chemical storage
- Propose mitigation measures that could reduce or eliminate identified impacts
- Offer an opinion on which of the alternative means of ash disposal would be preferable from a groundwater perspective, with or without mitigation measures
- Offer an opinion on site layout within each of the alternative sites
- Offer an opinion on the preferred site, from a groundwater perspective, with or without mitigation measures
- Compile a report that reflects the above and includes appropriate mapping

3 METHODOLOGY

GCS undertook both a desktop study and field investigations in order to collate sufficient information to compile the groundwater impact assessment and the candidate site assessment report.

These data were assessed to enable GCS to address the hydrogeological aspects of the proposed power generation project, which includes a high-level risk assessment with regards to potential impacts associated with the proposed power station and ancillary infrastructure, the use of flue gas desulphurisation (FGD) technology, and ash disposal, on the groundwater environment.

The project methodology allowed for a literature review, data compilation and assessment, and field investigations to obtain site-specific data.

The fieldwork comprised site visits, mapping of geological outcrops / road cuttings, borehole census of groundwater users and usage on the candidate sites.

Allowance had been made for the drilling and testing of monitoring boreholes on the sites, however, it was decided that the monitoring boreholes must only be constructed once the project had received approval and that the site layout plans have been finalised.

3.1 Data sources

The following data sources were used during the study: -

- Map of Boreholes South of Kendal (Report 7/1952)
- De Klerk, L. Coal and Clay Potential for 1:50 000 2628 BB Kendal
- Boshoff, H.P. Analyses of Coal Product samples taken by the division of energy technology during 1988.
- The groundwater harvest potential of the Republic of South Africa. Department of Water Affairs and Forestry, 1996
- GRDM, Groundwater Resource Directed Measures, GRDM Training Manual
- SAGT, South African Groundwater Decision Tool
- The groundwater resources of the Republic of South Africa, sheets 1 and 2. Water Research Commission and Department of Water Affairs and Forestry, 1995
- The national groundwater database, Department of Water Affairs and Forestry, Pretoria
- The Water use Authorisation and Registration Management System (**WARMS**) database, Department of Water Affairs and Forestry, Pretoria
- Weaver, J.M.C. (1992). Groundwater sampling a comprehensive guide for sampling methods. Water Research Commission Report No. TT 54/92.

3.2 Fieldwork

The fieldwork conducted during the study included several site visits and a hydrocensus of groundwater users and usage at the two candidate sites.

The following information was recorded during the hydrocensus.

- The GPS locations of boreholes and springs were recorded and mapped accordingly
- Geological assessment, of geological outcrops, on the two candidate sites
- Aquifer potential including; borehole depth, static water level measurements and borehole yield,
- Determine groundwater usage and identify groundwater users
- Discussions with groundwater users, farm owners, etc.

4 PROJECT DETAILS

The project aimed at assessing the groundwater resources within the two candidate sites. The two candidate sites are referred to as candidate site X and candidate site Y (Figure 1 Site Layout).

Candidate site X includes portions of the farms: -

- Hartbeesfontein 537 JR
- Klipfontein 566JR

Candidate site Y includes portions of the farms: -

- Blesbokfontein 558JR
- Witpoort 563JR
- Nooitgedacht 564 JR
- Dwaalfontein 565 JR

4.1 Desktop study

All available geological and hydrogeological data for the study area was compiled from various sources and analysed.

Data from the relevant hydrogeological databases, the National Groundwater Database and the Water Use Authorisation and Registration Management System (WARMS) database, were obtained from the Department of Water Affairs and Forestry.

A data search of relevant geological data, for the study area, was conducted at the Council of Geoscience in Pretoria.

Aerial photographs were viewed at the Survey General's office in Pretoria. Aerial Photographic Interpretation (API) was conducted to determine possible geological structures on each of the candidate sites.

Figure 1: Site layout

Satellite imagery, available on Google Earth (http:/earth.google.com), was viewed to obtain additional data regarding geology (structures), land use, and surface water bodies.

Based on the available data a conceptualisation of the aquifer conditions and the on site geological conditions were formulated and were used during the site selection process.

4.2 Site visit

The fieldwork included several site visits to the candidate sites followed by a detailed hydrocensus on the six farms identified in Figure 1.

All relevant hydrogeological data and geological data, such as on site geological conditions water levels, abstraction, hydrochemistry, and drilling records, were recorded to assess the groundwater conditions of the study area.

The boreholes located during the hydrocensus are presented in Figure 1 and the results discussed in Section 7.

5 REGIONAL GEOLOGY

The regional geology for the area comprises sediments and intrusive rocks of Vaalian to Permian age. Vaalian aged intrusive rocks, which from part of the Bushveld Complex, are mapped within the study area. The lithostratigraphy is presented in Table 1.

Table 1 Lithostratigraphy

Age	Sequence	Group	Formation	Lithology
Permian	Karoo		Ecca	(Pe) Shale, shaly sandstone, grit sandstone, conglomerate, **coal** in places, near grit and top
Permian	Karoo		Dwyka	(Pd) Tillite, shale
Mogolian[1]			Intrusive	(di) Diabase
Vaalian	Rashoop Granophyre Suite		Intrusive	(Vra) Red to grey granophyric quartz feldspar rocks
Vaalian			Loskop	(Vl) Shale, sandstone, conglomerate, volcanic rocks
Vaalian		Pretoria	Magaliesburg	(Vm) Quartzite, minor hornfels
Vaalian		Pretoria	Silverton	(Vsi) Shale, carbonaceous in places, hornfels, chert
Vaalian		Pretoria	Daspoort	(Vdq) Quartzite

Figure 2 presents a portion of the 1:250 000 scale geological map, entitled 2528 Pretoria. This large scale map indicates the regional geology across the study area.

The Karoo Supergroup sediments, located within the study area, consist of the Ecca and Dwyka formations. These younger Ecca Formation rocks lie conformably on the pre-existing glacially-produced tillite of the Dwyka Formation.

The Karoo Sequence rocks are unconformably underlain by Pretoria Group formations.

The Magaliesburg formation consists of several quartzite layers separated from one another by argillaceous rocks, which have been metamorphosed to hornfels.

Older rocks mapped on site are shale, carbonaceous in places with hornfels, and chert of the Silverton Formation and quartzite of the Daspoort Formation.

The Rashoop Granophyre Suite, consisting of red to grey granophyric quartz feldspar rocks, intruded into the Pretoria Group rocks.

Younger diabase intrusions into the Pretoria Group in the form of sills occur within the study area. The diabase is often deeply weathered and has little in the form of structural presence.

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[1] Often referred to as Mokolian

Figure 2 Geological Map

6 REGIONAL HYDROGEOLOGY

Based on regional data, obtained during the literature review and from the National Groundwater Database (NGDB) and the WARMS database, the following information is relevant regarding the hydrogeology of the study area: -

- The groundwater potential of the formations located in the study area is limited in their pristine state due to low primary permeability, storage, and transmissivity. Secondary processes, such as weathering, fracturing, etc., are required to enhance the groundwater potential.
- Groundwater potential of the Ecca Formation sediments is negligible in the primary state unless altered by weathering, fracturing, faulting, or diabase intrusion. The aquifer system consist of a intergranular or fractured aquifer system with typical borehole yields between 0.5 and 2 l/s
- Two important quartzite horizons of the Pretoria Group include the Daspoort and the Magaliesburg formations, which provide the dominant aquifers. The aquifer potential of the quartzite is the result of secondary weathering and the extent of jointing and fracturing within the rocks. The Magaliesburg Formation is mapped on Site Y. The Daspoort Formation is mapped on the north east boundary of Site X (Figure 2).
- The contact between the shale and quartzite layers generally form good groundwater targets and have a high aquifer potential.
- The shale horizons of the Silverton Formation are not considered viable aquifer units due to the presence of swelling clays and the generally poor quality water associated with the shale.
- The aquifer system of the Dwyka Formation can be regarded as a fractured aquifer system with typical borehole yields between 0.5 and 2 l/s. Groundwater derived from the Dwyka Formation tillite can often be of poor quality water and boreholes characteristically have low sustainable yields.
- The two candidate sites fall within the B20F quaternary catchment with a total area of 504 km^2 and an average rainfall of 667 mm/annum.

The following hydrogeological data for the catchment area is available from the South African Groundwater Decision Tool[2] (SAGT): -

- The rainfall component to groundwater recharge equals a volume of 32.7 Mm^3/a (million cubic meters per annum over the 504 km^2 area).
- The groundwater component of river flow equals a total volume of 1.8 Mm^3/a.
- The total population for the sub-catchment area equals 3 400 persons with basic human need of 31 x 10^6 m^3/annum.

The Groundwater Resources of the Republic of South Africa sheet 1 (DWAF, 1995) indicates the following information: -

- The probability of drilling a successful borehole (yield > 0.1 l/s) ranges between 40 and 60%
- The recommended drilling depth for the area is between 30 and 50 meters below ground level
- The depth of the groundwater level ranges between 10 and 20 meters below surface for the sub-catchment

[2] It must be noted that information is associated with the regional geology of the study area and not site specific

PHASE I CANDIDATE SITE ASESSEMENT

7 SITE GEOLOGY

The general site geology of the area was assessed during the desktop study (Section 5). These information plus geological data obtained from the unpublished Council of Geoscience 1:50 000 field geological maps, aerial photograph interpretations, and the geological outcrop assessments conducted during the hydrocensus phase, were all used to detail the underlying geology on the candidate sites.

The surface geology of the area is presented in Figure 3, a portion of the unpublished 1:50 000 geological map entitled 2528 DD Balmoral. This map provides more site-specific data when compared to the regional geological map.

7.1 Candidate site geology

SITE X

Farm Hartbeesfontein 537 JR

Members of the Pretoria Group and the Karoo Sequence underlie the majority of this farm. The Karoo Sequence rocks lie unconformably on the older Pretoria Group formations.

Younger diabase intrusions into the Pretoria Group in the form of a sill are visible towards the southern part of the farm, and a small section towards the northern portion of the farm.

No additional pre-Transvaal structures, such as faults, fractures, or shear zones, could be derived from geological map interpretations or from the field investigation carried out on the farm.

Smaller scale mapping by the Council of Geoscience indicates that shale of the Silverton Formation outcrops in the northeast of Site X, and not quartzite of the Daspoort Formation as indicated on Figure 2, the regional geology map.

Farm Klipfontein 566 JR

Tillite and shale of the Dwyka Formation underlie the majority of the farm. Younger intrusive diabase is visible towards the northern portion of the farm. The diabase has intruded into the Pretoria Group rocks present in this area.

The contact between the older shale, diabase, and the tillite allow for the development of springs along the boundary of the two farms on Site X.

SITE Y

Farm Blesbokfontein 558JR

Site Y1 covers only a small portion of the farm Blebokfontein 558JR. Thick quaternary soil covers a diabase sill, which dominates the geology on this farm. No surface outcrop of diabase was visible on the farm.

Figure 3: Surface Geology Map

Farm Witpoort 563JR

Shale of the Silverton Formation underlies the farm with the majority of the area being intruded by a younger diabase sill (refer Figure 3).

Farm Nooitgedacht 563JR

The northern section of the farm is underlain by Silverton Formation shale. Extensive diabase intrusions have been mapped in this area. The majority of the farm consists of thick soil (weathered parent material) cover over an extensive diabase sill.

Rocks of the Bushveld Complex, comprising: -

- The Rashoop Granophyre Suite, consisting of granophyric quartz feldspar rocks, and
- The Dwarsfontein Complex (upper and main zones) comprising undifferentiated gabbro, magnetite, diorite, quartz gabbro, and pyroxenite

has intruded into the southern portion of the farm.

This intrusive lithology has intruded into the Pretoria Group rocks, causing zones of weakness, which allowed for the intrusion of younger diabase.

Farm Dwaalfontein 565 JR

Members of the Loskop Formation consisting of shale, sandstone, conglomerate, volcanic rocks underlie this site.

7.2 Groundwater resources

Borehole information derived from the Department of Water Affairs and Forestry's (DWAF) National Groundwater Database (NGDB) and WARMS database were used together with the hydrocensus carried out on candidate site X and candidate site Y to evaluate the groundwater resources within the study area. The NGDB and WARMS data were obtained for the B20F quaternary catchment area.

The hydrocensus was only carried out in the selected areas indicated in Figure 4 and Figure 5, in order to obtain site specific data regarding the candidate sites. A total of nineteen (19) boreholes and three (3) springs were located in site X. A total of thirteen (13) boreholes were located in site Y during the field investigations.

The boreholes and springs recorded during the desktop study and the hydrocensus are presented in Tables 2 to 5. Only the NGDB and WARMS boreholes that fall within the two selected sites are presented in Table 4 and Table 5. Additional boreholes that fall within the B20F quaternary catchment are shown in **Appendix A**.

Borehole density and groundwater use - site X

A total of 19 boreholes were located during the hydrocensus field investigation within Site X. The WARMS database indicates three registered water users within this site and four boreholes from the NGDB database are recorded within the site. Due to the overlapping of the hydrocensus and the NGDB data the total amount of boreholes located within the 48 km^2 site are 20, which calculate to a low borehole density of 1: 2.4 km^2. Three springs were located on the site (Figure 4). Plate1 and Plate 2 illustrate the two spring's S1 and S2 located on the eastern portion of the farm Klipfontein 566JR.

Plate 1: Spring S1

Plate: 2 Spring 2

Table 2: Hydrocensus data site **X** (August 2006)

BH ID	X- Co-ordinate	Y- Co-ordinate	Depth	SWL	Yield	pH	EC	Abstraction	Comments
	WGS 84 DD	WGS 84 DD	(m)	(mbgl)	lph		mS/m	m^3/day	
XBH1	28.90163	-25.91197	-999	8.71	-999	-999	-999	-999	Open borehole, not in use
XBH2	28.91656	-25.90763	-999	20.5	-999	7.31	13	2.5	Borehole used for domestic purposes, and drinking water for cattle
XBH3	28.93283	-25.90936	100	21.8	1000	7.85	5	8.5	Borehole used for domestic purposes, and drinking water for cattle
XBH4	28.93538	-25.89566	100	5.96	1000	8.31	16	6	Groundwater use for domestic purposes
XBH5	28.93456	-25.89285	0	-999	-999	-999	-999	-999	Not in use
XBH6	28.91800	-25.93322	17	7.5	1000	7.58	10	1.5	Domestic use
XBH7	28.91879	-25.93387	-999	7.55	1000	7.52	9	0	Open borehole, not in use
XBH8	28.92244	-25.93339	-999	7.8	-999	7.42	7	0	Open borehole, not in use
XBH9	28.92313	-25.93291	-999	7.54	-999	-999	-999	0	Pump recently stolen borehole not in use
XBH10	28.92395	-25.94592	-999	-999	-999	7.74	166	15	Borehole pumping at the time, no SWL measurements
XBH11	28.92361	-25.94694	-999	0	-999	9.5	40	-999	Not equipped, artesian borehole
XBH12	28.92469	-25.94722	-999	0	-999	9.69	48	-999	Not equipped, artesian borehole
XBH13	28.93150	-25.93333	80	5.6	-999	7.56	3	-999	Domestic Use
XBH14	28.92650	-25.95400	-999	10.25	-999	8.46	8	1.5	Domestic use for 1 household
XBH15	28.93014	-25.95578	30	-999	800	8.46	20	2	Domestic use for 1 household
XBH16	28.90701	-25.97355	50	-999	5000	8.14	14	3	No Complaints - good water quality
XBH17	28.90555	-25.97730	30	5.6	-999	7.89	6	-999	Open Borehole
XBH18	28.89921	-25.89931	-999	-999	600	7.85	10	1.5	Windmill, Borehole pump dry , Domestic use
XBH19	28.90784	-25.95009	-999	5.6	800	8.5	12	1.5	Borehole equipped with a submersible pump
S1	28.92936	-25.92897	0	0	5000	8.0	3	0	Water reticulated into a dam no current use
S2	28.92996	-25.92857	0	0	8000	7.5	4	0	Water reticulated into a dam no current use
S3	28.89640	-25.92547	0	0	3000	-999	-999	0	No Use

SWL – static water level
mbgl meters below ground level
lph liters per hour
-999 No data

Table 3: Hydrocensus data site **Y** (August 2006)

BH ID	X- Co-ordinate	Y- Co-ordinate	Depth	SWL	Yield	pH	EC	Abstraction	Comments
	WGS 84 DD	WGS 84 DD	(m)	(mbgl)	lph		mS/m	m^3/day	
YBH1	28.82089	-25.95528	-999	-999	-999	-999	-999	0	Borehole blocked at 10 meters below ground level
YBH2	28.81761	-25.96278	-999	5.1	5000	8.02	17	10	Borehole used for domestic purposes and the watering of livestock
YBH3	28.84128	-25.96667	15	4.4	-999	7.37	94	5	Domestic water supply
YBH4	28.86111	-25.98000	12	Equipped	40 000	7.48	4	10	Domestic use and cattle
YBH5	28.85861	-25.97833	18	5.5	35 000	7.5	41	5	Domestic use for 1 household and the workshop
YBH6	28.86236	-25.99194	12	Equipped	40 000	-999	-999	0	Windmill not in a working condition
YBH7	28.84697	-25.98586	30	5.15	-999	-999	-999	3	Domestic use and cattle
YBH8	28.86586	-25.96947	18	5	<1000	-999	-999	0	Open borehole
YBH9	28.81761	-25.96278	-999	-999	-999	8.15	8	2.5	Domestic water supply for a school
YBH10	28.85739	-25.97800	20	7.5	-999	7.72	71	-999	Domestic use for 1 household and the workshop
YBH11	28.85513	-25.99710	-999	-999	-999	-999	-999	0	Not in use
YBH12	28.86637	-25.99526	-999	-999	-999	-999	-999	0	Not in use
YBH13			20	4.35	2000	7.89	28	10	Domestic use

mbgl meters below ground level
lph liters per hour
-999 No data

Table 4: NGDB data located within Site X and Site Y

SITE_ID	Farm Name	DRAINAGE_R	X_WGSDD	Y_WGSDD	ALTITUDE	DEPTH	Water Level
2527DC00157	HARTBEESTFONTEIN	B20	28.91637	-25.89223	1480	25.90	9.14
2527DC00158	HARTBEESTFONTEIN	B20	28.91636	-25.89224	1480	19.81	19.50
2528DD00021	HARTBEESTFONTEIN	B20	28.90582	-25.89696	1440	No data	4.57
2528DD00022	HARTBEESTFONTEIN	B20	28.90583	-25.89696	1440	45.00	No data
2528DD00023	HARTBEESTFONTEIN	B20	28.90582	-25.89697	1440	5.80	No data
2528DD00024	HARTBEESTFONTEIN	B20	28.90584	-25.89696	1440	73.00	No data
2528DD00031	HARTBEESTFONTEIN	B20	28.90582	-25.89698	1440	No data	No data
2528DD00054	HARTBEESTFONTEIN	B20	28.90912	-25.89669	1460	No data	No data
2528DD00055	HARTBEESTFONTEIN	B20	28.90914	-25.89667	1460	16.00	16.00
2528DD00056	HARTBEESTFONTEIN	B20	28.90915	-25.89668	1460	No data	16.76
2528DD00060	HARTBEESTFONTEIN	B20	28.90914	-25.89667	1460	16.00	No data
2528DD00061	HARTBEESTFONTEIN	B20	28.90913	-25.89666	1460	No data	No data
2528DD00026	KLIPFONTEIN	B20	28.91749	-25.94780	1460	76.00	No data
2528DD00027	KLIPFONTEIN	B20	28.91750	-25.94779	1460	76.00	No data
2628BB00017	KLIPFONTEIN	B20	28.92582	-26.01139	1520	65.00	20.00

Table 5: WARMS data located within Site X and Site Y

REGISTER NO	REGISTERST	RESOURCE_T	RESOURCE_N	X_WGSDD	Y_WGSDD	VOLUME_REG	VOLUME	INTERVAL_T
24016609	CLOSED	BOREHOLE	BOREHOLE	28.90971	-25.86057	730	CUBIC METRES	PER YEAR
24012774	ACTIVE	SPRING/EYE	SPRING 1	28.79971	-26.04056	438000	CUBIC METRES	PER YEAR
24075000	ACTIVE	SPRING/EYE	SPRING	28.92415	-26.01106	26034	CUBIC METRES	PER YEAR
24025582	ACTIVE	SPRING/EYE	FOUNTAIN	28.94971	-25.94057	15285	CUBIC METRES	PER YEAR

Figure 4: Site X Hydrocensus Boreholes

Figure 5: Site Y Hydrocensus Boreholes

Of all the boreholes recorded on Site X only 15 are currently in use. The groundwater use on site consists mainly of domestic water supply and drinking water for livestock. Small-scale irrigation for small gardens occurs in certain sections of the site.

The two springs, S1 and S2, have previously been utilised by diverting the flow into a dam for irrigation. The springs are currently not being used and feed into the unnamed non-perennial stream indicated on Figure 4.

Borehole density and groundwater use - site Y

Thirteen boreholes were located within an area of approximately 21km^2. No registered water users and NGDB records were available for site Y. The borehole density for the area equals 1 borehole per 1.6 km^2

Four of the thirteen boreholes are currently not in use; the remaining nine boreholes are mainly used for domestic purposes and livestock watering. No large scale irrigation occurs within site Y.

The domestic groundwater users in the area is solely reliant on groundwater as there is no alternative source of groundwater available in both site X and site Y

Depth to groundwater, borehole yields, and abstraction volumes – Site X

The depth to groundwater varies between 0 (two artesian boreholes) and 10.75 meters below ground level.

Boreholes XBH2 and XBH3 indicate water levels deeper than 20 meters below ground level, the water levels were measured during the pumping of the boreholes and the data does not reflect the static water level for the area

Plate 3 and Plate 4 show the two artesian boreholes located on the northern portion of the farm Klipfontein 566JR.

The average depth to water level across the site is approximately 7 meters below ground level.

The yields of boreholes located on Site X vary between 1 000 and 5 000 liters per hour (0.28 and 1.39 l/s). The strongest yield occurs in spring S2 with a yield of approximately 8 000 liters per hour (2.2 l/s). The lowest borehole yields are located on the Farm Hartbeesfontein 537JR and towards the western portion of the farm.

The geology of the low yielding aquifers in the area consists mainly of the Dwyka Formation tillite.

Low abstraction volumes occur within the study area with abstraction volumes between 1 and 8.5 m^3/day. The total abstraction for Site X equals ± 43 m^3/day. The limited groundwater abstraction in the area is mainly due to the low population density and the dry land agricultural activities in the area.

Plate 3: Artesian Borehole XBH 11

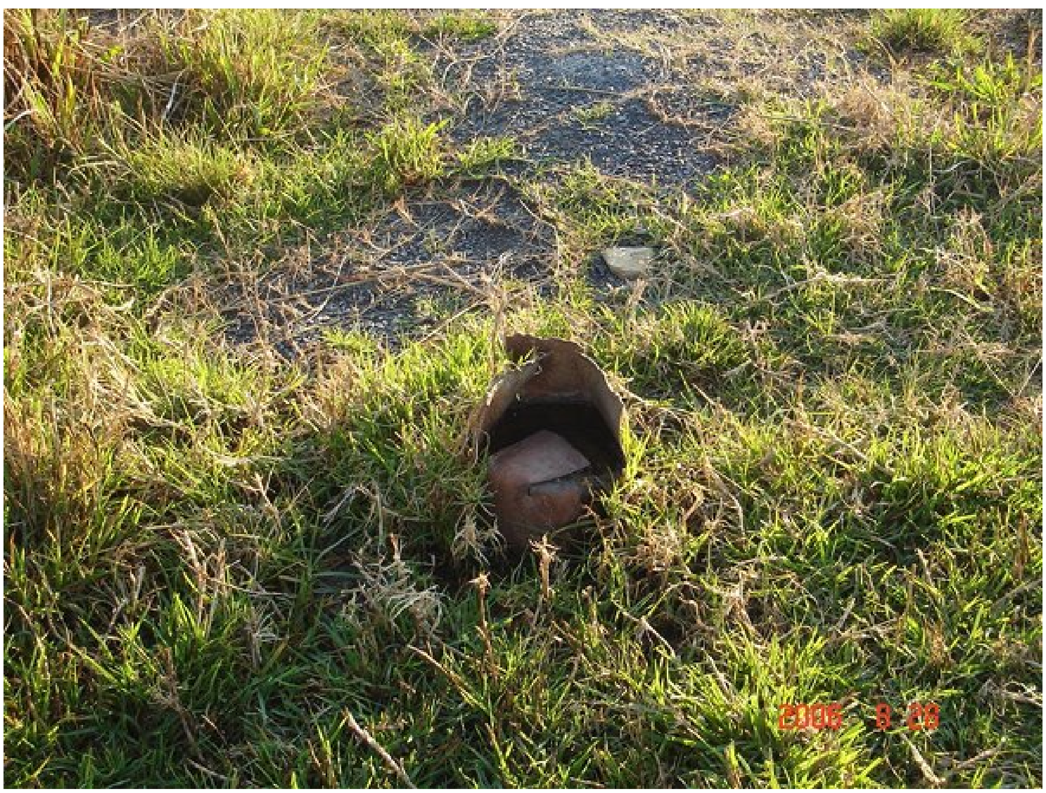

Plate 4: Artesian Borehole XBH 12

Depth to groundwater level, borehole yields and abstraction volumes – Site Y

Depth to groundwater level varies between 4.3 and 7.5 meters below ground level with an average depth of 5.2 m on site Y. No artesian boreholes were located on the site (Figure 5).

Borehole yields on the site vary between 2 000 and 40 000 litres per hour (0.56 and 11.1l/s) with the strongest borehole yields located on the Farm Nooitgedacht. The positions of the boreholes relative to the site and the underlying geology are presented in Figure 3 (field geology).

Geological logs / records of the high yielding boreholes, labelled YBH4, YBH5, and YBH6, indicate that the boreholes intersected the weathered material and diabase.

The major aquifers (yields greater than 5 l/s) occur on the contact between the thick soil layer and the diabase sill intrusion with shallow borehole depths less than 20 meters deep in the area.

The abstraction volumes for the area vary between 2.5 and 10 m^3/day. The total abstraction for the area equals approximately 45.5 m^3/day. The low abstraction volumes in the area are mainly due to the boreholes being used for limited domestic purposes. No groundwater abstraction for irrigation purposes occur in the area.

7.3 Groundwater balance and groundwater potential

Based on the data obtained during the desktop study and field investigation a preliminary groundwater balance was calculated for each of the candidate sites (on a sub-catchment scale). The methodology used in the groundwater balance calculation is based on the methodology as set out in the Groundwater Resource Direct Measures by the Department of Water Affairs and Forestry.

In order to determine the volume of groundwater that can safely be abstracted from the study area without 'mining" the resource, i.e. without removing groundwater from storage, a water balance is calculated.

The groundwater balance is calculated using the following variables: -

- Area of sub-catchment
- Rainfall recharge and effective storage
- Existing abstraction
- Ecological reserve

Area of the catchment

Both site X and site Y fall within the B20F quaternary catchment, the size of each of the sites relative to the B20F catchment are presented in Figure 1.

- Site X: consists of a 48 km^2 portion of the B20F catchment area
- Site Y: consists of a 21 km^2 portion of the B20F catchment area

Rainfall recharge

The effective groundwater recharge from rainfall is the portion of rainfall that reaches the groundwater. The remainder of the rainfall comprises surface water run-off, evapotranspiration, and soil moisture.

The effective rainfall recharge is dependant on the catchment geology, soils, surface run-off, and stream morphology but most importantly for the study area, the effective storage.[3]

Based on Bredenkamp *et. al.*[4] and previous studies carried out by GCS in the same geological formations the recharge to the different geological units were determined.

Site X: recharge calculation (Figure 4)

Dwyka Formation tillite underlies 70% of the site. Area 33.6 km^2
Dwyka Formation tillite will have a recharge potential of 0.5% of the MAP[5]
Rainfall recharge = 0.5% x 667mm X 33.6 km^2

= 112 000 m^3/annum

[3] Recharge occurs regularly but cannot all be absorbed into the aquifer because of low storage.
[4] Manual on quantitative estimation of groundwater recharge and aquifer storativity, Bredenkamp, Botha, van Tonder, and van Rensburg, WRC Report TT73/95, June 1995
[5] MAP – Mean annual precipitation

The Silverton Formation shale underlie 20% of the site X, an area of 9.6 km^2
The recharge potential of the Silverton Formation shale varies between 1 and 3 % of the MAP (average 2% of the Map)

Rainfall recharge = 2% x 667mm X 9.6 km^2

= 128 000 m^3/annum

The diabase sill underlies 10% of the site. The recharge potential of the diabase in the pristine stage will be extremely low, < 1% of the MAP. The contact between the diabase and the Silverton Formation will have a higher recharge potential (due to contact metamorphism) of approximately 5%. The weathered aquifer in the diabase will also have a higher recharge of up to 7% of MAP. Rainfall recharge of the section was, therefore, conservatively calculated to be 3% of the MAP.

Rainfall recharge = 3% x 667mm X 4.8 km^2

= 96 000 m^3/annum

Groundwater Contribution to River flow

The groundwater contribution to river flow for the B20F (504 km^2) catchment equals 1.8 Mm^3/a.

Site X contains 48 km^2 of the catchment, therefore, the groundwater contribution to baseflow within this sub-catchment is calculated to be 171 428 m^3/annum.

Groundwater balance calculation

The groundwater balance for the sub-catchment containing Site X is: -

Rainfall Recharge	920 m^3/day
Existing Abstraction	-43 m^3/day (Section 7.2)
Base flow component	- 470 m^3/day
Volume available	**± 400 m^3/day**

Site Y Recharge calculation

The Silverton Formation shale underlies 10 % of the site, recharge is 2% of the MAP, and the area covered is 2.1 km^2.

Rainfall recharge = 28 000 m^3/annum

The Diabase sill underlies 35% of the site, with 3% of the MAP recharge and an area of 7.35 km^2

Rainfall recharge = 147 000 m^3/annum

The diabase sill has a thick soil cover in places across site Y. The shallow high yielding boreholes drilled into the formation indicate the presence of a highly weathered shallow aquifer with a high yielding potential. The recharge potential to the section was calculated to be 7% of the MAP.

The quaternary soil on site, receiving 7% of the MAP over an area of 1.05 km^2

Rainfall recharge = 49 000 m^3/annum

The Loskop Formation, consisting of shale, sandstone, conglomerate, and volcanic rocks, underlies 15% of this site, assuming 2% of MAP recharge over an area of 3.15 km^2

Rainfall recharge = 42 000 m^3/annum

Groundwater balance calculation

The groundwater balance for the sub-catchment containing site Y is: -

Rainfall Recharge	730 m^3/day
Existing Abstraction	- 45.5 m^3/day
Base flow component	- 205 m^3/day
Volume available	**± 480 m^3/day**

Summary

The preliminary groundwater balance calculated for each of the sub-catchments containing the candidate sites indicates: -

- Site Y receives higher rainfall recharge than site X, due to geology
- Existing abstraction is higher on site Y than site X, even though site Y is almost half the size of site X
- Site Y has higher volumes of groundwater available than site X, even though site Y is almost half the size of site X

7.4 Ambient hydrochemistry

Ambient hydrochemistry data were obtained from both the sites with the use of handheld Electrical Conductivity and pH meters during the hydrocensus phase. The conductivity measurements gave an indication of the concentrations of dissolved solids (salinity) within the groundwater. These field measurements were compared to the South African water quality guidelines shown in Table 6. The recorded field measurements are listed in Table 2 (Site X hydrocensus data).

Table 6: South African water quality guidelines target ranges for domestic, agricultural and livestock watering use.

Parameter	Domestic	Agriculture (Irrigation)	Livestock Watering
pH-Value at 25 °C	6.0 - 9.0	6.5 - 8.4	NA
Conductivity at 25°C in mS/m	0 - 70	0 - 40	NA

Table 2, which list the hydrocensus data for Site X, shows that all of the field measurements fall within the target water quality range with the exception of borehole XBH10 that exceed the Electrical Conductivity target water quality guidelines for domestic and agricultural use. The EC concentration in borehole XBH12 slightly exceeds the guideline value for irrigational use, but not domestic use.

The pH value of boreholes XBH14 and XBH19 exceed the target value for irrigational use, while that of boreholes XBH11 and XBH12 exceed the domestic use guideline as well. Water tastes bitter at a pH higher than 9 and the probability of toxic effects due to deprotonated species (for example ammonium deprotonating to ammonia) increases sharply.

The groundwater quality in the area is generally of a good quality, the only complaints regarding the water quality was obtained from Mr. Deon Nel on the Farm Klipfontein, where the groundwater quality in borehole XBH17 is brackish. The reason for this complaint is unknown as brackish normally has an elevated EC value (>70). The EC value measured for the water in this borehole is 6 mS/m.

Table 3, the hydrocensus data for Site Y, indicates electrical conductivity values that ranges between 8 and 91 mS/m. All of the boreholes fall within the target water quality range with only boreholes YBH3 and YBH10 that marginally exceed the target water quality ranges for irrigational and domestic use.

No complaints regarding hydrochemistry of any of the boreholes were obtained from the landowners in the Site Y area.

7.5 Aquifer Classification

Aquifer Classification - Site X

The portions of the farms Hartbeesfontein 537 JR and Klipfontein 560JR, located within site X, are classified as either non-aquifer or minor aquifer systems, according to Parsons classification (Parsons, 1995), [6] where:-

Non-Aquifer Systems occurs where the formations have negligible permeability and are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risks associated with persistent pollutants.

Where groundwater potential has been enhanced along areas of secondary processes, such as diabase intrusions on site X then there has been the development of discrete minor aquifer systems, where: -

A **Minor Aquifer System** comprises fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow for rivers.

Aquifer Classification - Site Y

The majority of the farm Nooitgedacht 564, which contains the high yielding boreholes associated with the permeable soil cover over the diabase intrusion can be classified as a major aquifer system.

A **Major Aquifer System** can be defined as highly permeable formations, usually with known or probable presence of significant fracturing. The aquifers might be highly productive and able to support large abstractions for public supply or other purposes. Water quality is generally very good (less than 150 mS/m)

The portion of the farm Witpoort 563 JR that is located within Site Y and underlain by the diabase sill can be regarded as a minor aquifer system.

[6] WRC Report No. KV 77/95, A South African Aquifer System Management Classification, R. Parsons December 1995.

7.6 Site selection

In order to evaluate the aquifer vulnerability from a groundwater perspective the Waste – Aquifer Separation Principle (WASP) was used.

The WASP model examines three factors, namely the Threat, Barrier, and Resource Factors to establish the site suitability.

The Threat Factor

Rainfall recharge moving through the site becomes enriched with elements and recharges the underlying groundwater with poor quality water. The threat posed is essentially proportional to the volumes of contaminants produced. Therefore, the threat is seen as a factor of the influenced area.

The threat factor in the case of the power station and additional facilities will be the alteration of the water quality (The threat factor, envisaged impacts, is discussed in detail in Section 9).

The threat factor is seen to be the same for both candidate sites.

The Barrier Factor

The unsaturated zone represents the barrier between the bottom of the potential contamination source(s) and the underlying or surrounding aquifer(s). It is within this zone that attenuation and biodegradation of the contaminants can occur.

Important processes in attenuation include chemical precipitation, absorption, adsorption, dilution, dispersion, and biodegradation. Attenuation is a complex combination of these processes and is difficult to predict. It is, therefore, the time that contaminants are exposed to attenuation, which determines the extent to which the threat is mitigated.

The travel time depends on the hydraulic conductivity (permeability) and porosity of the unsaturated zone. The longer the travel time the less the threat.

The Resource Factor

This factor attempts to establish the significance of the underlying aquifer. The users of the aquifer as well as the potential of the groundwater resource are considered using the results of the hydrocensus.

Site evaluation

The WASP approach, together with the data obtained from the preceding phases, was used to carry out the site selection from a groundwater perspective.

The threat factor

The threat factor for site Y and site X in terms of the threat posed from infrastructure will be the same for both the sites as the sites is in close proximity of one another and the rainfall across the two sites is seen to be equal.

The Barrier factor

Site Y is more vulnerable when compared to site X in terms of the barrier factor, due to the following conditions:-

- The average depth to groundwater is shallower in Site Y (5.2 m) when compared to Site X (7 m). The threat posed from the shallower groundwater levels will be reduced travel times of pollutants.
- A shallow weathered major aquifer is located on site Y. The shallow aquifer comprises extensive highly permeable sand overlying a diabase sill. The aquifers on site X are discrete deeper fractured rock aquifers, as seen in the borehole depths (Table 2 and Table 3).
- The high yielding aquifer within the weathered diabase formation will reduce the travel time of pollutants and facilitate the migration of pollution plumes. The lower yielding aquifers on site X will have a low transmissivity and thus limited pollution plume migration is envisaged.

The Resource Factor

Site Y is more vulnerable than site X in terms of the resource factor due to the following conclusions: -

- The groundwater recharge from rainfall on site Y is greater than site X, $31m^3/day/km^2$ compared to $19\ m^3/day/km^2$ (Section 7.3).
- The amount of groundwater available without impacting on the resource is approximately $480\ m^3/day$ for site Y and $400\ m^3/day$ for site X.
- The majority of site Y is classified as a major aquifer system, only a small portion of the site Y towards the south eastern portion can be classified as a minor aquifer system.
- Area X is classified as either a minor aquifer system or a non-aquifer system.
- The groundwater use on both site X and site Y is mainly used for domestic purposes; both sites have a low borehole density due to the low population and the land use mainly for agricultural purposes. Site Y does, however, have the potential to develop large scale sustainable groundwater supplies.
- The hydrochemistry on site Y is, according to owners and users, of potable quality. Brack water was recorded on site X.

Site X is, based o the site selection process, the preferred site from a groundwater perspective.

7.7 Preferred site layout

Site X

Site X is identified as the preferred site from a groundwater perspective. The preferred layout of the infrastructure from a groundwater perspective is presented in Figure 6.

The layout of the site was selected from a groundwater perspective as discussed in the preceding phases. Site X has been divided into thee preferred areas for development, labeled; 1, 2, and the northern section 3, on the farm Hartbeesfontein 537JR. These three sections should be considered for the power station and ancillary infrastructure as indicated on Figure 6.

Site Y

In addition to the three areas an additional area was identified on a portion of site Y, towards the southern portion of the farm Klipfontein 566 JR (labeled 4 on Figure 6).

Site Y present a major aquifer system for the majority of the site with the exception of the southeastern portion of site Y, refer Figure 6.

The Loskop Formation shale and lava underlies the southeastern portion. This is an area of low recharge and poorly developed aquifers, which can possibly be classified as a non-aquifer system as no groundwater users were identified in the area.

It is recommended that the proposed site boundary as indicated in Figure 6 not be exceeded due to change in geological conditions and the neighbouring major aquifer system.

Figure 6 –Preferred site layout

PHASE II EIA

8 PROPOSED POWER STATION

A coal-fired power station is to be developed on a green fields site. The power station will be capable of delivering between 3 600 and 5 400 MW depending on the technology to be used, which is still to be decided by Eskom.

8.1 Typical infrastructure

A coal-fired (6 pack) power station capable of delivering 5400 MW typically comprises the following ancillary infrastructure: -

- A HV yard
- Water supply pipelines
- The coal stockpiles
- The raw water dam
- Water and waste water treatment facilities
- The sewage plant and dams
- Treated (de-ionized) water system
- Evaporation dams (x2)
- Recovery (dirty water) dams (x2)
- Bunker fuel oil storage
- Chemical storage
- Ash dump / deposition system
- Ash dump toe dam
- Solid waste site
- Conveyor system
- Roads and office buildings

8.2 Impacts of similar power stations on groundwater

The possible sources of contamination or infrastructure that may impact on the groundwater are: -

- The coal stockpiles - potential acid generation area
- The raw water dams (x2) - source of artificial recharge to the groundwater
- The sewage plant and dams - irrigation of effluent may impact on groundwater
- Treated (de-ionized) water system - brine added to fly ash for deposition on ash dump
- Recovery (dirty water) dams (x2) - overflow and irrigation may impact on groundwater
- Bunker fuel oil - oil enters water and requires treatment
- Ash dump - source of “poor” quality artificial recharge
- Ash dump toe dam - source of artificial recharge
- Solid waste site - source of leachate or poor quality water

Groundwater monitoring from similar coal fired power stations indicate that power stations and the ancillary infrastructure impact on the groundwater levels as well as the hydrochemistry.

Extended (since 1987) groundwater monitoring at power stations in South Africa indicate some degree of groundwater quality deterioration with time. Groundwater levels are also recorded to indicate artificial recharge as a result of water management on the sites.

8.2.1 Water level monitoring

Groundwater level depths are measured before the establishment of power stations. The groundwater levels are typically 5 m to 10 m below surface within the study area Karoo geology.

The power station infrastructures, including run-off dams, dirty water dams, coal stockpiles, ash dumps and toe dams, all provide areas of artificial recharge. Water level records indicate that the groundwater levels can rise markedly due to the seepage into the ground. Groundwater contamination can occur as a result of poor quality water recharging the underlying aquifers.

Examination of the rise in groundwater levels and the hydraulic response of the aquifer in areas away from the artificial recharge points, known as the equalisation reaction, provide an indication of the hydraulic characteristics of the aquifer. Typically there is a localised nature of the groundwater mounds around the recharge points and the limited zone of influence suggests low regional permeabilities within the Karoo sediments.

The groundwater level data typically indicates interconnectivity between the power station water infrastructure and the aquifers over a relatively small area, and that groundwater contamination could occur but would migrate at a very slow rate. Pollution plume migration, within the tillite and shale, is predicted to be retarded, due to indirect flow paths along fractures in the rock and because of chemical reactions and ionic bonding.

Groundwater level monitoring generally indicates that deeper water levels are recorded away from power stations and infrastructure. It is concluded that the hydraulic response due to artificial recharge is localised.

8.2.2 Hydrochemistry

Long term groundwater monitoring by Eskom at similar power stations indicates some degree of groundwater quality deterioration.

The groundwater quality can be variable, not only due to persistent contaminant sources on site but also due to the sediments naturally containing salts, which is a result of: -

- The drilling exposes impermeable formations, such as shale, to water, which allows for the release of salts into the groundwater (natural pollution of the borehole)
- Natural salinities in the groundwater can be high due to long residence time. The groundwater enrichment could occur allowing for high concentrations of almost all macro constituents.

Typically groundwater monitored within boreholes adjacent to power stations and ancillary infrastructure indicates a rise in the salt content of the groundwater due to seepage from surface sources and also because of the dissolution of salt from the previously unsaturated impermeable zones. The increase in salinity is, therefore, a combination of artificial recharge of poor quality (saline) surface water sources and the mobilisation of salts in the exposed impermeable zones in the boreholes.

Natural or artificial contamination from site activities result in vertical stratification of contamination within monitoring boreholes and the recognised protocol for stratified sampling requires representative samples to be collected.

Monitoring at coal stockpiles often indicate groundwater quality of low pH and elevated sulphate concentrations as a result of the oxygenation of sulphides associated with the coal.

The groundwater monitoring allows for pollution plume mapping and predictions regarding impacts on surrounding groundwater users and resources.

8.3 Ash disposal

Ash and effluents, waste products from the power generation process, are typically co-disposed at power stations. Ash has to be disposed in such a manner that the long-term potential of the ash to encapsulate effluents is not compromised, as this could pose a threat to the groundwater. The effluents include: -

- Cooling water sludge from the lime softening process, which can act as quick sand and is of moderately high salinity, must always be co-disposed with ash
- Sludge from the clarification process of cooling water is regarded to be similar in hazard potential to cooling water sludge, and thus should also be co-disposed with ash
- Sludge and sediments collected from dirty drainage grit separation facilities and dams are regarded as high salinity sludge and must be mixed with ash prior to disposal
- Spent neutralised regeneration effluents, including caustic soda and sulphuric acid regenerants, must always be disposed as a semi-homogeneous mixture with ash
- Desalination plant brine, a high salinity effluent, is co-disposed with the ash

Thus ash disposal is typically not only ash but a co-disposal of ash and effluents.

Ash disposal can take place both above and below ground. There are three methods of disposing of ash that have been considered for the proposed power station; namely above ground ashing, in-pit ashing, and back-ashing. These three options are described below: -

- Above ground ashing – Ash is disposed on an ash dump. The ash dump is rehabilitated over time, using accepted rehabilitation methods.
- In-pit ashing – The ash is dumped directly into open cast voids at the colliery that supplies coal to the power station. Overburden and topsoil are placed on top of the ash.
- Back-ashing[7] – The overburden at the colliery is returned to the open pit voids prior to the ash. The ash is then covered with soil and rehabilitated.

These different methods have different impacts on the groundwater environment. In order to identify and quantify these impacts the ash first has to be characterised chemically and physically.

CHEMICAL AND PHYSICAL CHARACTERISATION

Ash is the product of the coal burning process and has the ability to contaminate the groundwater. The major potential impacts of ash disposal on groundwater resources are generally associated with changes in the pH of the water and the concentration of the potentially toxic elements. The most important factor in determining the resulting pollution impact of the ash is the way in which it is disposed.

Ash can be disposed of in two ways, namely dry or wet disposal. During dry disposal, the ash still has a moisture content of up to 15%. This water is added to suppress the dust and to take care of specific effluents. The effluent most commonly taken care of in this way is that of the demineralisation complex which contains high concentrations of sodium and sulphate.

[7] Returning ash into underground voids could also be considered, however, these voids would have to be allowed to flood. Preliminary indications are that the colliery supplying the coal will utilise open cast mining methods

Dry disposal is advantageous in that the contact with water is reduced. Disadvantages, however, include dust and wind erosion as well as stability of the ash pile in the case of above surface disposal.

Wet ash disposal sites transport fly ash in suspension with water to the disposal area where it is released on dried ash. Here the water evaporates and the ash is left behind. As soon as the ash has dried, another layer is deposited on top. This effectively prevents the top layer of ash to be subjected to natural wetting and drying cycles, which leads to the formation of the pozzolanic[8] layer.

Fly ash mainly consists of small, glassy hollow particles with grain sizes varying between 0.01 and 100 µm. It can contain all the natural elements, and in comparison with the parent material is enriched in trace elements. Studies show that trace elements are usually concentrated in the smaller particles (Carlson et al. 1993). The ash is usually enriched in arsenic, boron, calcium, molybdenum, sulphur, selenium, and strontium.

By understanding the chemistry of the ash, a better insight into its reaction with various other elements can be reached. The pH of the ash is elevated due to the abundance of calcium oxide. Calcium oxide usually constitutes about 8 % of the ash and is of great importance in the forming of the pozzolanic layer. As stated above another factor that plays an important role is the presence of water in the ash. If there is enough water to isolate the ash from the atmosphere (as is the case with wet disposal) the ash will not be able to react with the oxygen in the air and the pozzolanic layer will not be able to form.

Should the ash be wetted and dried cyclically, the ash will have time to react with the atmosphere. This will cause a reaction between calcium oxide and the carbon dioxide that will then lead to the crystallisation of calcium carbonate (limestone).

Another reaction that occurs is that between calcium and sulphate that results in the crystallisation of gypsum ($CaSO_4 \cdot 2H_20$).

These two minerals (calcium carbonate and gypsum) form the so-called pozzolanic layer, which is a layer of very low permeability. The layer can be expected to occur in the upper 0.5 m of the ash disposal infrastructure.

It is thus evident that the formation of the pozzolanic layer is mostly confined where wetting and drying of ash occurs, during deposition in the wet process and near the surface on a dry ash pile.

Leaching from these disposal sites will occur. Leaching experiments show that the element composition of the leachate does not necessarily reflect that of the whole ash sample proportionally. This suggests that for some elements a correlation of leachate quality to whole ash comparison cannot be made.

This is because the rate at which these elements will leach from the ash is dependent on: -

- The form in which the element is present
- The location of the element within the ash matrix
- Or whether the element has been absorbed onto the ash particle surface

The ash spheres are chemically stable in the environment and are resistant to weathering due to the alumino silicate matrix. Any element present in this matrix will be less readily available for leaching.

[8] **Pozzolanic (industrical) ash** is an alumino-siliceous material which reacts with calcium hydroxide in the presence of water to form compounds possessing cementitious properties at room temperature.

Elements absorbed onto the surface of the ash spheres will be more readily leached. Uncombusted mineral material may account for the presence of high concentrations of certain elements in the whole ash analysis. However, leachate generated from these ashes may not reflect the high concentrations because the extraneous material associated with the ash are not in a form that is susceptible to leaching.

No ash data was available for the proposed power station or from the adjacent existing Kendal Power Station ash dump; however, ash samples from a coal fired boiler[9] were obtained and assessed to determine the possible leachate, which could result from ash disposal.

TCLP[10] extract tests were carried out on ash samples from an above ground boiler ash pile. This was done to determine the quality of potential leachate from the ash pile. The concentrations were measured in mg/l and compared against acceptable environmental risk standards supplied by Department of Water Affairs and Forestry[11].

The leachate results indicate that, when compared to the acceptable environmental risk standards, elevated concentrations of metals were recorded. Table 7 presents the results of the TCLP tests on six ash samples collected from an above ground ash disposal site.

The variable results are as a result of the variable ash and effluents chemistry, concentrations of leachable elements, variable permeability, and the buffer capacity (ash has a base pH) of the ash.

Ash water chemistry

Water used to transport ash to an ash dam is typically decanted off the ash pile for reuse. The addition of water allows for chemical reactions, between the ash, air, and water, to take place. These include: -

- $CaO + H_2O = Ca(OH)_2$, with a rise in the pH of the water to above 12
- Precipitation of all heavy metals, except aluminium takes place (onto the ash pile)
- Precipitation of all magnesium occurs

This allows for an increased concentration of metals and salts within the ash pile, which could potential leach from the ash pile.

The water is decanted off the ash dump, usually through penstocks, which takes a number of days due to the permeability of the ash and effluents. During this time the water is exposed to carbon dioxide within the air. This drops the pH of the ash water: -

- $Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$, to a pH just above 7.0
- Aluminium precipitates as aluminium oxide and ettringite[12]
- Gypsum ($CaSO_4.2(H_2O)$) precipitations also occurs

[9] The ash was from similar coal to that to be used at the proposed power station. The ash had been exposed to carbon dioxide and rain.
[10] Toxicity Characteristic Leaching Procedure (TCLP) is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphasic wastes. An acetic acid solution (pH – 4.2) is used to simulate the result of rainwater infiltrating the ash pile, reacting with the ash, and then leaching through the ash being tested. The resultant leachate is analysed to determine the threat posed to human health and the environment.
[11] Department of Water Affairs and Forestry Minimum requirements for the handling, classification, and disposal of waste, second edition 1998
[12] Hydrated calcium aluminium sulphate hydroxide

The end result is water at near-neutral pH, with no heavy metals, almost no magnesium, intermediate calcium, and high sulphate and sodium concentrations. This water is suitable for use in transporting the ash.

The water, when stored in a dam, can potentially act as a source of poor quality artificial recharge.

Table 7: Chemical concentrations of the ash extraction

Parameter	Acceptable Environmental Risk[13]	Ash samples					
		A	B	C	D	E	F
Sulphate as SO_4	NS	108	45	14	11.3	9.7	4.6
Chloride as Cl	NS	1.3	2.9	1.3	3.9	3.9	2.4
Calcium as Ca	NS	273	740	304	43	119	514
Magnesium as Mg	NS	10.9	198	111	29	39	148
Potassium as K	NS	5	3.3	5.4	2.6	3.4	3.8
Aluminium as Al	0.39	0.88	0.84	2	0.22	0.17	0.18
Iron as Fe	9	0.08	<0.001	<0.001	0.07	0.04	<0.001
Manganese as Mn	0.3	0.21	0.88	0.95	0.05	0.08	1.2
Arsenic (As)	0.43	<0.02	<0.02	<0.02	0.02	<0.02	<0.02
Selenium (Se)	0.26	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Titanium (Ti)	0.73	0.006					
Nickel (Ni)	1.14	0.02	0.03	0.03	0.004	0.008	0.04
Vanadium (V)	1.3	0.02	0.008	0.008	0.01	0.01	0.01
Zinc ((Zn)	0.7	0.14	0.13	0.18	0.08	0.13	0.23
Antimony (Sb)	0.07	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lead (Pb)	0.1	0.01	0.02	0.02	0.007	0.02	0.01
Cobalt Co (Co)	6.9	0.01	0.004	0.003	0.001	0.002	<0.001
Copper (Cu)	0.1	0.01	0.01	<0.002	0.007	0.03	<0.002
Total Chromium (Cr)	4.7	0.008	0.02	0.02	0.005	<0.003	0.005
Silicon (Si)	NS	11.9					
Tin (Sn)	NS	<0.02					
Zirconium (Zr)	2	0.002					
Gallium (Ga)	NS	<0.002					
Germanium (Ge)	NS	<0.01					
Indium (In)	NS	<0.004					
Thallium (TI)	NS	<0.009					
Beryllium (Be)	NS	<0.0012					
Cadmium (Cd)	0.031	<0.001	0.02	<0.001	<0.001	<0.001	<0.001
Boron (B)	NS	0.5	0.66	0.27	0.17	0.08	0.21
Phosphorus (P)	NS	13.4					
Uranium (U)	NS	<0.004					
Molybdenum (Mo)	NS	<0.001					
Barium (Ba)	7.8	0.74					
Silver (Ag)	2	<0.004					
Mercury (Hg)	0.022	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

NS – Not specified

[13] Minimum requirements for the handling, classification, and disposal of waste, second edition 1998

Ash disposal methods and the associated environmental risks

Above surface disposal

During above surface disposal the ash is stored in carefully designed and managed ash dumps. The fly ash is used to construct the walls of the dump, while the bottom ash stored in the centre.

One of the reasons for using the fly ash as wall material is that the fine-grained material has a relatively low permeability, therefore limiting seepage of contaminated water from the dump through the walls.

Risks to the water environment associated with surface disposal of the ash material can be described as: -

- **Elevated constituent concentrations**: It is evident that it can be expected that calcium and sulphate will be present in elevated concentrations in the material. Other constituents that could be present in high concentrations are silicon, magnesium, sodium, and potassium. Trace elements that can be present in elevated concentrations include arsenic, boron, calcium, molybdenum, sulphur, selenium, and strontium.

- **Chemical changes due to exposure to air**: The chemistry of the ash material can be expected to change due to exposure to carbon dioxide in the air. A chemical reaction will occur between calcium oxide and carbon dioxide that will lead to the crystallisation of calcium carbonate (limestone) as described above. Calcium will also react with sulphate that forms due the oxidation of sulphur minerals and gypsum will crystallise. It can be expected that sulphate concentrations will be elevated.

- **Leaching of constituents[14]**: Water contained in the ash material during deposition can leach constituents from the ash dump and transport it to the surrounding environment. Additional water that is recharged from rainfall will supplement the interstitial water and contribute to the leaching of elements.

  The water that migrates through the dump can either daylight along the edge of the ash dump and enter the surrounding environment as surface water, or migrate vertically to the bottom of the dump and enter the underlying soil from where it can recharge and contaminate the aquifers.

The quality of the water seeping from the ash dump can be predicted by performing leach and element enrichment testing. The results of the tests will show which elements can be expected to be present in elevated concentrations in the long term. The element concentration range can also be determined based on the results.

The volume of water that will seep from the ash dump in the long term will be affected by the recharge from rainfall.

In order to minimise the seepage volumes the dump must be capped[15] with a low permeability (1×10^{-7} to 1×10^{-9} cm/s) material, and shaped to prevent ponding of water. This will reduce recharge and ultimately the seepage volumes.

[14] Studies indicate that fly ash contains 55 kg base potential per ton of ash, at a pH of 7. The ash can therefore counteract acidity. However this base potential decreases with time.
[15] The envisaged dump will be large and capping will be expensive, designs must considered methods of reducing the footprint and final size of the ash dump.

Water that daylights along the walls of the ash dump must be collected in pollution control ponds from where the water can either be evaporated, or pumped to the reverse osmosis plant for treatment and re-circulation in the system.

The most effective way of preventing vertical seepage from the ash dump to the underlying aquifers is to either install a liner system or a drain system. The liner system will effectively prevent any vertical migration into the underlying soil and cause the water to migrate under gravity on top of the liner system to the edge of the ash dump where it can be collected for evaporation or treatment. Installing a drain system will collect the vertical moving water and transport it to an evaporation pond or the reverse osmosis plant for re-circulation in the system.

An alternative to this is to install a shallow (3 m deep) trench in the weathered material on the down gradient side of the ash dump. This will assist in collecting any shallow seepage from the dump. A shortcoming of this system is that it is not able to intercept contamination deeper than the bottom of the trench.

Sub-surface disposal

Two methods of sub surface disposal are proposed. These are:

- Back-ashing: This refers to dumping ash within the opencast coal mine, after all the usable coal has been excavated. The overburden (that layer of surface material that is removed prior to mining the coal) would be returned to line the excavation before the ash is placed on top of it. The ash would then be stacked, spread, rehabilitated with topsoil and re-vegetated.
- In-pit ashing: The difference between this method and back ashing is that the ash would be placed directly into the existing excavation and the overburden and topsoil would be placed on top of the ash. Thereafter the dump would be re-vegetated.

Both of these disposal methods can lead to the direct contamination of the surrounding aquifers because the ash material is likely to be below the regional groundwater level once the water levels have recovered in the post operational environment where dewatering and thus drawdown of groundwater levels have stopped.

It is expected that the permeability of the rehabilitated material will be slightly higher than that of the surrounding natural rock matrix. This will cause higher recharge into the rehabilitated area from ponded water.

Because the groundwater flow will be directed away from the pit area any salts leached from the ash material will migrate away from the immediate pit area, and into the surrounding environment.

The coal seam contact with the over- and underlying Karoo sediments act as a preferential groundwater flow path in many of the coalmines of South Africa. This, together with other geological features such as fractures and dyke intrusions intersected by the mine pit area can assist in the contaminant migration through the fractured rock aquifer.

Contaminant migration, through the weathered material aquifer, occurs when the recovering groundwater levels reach the elevation of the contact between weathered and competent rock. Contamination can then migrate down gradient along the contact.

Where the aquifers contribute to base flow of rivers or streams, the contamination can enter the surface water and influence the water quality. This is especially true of the weathered material aquifer that is a major contributor to base flow.

Decant can occur in some areas due to either migration along the coal seam contact, or in areas where the rehabilitated elevation is below that of the recovered groundwater level. The decanting water must be collected in evaporation ponds, or piped to the treatment plant for re-cycling in the system.

From the above description of the back-ashing and in-pit ashing methods and contamination migration pathways it is evident that back-ashing is the preferred method of the two (from a groundwater perspective). During the lining process, the overburden can be compacted, thereby reducing the transmissivity of the material and effectively forming a flow barrier.

This will decrease the volume of water that can migrate from the pit area to the surrounding aquifers and contaminate the environment. It will also decrease inflow of water from surrounding aquifers thereby effectively decreasing decant potential and volumes.

Comparison between surface and back ashing disposal methods

Surface disposal is the most conventional and often used method. The advantage of surface disposal is that once a proper drainage or liner and water management system is installed, the contamination from the ash dump to the surrounding groundwater sources can effectively be controlled.

Un-capped surface disposal sites can cause air pollution that can eventually find its way to water resources. However, this contamination is usually considerable less than that of direct contamination to the aquifer.

Once the surface disposal site is capped, water and air infiltration will be reduced. Natural wetting and drying due to rainfall events will cause a pozzolanic layer to form that will further protect the underlying ash material from water infiltration. This will reduce chemical reactions and leach volumes; however, the rate of decline in chemical reactions will be relatively slow.

Leach testing and geochemical modelling can provide an indication of the time and leaching volumes needed before element concentrations are below risk levels.

Back-ashing poses the risk of direct contamination to the surrounding aquifers, even through the lining of compacted overburden. Once the contamination has entered the aquifer, it will be difficult to remediate the site.

There is no direct advantage of placing ash below groundwater[16] (submerged) as the removal of oxygen only affects the sulphides reactions (AMD). The low pH mine water will leachate elements form the ash; however, the acid production (due to the removal of oxygen) will decrease. The reduction of acid with time will reduce the leachate generation associated with the ash.

Research indicate that when water of three to four times the pore volume of that of the rehabilitated (including ash) material has moved through the material and removed salts the resultant water quality will have improved significantly. This needs to be verified using an extensive geochemical study.

Legal Considerations

According to Section 20 Waste management of the Environment Conservation Act Part IV Control of Environmental Pollution, the Minister may exempt any person or category of persons from obtaining a permit, subject to such conditions as he may deem fit.

[16] Other than removing the ash from view

The exemptions, detailed in the Identification of Matter as Waste – Environment Conservation Act, 1989, includes: -

> Ash produced by or resulting from activities at an undertaking for the generation of electricity under the provisions of the Electricity Act, 1987 (Act No. 41 of 1987).

Thus the ash generated and disposed of on site does not require a waste disposal permit. It does, however, require the following: -

- The design of the ash disposal facility needs to be approved by the Department of Water Affairs and Forestry
- According to the National Water Act, the ash disposal facility will require a Water Use License as defined under Section 21 (g) – disposing of waste in a manner which may detrimentally impact on a water resource

8.4 Water use

The existing Kendal power station obtains water via a pipeline from the Vaal River Eastern Sub-system. Water is piped from the Khutala pump station into the Kendal power station's raw water reservoir. It is envisaged that the proposed power station will receive water, via a pipeline, from the Kendal power station.

According to the Department of Water Affairs and Forestry (DWAF) water from the Vaal Dam (160 million m^3/year) will be transferred into the Vaal River Eastern Sub-system (known as the Vaal River Eastern Sub-system augmentation project) by October 2007. A portion of this water will be made available for the proposed power station.

Water consumption at a dry cooled power station is in the order of 0.1 to 0.2 l/kWh (litres per unit of electricity produced). The average water use is 0.12 l/kWh sent out. For a power station capable of generating 3 990 MWh with an Energy Availability Factor (EAF) of 94[17], the water demand is ± 3.3 million m^3/annum.

The power station requires an assured reliable water source in order to generate sufficient energy to meet its demands. The Vaal River Eastern Sub-system augmentation project provides the water at an assurance of 99.5%, which equates to a once in 200 years failure of supply.

Cooling

The turbines at the proposed coal fired power station will be steam driven. The steam is produced using demineralised water, this water needs to be recovered in order to save water and due to the high costs involved with water treatment.

The steam from the turbines are a low pressure, high volumes, and at ± 40ºC. Condensation is required to recover the water. Condensation, or cooling, is achieved through condensers, cooling water, and (in most cases) cooling towers. Cooling water flows through condenser tubes with the steam on the outside. The resultant temperature difference between the steam and the cooling water allows for condensation.

In wet cooling systems the upward movement of air allows for a substantial amount of water to be lost as pure water vapour. A conventional wet-cooled power station loses ± 85% of the total water supplied to the power station through evaporation. In contrast dry cooling technology, although less efficient, does not rely on evaporative cooling. The water use is approximately 15 times lower than

[17] The power station produces full capacity 94% of the time.

wet cooled power stations. For this reason only dry cooled technology is considered for the proposed power station

Dry cooling systems comprise either direct or indirect cooling methods.

The **indirect system** also uses a cooling tower and water, however, the principle of operation is similar to that used in a car radiator. Heat is conducted from the water through A-frame bundles of cooling elements arranged in concentric circles inside the cooling tower. The cooling water flows through these elements, cools down as the cool air within the tower passes over the A-frame bundles. Once cooled the water is returned to the condenser. This is a closed system with no water loss due to evaporation.

The **direct system** allows steam from the last stage turbine blades to be channelled directly into radiator-type heat exchangers (no cooling towers). The heat is conducted from the steam to the metal of the exchanger.
Air passing through the exchanger is supplied by a number of electrically driven fans. The air removes the heat, thus condensing the steam back to water, which is reused in the boiler.

- The existing Kendal Power Station, located near the proposed power station, is an indirect dry cooled power station. The water consumption is in the order of 0.08 litres per kWh of electricity sent out. The indirect dry cooling, through indirect contact with air in the cooling towers, ensures that virtually no water is lost in the transfer of the waste heat.

- Matimba Power Station, near Lephalale, is an example of a direct dry cooled power station. Water consumption is in the order of 0.1 litres per kWh of electricity sent out (compared to 1.9 litres on an average wet cooled station).

Based on the need to conserve water in an area where the water supply to the power station is augmented from the Vaal Dam, it is envisaged that dry cooling will be implemented. Either indirect or direct dry cooling could be used as the water savings are similar, thus the impacts on the water resources will be similar.

8.5 Emission control technologies

If air quality predictions (modelling) regarding the proposed power station indicate an incremental impact on the air quality then Eskom will consider the feasibility of including sulphate dioxide reduction in their power station design.

An assessment of suitable flue gas emissions reduction technologies was conducted to determine the possible impacts and management of utilising these technologies with respect to the groundwater resources.

SOx control technologies

Sulphate dioxide (SO_2) is a result of coal combustion required for power generation. Emission removal techniques include the introduction of a sorbent to effectively remove SO_2.

Eskom assessed the various technologies based on the following criteria: -

- Resource availability (sea water or ammonia scrubbers are not viable due to availability)
- Proven technology (the technology must have a proven track record)
- Must comply to World Bank standards
- Must reach removal limits
- Risks using the technology must be low
- Must be economically viable

The most suitable flue gas desulphurization (FGD) technologies for the proposed power station include the use of wet or dry (semi-wet) scrubbers. These technologies allow for the introduction of calcium (Ca), which removes the SO_2 through the formation of calcium sulphite ($CaSO_3$) or calcium sulphate ($CaSO_4$).

The sources of the Ca include: -

- Lime (CaO) – unslaked lime
- Limestone ($CaCO_3$ and $MgCO_3$)
- Calcrete (precipitated calcite)
- Dolomite (limestone with magnesium carbonate ($MgCO_3$) greater than 8%)

Wet process

In the wet FGD process, flue gases are brought into contact with an absorber (scrubber). The SO_2 reacts with the Ca to form CaSO3 or $CaSO_4$ slurry.

Wet scrubbers are most widely used throughout the world and are proven to reach 99% SO_2 removal.

The Ca slurry sorbent allows for the removal of SO_2 through the reaction: -

$$CaCO_3 + SO_2 = CaSO_3 + CO_2$$

The calcium sulphite ($CaSO_3$) waste product can be oxidised to form gypsum (hydrated calcium sulphate ($CaSO_4$ – 2(H_2O)), which may have commercial value.

Alternatively the generated waste can be dewatered (for some water reclamation) and mixed with fly ash for deposition on a waste site. This process is water intensive.

Dry process

In a dry absorption system, only 60% of the water used in the wet process is required to dissolve or suspend the reacting chemical. This process does, however, have a higher chemical consumption and has lower efficiencies.

This technology is proven but not as popular as wet process FGD. The dry process is capable of 90% SO_2 removal.

This technology is more suitable to retrofit existing power stations but has high operational costs.

Typical dry scrubber processes include circulating fluid bed (CFB) or spray dry FGD. The CFB process is more beneficial as it has less moving parts and can remove 90% SO_2.

Comparison of processes

Water consumption for a typical 3 pack power station for achieving the World Bank (WB) and European Union (EU) standards are shown in Table 8.

Table 8: Water consumption comparison

Standards	Dry Process	Wet Process
EU	0.14 l/kWh	0.21 l/kWh
WB	0.097 l/kWh	0.147 l/kWh

l/kWh = litre per kilowatt-hour

The water consumption values indicate that the dry FGD process uses 35 % less water than the wet processes.

The wet process is, however, cheaper due to the higher costs of sorbents and the larger amount required in the dry process.

Waste

Both processes produce waste, either calcium sulphite ($CaSO_3$) or calcium sulphate ($CaSO_4$), which can be altered to form gypsum. Gypsum can have a commercial value.

The waste can be dewatered and the poor quality water reused until no longer suitable. This water will then have to be disposed on a waste (ash dump) site or in an evaporation dam.

The slurry can be mixed with fly ash and fixation lime (approximately 5%) and deposited on a landfill site.

Possible methodology regarding FGD slurry disposal includes: -

- Dewater the slurry waste
- Blend it with fly ash and fixation lime
- Deposit on an ash dump
- Or used as backfill in the old colliery workings (still to be ratified)

The potential for treating the $CaSO_3$ and $CaSO_4$ slurry to generate gypsum was investigated. The creation of gypsum is not considered viable due to: -

- The large volumes of gypsum that would be generated
- Limited or no local demand for gypsum
- The low gypsum price (< $50 / ton)
- Poor quality gypsum would be generated with no market (good quality is required)
- Eskom is in the power generation business, not gypsum / chemical industry

In addition, the gypsum is classified as a treated waste and would require a hazardous waste rating / classification. Based on the results it is assumed that the gypsum (and the power station ash) would have to be deposited on suitable licensed landfill sites, according to the Department of Water Affairs and Forestry's minimum requirements for waste disposal by landfill (DWAF, 1998).

The generation of gypsum would, therefore, require an additional licensed landfill site, for temporary storage before being sold, if possible.

Ash and FGD waste could be co-deposed on a single suitable waste disposal facility, which would be more environmentally acceptable.

The use of FGD technology on site will increase the impact on the groundwater environment due to the additional wet waste that will be generated. The waste will require a hazard rating, once the waste has been hazard classified the waste disposal site will be required to conform to the DWAF minimum requirements for waste disposal by landfill.

The correctly designed waste disposal facility will reduce the impact of the slurry waste and water on the groundwater resources.

The gypsum generated during the emissions reduction is classified as waste, as it is not excluded even though it is generated during the production of electricity. The classification of waste is not known at this point as no samples are available for TCLP testing. It is envisaged that metals may be collected during the FGD process, which could potentially leach form the gypsum dump / stock pile. This may result in a hazardous waste classification, requiring the necessary waste disposal permit, according to the Minimum Requirements (DWAF, 1998).

The gypsum can be stockpiled and sold. As there would be a continuous storage of gypsum on one specific site the stockpile area will require permitting. Typically waste that is not stored for longer than 90 days does not require a permit; however, according to the regulations as the site will be used continuously it requires permitting.

Should the gypsum be sold to farmers then a certificate is required from the Department of Agriculture stating that the gypsum is suitable for soil modification.

8.6 Impact summary

Based on the available data the following conclusions are made: -

- Borehole yields and groundwater potential within the proposed power station area are very low.
- Water levels in the boreholes adjacent to the power station and infrastructure can become elevated by 5 – 10 m because of infiltration (artificial recharge from water use on site). This can lead to waterlogged areas and seepage (day lighting) in shallow groundwater areas.
- Artificial recharge from the power station infrastructure can impact on the groundwater.
- The hydraulic response in the aquifer can be much faster than that of the spread of contaminants (water rise in the boreholes but there is no associated increase in salinity), the elevated water levels are thus not an indication of contamination rather recharge.
- Groundwater quality monitoring can indicate that the groundwater quality is variable and can contain elevated dissolved salts. The source of salinity can either be naturally occurring salt (released from impermeable lithologies exposed during drilling) or derived from pollution sources at the power station.
- Pollution plumes are envisaged to only extend over small areas / distances due to the poorly developed discrete aquifers.
- Persistent sources of contaminants can alter the hydrochemistry, causing an increase in dissolved solids and metals.

Recommendations regarding the power station

As Eskom are a large consumer of freshwater in the study area and the area is relatively water scarce, necessitating the need for inter-basin transfers (water augmentation from the Vaal River), the proposed power station must be designed, constructed, and operated to limit water consumption and to contribute to sustainable water use in the area.

Eskom have developed a Water Management Policy, which allows for the use of technology to ensure the beneficial use of water.

- **Dry cooling technology** – It is recommended that dry cooling must implement at the proposed power station, despite it being less efficient and more expensive (capital and operating). This will allow for effective water conservation when compared with wet cooling.

  Either indirect or direct dry cooling could be used as the water savings are similar, thus the impacts on the water resources will be similar.

- **Desalination** – Based on Eskom's policy of zero liquid effluent discharge (ZLED), water must be recycled from good to poor quality uses until all pollutants are finally captured as waste for disposal with the ash deposition. The objective is to dispose of the maximum mass of salts with the smallest possible volume of water without compromising the ability of the ash to encapsulate the salt load imposed (i.e. impacting on the ash's ability to form pozzolanic layers).

- **Water infrastructure** – Eskom are contributing (main contributor) to the pipeline linking the Vaal Dam to the water supply system at Kendal Power Station. This contribution plus monitoring and maintenance by Eskom will ensure water security for the project.

- **Water metering** – Eskom must ensure that their metering procedure, of water supplied to the proposed power station, must measure to a level of accuracy of 0.5%. Water and salt balances must be carried out once month to verify performance and identify potential problems.

  Leak detection and inspections, on site and along the pipelines, must be implemented.

- **Ash disposal** – Above ground ash disposal has the least risk to the groundwater resources as it can be effectively managed. In-pit and back-ashing should only be considered once Acid-Base Accounting has been conducted on the lithologies to be disturbed during mining. Ash could be considered as part of the back filling to assist in reducing the risk of Acid Mine Drainage at the mine.

- **FGD** – The use of FGD on site will significantly increase the volumes of water used at the power station. The generation of additional wet waste and the possible need for an additional waste disposal facility (gypsum dump) will increase negative impact of the power station on the groundwater resources.

Should Eskom be required to implement SO_2 emission reduction then the least water intensive process should be considered. FGD process evaluation conducted by Eskom indicates that dry FGD processes use ± 35% less water than the wet processes; however, there is a significant cost difference.

From a water resources perspective it is recommended that options that reduce water use and allow for recycling of water be used when reducing SO_2 emissions.

9 RISK ASSESSMENT

In order to assess the potential impacts of the proposed power station, associated infrastructure, and power generation activities on the groundwater environment, a risk assessment was compiled.

The risk assessment allowed for the identification of hazards associated with the proposed project, namely;

- The power station and ancillary infrastructure
- The use of flue gas desulphurization technology
- The disposal of ash

The possible impacts, magnitude (significance), probability, and duration were assessed in order to develop the optimum risk reduction and threat mitigation measures, which are to be included in the Environmental Management Plan (EMP) for the proposed power station.

9.1 Power station and associated infrastructure

Description of intention

It is the intention to construct a new power station and infrastructure in the vicinity of the existing Kendal Power Station in the Witbank area, Mpumalanga.

A risk assessment was compiled to determine the various threats posed by the proposed power station and infrastructure on the groundwater resources. The risk assessment aimed at providing information regarding the management of recognised risks and allowing for the optimum management to mitigate the risks.

Hazard identification

The hazards identified with the proposed power station and associated infrastructure are related to the use of water in the power generation process, the creation and storage of poor quality water and waste, and its impact on the groundwater environment.

These hazards include: -

- Poor quality water stored on site recharging the groundwater
- Artificial recharge impacting on groundwater
- Solid waste site
- Poor quality surface water on site
- Sewage facilities
- Fuel (bunker) oil
- Coal stockyard
- Chemical conveyance and storage

Please note:
- The risk assessment does not include surface water.
- The spent chemicals will, however, have to be co-deposited on waste (ash) dumps. This is discussed in Sections 8.3 and 9.3.

An estimation of the probability and magnitude of the consequences of the hazards

The probability and magnitude of the consequences of any or all of the identified hazards occurring has been estimated.

This exercise allows for the development of the correct management plan to be developed to ensure that the operation or process failure at the proposed power station and infrastructure that can lead to the hazard occurring is addressed. The correct management plans can reduce the possible negative impacts on the groundwater resources in the study area.

Table 9 provides a summary of the identified hazards, the consequences of the hazard becoming a reality, the probability of the hazard occurring, and the magnitude of these consequences.

A risk estimate

An estimation of risk for each hazard can be calculated based on the combination of the probability of the hazard occurring and the magnitude of the consequences of such a hazard becoming a reality.

The risk (R) is the product of the probability (P) and magnitude (M) of the given consequence.

A risk value for each hazard is calculated for comparison in order to determine the most serious hazard or threat.

The following values represent the various probabilities and magnitudes: -

PROBABILITY	**SCORE**	**MAGNITUDE**
High	5	Severe
Medium	3	Moderate
Low	1	Mild
Negligible	0	Negligible

Table 9: Hazards associated with power station infrastructure

Hazard	Consequences	Probability	Magnitude	Duration
Hazard 1 Poor quality water entering the groundwater	An alteration in the ambient groundwater quality. Contamination can move off site and impact on other users.	**Medium:** Poor quality recharge will occur through permeable soil and weathered material	**Moderate:** The cost of groundwater clean up is expensive. The plume migration is however expected to be localised	Will occur during operational phase Closure must allow for removal of all infrastructure (excluding ash dump)
Hazard 2 Artificial recharge to groundwater	Groundwater mounds created adjacent to raw water dams, alteration in groundwater flow patterns Mobilisation of salts with infiltration	**Medium:** Artificial recharge will occur through permeable soil and weathered material	**Negligible:** Limited zone of impact expected, very localised changes to groundwater flows	Will occur during operational phase Closure must allow for removal of all infrastructure (excluding ash dump)
Hazard 3 Poor quality run off from solid waste site	Contaminated run off water can recharge groundwater	**Low:** Limited rainfall run-off over small area. Area managed to prevent ponding of poor quality water	**Negligible:** Limited volumes of poor quality water	Will occur during operational phase Closure must allow for capping of site
Hazard 4 Poor quality surface water on site	Rainfall will form “dirty” run-off within the site and can leave site Ponding of poor quality can recharge groundwater	**Low:** Surface water controls, separating clean and dirty water, to be implemented Storm water controls to be put in place	**Mild:** Small volumes of poor quality surface water generated and limited drainage channels Topography will reduce ponding	Will occur during construction and operational phase Closure must allow for rehabilitation of topography
Hazard 5 Poor quality water associated with the sewage facilities	Seepage, spills or overflow can enter the groundwater and alter the hydrochemistry.	**Low:** Correctly designed and managed facility	**Moderate:** The cost of groundwater clean up is expensive. Existing groundwater use	Will occur during operational phase Closure must allow for removal of sewage infrastructure

Table 9 – Hazards associated with power station infrastructure (Page 2)

Hazard	Consequences	Probability	Magnitude	Duration
Hazard 6 **Fuel (bunker) oil in water migrating off site**	Oil in the recovery / surface water run-off dams, can overflow and add hydrocarbons to soil and groundwater	**Medium:** Oil is collected from existing recovery dams at similar power stations	**Mild:** Limited volumes of oil in the water expected, overflow during rainfall events can occur	Will occur during operation phase only
Hazard 7 Coal stockyard	Seepage from the wet coal can recharge the groundwater Acid mine drainage (AMD) can occur associated with the coal	**Medium:** Wet coal if stockpiled on bare ground with no lining will impact on the groundwater Temporary piles reduces constant contaminant source	**Moderate:** Coal on stockpile, < 37 mm size, thus low permeability	Will occur during operation phase only
Hazard 8 Chemical conveyance and storage	Regeneration effluents in un-protected concrete can have potential disastrous implications for concrete and groundwater through seepage	**Low:** Acid proofing with tiles and coatings is utilised and inspected annually	**Severe:** Failures of sumps and trenches can injure personnel and impact on environment	Will occur during operation phase only

For the eight (8) recognised hazards, the risk estimates are: -

Hazard 1: Poor quality water entering the groundwater
Risk = Medium probability (3) x Moderate magnitude (3) = 9

Hazard 2: Artificial recharge to groundwater
Risk = Medium probability (3) x Negligible magnitude (0) = 0

Hazard 3: Poor quality run-off from solid waste site
Risk = Low probability (1) x Negligible magnitude (0) = 0

Hazard 4: Poor quality surface water on site
Risk = Low probability (1) x Mild magnitude (1) = 1

Hazard 5: Sewage facility
Risk = Low probability (1) x Moderate magnitude (3) = 3

Hazard 6: Fuel oil
Risk = Medium probability (3) x Mild magnitude (1) = 3

Hazard 7: Coal stockyard
Risk = Medium probability (3) x Moderate magnitude (3) = 9

Hazard 8: Chemical conveyance and storage
Risk = Low probability (1) x Severe magnitude (5) = 5

The groundwater risk assessment has identified artificial recharge from pollutant sources as having the most significant hazard on the groundwater resources. Any proposed potential persistent source of contamination will therefore have to be designed and managed to reduce this risk / threat.

Risk evaluation

The risk evaluation allows for the determination of the significance of the impact should the hazard be realised.

Hazard 1: Poor quality water recharging the groundwater

If poor quality water, impounded in the sewage ponds, evaporation dams, and recovery dams, enters the groundwater the significance of the impact on the groundwater will depend on the quality of the recharging water and the volumes involved.

The significance of the hazard being realised will be reduced due to the limited groundwater resources on site[18] due to the low aquifer properties associated with the geology (low yielding boreholes).

Limited groundwater use and the slow possible pollution plume migration indicate reduced impacts.

[18] The site selection study conducted from a groundwater perspective indicates that the proposed power station and ancillary infrastructure should be located on the Dwyka tillite and shale, which have poor groundwater resources and potential.

Hazard 2: Artificial recharge to groundwater

Seepage or overflow from the raw water dam can artificially recharge the groundwater immediately adjacent to the dam(s). The significance of this impact will depend on the quality of the raw water and the volumes involved.

The significance of the hazard being realised will be reduced by: -

- The localised impact area (limited discrete aquifers)
- Good recharge (dilution) due to regular high rainfall (MAP = 667 mm/year)

Hazard 3: Poor quality run-off from solid waste site

The significance of this threat will depend on the volume of poor quality water generated within the solid waste area and whether this water can leave site or recharge the groundwater.

The expected volumes, due to the envisaged waste site size and design / construction, will be limited thus the significance of this threat being realised is reduced.

Hazard 4: Poor quality surface water on site

The significance of this threat will depend on the volume of "dirty" water generated on site and whether this water can recharge the groundwater.

The expected volumes will be limited as ponding will be reduced due to the site topography.

The significance of this threat being realised is moderate.

Hazard 5: Sewage system

It is envisaged that a new plant will be constructed at the power station.

Utilising a correctly designed, sized, and constructed facility will reduce the significance of this threat.

Hazard 6: Fuel oil

The significance of this threat, if realised, is high should poor quality water migrate off site and impact on down gradient users. The volumes of oil expected are small and thus the risk is reduced.

Hazard 7: Coal stockyard

There is a probability that the wet coal can impact on the groundwater if the stockyard is not lined.

The significance of this threat, if realised, is moderate should poor quality water migrate off site as the possible plume migration will be slow.

Hazard 8: Chemical conveyance and storage

The probability of the chemicals being stored in un-protected concrete is remote as the risk of structural failure is too high.

The significance of the threat, if realised, is high as the regeneration chemicals, caustic soda and sulphuric acid, could impact on human health and the environment.

Overall risk assessment

The risk estimate and risk evaluation for each of the eight (8) hazards is combined to obtain an overall risk assessment.

Hazard 1: Poor quality water recharging the groundwater

The probability of poor quality water recharging the groundwater is moderate if the “dirty” water dams are not lined. Groundwater mounds will form adjacent to the dams and pollution plumes will form.

The significance and magnitude of the hazard being realised is reduced due to the limited groundwater use on and adjacent to the sites and the possible pollution plume migration will be limited due to the poor aquifers underlying the site.

The overall risk assessment for this hazard on the groundwater is **TOLERABLE**.

Hazard 2: Artificial recharge

The probability of artificial recharge, from a raw water dam, occurring is moderate as the underlying soil and weathered material is permeable. The impact will, however, be localised as the aquifers in the areas are poorly developed.

The magnitude of the consequences of the hazard becoming reality is mild as the volumes of recharge will be limited and the raw water may have a positive impact on the groundwater.

The overall risk associated with this hazard is **TOLERABLE**.

Hazard 3: Poor quality run-off from solid waste site

The threat posed by poor quality run-off is reduced due to the envisaged waste site size and construction (to prevent surface water ponding).

The significance of this threat will be reduced due to the limited volumes of poor quality water envisaged.

The overall risk assessment for this hazard on the groundwater or surface water is **TOLERABLE** but adequate storm water controls are required to ensure the management of any poor quality water generated at the solid waste site.

Hazard 4: Poor quality surface water on site

The threat posed by poor quality run-off depends on the volumes involved and whether ponding will occur. The significance of this threat is recognised to be mild as the volumes of poor quality water will be limited and the engineered site topography will reduce ponding of poor quality surface water.

The overall risk assessment for this hazard on the groundwater is **TOLERABLE** but adequate storm water controls, separation of clean and dirty water, and leveling are required to ensure the management of any poor quality surface water.

Hazard 5: Sewage facility

Seepage or overflow of poor quality water at the sewage facility may occur but the impact on the groundwater system within the study area will be limited due to poor aquifers, natural attenuation (long travel times to groundwater), intermittent contamination from overflows, and correct design and management.

The overall risk assessment for this threat is **TOLERABLE**. Eskom must ensure that the sewage system is correctly managed and maintained.

Hazard 6: Fuel oil

The severity of oil entering the surface or groundwater is high based on the cost and difficulty in remediating the organic contaminants. The limited volumes of waste oil expected plus the implementation of oil traps and separators will ensure that the overall risk associated with this threat is **TOLERABLE**.

Hazard 7: Coal stockyard

There is a probability that the wet coal stockpiled for use at the power station can recharge the groundwater. Water quality associated with the coal may have low pH and elevated sulphate concentrations (AMD).

The coal, however, is fine (< 37 mm) having reduced permeability and is moved regularly.

The overall risk associated with the coal stockyard is **TOLERABLE** but will require management to ensure limited impacts on the groundwater.

Hazard 8: Chemical conveyance and storage

All hazardous rated chemicals and chemical effluents will be stored and transported in protected (lined with tiles and coatings) concrete. Thus the probability of seepage from these structures is low.

The consequence of concrete corrosion can have potential disastrous implications to human health and the groundwater environment should leaks occur.

The overall risk is seen as **TOLERABLE** assuming that the design and construction of the concrete sumps and trenches include acid proofing and that the structures are inspected annually by a recognised specialist.

The risk assessment regarding the proposed power station and infrastructure **did not identify any intolerable risks** to the groundwater resources. Management is, however, required to ensure that the proposed power generation project will not impact negatively on the groundwater resources during operations and after closure. These risk reduction plans are discussed in Section 10.

9.2 FGD Technology

An assessment of the risks associated with using FGD technology with regards to water resources[19] was conducted to assist in making decisions and management plans.

The hazards identified with the use of FGD technology at a power station are related to the use of water in the emissions reduction process, the creation and storage of poor quality water and waste, and its impact on the groundwater environment.

These hazards include: -

- Increased water demand
- Poor quality water stored on site recharging the groundwater
- Wet waste disposal
- Removal of surface water from catchment
- Gypsum temporary stockpile

Please note that this preliminary risk assessment only assess possible impacts / threats to the water resources. No consideration for the hazards of calcium (which will be used as a sorbent) mining at source, transport, material and waste handling, or economic impacts (increased power costs) have been included.

An estimation of the probability and magnitude of the consequences of the identified hazards

The probability and magnitude of the consequences of any or all of the identified hazards occurring has been estimated, allowing for the development of the correct management plan to be developed to ensure that the operation or process failure that can lead to the hazard occurring is addressed.

Table 10 provides a summary of the identified hazards, the consequences of the hazard becoming a reality, the probability of the hazard occurring, and the magnitude of these consequences.

[19] Surface water was included as FGD uses large volumes of water, which will be sourced from the Vaal River

Table 10: Hazards associated with FGD

Hazard	Consequences	Probability	Magnitude	Duration
Hazard 1 Increased water demand	Reduction of surface water for development in the Vaal River Eastern Sub-system Impact on downstream users within the Vaal River	**High:** Eskom is of a strategic importance to RSA so water will be made available for power generation	**Moderate:** The water augmentation scheme will ensure that the impact of increased water use by Eskom is minimised	The high water use, should FGD be implemented, would occurring during the operational phase of the power station
Hazard 2 Poor quality water stored on site recharging the groundwater	FGD waste will be dewatered and the poor quality water stored on site for reuse in the FGD process	**Medium:** Artificial recharge will occur through permeable soil and weathered material	**Mild:** Limited zone of impact, localised changes to groundwater resources	Artificial recharge will only occur during the operational phase
Hazard 3 Wet waste disposal	Contaminated water associated with the waste can recharge groundwater and run off site and impact on surface water	**High:** The wet waste will have the potential for leachate generation which could migrate into the underlying aquifers or form run-off and migrate off site	**Moderate:** The poor quality leachate can contain heavy metals[20] and high dissolved solids content, which will impact on the ambient water qualities The waste must be deposited on a correctly designed waste disposal facility	Leachate generation will occur during the operational phase and can continue after closure.

[20] Eskom's research indicates heavy metals can be concentrated within the FGD slurry

Table 10: Hazards associated with FGD (Page 2)

Hazard	Consequences	Probability	Magnitude	Duration
Hazard 4 Removal of surface water from catchment	The water used in the FGD process will become of such poor quality that it has to be deposited on a waste site, thus the water cannot be treated and returned for use in the catchment	**High:** The water used in the FGD processes cannot be treated for discharged back into the river	**Moderate:** The study area is located within a water scarce area and any loss of water impacts on other possible developments within the catchment. The augmentation of the surface water resource will reduce the impact	High water use for FGD will only occur during the operational phase
Hazard 5 Gypsum temporary stockpile	Gypsum manufacturing will require stockpiling according to minimum requirements as it has the potential to impact negatively on the groundwater and environment	**Low:** Gypsum manufacture is not commercially viable for Eskom	**Mild:** Any temporary stockpiling of gypsum must take place on a correctly designed waste disposal facility	Gypsum generation will only occur during the operational phase

A risk estimate

An estimation of risk for each hazard was calculated based on the probability of the hazard occurring and the magnitude of the consequences of such a hazard becoming a reality.

A risk value for each hazard is calculated for comparison in order to determine the most serious hazard or threat (the calculations are based on the values presented in Section 9.1).

For the five (5) recognised hazards, the risk estimates are: -

Hazard 1: Increased water demand
Risk = High probability (5) x Moderate magnitude (3) = 9

Hazard 2: Poor quality water stored on site recharging the groundwater
Risk = Medium probability (3) x Negligible magnitude (0) = 0

Hazard 3: Wet waste disposal
Risk = High probability (5) x Mild magnitude (1) = 5

Hazard 4: Removal of surface water from catchment
Risk = High probability (5) x Moderate magnitude (3) = 15

Hazard 5: Gypsum temporary stockpile
Risk = Low probability (1) x Mild magnitude (1) = 1

The risks associated with the use of additional surface water in the water stressed / scarce environment have the highest threats, and will require effective management.

Risk evaluation

The risk evaluation allows for the determination of the significance of the impact should the hazard be realised.

Hazard 1: Increased water demand

An increase in water demand for the proposed power station will reduce the amount of water in the study area. As the power station requires an assured supply of 99.5% (Section 8.4) a large volume has to be set aside by DWAF to obtain the assurance. This volume further reduces the amount of water available for development in Vaal River Eastern Sub-system area.

The Vaal River Eastern Sub-system augmentation project will reduce the impact on downstream users and any other proposed water intensive developments within the study area.

Hazard 2: Poor quality water recharging the groundwater

If poor quality water, dewatered from the slurry waste for reuse, is collected in a holding dam or disposed of on the waste (ash) dump or in an evaporation dam, enters the groundwater the significance of the impact on the groundwater will depend on the quality of the recharge water and the volumes involved.

The significance of the hazard being realised will be reduced due to the limited groundwater resources on site due to the poor aquifer properties of the underlying geology.

Little or no groundwater use or users are located within the proposed preferred area and due to the envisaged retarded pollution plume migration reduced impacts are expected.

Hazard 3: Wet waste disposal

Seepage or overflow from the wet waste disposed on the waste disposal site can artificially recharge the groundwater immediately below and adjacent to the waste site. The significance of this impact will depend on the quality of the waste water and the volumes involved.

The significance of the hazard being realised will be reduced by: -

- The localised impact area
- The variable natural hydrochemistry

Hazard 4: Removal of surface water from the catchment

Large volumes of water (Table 8) will be required to ensure the FGD processes achieve World Bank or European Union standards with regards to SO_2 emissions removal. This water can be recycled from the slurry waste and returned to the FGD process. The water will, however, with time become unusable in the FGD process.

Without expensive treatment this water has to be disposed of on a waste disposal site (possibly through irrigation to enhance evaporation) or into an evaporation dam. This water can not be returned to the catchment for use downstream.

Hazard 5: Gypsum temporary stockpile

In theory the FGD process waste can be converted to gypsum, which could be sold. In practice the gypsum will be of poor quality and have a limited market. Should gypsum be manufactured at the power plant then it will require storage on a separate landfill site so that it can be removed and sold.

The need for a second waste disposal facility increases the negative impacts associated with the disposal of wet waste (Hazard 3). This hazard is reduced as the likelihood of Eskom storing and selling gypsum on site is remote.

<u>Overall risk assessment</u>

The risk estimate and risk evaluation for each of the five (5) hazards is combined to obtain an overall risk assessment.

Hazard 1: Increased water demand

The FGD process is water intensive which will require DWAF to allocate more water to Eskom in a water scarce area. The possible increased water requirements by Eskom, for FGD, are expected to be met with opposition from the Interested and Affected parties in the study area.

Large volumes of water will have to be assigned to Eskom to achieve the 99.5% assurance in supply; this reduces the amounts of water available in the area for additional developments which can impact on the regional economy.

As power generation is of national importance as well as the need to protect the environment, it is recognised that the overall risk is **TOLERABLE**; however, the optimum FGD process must be selected if it is to be employed. Management procedures (water recycling) and implementing less water intensive technology are required to ensure the negative impacts are reduced.

Hazard 2: Poor quality water recharging the groundwater

The probability of poor quality water recharging the groundwater is moderate if the “dirty” water dam or waste disposal site is not lined. Groundwater mounds will form adjacent to the persistent pollution sources, which will allow for the migration of pollution plumes.

The significance and magnitude of the hazard being realised is reduced due to the limited groundwater use on and adjacent to the proposed power station site and the possible pollution plume migration will be limited due to the discrete low yielding aquifers associated with the geology.

The overall risk assessment for this hazard on the groundwater is **TOLERABLE**.

Hazard 3: Wet waste disposal

Wet slurry waste will be generated during the FGD process. This waste can be dewatered and reused in the FGD process. The waste will, however, contain a certain amount of water to allow for disposal.

The water quality will be impacted on by the FGD process and the waste will have the potential to generate leachate, which could potentially recharge the groundwater.

The probability of this is low as the waste must be deposited on a correctly designed (DWAF minimum requirements) waste disposal site. The volumes, after dewatering or associated with dry FGD processes, will not be significant.

Recycled water, when unsuitable for use, can be irrigated on the waste pile so as to improve evaporation and reduce the leachate potential.

The overall risk assessment for this hazard on the water resources is **TOLERABLE** if correctly managed.

Hazard 4: Removal of surface water from the catchment

Water used in the FGD process will become unsuitable for use and will have to be disposed of on a waste disposal site. This will result in water loss from the catchment. DWAF will augment the water resources in this water scarce area.

The overall risk assessment for the surface water loss is **TOLERABLE**; however, management of the water is required to ensure the recycling of water.

Hazard 5: Gypsum temporary disposal

Temporary stockpiling of gypsum on site will have a negative impact as it will require an additional waste disposal facility.

The overall assessment of this hazard is **TOLERABLE** as the gypsum would be piled on a correctly designed waste storage facility.

The impacts of FGD on the groundwater resources are tolerable as long as threat mitigation measures are in place to minimise the impact of possible artificial recharge, with poor quality water.

The increased use in water resources will have a negative impact and the removal of additional water from the Vaal River requires investigation (out side the scope of this study).

Management options, monitoring recommendations, and mitigation measures are presented in Section 10.

9.3 Ash disposal

A preliminary assessment of the risks associated with the three methods of ash (and co-disposed effluents) disposal (as discussed in Section 8.3) with regards to groundwater resources was conducted as limited geochemical data is available regarding the ash, effluents, mine lithologies, and mine rehabilitation plans. The risk assessment aims at providing preliminary input into decision making regarding ash disposal from a groundwater perspective.

The risk assessment assesses the potential impacts each of the three proposed ash disposal methods, namely; above ground, back-ashing, and in-pit ashing, will have on the groundwater regime.

An estimation of the probability and magnitude of the consequences of the hazard(s)

The probability and magnitude of the consequences to the groundwater regime has been estimated.

This exercise allows for a preliminary assessment of possible ash disposal and highlights the need for geochemical testing and modelling to ensure the optimum ash disposal method is developed for the project.

Table 11 presents a summary of the hazards (including probability and magnitude) associated with each of the proposed ash disposal methods.

A risk estimate

An estimation of risk for each proposed ash disposal method was calculated based on the combination of the probability of the hazard occurring and the magnitude of the consequences of such a hazard becoming a reality.

The risk (R) is the product of the probability (P) and magnitude (M) of the given consequence (see Section 9.1).

Hazard 1: Above ground - Seepage below ash dump

Risk = High probability (5) x Moderate magnitude (3) = 15

Hazard 2: Back-ashing – Persistent contamination

Risk = Medium probability (3) x Moderate magnitude (3) = 9

Or = Medium probability (3) x Severe magnitude (5) = 15

Hazard 3: In-pit ashing – Mobilisation of contaminants

Risk = High probability (5) x Severe magnitude (5) = 25

Table 11: Hazards associated with ash disposal

Hazard	Consequences	Probability	Magnitude	Duration
Above ground ash disposal				
Hazard 1 Seepage below ash dump	Contaminated water can alter the groundwater quality. The contaminated groundwater can impact on other users.	**High:** Existing unlined ash dumps are recognised to impact on groundwater, a new dump would have the same impact if unlined Initial ash disposal will have high seepage rates from transport water and precipitation Fly ash and resultant pozzolanic layers reduce permeability and reduce leaching	**Moderate:** The cost of groundwater clean up is expensive. The plume migration will be slow and localised Attenuation and dilution will occur and the slow travel times (attenuation) will reduce the threat.	During the operational phase and closure, until rehabilitation stops recharge into dump
Back ashing				
Hazard 2 Long term impacts of persistent contamination sources	TCLP tests indicate that metals and salts can be leached from the ash Ash dump can act as a persistent source of contaminants which can alter the groundwater quality.	**Medium:** The top soil on top of ash will reduce the recharge into ash Ash is returned on top of overburden and may not be in direct contact with groundwater	**Moderate:** If the groundwater levels do not rebound into the buried ash, leaching will only occur through reduced rainfall recharge Severe: Should AMD from the colliery enter the ash there the low pH water can mobilise metals and salts from the ash which can migrate off site and impact on users	During rehabilitation of the mine voids and after closure

Table 11 Hazards associated with ash disposal (Page 2)

Hazard	Consequences	Probability	Magnitude	Duration
In-pit ashing				
Hazard 3 Mobilisation and migration of metals and solids	Ash would be in contact with low pH water as a result of oxidation of sulphides in the pit. Depending on the buffer capacity of the ash, metals and salts can be leached from the ash	**High:** TCLP results indicate that low pH water can cause the leaching of metals and salts from the ash	**Severe:** Once groundwater levels rebound and groundwater flow patterns allow flow from the mine then the low pH water can mobilise metals and salts from the ash which can migrate off site and impact on users	During rehabilitation of the mine voids and after closure. Indications are that the voids would have to be flushed several times before contamination concentrations will decrease / stop

Disposal of ash in a low pH water environment has the highest risk to the groundwater regime. All three disposal methods can have negative impacts on the groundwater regime and, therefore, need managing.

Risk evaluation

The risk evaluation allows for the determination of the significance of the impact should the hazard be realised.

Hazard 1: Above ground - Seepage below the ash dump

There is a high probability that a new ash dump will impact on the groundwater if the ash dump is not lined, especially during the initial ash disposal onto bare rock.

The significance of this threat, if realised, is high should poor quality water migrate off site and potentially impact on down gradient users.

Hazard 2: Back-ashing - Long term impacts of persistent contamination source

Should the ash be deposited into the old open cast workings, such that the ash is not in direct contact with the low pH mine water then the risk associated with the leaching of metals and salts from the ash is reduced.

Should the groundwater rebound (after mining ceases) into the ash pile, leaching can occur. Seasonal rise and decline of groundwater levels could expose the ash to oxygen and mine water, which could increase the leaching of the ash over a long period of time.

Rebound of groundwater levels after mining will facilitate the migration of contaminants from the old workings. The significance of this threat is significant as pollution plumes can impact on surrounding groundwater users and resources.

Hazard 3: In-pit ashing - Mobilisation and migration of metals and solids

TCLP tests indicate that metals and salts mobilise from the ash in low pH water. The mine water associated with the old open cast workings is expected to be at a low pH due to the oxidation of sulphides within the geological units (coal, carbonaceous shale, etc.). The buffer capacity is recognised to decrease with time, thus the elements can be mobilised from the ash as additional low pH water enters the ash over time.

Thus the risk of groundwater contamination is significant.

Overall risk assessment

The risk estimate and risk evaluation for each of the three ash disposal methods is combined to obtain an overall risk assessment.

Hazard 1: Above ground - Seepage below the ash dump

The probability of poor quality water recharging the aquifer(s) below a new unlined ash dump is high, especially during the initial deposition. The magnitude and significance of the impact of artificial poor quality recharge on the groundwater will be moderate due to the low infiltration rates, slow plume migration, and the implementation of the correct drainage or lining.

The overall risk associated with this hazard is: -

- **HIGH** if the new ash dump is unlined,
- **TOLERABLE** if the ash is deposited on a lined ash dump or on an ash dump which is designed to incorporate a drainage system

Hazard 2: Back-ashing - Long term impacts of persistent contamination source

The volumes of leachate generated when the ash is used as back fill for the old open cast voids depends on where the ash is deposited in relation to the pre-mining groundwater levels. Assuming the groundwater rebounds to the pre-mining levels and the ash is above this level then only rainfall recharge water (through the re-vegetated top soil). The potential volumes of leachate generated would be **TOLERABLE**, assuming the rehabilitation was correct.

Ash disposed within the groundwater would be leached causing deterioration of the groundwater and pollution plumes. Seasonal groundwater level fluctuations within the ash would provide a persistent source of contaminants leached from the ash. Groundwater rehabilitation (such as scavenger wells) would be required to manage this impact.

Uncontrolled acid mine generation and discharge is **INTOLERABLE**, especially if back-ashing has cause a further deterioration in the groundwater quality.

Hazard 3: In-pit ashing - Mobilisation and migration of metals and solids

The preliminary risks associated with in-pit ashing are **HIGH** due to the leaching and mobilisation of metals and salts from the ash in low pH water.

Geochemical analyses on the lithologies, overburden, and ash plus geochemical modelling is required to determine the actual impact of in-pit ashing. The risks associated with this type of ash disposal in terms of groundwater remediation (cost and difficulty) would require careful consideration before implementation.

There are risks to the groundwater with each of the three ash disposal methods. From a groundwater perspective the above ground ash disposal has the least risk as management / mitigation measures can be implemented to safe guard the groundwater regime (Section 10).

PHASE III EMP Input

10 RISK MANAGEMENT

Based on the hazard identification and risk assessment, mitigation measures have been compiled to reduce the impacts of the power station and ancillary infrastructure, the FGD, and the ash disposal.

The development and implementation of threat reduction measures as well as implementing the power station recommendations (Section 8.6) will allow for the optimum management procedures with regards to the impact of power generation on the groundwater regime.

10.1 Mitigation methods

Power station and ancillary infrastructure

Hazard 1: Poor quality water entering the groundwater

Geophysical surveys, comprising magnetics and electromagnetics, must be conducted during dam site selections, to ensure that the dams are not located on underlying geological structures, which can act as preferential flow paths.

Existing boreholes should be used, up and down gradient of the power station where possible, else new ± 20 m monitoring boreholes must be constructed. All existing boreholes located within the power station and ancillary infrastructure footprint must be backfilled using a cement – bentonite slurry so as to prevent direct migration of potentially poor quality water into the aquifers.

Monitoring should begin one year prior to the start of construction.

The dams must be correctly sized (to prevent overflow) and constructed to have a low permeability base. This will reduce infiltration.

Groundwater levels and quality must be monitored on a regular basis. It is recommended that this is conducted quarterly at first and then reduced to bi-annually with time.

Hazard 2: Artificial recharge to groundwater

The monitoring and management for artificial recharge is the same as for Hazard 1 above.

Management (of water volumes kept in the dams) and maintenance of the dams, pipelines, and channels is required to minimise the volumes of water than can be “lost” to the groundwater.

This must begin at the start of operations and continue for the life of the project.

Hazard 3: Poor quality run-off from the solid waste site

In order to prevent clean water run-off from being contaminated by on-site “dirty” areas clean and dirty run-off separation controls, comprising berms and furrows, must be installed on site, especially around the waste site(s).

The run-off controls must allow clean water to continue across the site without becoming contaminated. These controls are to be installed during the construction phase and maintenance of these controls during the life of the operations must be implemented.

The gradients of the controls and disturbed areas must be ensured to prevent ponding of water on site. This will reduce the risk of artificial recharge.

Poor quality run-off from the waste area must be diverted into a lined evaporation or recovery dam.

Hazard 4: Poor quality surface water on site

The monitoring and management for poor quality surface water on site is the same as for Hazard 3 above.

Surface water run-off from disturbed areas, which is deemed to be “dirty” cannot leave the site or be allowed to pond / accumulate in an unlined area. This will ensure that the water resources and down gradient / stream users are not impacted upon.

Poor quality water, not suitable for use in the power generation activities, could be used for irrigation (lawns, rehabilitated areas, etc.) if suitable. Water quality will require monitoring.

Monitoring should begin some six months prior to the start of construction.

Hazard 5: Sewage facility

A correctly sized, designed, and managed sewage facility will ensure that the possible impact on the groundwater will be reduced.

Groundwater monitoring boreholes are required down gradient of the sewage infrastructure. Groundwater quality should be monitored on a quarterly basis.

Groundwater monitoring should begin six months before the sewage plant is put into operation.

Hazard 6: Fuel oil

Oil may be present in the water within the recovery dams, due to spills or leaks on site. The water then requires treatment prior to being used on site, as possible irrigation water.

To reduce the probability of oil entering the water system, the following recommendations are made: -

- Contain all oil storage facilities within a bunded area
- Ensure correct protocols regarding clean up of spills or leaks
- All recovery dams to be equipped with oil separators
- Accurate records of oil volumes, purchased, disposal, and recycled

The mitigation measures must be included in the design phase and regular water sampling for LNAPL (light non-aqueous phase liquids) should be done bi-annually once the power station is in operation.

Hazard 7: Coal stockyard

There is a probability that water associated with the wet coal stockpiled for use at the power station can recharge the groundwater.

Direct rainfall, rainfall run-off, and seepage from the coal stockyard can be a source of artificial recharge to the groundwater, and poor quality run-off could migrate off site.

To minimise the impact of the coal stockyard on the water resources, the following mitigation measures must be implemented: -

- Place the coal on a clay-lined base
- Separate clean and dirty run-off, minimise coal stock piles and size of the stockyard
- Install and maintain surface water controls, including berms and furrows
- Slope the topography to prevent ponding of surface water
- Install monitoring boreholes to monitor water levels and quality

The mitigation measures must be included in the design phase and groundwater sampling should begin six months before coal is piled on site.

Hazard 8: Chemical conveyance and storage

The conveyance and storage of hazardous chemicals and effluents must be through or in acid proofed infrastructure, including tiles and coatings, concrete channels, trenches, and sumps.

The chemicals are to be stored in above ground storage tanks located within suitable secondary containment (bunded) areas.

All acid proofed infrastructures must be inspected annually by a qualified person (civil engineer). Recommendations with respect to repair procedures must be compiled and conducted by a recognised specialist.

Effluent disposal measures are discussed under the ash disposal section below.

The acid proofing and suitable material selection must be conducted during the design phase.

Table 12 contains a summary of the risk assessment, including hazards, consequences, probabilities, overall risks, and management actions required.

Table 12: Power station and infrastructure risk management summary

Hazard	Consequences	Probability	Overall risk	Management options
Hazard 1 Poor quality water entering the groundwater	An alteration in the ambient groundwater quality Contamination can move off site and impact on other users	**Medium:** Poor quality recharge will occur through permeable soil and weathered material	Risk is reduced due to limited groundwater use and potential, and localised impacts The overall risk is **TOLERABLE**	• Geological assessment • Backfill existing boreholes • Ensure sufficient capacity, prevent spillage / overflow • Construct lined dams, investigate for local clay • Monitor groundwater quality and water levels • Monitor neighbouring boreholes • Monitor up and down gradient of power station and infrastructure
Hazard 2 Artificial recharge to groundwater	Groundwater mounds created adjacent to raw water dams, alteration in groundwater flow patterns Possible mobilisation of salts with infiltration	**Medium:** Artificial recharge will occur if the dam is unlined	Limited volumes of recharge with a localised impact Artificial recharge may have positive impact Overall risk is **TOLERABLE**	• Ensure sufficient capacity and prevent • Clay base to minimise seepage • Install a down gradient monitoring borehole to monitor quality and water levels
Hazard 3 Poor quality run off from solid waste site	Contaminated run off water can recharge groundwater	**Low:** Limited rainfall run-off over small area. Area managed to prevent ponding of poor quality water	Limited volumes of poor quality water are envisaged due to small area. Overall risk is **TOLERABLE** providing water controls are installed	• Install clean and dirty run-off separation controls • Ensure gradients to prevent ponding • Poor quality water to be diverted to lined recovery dams

Table 12: Power station and infrastructure risk management summary (Page 2)

Hazard	Consequences	Probability	Overall risk	Management options
Hazard 4 Poor quality surface water on site	Rainfall will form "dirty" run-off within the site and can leave site Ponding of poor quality can recharge groundwater	**Low:** Surface water controls, separating clean and dirty water, to be implemented	The volumes of poor quality water will be limited Overall risk is **TOLERABLE** providing storm water and separation controls are installed	• Separate clean and dirty run-off, • Minimise disturbed areas • Install and maintain controls, including berms and furrows • Slope topography to prevent ponding • Monitor the water quality if used for irrigation
Hazard 5 Sewage facility	Seepage, spills, or overflow can enter the groundwater and alter the hydrochemistry.	**Low:** The facility must be correctly designed and managed	Poor quality water seepage or overflow may occur but the impact will be localised due to poor aquifers The overall risk assessment for this threat is **TOLERABLE**.	• Correctly sized, designed and constructed facility • Groundwater monitoring down gradient of sewage infrastructure
Hazard 6 Fuel (bunker) oil in water migrating off site	Oil in the recovery / surface water run-off dams, can overflow and add hydrocarbons to soil and groundwater	**Medium:** Oil is collected from existing recovery dams	Costly and difficult to clean up, however, only small amounts envisaged The overall risk is **TOLERABLE** if oil management measures are in place	• Contain oil in bunded area • Ensure clean up protocols in place and followed • Install oil traps and separators • Keep accurate oil records (purchased, disposal, and recycled)

Table 12: Power station and infrastructure risk management summary (Page 3)

Hazard	Consequences	Probability	Overall risk	Management options
Hazard 7 Coal stockyard	Seepage from the wet coal can recharge the groundwater AMD can occur associated with the coal	**Medium:** Wet coal if stockpiled on bare ground with no lining will impact Temporary piles reduces constant contaminant source	The overall risk associated with the coal stockyard is **TOLERABLE** but will require management to ensure limited impacts on the groundwater.	• Construct clay / low permeable base • Separate clean and dirty run-off • Minimise coal stock piles and size of yard • Install and maintain surface water controls • Slope topography to prevent ponding • Monitor groundwater levels and quality
Hazard 8 Chemical conveyance and storage	Regeneration effluents in un-protected concrete can have potential disastrous implications for concrete and groundwater through seepage	**Low:** Acid proofing with tiles and coatings is utilised and inspected annually	The overall risk is seen as **TOLERABLE** assuming that the design and construction of the concrete sumps and trenches include acid proofing and that the structures are inspected annually by a recognised specialist.	• Acid proofing including tiles and coatings • ASTs and bunded areas • Annual inspections • Repairs using a recognised specialist

10.2 FGD Technology

Hazard 1: Increased water demand

Should Eskom be required to implement SO_2 emission reduction then the least water intensive process should be considered.

FGD process evaluation conducted by Eskom indicates that dry FGD processes use ± 35% less water than the wet processes; however, there is a significant cost difference.

From a water resources perspective it is recommended that options that reduce water use and allow for recycling of water be used when reducing SO_2 emissions.

Hazard 2: Poor quality water recharging the groundwater

Although the area has limited groundwater resources, usage or potential, groundwater flow through these rocks, although imperceptible, does take place. The holding or evaporation dams, required in FGD, can provide a source of persistent pollutants, which will impact negatively on the groundwater regime with time.

In order to reduce the risk of poor quality water entering the groundwater the following measures should be employed: -

- Assess underlying geological structures prior to positioning of the dams
- Backfill and seal any existing boreholes (production or exploration) prior to construction
- Design dams to ensure sufficient capacity
- Construct dams to minimise seepage, i.e. lined dams
- Install monitoring boreholes and monitor groundwater quality and water levels
- Monitor neighbouring down gradient users

The geophysical surveys should be conducted during the design phase. Monitoring should begin six months before FGD is implemented.

Hazard 3: Wet waste disposal

The optimum recycling techniques must be employed to ensure that the maximum amount of water, for recycling, can be removed from the waste.

The disposal methodology must be examined to ensure that the waste with the smallest amount of moisture can be economically deposited on the waste pile.

Monitoring of groundwater down gradient of the waste site must be monitored. Monitoring should begin six months before FGD is implemented.

Hazard 4: Removal of surface water from the catchment

The optimum FGD process must be considered to ensure minimum water use and maximum recycling.

The use of recycled water from through out the power generation process must be considered prior to using clean water for FGD.

Water use management, water wastage reduction, and implementation of less water reliant processes in the power generation process could reduce Eskom's water demand

Water use, hydrochemical analysis, and recycling must be employed to ensure the minimum amount of clean water is lost from the catchment.

Hazard 5: Gypsum temporary disposal

Should gypsum be manufactured and stored on site then the temporary stockpile area must be designed and managed according to the DWAF minimum requirements for waste disposal by landfill.

Table 13 contains a summary of the risk assessment, including hazards, consequences, probabilities, overall risks, and management actions required with regards to the use of FGD on site.

Table 133: FGD risk management summary

Hazard	Consequences	Probability	Overall risk	Management options
Hazard 1 Increased water demand	Reduction of surface water for development in the study area Impact on downstream users within the Vaal River	**High:** Eskom is of a strategic importance to RSA so water will be made available for power generation and environmental issues	It is recognised that the overall risk is **TOLERABLE**; however, the optimum FGD process must be selected. Management procedures and augmentation of water resources are required to ensure the negative impacts are reduced.	• Select least water intensive FGD • Maximise water recycling • Minimise water wastage • Monitor water use
Hazard 2 Poor quality water stored on site recharging the groundwater	Waste will be dewatered and the poor quality water stored on site for reuse in the FGD process	**Medium:** Artificial recharge will occur through permeable soil and weathered material	The overall risk assessment for this hazard on the groundwater is **TOLERABLE**.	• Geological assessment for dam site selection • Backfill existing boreholes • Ensure sufficient capacity • Construct lined dams • Monitor groundwater quality and water levels • Monitor neighbouring boreholes

Table 13: FGD risk management summary (Page 2)

Hazard	Consequences	Probability	Overall risk	Management options
Hazard 3 Wet waste disposal	Contaminated water associated with the waste can recharge groundwater and run off site and impact on surface water	**High:** The wet waste will have the potential for leachate generation which could migrate into the underlying aquifers or form run-off and migrate off site	The overall risk assessment for this hazard on the water resources is **TOLERABLE**.	• Select optimum waste dewatering scheme • Evaluate water disposal technique to reduce water in waste disposal • Monitor water resources
Hazard 4 Removal of surface water from catchment	The water used in the FGD process will become of such poor quality that it has to be deposited on a waste site, thus the water cannot be treated and returned for use in the catchment	**High:** The water used in the FGD processes cannot be treated for discharged back into the river	The overall risk assessment for the surface water loss is **TOLERABLE**; however, management of the water is required to ensure the recycling of water.	• Ensure minimum water use in FGD • Ensure maximum recycling throughout power plant • Reuse of water, minimise clean water use • Implement less water reliant processes
Hazard 5 Gypsum temporary stockpile	Gypsum manufacturing will require stockpiling according to minimum requirements as it has the potential to impact negatively on the groundwater and surface water resources	**Low:** Gypsum manufacture is not commercially viable for Eskom	The overall assessment of this hazard is **TOLERABLE** as the gypsum would be piled on a correctly designed waste disposal facility.	• Stockpile on correctly designed disposal facility • Must be managed

10.3 Ash disposal

Hazard 1: Above ground - Seepage below the ash dump

Assuming a new ash dump will be constructed, the wet ash and effluents, such as brine (from the deionisation of the raw water), provide a constant source of contaminants, which can migrate off site. The resultant pollution plumes can impact on the down gradient users and can introduce a salt load into the surface water resources.

Direct rainfall, rainfall run-off, and seepage from the ash dump must be collected in a toe dam. This dam has the potential to form a source of artificial recharge to the groundwater.

In order to minimise the risks associated with the ash dam the following measures must be in place: -

- Compact the soil below the proposed ash dump to reduce permeability
- Design a horizontal drainage system below the ash dump to collect water in order to minimise seepage and maximise water collection (for recycling)
- Design and construct the toe dam to ensure sufficient capacity and maximise water collection
- Monitoring boreholes should be installed adjacent to the ash dump and toe dam
- Install surface water controls to minimise poor quality run-off and minimise run-off reduction in the catchment

Co-disposal of ash and neutralised regeneration effluents must always be disposed as a semi-homogeneous mixture and spread across the ash pile. Prolonged disposal of neutralised regeneration effluents in one location can compromise the pozzolanic characteristics of the ash (due to high sulphate concentrations), which will increase the risk of leaching.

Hazard 2: Back-ashing - Long term impacts of persistent contamination sources

A geochemical study, comprising sampling, acid-base accounting, modelling and groundwater modelling (to predict groundwater rebound, inflow volumes, and resultant groundwater flow) is required to determine the suitability of back-ashing.

The mine pan and rehabilitation strategy are required from the colliery to determine whether ash disposal will be suitable.

Should back-ashing be conducted then groundwater monitoring boreholes will be required up gradient, within the rehabilitated void(s), and down gradient of the old open cast voids. Groundwater levels and quality must be monitored on a quarterly basis.

These data must be assessed annually to recalibrate the geochemical and groundwater models to verify / evaluate predictions.

Hazard 3: In-pit ashing - Mobilisation and migration of metals and solids

Based on available information there is a high risk associated with disposing ash into low pH water. It is, therefore, not recommended that this method of ash disposal be considered without an extensive geochemical assessment being conducted.

Should in-pit ashing be conducted then extensive monitoring must be conducted, this will comprise: -

- Monitoring of groundwater monitoring holes (up and down gradient of the rehabilitated voids)
- Predicting and monitoring inter mine flow
- Determining and sampling of decant
- Monitoring of surface water (discharge into surface water)

Backfilling, using a mixture of overburden and ash, in the mining voids above the predicted rebound groundwater levels, could be considered. Ensuring the ash is not deposited within the low pH groundwater (mine) water combined with a low permeable cap over the rehabilitated mining void could be considered as this would potentially have limited leaching capability.

Long term monitoring; prior, during (ashing), and after closure; will be required for geochemical modelling and to verify predictions.

Table 14 contains a summary of the risk assessment, including hazards, consequences, probabilities, overall risks, and management actions required with regards to ash disposal on site.

Table 144: Ash disposal risk management summary

Hazard	Consequences	Probability	Overall risk	Management options
Hazard 1 Above ground Seepage below ash dump	Contaminated water can alter the groundwater quality The contaminated groundwater can impact on other users and future groundwater development	**High:** Existing unlined ash dumps are unlined and are recognised to impact on groundwater Initial ash disposal will have high seepage rates Fly ash and resultant pozzolanic layers reduce permeability and reduce leaching	The risk of a constant contamination source associated with an unlined ash dump is **HIGH** The overall risk is **TOLERABLE** if the ash dump is correctly designed	• Design a drainage system • Install drainage system below ash • Design optimum toe dam • Back fill existing holes and install monitoring holes • Surface water controls to be installed and maintained • Spread neutralised regeneration effluents across pile
Hazard 2 Back ashing Long term impacts of persistent contamination sources	TCLP tests indicate that metals and salts can be leached from the ash Ash dump can act as a persistent source of contaminants which can alter the groundwater quality.	**Medium:** The top soil on top of ash will reduce the recharge into ash Ash is returned on top of overburden and may not be in direct contact with groundwater	Back ashing above the groundwater table is **TOLERABLE** if rehabilitation of topsoil occurs. Ash deposition which increases impact of AMD is **INTOLERABLE**	• Conduct kinetic acid-base tests on lithologies and ash • Determine optimum mine rehabilitation and determine whether ash is suitable • Conduct geochemical and groundwater (rebound) modelling to determine long term impacts • Extensive groundwater (long term) monitoring will be required

Table 14: Ash disposal risk management summary (Page 2)

Hazard	Consequences	Probability	Overall risk	Management options
Hazard 3 Mobilisation and migration of metals and solids	Ash would be in contact with low pH water as a result of oxidation of sulphides in the pit. Depending on the buffer capacity of the ash, metals and salts can be leached from the ash	**High:** TCLP results indicate that low pH water can cause the leaching of metals and salts from the ash	The preliminary risks associated with in-pit ashing are **HIGH** due to the leaching and mobilisation of metals from the ash in low pH water Preliminary risks indicate risk to groundwater too high and therefore **INTOLERABLE** unless additional geochemical studies prove otherwise	• Extensive monitoring of groundwater monitoring holes, inter mine flow, decant, and discharge into surface water needs to be monitored prior, during (ashing), and after closure • Extensive geochemical monitoring, laboratory analysis and modelling is required

10.4 Monitoring plan

The detailed design of the proposed power station and associated infrastructure, the layout, and the preferred site has not yet been decided. The proposed groundwater monitoring plan, based on the risk / impact assessments and existing power stations, is suggested but requires finalisation once all designs and layouts are complete.

Boreholes

It is envisaged that the power station infrastructure, including run-off dams, dirty water dams, coal stockpile, ash dump[21], and toe dam, will provide areas of artificial recharge. Monitoring of groundwater levels and hydrochemistry will be required at each of the potential pollution sources.

It is recommended that shallow (20 m) monitoring boreholes, constructed using uPVC plain and slotted casing (140 mm diameter), be installed adjacent and down gradient of the these potential pollution sources.

Existing boreholes, if suitably located, could be utilised for monitoring purposes.

Up gradient monitoring boreholes must be monitored to determine ambient groundwater quality entering the site. These groundwater levels and hydrochemical data can be used for comparison with the other monitoring boreholes to determine the impact of the proposed power station.

Additional monitoring boreholes have to be installed down gradient of the potential pollution sources. The monitoring data obtained from these boreholes will assist in determining the impact of the power station infrastructure and activities on the groundwater levels and quality. The obtain data can also be used to update the geochemical and pollution migration models.

In order to assist with pollution plume modelling in order to predict migration, it is recommended that additional monitoring boreholes be constructed a further 5 to 10 m down gradient of the potential pollution sources.

Depending on the final design and location it is envisaged that 15 to 20 monitoring boreholes will be required.

Water levels

It is recommended that rainfall be recorded on site. Samples of the rainfall should be analysed for chloride concentrations, which will assist in determining recharge rates across the site.

The water levels in the boreholes should be measured on a quarterly basis, to determine the response to dry and wet seasons and to determine the impact of artificial recharge. Groundwater level fluctuation due to rainfall recharge in boreholes unaffected by artificial recharge from the power station infrastructure combined with the rainfall data can be used to accurately calculate the recharge percentage.

Water level data must be recorded prior to any sampling as this is required to determine the purge volumes.

[21] It is assumed that even if back-ashing is utilised a temporary ash dump will be constructed.

Hydrochemistry

Prior to groundwater sampling down-the-hole electrical conductivity profiles must be conducted to determine stratification within the boreholes. Variations in vertical hydrochemistry can be interpreted, either as poor quality ingress or natural salinity (release of salts from impermeable shale). This will assist in selecting the optimum sampling procedure and depths.

It is recommended that the boreholes be sampled on a quarterly basis. Once hydrochemical trends have been established it can be motivated that the sampling, frequency and elements, can be reduced.

During routine groundwater monitoring the groundwater samples must be described. Light aqueous phase liquids (LNAPLs) floating on the groundwater samples, if recorded, may indicate hydrocarbon contamination. The groundwater sample(s) must then be analysed for organic compounds, such as BTEX, TPH, GRO, and DRO[22] to determine the source of the hydrocarbons.

As groundwater is utilised for domestic purposes in the study area it is recommended that the following determinants (Table 15) be analysed and that the results be compared to the ambient groundwater quality and the SABS 241 maximum allowable limits for drinking water (SABS, 2001).

Table 15: Monitoring records and analyses

Item	Units	SABS 241 Maximum allowable limit
Depth	m	-
Water level	mbgl	-
Sample description:		
Determinants		
pH	pH units	4.0 – 10.0
Conductivity	mS/m	370
Alkalinity	mg/l $CaCO_3$	NS
Aluminium	mg/l Al	0.5
Bicarbonate	mg/l HCO_3	NS
Boron	mg/l B	NS
Barium	mg/l Ba	NS
Beryllium	mg/l Be	NS
Bromine	mg/l Br	NS
Calcium	mg/l Ca	300
Cadmium	mg/l Cd	0.01
Chloride	mg/l Cl	600
Cobalt	mg/l Co	1
Total chromium	mg/l Cr	0.5
Copper	mg/l Cu	2
Fluoride	mg/l F	1.5
Iron	mg/l Fe	2
Potassium	mg/l K	100
Lithium	mg/l Li	NS
Magnesium	mg/l Mg	100
Manganese	mg/l Mn	1
Molybdenum	mg/l Mo	NS

[22] BTEX – Benzene, Toluene, Ethyl – Xylenes, Xylenes
TPH – Total petroleum hydrocarbons
GRO – Gasoline range organics
DRO – Diesel range organics

Sodium	mg/l Na	400
Nickel	mg/l Ni	0.35
Nitrite	mg/l NO_2	20 (as N)
Nitrate	mg/l NO_3	20 (as N)
Lead	mg/l Pb	0.1
Otho-phosphate	mg/l PO_4	NS
Selenium	mg/l Se	0.05
Sulphate	mg/l SO_4	600
Strontium	mg/l Sr	NS
Vanadium	mg/l V	0.5
Zinc	mg/l Zn	10
Sewage area - include		
Ammonia	mg/l NH_4	2
Chemical oxygen demand	mg/l	NS
Hydrocarbons – if LNAPL detected		
BTEX	ppb	NS
TPH	ppb	NS
GRO	ppb	NS
DRO	ppb	NS

NS – Not specified

All groundwater sampling, including sample preservation and stabilisation, must be conducted according to recognised procedures, such as Weaver's groundwater sampling manual.

11 CONCLUSIONS

Power station and ancillary infrastructure

- The study area is underlain by complex faulted Pretoria Group sediments and intrusives on site Y and younger Dwyka Group tillite and Karoo sediments on site X.
- Minor faulting and younger intrusive bodies occur across site Y. These geological structures have enhanced the groundwater potential in this area and can act as preferential pathways for groundwater and contaminant migration.
- The hydrogeology on the majority of site X comprises a non-aquifer system, with very low yielding boreholes and limited groundwater potential.
- Little or no groundwater use occurs within site X; however, persistent contamination can have an impact on the groundwater users with time.
- Groundwater can be impacted on by the proposed power station and infrastructure; causing elevated groundwater levels and altering hydrochemistry.
- A preliminary site suitability assessment indicates that the groundwater resources within Site X are the less vulnerable to external impacts on groundwater quality and quantity. Therefore, areas within Site X are more suitable for the development of a new power station and associated infrastructure from a groundwater perspective.
- An initial risk assessment identifies that sources of artificial recharge, such as an unlined ash dump or dirty water dams, require risk reduction measures.
- The correct site selection, construction, and management of the new power station and infrastructure will ensure that the overall risk to the groundwater resources is acceptable.

FGD Technology

- Eskom implements emission reduction devices and chimney designs to reduce concentrations at ground level. Incremental impacts on air quality may, however, require additional emissions reduction.
- Flue gas desulphurisation (FGD) is recognised as the most suitable (proven) technology to reduce SO_2 emissions; however it is water and sorbent (calcium) intensive.
- The dry (semi-wet) FGD process uses ± 35% less water than the wet FGD process, however, water use at the proposed power station would double if FGD is utilised.
- The use of FGD technology has a negative impact on the environment due to increased mining (calcium source), increased water use for industrial purposes, and increased waste generation ($CaSO_3$ and $CaSO_4$ slurry).
- The slurry waste can be converted to gypsum, which can have commercial value. The gypsum can be, however, low grade and there is a limited market.
- Water augmentation is required to ensure that the additional water required for the power station can be assured. The use of FGD will increase Eskom's water demand and will require larger volumes of water being set aside to ensure Eskom a reliable assured supply (99.5%).
- The limited groundwater resources in the study area can be impacted on by the FGD process, due to the need to store poor quality (recycled) water and due to the large volumes of wet waste that will be generated.
- The preliminary risk assessment indicates that any proposed FGD technology to be incorporated in the power station must aim at reducing the amount of water required and that recycling and treatment be utilised to ensure the impacts of additional clean water use be minimal.
- The gypsum stockpile will require waste characterisation and suitable waste disposal facility design, construction, and permitting

Ash disposal

- Above ground ash disposal has the least risk to the groundwater resources as it can be effectively managed. The ash dump must be constructed on a compacted (low permeable) layer (either natural soil or imported clay) which is overlain by a horizontal drainage system to reduce seepage below the ash dump.

- In-pit and back-ashing should only be considered once a comprehensive geochemical assessment has been conducted, in conjunction with the mining house involved with the supply of coal.

- Back-ashing or in-pit ashing can only be considered if it can be scientifically demonstrated that the risks or impacts on the groundwater can be managed and that future (long term) liabilities can be accurately predicted.

- Backfilling, using a mixture of overburden and ash, in the mining voids above the predicted rebound groundwater levels, could be considered. Ensuring the ash is not deposited within the low pH groundwater (mine) water combined with a low permeable cap over the rehabilitated mining void could be considered as this would potentially have limited leaching capability.

12 RECOMMENDATIONS

- All risk reduction recommendations must be considered during the planning of the new power station.
- All recommendations compiled in Section 8.6, concerning dry cooling technology, desalination, water infrastructure, water metering, FGD, and ash disposal must be included in the power station planning.
- The proposed power generation project must comply with the National Water Act (Act No. 36 of 1998). It is, therefore, recommended that all proposed water related activities be assessed to ensure compliance.
- It is recommended that the required water use license application(s) be made. The relevant licensing includes: -

  21(a) Taking water from a resource
  21(b) Storing water (includes dirty water)
  21(f) Discharging waste or water containing wastes into a water resource (this includes the sea, a stream, or an aquifer).
  21(g) Disposing of waste in a manner which may detrimentally impact on a water resource

- It is recommended that cooling water sludge, from the cold lime softening process, be co-disposed with ash.
- Sludge removed from the raw water storage dams and reservoirs is not regarded as waste and it is recommended as use in borrow pits or cover for waste sites.
- Should “dirty” water generated on site be considered for irrigation, it is recommended that the water be tested to determine its suitability in terms of salinity and Sodium Absorption Ratio (SAR).

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APPENDIX A

Additional NGDB and WARMS data