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SURFACE-, GROUNDWATER & ENVIRONMENTAL SCIENTISTS

Hendrina Power Station ASH CLASSIFICATION OCTOBER 2011

PROJECT TEAM

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07 November 2011

Our ref.: RVN 619.1/1267

FOR ATTENTION:

Dear Madam/sir,

HENDRINA POWER STATION ASH CLASSIFICATION REPORT

It is our pleasure in enclosing 4 copies of the report RVN 586.1/1078: “HENDRINA POWER STATION – ASH CLASSIFICATION REPORT”

We trust that the report will fulfil your expectations and we will gladly supply any additional information required.

Yours sincerely,

Louis J van Niekerk (Pr.Sci.Nat.)

*Copies: 1 (one) electronic copies to Ashlea Strong
Senior Environmental Assessment Practitioner
Lidwala Consulting Engineers*

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1 INTRODUCTION

1.1 General

Hendrina Power Station is located on the farm Hendrina 162 IS, which is situated on the southwestern border of Pullenshope. Pullenshope is approximately 5 km west of the N11 between Middelburg and Hendrina. The facility is situated well south of Optimum Colliery, which supplies coal to the power station. The basic facilities at the power station consist of ash dams, ash return water dams, coal stockyards, a solid waste disposal facility and sewage works. Of these facilities the ash disposal and coal stockyard activities have, in view of the scale of operations, the greatest potential to pollute groundwater.

Coal mining operations forms an integrated part of the Hendrina power generation activities. Big scale coal mining operations occurred in the local catchment area of the power station.

1.2 Scope of work

The scope of this study is to classify the waste (specifically the ash from the coal fired power station). Furthermore to determine the content and properties of the ash with regards to permeability and pollutant potential to be expected to leach from the ash.

1.3 Methodology

In order to do a waste classification of the ash, the following methodology will be employed:

- Sampling and drilling of auger holes to obtain a representative sample distribution,
- XRD (X-ray diffraction) scan to obtain mineralogical composition,
- XRF (X-ray fluorescence) scan to determine scan to determine the chemical composition,
- Sieve analyses to obtain the particle size distribution and geohydrological parameters such as permeability,
- Leach test whereby the ash is mixed with water to determine the chemical components expected to be leached from the ash.
- Acid-Base Accounting (ABA)

2 DISCRIPTION OF THE ENVIROMENT

2.1 Locality of Hendrina Power Station

Hendrina Power Station is located on the farm Hendrina Power Station 162 IS, which is situated on the south western border of Pullenshope. Pullenshope is approximately 5 km west of the N11 between Middelburg and Hendrina.

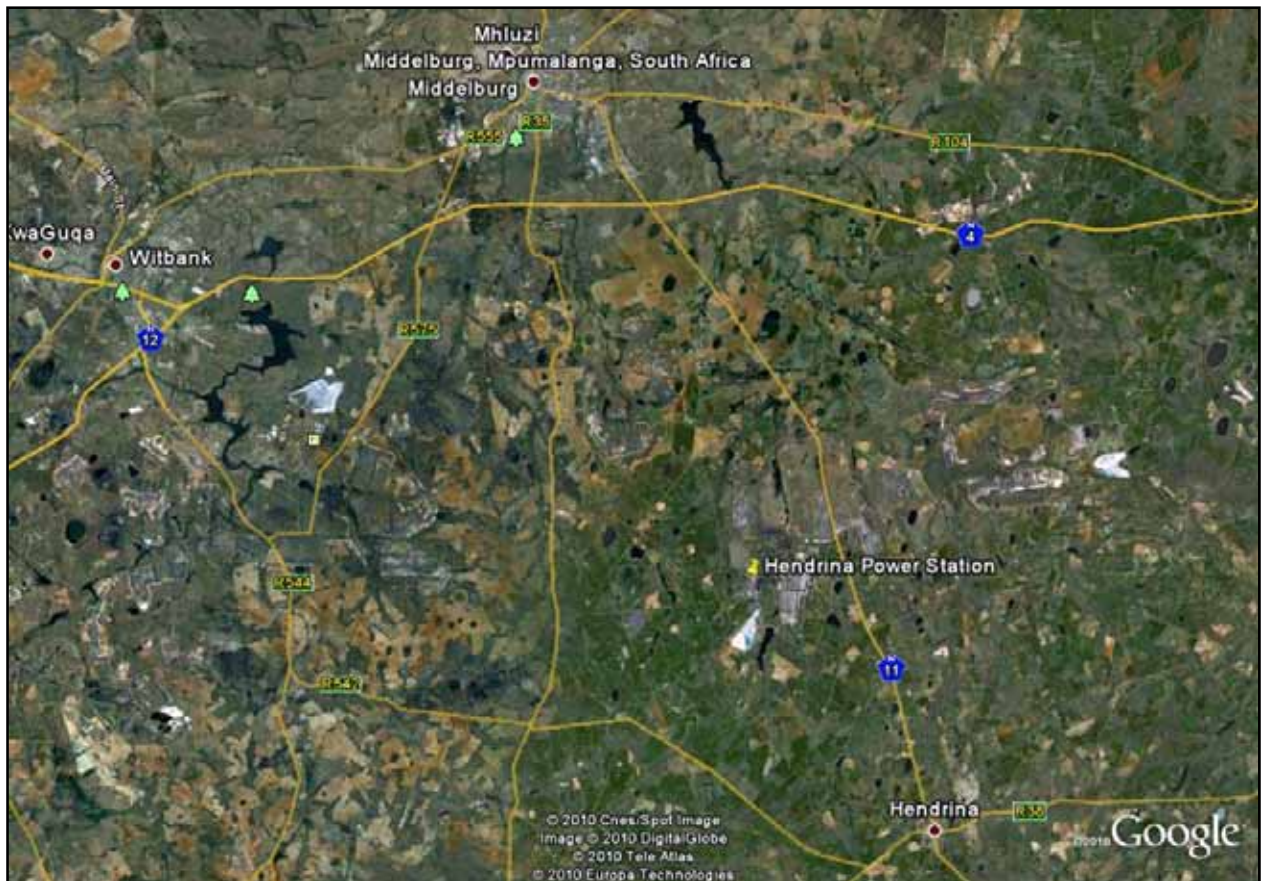


Figure 1. Locality map Hendrina Power Station (Google earth 2010).

2.2 Topography

The surface topography of the area is typical of the Mpumalanga Highveld, mainly a gently undulating plateau, varying between approximately 1680 mamsl underneath Ash Dam 4 to 1600 mamsl along the Woest-Alleen Spruit (East) and the lower reaches of the Woest-Alleen Spruit (West). The Power Station area is situated between the contour lines of the 1610 mamsl to 1630 mamsl.

Several man-made features are also of significance at the site. Numerous dams have been constructed for a variety of purposes, the most obvious of which are the ash disposal dams

2.3 Climate

2.3.1 Regional climate

Hendrina Power Station is situated on the Mpumulanga Highveld. The usual highveld weather conditions prevail with warm summers and cold winters with the main temperature at 14:00 in winter being about 17°C. The climate of the area under investigation is classified as the Highveld region (Region H), which is defined as a climate with a temperate to warm temperature and summer rains.

2.3.2 Rainfall data

The average annual precipitation in the Highveld region varies from about 900 mm on its eastern border to about 650 mm in the west. The rainfall is almost exclusively due to showers and thunderstorms and falls mainly in summer, from October to March, the maximum fall occurring during January. The winter months are normally dry and about 85% of the annual rainfall falls in the summer months; heavy falls of 125 mm to 150 mm occasionally fall in a single day. This region has about the highest hail frequency in South Africa; about 4 to 7 occurrences may be expected annually at any one spot.

Hendrina Power Station lies within quaternary sub-catchment B12B of rainfall zone B1B. The average precipitation for this region at weather station 0516 480 is 672 mm.

The average monthly rainfall recorded at weather stations within quaternary sub-catchment B12B is summarised in Table 1 and displayed graphically in Figure 2. Data from the measurements taken during 70 years (1920 - 1989) were obtained. From the data listed in Table 1 it can be seen that the wettest months (on average) are November, December and January whilst the driest months are June, July and August.

Table 1. Average rainfall recorded at weather station within quaternary sub-catchment B12B.

Month	Average rainfall	
	(516 480)	(516 414)
Jan	115.92	115.75
Feb	87.36	87.23
Mar	72.31	72.20
Apr	42.07	42.00
May	14.92	14.90
Jun	7.73	7.72
Jul	6.45	6.44
Aug	6.85	6.84
Sep	25.00	24.96
Oct	68.54	68.44
Nov	113.43	113.26
Dec	109.67	109.51

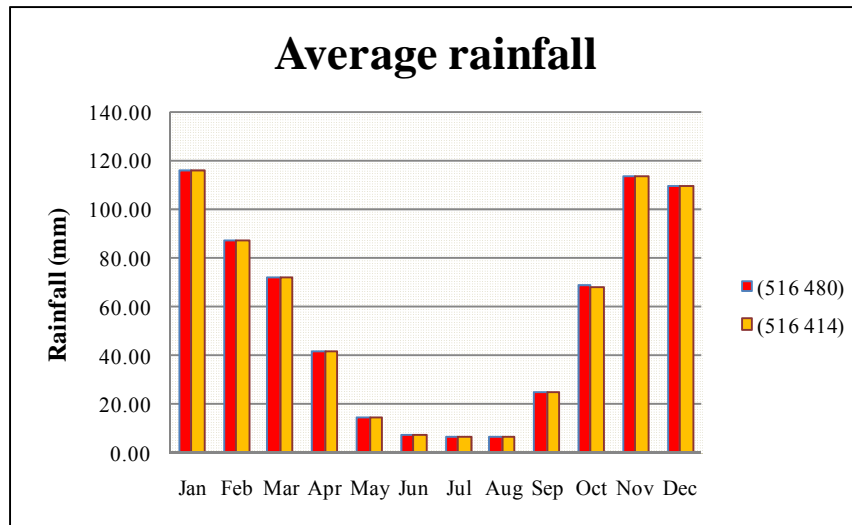


Figure 2. Average rainfall recorded at weather station 0516 480 (Over a period of 70 years).

2.3.3 Temperature data

Average daily maximum temperatures are roughly 27°C in January and 17°C in July but in extreme cases these may rise to 38°C and 26°C respectively. Average daily minima range from about 13°C in January to 0°C in July, whereas extremes can sink to 1°C and –13°C respectively. The period during which frost is likely to form lasts on the average for about 120 days from May to September.

Table 2. Average monthly temperatures. – Climate of SA, WB 42 (1961 – 1990).

	AVERAGE OF DAILY			
	MAX	MIN	MEAN	RANGE
	TX	TN	(TX+TN)/2	TX - TN
J	25,6	13,8	19,7	11,8
F	25,2	13,2	19,2	12,1
M	24,6	11,8	18,2	12,8
A	21,8	8,6	15,1	13,2
M	19,5	4,4	11,9	15,1
J	16,5	0,8	8,7	15,6
J	17,1	1,0	9,0	16,2
A	19,9	3,8	11,9	16,1
S	23,2	7,5	15,3	15,7
O	23,9	9,9	17,0	14,1
N	24,0	11,8	17,9	12,3
D	25,3	13,1	19,2	12,2
YR	22,2	8,3	15,3	13,9

Table 3. Average Max temperatures. – Climate of SA, WB 42 (1961 – 1990).

	MAXIMUM (TX) P = 26 Years											
	HIGHEST (TXX)			AVERAGE NUMBER OF DAYS WITH TX						LOWEST (TXN)		
	MAX	YY/DD	MEAN	>=35	>=30	>=25	>=20	>=15	<10	MEAN	MIN	YY/DD
J	33,7	69/13	30,0	0,0	2,0	19,5	29,5	30,9	0,0	18,8	13,1	72/23
F	34,4	83/27	29,5	0,0	1,2	16,3	26,9	28,2	0,0	18,6	13,2	76/12
M	32,6	73/15	28,7	0,0	0,7	15,4	28,8	30,6	0,0	17,4	11,5	67/19
A	30,0	87/04	26,3	0,0	0,0	4,9	22,9	29,0	0,1	14,6	7,9	72/30
M	27,0	83/01	23,8	0,0	0,0	0,4	14,4	28,9	0,1	13,0	7,9	72/12
J	23,5	66/11	20,9	0,0	0,0	0,0	3,2	23,2	1,1	9,5	3,3	84/14
J	24,6	88/17	21,5	0,0	0,0	0,0	4,4	25,5	0,8	9,8	2,5	67/14
A	26,6	65/22	25,1	0,0	0,0	1,4	17,4	28,6	0,6	11,3	6,0	68/10
S	32,0	83/29	28,8	0,0	0,2	12,9	24,0	28,4	0,4	12,2	6,4	88/02
O	33,0	65/31	29,9	0,0	1,7	14,8	25,3	29,8	0,1	14,1	8,0	81/04
N	32,6	68/07	29,4	0,0	1,2	13,5	26,0	29,0	0,2	15,4	6,8	68/11
N	33,0	68/29	29,6	0,0	1,4	18,0	29,2	30,9	0,0	18,0	14,1	73/10
YR	34,4	83/27	31,6	0	9	117	252	343	3	7,1	2,5	67/14

A correlation exists between the temperatures and the evaporation tempo, therefore the highest temperatures and evaporation occurs during the summer.

Table 4. Average Min temperatures. – Climate of SA, WB 42 (1961 – 1990).

MINIMUM (TN) P = 26 Years												
HIGHEST (TNX)			AVERAGE NUMBER OF DAYS WITH TN						LOWEST (TNN)			
MAX	YY/DD	MEAN	>=20	<15	<10	<5	<0	<-5	MEAN	MIN	YY/DD	
18,5	83/29	16,6	0,0	22,2	1,1	0,0	0,0	0,0	9,7	6,5	77/02	J
20,5	79/05	16,6	0,0	22,2	2,4	0,0	0,0	0,0	8,6	5,5	63/28	F
20,1	79/20	15,8	0,0	28,6	6,3	0,2	0,0	0,0	6,6	0,5	74/19	M
15,5	87/05	13,4	0,0	30,0	18,7	3,7	0,2	0,0	2,2	-1,4	88/26	A
12,7	79/04	9,6	0,0	31,0	30,0	17,7	2,1	0,0	-1,3	-3,9	63/31	M
10,5	79/01	6,3	0,0	30,0	30,0	26,7	11,4	0,8	-4,4	-9,2	64/27	J
8,7	83/14	6,1	0,0	31,0	31,0	28,5	11,0	0,5	-4,1	-8,0	64/26	J
11,5	86/28	9,5	0,0	31,0	30,4	18,7	4,2	0,2	-2,8	-7,5	72/02	A
14,8	65/18	12,7	0,0	30,0	22,6	5,9	0,9	0,0	0,4	-4,8	74/08	S
16,9	67/24	14,7	0,0	30,5	13,4	2,1	0,2	0,0	3,7	-1,2	65/21	O
18,0	80/11	15,6	0,0	28,1	5,8	0,4	0,0	0,0	6,6	3,0	69/12	N
17,7	87/21	16,1	0,0	25,2	2,0	0,1	0,0	0,0	8,2	2,6	70/07	D
20,5	79/05	17,3	0	340	194	104	30	1	-5,5	-9,2	64/27	YR

2.3.4 Evaporation data

The mean monthly evaporation records are obtained from Hydrological Information Publication No. 13, Evaporation and Precipitation Records, WB42, 1990. These records are listed in Table 5.

Table 5. *Evaporation data. – Climate of SA, WB 42.*

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1963	167.6	202.2	117.2	107.2	97.3	60.5	79.2	141.2	176.3	188	151.4	216.7
1964	177	180.6	187.7	123.7	106.9	78.5	94.5	142.5	194.3	160.9	189	158
1965	185.4	179.6	174.2	106.4	105.2	80.3	90.4	137.7	168.7	222	185.7	217.4
1966	187.7	135.1	179.3	128.8	121.2	82.3	115.3	142	181.4	196.3	189	166.4
1967	170.9	115.8	140	87.1	83.6	78.7	80.8	117.9	178.8	199.6	166.9	204
1968	200.5	188	110.2	102.2	78.4	67.8	106.2	137.3	186.9	241.1	155.7	209.5
1969	228.1	162.3	110.2	111.3	70.7	83.2	87.9	131.9	180.2	168.3		
1970		154.7	189	140.1	123.2	92.3		178.2		212	199.7	256.6
1971	163.3	154.1	195.5	123.8	98	93.4	117.7	167	200.8	196		198
1972	153	160.8	137.7	131.3	104.9	101.2	121.6	166.7	209.7	211.9	179.1	264.4
1973	227.4	157.2	188.5	98.6	114	105.6	108	147.4	230.9			190
1974	153.9	161.7	170.9	93.7	104	99.6	103	168.3	213.4	259.4	168.8	218.4
1975	174.5	136.6	138.5	103.2	81.8	66.2	81.9	116.3	142.2	174.6	158	
1976		130.6	100.2		59.5		75.5			157.6	159.7	174.9
1977	179.3	136.4	108.4	103.5	97.7	91.9	85.5	119.2	130.7			
1978					92.8		67.6	124.3	144.9	176	163.6	186.4
1979	178.6	157.1	151.6	117.2	84.9	73.9		104.5		165.5	159.8	164.5
1980	189.3	130.6	130.8	123.3	101.2	66.2	73.1		137.7	198.2	181.2	168.2
1981	156.2	109.5	131.5	102.8	70.8	74.3	72.4	88.8	144.2	148.5	175.7	184.8
1982	174.1		139	92.4	86.8	71.2	76	106	133.3	158.2	140.2	222.8
1983	177.3	153.5	141.9	109.7	102.6	69.9	82.4	104.2	167.4	153.4	169.9	158.5
1984	161.5	144.2	127.1	99.6	96.2	64.4	69.5	108.7	124	153.2	139.9	201.7
1985	164.1	123.5	130.4	116.4	85.5	76.9	82.2	114.6	125.8	169.2	174.5	189.2
1986	196.7	148.8	153.1	108.9	93.4	66.4		127.1	128.4	146.7	143.1	166.1
1987	189	153.2	139.4	123.2	110.3	77.1	87	122	118			184.5
AVE	179.8	151.1	147.8	111.1	94.8	79.2	89	132	167	186.6	167.6	195.9

YEAR AVE : **1702**

2.3.5 Wind

On the whole winds are light except for the short periods during thunderstorms. Very occasionally tornadoes do occur and cause tremendous damage if they happen to strike a populated area.

Table 6. Hourly wind analysis. – Climate of SA, WB 42 (Witbank 1993 - 2000).

Hourly Wind Analysis																																	
Percentage frequency (f) for each direction (incl calms) and average speed (s) in m/s																																	
Analysis based on hourly values. - Witbank (1993/11/01 - 2000/12/31)																																	
Month	Calm	N		NNE		NE		ENE		E		ESE		SE		SSE		S		SSW		SW		WSW		W		WNW		NW		NNW	
		f	s	f	s	f	s	f	s	f	s	f	s	f	s	f	s	f	s	f	s	f	s	f	s	f	s	f	s	f	s	f	s
1	5	9	3	4	3	3	2	4	3	19	4	19	4	7	4	3	4	4	3	3	3	2	3	2	3	5	3	4	3	3	3	5	3
2	4	8	3	4	2	3	2	4	3	21	4	22	4	6	3	3	3	5	3	3	3	2	3	2	3	5	3	3	3	3	2	3	2
3	6	10	3	4	3	3	2	4	2	17	3	17	4	6	3	3	3	4	3	2	3	2	3	2	3	5	3	5	3	5	3	5	3
4	8	11	3	4	3	2	2	2	2	12	3	12	3	6	3	4	3	6	3	3	3	2	3	3	3	6	3	7	3	6	3	5	3
5	8	8	3	3	2	2	2	2	2	7	3	11	3	7	3	4	3	8	3	6	3	5	3	5	3	9	3	7	3	6	2	4	2
6	11	8	3	2	2	1	2	1	3	4	3	8	3	6	3	4	3	9	3	7	3	4	3	5	3	9	3	8	3	7	3	5	2
7	9	11	3	3	3	2	3	2	2	8	4	12	4	7	3	4	3	7	3	5	4	3	3	3	3	7	3	7	3	6	3	6	3
8	7	14	3	5	3	3	2	3	3	9	3	10	3	5	3	2	3	6	3	6	4	3	4	3	3	6	3	6	3	6	3	6	3
9	4	20	3	7	3	4	3	4	3	12	4	7	4	3	3	1	3	3	3	4	4	3	4	2	3	5	3	6	3	6	3	10	3
10	3	19	4	8	3	5	3	4	3	14	5	10	5	3	4	2	3	4	4	2	4	1	4	2	3	5	3	5	3	5	3	8	3
11	3	24	3	8	3	5	3	5	3	11	4	7	4	3	3	1	3	3	4	3	4	2	4	2	3	4	3	5	4	6	3	7	4
12	3	20	3	6	3	4	3	4	3	13	4	9	4	3	4	2	3	3	4	2	4	1	3	2	3	5	3	7	3	6	3	8	3
Year	6	13	3	5	3	3	3	3	3	12	4	12	4	5	3	3	3	5	3	4	4	3	3	3	3	6	3	6	3	5	3	6	3

2.4 Geology

Hendrina Power Station is located near the contact between sedimentary rocks of the Karoo Supergroup and older extrusive volcanic rocks of Vaalian age in the form of porphyritic rhyolites. Quaternary aged alluvially deposited sands and Jurassic aged dolerite intrusives are present in the vicinity of the Power Station.

The Karoo rocks that occur in the vicinity of the Power Station predominantly belong to the Vryheid formation of the Eccca Group, and minor sediments of the Dwyka formation. The sediments consist of shales, sandstones, conglomerates and coal deposits. Combinations of these rock types are often found in the form of interbedded siltstone, mudstone and coarse-grained sandstone. The sediments of the Vryheid Formation were deposited in a fluvio-deltaic environment where swamps and marshes existed, in which peat accumulate. The Dwyka Formation is essentially comprised of a succession of glacial deposits characterized by angular to rounded clasts of basement within a silt and clay matrix that were emplaced from the Late Permian, although varved shales, sandstone, and conglomerates typical of a fluvio-glacial environment also occur (Botha et al., 1998).

Vaalian aged rocks occurring in the vicinity of the Power Station belongs to the Transvaal Supergroup. Rhyolite intrusives belonging to the Selonsriver formation, of the Transvaal Supergroup, intruded into the sedimentary formations of the Eccca Group and Dwyka formation. The Selonsriver formation rhyolites exhibit a porphyritic texture.

Late Triassic to Middle Jurassic aged Dolerite sills and feeder dykes are common in the Karoo Basin, which intruded the Vryheid Formation.

Boreholes B16 (Figure 3) and B42 (Figure 4) are typical representations of the geological sequence. Both boreholes are 40 m deep, which is sufficient to describe the geohydrology.

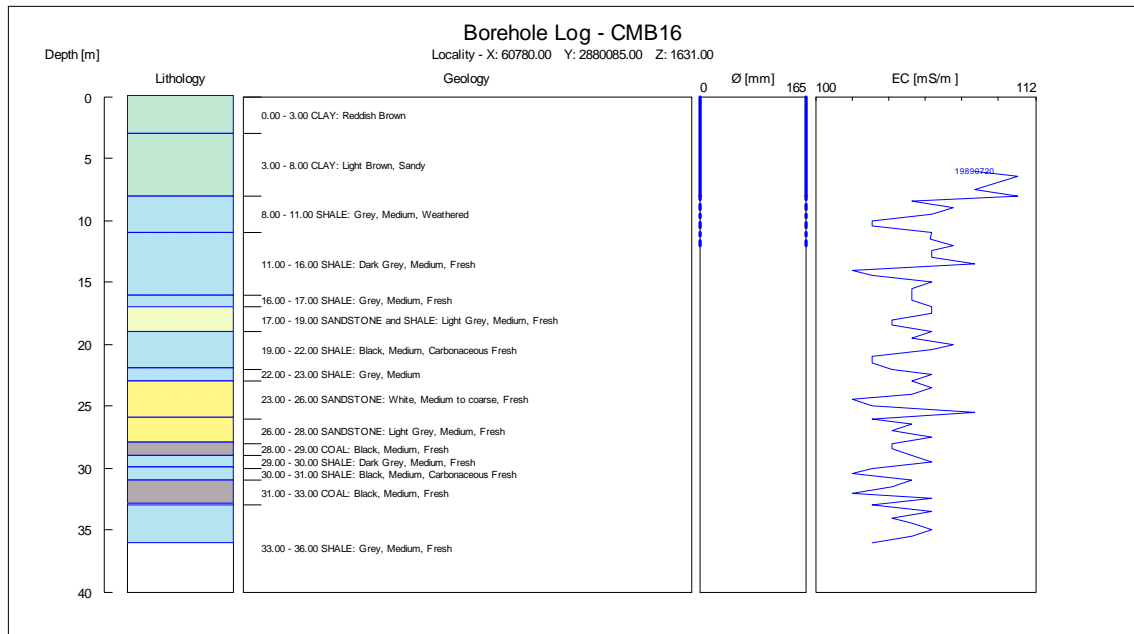


Figure 3. Geological log of monitoring borehole B16.

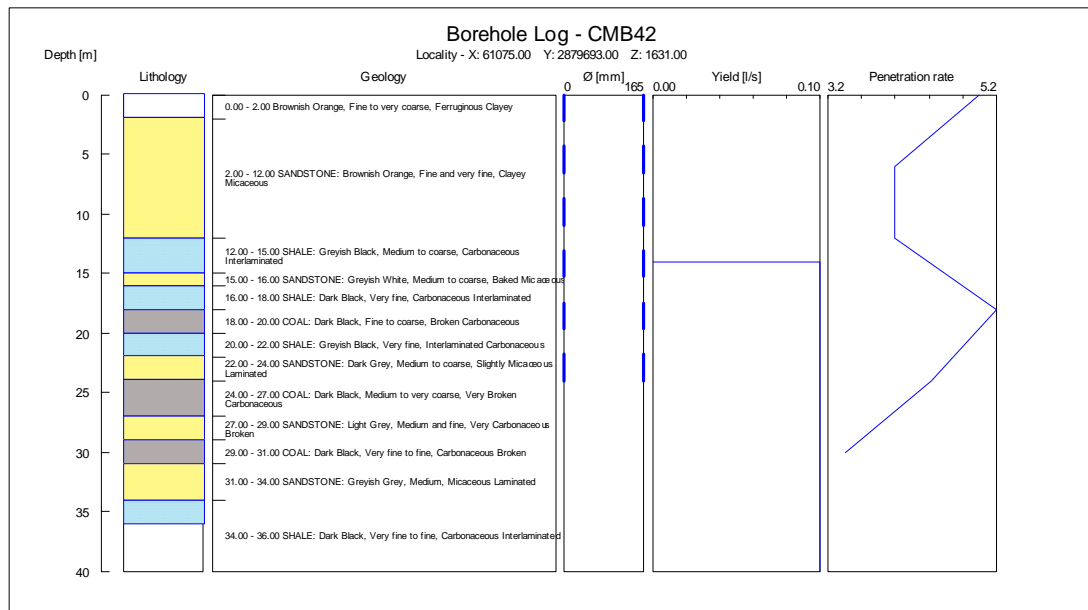


Figure 4. Geological log of monitoring borehole B42.

2.5 Geohydrology

The main water bearing aquifers in the vicinity of the Power Station are fractured rock aquifers. The term fracture refers to cracks, fissures, joints and faults, which are caused by (i) geological and environmental processes, e.g. tectonic movement; secondary stresses; release fractures; shrinkage cracks; weathering; chemical action; thermal action and (ii) petrological factors like mineral composition, internal pressure, grain size, etc.

From a hydrogeological point of view, a fractured rock mass can be considered a multi-porous medium, conceptually consisting of two major components: matrix rock blocks and fractures. Fractures serve as higher conductivity conduits for flow if the apertures are large enough, whereas the matrix blocks may be permeable or impermeable, with most of the storage usually contained within the matrix. Actually, a rock mass may contain many fractures of different scales. The permeability of the matrix blocks is in most cases of practical interest a function of the presence of micro-fractures. A rock mass which consists only of large fractures and some matrix blocks with no micro-fissures (or smaller fractures) lead to a term called purely fractured rocks. In this case, the domain takes the form of an interconnected network of fractures and the rock matrix, comprising the blocks surrounded by fractures, is impervious to flow. However, there may still be porosity. In the case where the domain is a porous medium (or a micro-scaled fractured medium) intersected by a network of interconnected fractures, the rock is termed a fractured porous rock and the domain is therefore characterized by at least two subsystems, each having a different scale of inhomogeneity (called scale effect).

2.5.1 Aquifer characteristics

Drilling data and work undertaken by previous researchers suggests that multiple aquifer types are represented at the site. These include:

- Unconfined aquifers present within soil horizons that have developed within colluvial and alluvial environments and the weathered upper levels of Vryheid Formation sediments. These aquifers are generally perched on less permeable underlying in situ sediments;
- Unconfined aquifers along the trend of dolerite dykes. These may also act as recharge points for confined aquifers within the Vryheid Formation at depth;
- Semi-confined aquifers within the Vryheid Formation. These aquifers are commonly confined along essentially horizontal bedding interfaces between different lithologies, but can be locally unconfined along the trend of fractures zones, which allows the aquifers to recharge seasonally. The aquifers can therefore be regarded as a semi-confined, or leaky confined, aquifer on a regional scale if the definition of Fetter (1994) is considered;
- Deeper confined aquifers within basement lithologies.

From a pollution management viewpoint, the presence of a perched shallow aquifer is problematic due to resulting localised decreases in the bearing capacity of site profiles, and the increased potential for pollutant transport. In this instance, site aquifers are generally seasonal, which suggests that they either drain quickly (i.e. they are relatively permeable), have a low storage potential, or that stored water can be lost via evapo-transpiration processes. Contaminant

movement away from pollution point sources can be reduced, or prevented entirely, through the construction of cut-off trenches and sub-soil drains to the confining layer at the base of the aquifer. This is generally not an option at sites where this layer occurs at significant depths, or when pollutants enter underlying regional aquifers.

3 STUDY AREA

3.1 Location of auger holes

Three (3) auger holes were drilled on the Hendrina ash dam. The first one was drilled on the old almost fully rehabilitated ash dam. Two samples HD01 and HD02 were taken at deferent depth. HD01 was taken at a depth of 0-1m and HD02 at 1-2m. The second auger hole HD03 was drilled on the part of ash dam that is current used for the dumping of ash. The last and third auger hole HD04 was drilled on an older part of the ash dam but not yet fully rehabilitated.

Refer to Figure 1 for the sampling positions

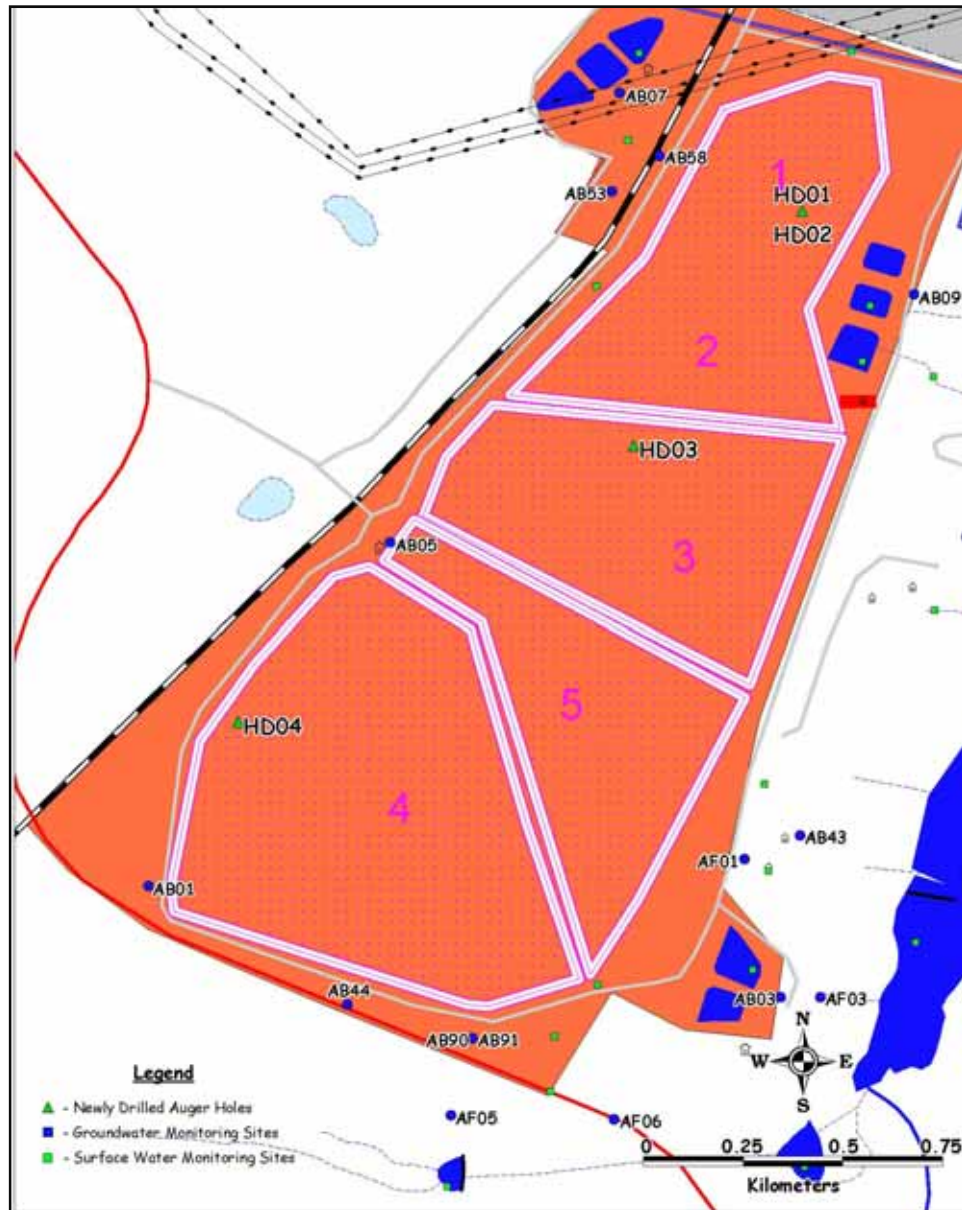


Figure 5. Auger hole sampling positions.

4 SOIL TEXTURE ANALYSES

4.1 General Ash dam properties

The Power Stations Operations produce in excess ± 65 thousand tons of ash per month. From 3:1 water to solids ratio, it is evident that large volumes of water are released onto the ash dams every month. Figures obtained from Eskom are that 70 - 80% of the water dumped onto the tailings will reach the return water dam. The remaining water will either be absorbed by the tailings, reach the ground-water table by infiltration or be evaporated mainly from the pool area.

According to Stanley (1987), fly ash may be described as a rock floor, comprising 0 - 5% fine sand and 0 - 10% clay fraction, with some 80% of the material falling within the silt classification.

According to van Niekerk (1991) up to a depth of ± 2.0 m, there is vertical movement of moisture, after which the moisture has to move horizontally, either to the centre of a ashing facility or to its side, where it can evaporate, explaining the precipitation of sulphates on the ashing facility surface. It furthermore means that there is no vertical flow past the depth of 2.0 m, hence limiting the influx of oxygen for oxidation of heavy minerals. This also correlates well with the work done on residue dump leaching procedures by James and Mrost (1971). The above-mentioned has the implication that water movement below a depth of 2 m is essentially in the horizontal direction, towards the sides of the ash dam (where it evaporates) or towards the saturated central part (pool area) of the ash dam (where it is intercepted by the drainage system).

It should, however, be stressed that the above-mentioned water movement only applies to parts of the ash dam above the phreatic surface, i.e. the unsaturated part of the slimes dam. If the saturated part of the slimes dam (i.e. the part beneath the phreatic surface) is considered, the situation changes significantly. In this region, there always exists a downward flux, due to the hydraulic gradient between the saturated part of the ash dam and the surrounding ground-water regime, as well as the chemical gradient between the two regimes.

Furthermore, van Niekerk (1991) noted that the stratification of finer and coarser layers in a slimes dam is enhanced by their water content. Generally fines tend to retain a larger portion of the available moisture than coarser materials.

4.2 Sieve Analyses

Table 7. Results of soil texture analyses in percentage.

Soil Texture Analyses				
Sample nr.	Clay	Silt	Clay+Silt	Sand
HD01	10.2	25	35.2	64.8
HD02	9.7	23.5	33.2	66.8
HD03	10.2	19	29.2	70.8
HD04	14.2	23	37.2	62.8

4.2.1 Discussion

According to the soil texture analyses (Refer to Table 7) the ash has mostly a sandy texture with some clay and silt.

4.3 Permeability

Sample No	Longitude °E	Latitude °S	Hole Diam (mm)	Sample Depth (m)	Auger hole Depth (m)	Porosity (%)	Average permeability (m/day)	Description
HD01	29.60595	-26.04699	90	0 - 1		45	10.7763	Ash
HD02	29.60595	-26.04699	90	1 - 2	2	55	11.1012	
HD03	29.60133	-26.05295	90	0 - 1	1	51	7.7109	Ash
HD04	29.59137	-26.05994	90	0 - 1	1	48	11.4293	Ash

4.3.1 Discussion

Very high permeability's are observed at all the ash samples that were obtained at Hendrina power station. See ash dam properties above (section 4.1)

5 CHEMICAL COMPOSITION OF ASH SAMPLES

5.1 X-Ray De-fraction (XRD) and X-Ray frequency (XRF)

XRF and XRD analyses were performed at the Geology Department of the University of the Free State.

Major elements were analysed on a glass bead made from the powdered sample fused with lithium tetra borate using an automatic XRF spectrometer. The major elements are determined as oxide equivalents. They are: Al, Ca, Fe, K, Mg, Mn, Na, P, Si and Ti.

XRF determination of the ash reveals the chemical constituents SiO_2 and Al_2O_3 are more than 90 % of the ash content, which suggests that the ash is perhaps best named as an Al silicate (Refer to Table 8). The Fe_2O_3 content of the ash is on average 3.5715% and CaO average content of the ash is 3.8757%.

Table 8. Results of XRF analysis of samples.

X - Ray Fluorescence Analysis. (XRF)											
Sample nr	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	Total
HD01	61.924	27.716	2.901	0.032	1.276	3.63	0	0.546	1.49	0.563	100.078
HD02	59.233	29.084	4.092	0.03	1.12	3.453	0	0.535	1.53	0.512	99.589
HD03	60.287	27.205	4.329	0.046	1.473	4.017	0	0.758	1.479	0.371	99.965
HD04	57.233	30.796	2.964	0.038	1.242	4.403	0	0.75	1.578	0.514	99.518

Concentrations are in %

Table 9. Results of XRD analysis of samples.

X-Ray Diffraction (XRD)					
Sample nr	Dominant mineral (>50%)	Major minerals (20-50%)	Minor minerals (10-20%)	Accessory minerals (2-10%)	Rare minerals (<2%)
HD01	Quartz	Mullite	-	Calcite	Rutile
HD02	Mullite	Quartz	-	Pyrite, Calcite	Rutile
HD03	Mullite	Quartz	-	Calcite	Rutile
HD04	Mullite	Quartz	-	Calcite	Rutile

IMPORTANT NOTES:

Results above does not include the amount of amorphous material, which is a typical constituent of these types of samples.

The amounts given above are therefore normalised to 100% of all the phases identified by means of XRD.

This can not be determined by the XRD technique as applied in the Department of Geology, UFS.

It is however evident that such material are present in all the samples, since a broad 'hump' can be seen in all the diffractograms.

According to literature, up to 85% of fly ash samples can consist of amorphous glassy material.

The results from the XRD (Refer to Table 9) shows the dominant minerals in the ash samples are Mullite and Quarts. Mullite is an Allumium silicate mineral. The accessory minerals are Calcite and Pyrite, calcite is calcium mineral and pyrite is an iron mineral. Pyrite is only present in sample HD02. The rare mineral that is present in all the sampled sites is Rutiel which is a Titanium mineral.

6 LEACH TEST

6.1 Theory

Leach test where performed to determine the chemical components expected to be leached from the ash. Firstly the ash was mixed with water to determine what will leach from the ash if the ash would come in contact with water. Secondly the ash was mixed with acid H_2SO_4 to determine what will leach from the ash if the environment would turn out to be an acid generator.

6.2 Leach test results

Table 10. Water soluble constituents in kg/t.

Water soluble constituents in kg/t					
Samples	HD01	HD02	HD03	HD04	Average
Initial pH	8.48	8.8	9.46	10.62	9.34
Ag	0.02327	0.02024	0.01870	0.04346	0.02642
Al	0.00743	0.00328	0.00251	0.00274	0.00399
As	0.00068	0.00202	0.00102	0.00000	0.00093
Ba	0.00047	0.00031	0.00046	0.00301	0.00106
Ca	0.14192	0.13772	0.25538	2.20078	0.68395
Cd	0.00003	0.00006	0.00004	0.00002	0.00004
Cr	0.00008	0.00019	0.00077	0.00643	0.00187
Co	0.00004	0.00004	0.00004	0.00004	0.00004
Cu	0.00007	0.00006	0.00009	0.00012	0.00008
Fe	0.00257	0.00057	0.00022	0.00008	0.00086
K	0.02788	0.01461	0.02443	0.09274	0.03991
Li	0.00036	0.00056	0.00120	0.00472	0.00171
Mg	0.04011	0.04991	0.08071	0.04011	0.05271
Mn	0.00015	0.00016	0.00019	0.00025	0.00019
Mo	0.00023	0.00027	0.00059	0.00327	0.00109
Na	0.04214	0.05381	0.03497	0.19254	0.08087
Ni	0.00009	0.00008	0.00010	0.00007	0.00009
Se	0.00016	0.00040	0.00038	0.00043	0.00034
Pb	0.00018	0.00017	0.00016	0.00012	0.00016
V	0.00129	0.00323	0.00604	0.00338	0.00348
Zn	0.00015	0.00012	0.00012	0.00008	0.00012
SO ₄	0.22408	0.10136	0.34690	5.70140	1.59343

Table 11. Acid H₂SO₄ soluble constituents in kg/t.

Acid (H ₂ SO ₄) soluble constituents in kg/t					
Samples	HD01	HD02	HD03	HD04	Average
Final pH	1.82	1.72	2.21	2.16	1.9775
Ag	0.08619	0.06250	0.07042	0.18145	0.10014
Al	7.76273	7.57316	9.03843	7.19820	7.89313
As	0.00300	0.00665	0.00000	0.00078	0.00261
Ba	0.00049	0.00046	0.00054	0.00066	0.00054
Ca	5.10142	5.07112	5.04821	4.81744	5.00955
Cd	0.00033	0.00043	0.00024	0.00034	0.00034
Cr	0.00729	0.00820	0.01143	0.02182	0.01219
Co	0.00390	0.00419	0.00318	0.00280	0.00352
Cu	0.00584	0.00742	0.00932	0.01302	0.00890
Fe	0.37981	0.82651	0.82704	0.49346	0.63170
K	0.25803	0.23388	0.36006	0.31899	0.29274
Li	0.00675	0.00729	0.01094	0.01279	0.00944
Mg	3.86456	3.47178	5.25325	4.36271	4.23807
Mn	0.11830	0.09073	0.16458	0.11498	0.12215
Mo	0.00000	0.00000	0.00000	0.00022	0.00006
Na	0.32145	0.32341	0.30532	0.49732	0.36188
Ni	0.00510	0.00674	0.00506	0.00549	0.00560
Se	0.00018	0.00015	0.00003	0.00038	0.00018
Pb	0.00133	0.00144	0.00098	0.00104	0.00120
V	0.02378	0.02878	0.03290	0.05362	0.03477
Zn	0.01172	0.01480	0.01551	0.01452	0.01414
SO ₄					

6.3 Landfill classification according to the draft standard for classification of waste for landfill disposal: Government gazette notice 433 of 2011- 1 July 2011

To determine the level of risk associated with the disposal of waste to landfill, the following are required-

- Identification of chemical substances present in the waste; and
- Sampling and analysis to determine the total concentrations (TC) and leachable concentrations (LC) for the chemical substances specified in paragraph 6 of the notice 433 of 2011- 1 July 2011 that are present in the waste.
- The TC and LC values of the chemical substances in the waste must be compared to the four levels of threshold limits specified in paragraph 6 of this Notice for total concentrations (TCT values) and leachable concentrations (LCT values) of specific chemical substances.

- Corresponding TCT and LCT values respectively, the level of risk associated with the disposal of the waste to landfill must be assigned to the waste in terms of paragraph 7 of the notice 433 of 2011- 1 July 2011.

Table 12. Some of the threshold values according to the government gazette notice 433 Of 2011 – 1 July 2011.

LCTi, LCTO, LCT and TCT Threshold Values								
Chemical Substances in Waste	LCTi mg/l	TCTi mg/kg	LCTO mg/l	TCTO mg/kg	LCT1 mg/l	TCT1 mg/kg	LCT2 mg/l	TCT2 mg/kg
<i>Metal/Ions</i>								
As, Arsenic	0.01	5.8	0.5	500	1	500	4	2000
B, Boron	0.5	150	25	15000	50	15000	200	60000
Ba, Barium	0.7	62.5	35	6250	70	6250	280	25000
Cd, Cadmium	0.005	7.5	0.25	260	0.5	260	2	1040
Co, Cobalt	0.5	50	25	5000	50	5000	200	20000
Cr Total. Chromium Total	0.1	46000	5.0	800000	10	800000	40	N/A
Cr(VI),	0.05	6.5	2.5	500	5	500	20	2000
Cu, Copper	1.0	16	50	19500	100	19500	400	78000
Hg, Mercury	0.001	0.93	0.05	160	0.1	160	0.4	640
Mn, Manganese	0.4	1000	20	25000	40	25000	160	100000
Mo, Molybdenum	0.07	40	3.5	1000	7	1000	28	4000
Ni, Nickel	0.07	91	3.5	10600	7	10600	28	42400
Pb, Lead	0.01	20	0.5	1900	1	1900	4	7600
Sb, Antimony	0.01	10	0.5	75	1	75	4	300
Se, Selenium	0.01	10	0.5	50	1	50	4	200
V, Vanadium	0.1	150	5.0	2680	10	2680	40	10720
Zn, Zinc	3.0	240	150	160000	300	160000	1200	640000
<i>Inorganic Anions</i>								
Sulphate	200	N/A	10000	N/A	20000	N/A	80000	N/A

Table 13. Waste Disposal Risk Rating according to the government gazette notice 433 Of 2011 – 1 July 2011.

Criteria	Waste Disposal Risk Rating	Description of Risk associated with Disposal to Landfill
$LC > LCT_2$, or $TC > TCT_2$	Type 0: Very High Risk	Considered very high risk waste with a very high potential for contaminant release. Requires very high level of control and ongoing management to protect health and the environment.
$LCT_1 < LC \leq LCT_2$, or $TCT_1 < TC \leq TCT_2$	Type 1: High Risk	Considered high risk waste with high potential for contaminant release. Requires high level of control and ongoing management to protect health and the environment.
$LCTO < LC \leq LCT_1$ and $TC \leq TCT_1$	Type 2: Moderate Risk	Considered moderate risk waste with some potential for contaminant release. Requires proper control and ongoing management to protect health and the environment.
$LCT_i < LC \leq LCTO$ and $TC \leq TCTO$	Type 3: Low Risk	Low risk waste with low potential for contaminant release. Requires some level of control and ongoing management to protect health and the environment.
$TC < 20 \times LCT_i$, or $LC \leq LCT_i$ and $TC \leq TCT_i$	Type 4: Inert Waste	Very low risk waste that- (a) does not undergo any significant physical, chemical or biological transformation; (b) does not burn, react physically or chemically or otherwise affect any other matter with which it may come into contact; and (c) does not impact negatively on the environment because of its very low pollutant content and because the toxicity of its leachate is insignificant. Only basic control and management required.

Table 14. The classification of auger hole HD01 according to the government gazette notice 433 of 2011 – 1 July 2011.

HD01					
LCTi, LCTO, LCT and TCT Threshold Values	Type 0	Type 1	Type 2	Type 3	Type 4
Chemical Substances in Waste	LC>LCT2 or TC>TCT2	LCT1<LC<=LCT2 or TCT1<TC<TCT2	LCT0 < LC < LCT1 and TC<=TCT1	LCTi<LC<LCTO and TC<=TCT0	TC<20*TCTi or (LC<=LCTi and TC<=TCTi)
<i>Metal/Ions</i>					
As, Arsenic				Type 3	Type 4
B, Boron					Type 4
Ba, Barium					Type 4
Cd, Cadmium					Type 4
Co, Cobalt					Type 4
Cr Total, Chromium Total					Type 4
Cr(VI),					Type 4
Cu, Copper					Type 4
Hg, Mercury					Type 4
Mn, Manganese					Type 4
Mo, Molybdenum					Type 4
Ni, Nickel					Type 4
Pb, Lead					Type 4
Sb, Antimony					Type 4
Se, Selenium					Type 4
V, Vanadium					Type 4
Zn, Zinc					Type 4
<i>Inorganic Anions</i>					
Sulphate				Type 3	N/A

Table 15. The classification of auger hole HD02 according to the government gazette notice 433 of 2011 – 1 July 2011. .

HD02					
LCTi, LCTO, LCT and TCT Threshold Values	Type 0	Type 1	Type 2	Type 3	Type 4
Chemical Substances in Waste	LC>LCT2 or TC>TCT2	LCT1<LC<=LCT2 or TCT1<TC<TCT2	LCT0 < LC < LCT1 and TC<=TCT1	LCTi<LC<LCT0 and TC<=TCT0	TC<20*TCTi or (LC<=LCTi and TC<=TCTi)
<i>Metal/Ions</i>					
As, Arsenic				Type 3	Type 4
B, Boron					Type 4
Ba, Barium					Type 4
Cd, Cadmium					Type 4
Co, Cobalt					Type 4
Cr Total, Chromium Total					Type 4
Cr(VI),					Type 4
Cu, Copper					Type 4
Hg, Mercury					Type 4
Mn, Manganese					Type 4
Mo, Molybdenum					Type 4
Ni, Nickel					Type 4
Pb, Lead					Type 4
Sb, Antimony					Type 4
Se, Selenium				Type 3	Type 4
V, Vanadium				Type 3	Type 4
Zn, Zinc					Type 4
<i>Inorganic Anions</i>					
Sulphate					N/A

Table 16. The classification of auger hole HD03 according to the government gazette notice 433 of 2011 – 1 July 2011.

HD03					
LCTi, LCTO, LCT and TCT Threshold Values	Type 0	Type 1	Type 2	Type 3	Type 4
Chemical Substances in Waste	LC>LCT2 or TC>TCT2	LCT1<LC<=LCT2 or TCT1<TC<TCT2	LCT0 < LC < LCT1 and TC<=TCT1	LCTi<LC<LCT0 and TC<=TCT0	TC<20*TCTi or (LC<=LCTi and TC<=TCTi)
<i>Metal/Ions</i>					
As, Arsenic				Type 3	Type 4
B, Boron					Type 4
Ba, Barium					Type 4
Cd, Cadmium					Type 4
Co, Cobalt					Type 4
Cr Total, Chromium Total					Type 4
Cr(VI),					Type 4
Cu, Copper					Type 4
Hg, Mercury					Type 4
Mn, Manganese					Type 4
Mo, Molybdenum					Type 4
Ni, Nickel					Type 4
Pb, Lead					Type 4
Sb, Antimony					Type 4
Se, Selenium				Type 3	Type 4
V, Vanadium				Type 3	Type 4
Zn, Zinc					Type 4
<i>Inorganic Anions</i>					
Sulphate					N/A

Table 17. The classification of auger hole HD04 according to the government gazette notice 433 of 2011 – 1 July 2011.

HD04					
LCTi, LCTO, LCT and TCT Threshold Values	Type 0	Type 1	Type 2	Type 3	Type 4
Chemical Substances in Waste	$LC > LCT_2$ or $TC > TCT_2$	$LCT_1 < LC \leq LCT_2$ or $TCT_1 < TC \leq TCT_2$	$LCT_0 < LC < LCT_1$ and $TC \leq TCT_1$	$LCT_i < LC < LC_{T0}$ and $TC \leq TCT_0$	$TC < 20 * TCT_i$ or $(LC \leq LCT_i$ and $TC \leq TCT_i)$
<i>Metal/Ions</i>					
As, Arsenic					Type 4
B, Boron					Type 4
Ba, Barium					Type 4
Cd, Cadmium					Type 4
Co, Cobalt					Type 4
Cr Total, Chromium Total				Type 3	Type 4
Cr(VI),					Type 4
Cu, Copper					Type 4
Hg, Mercury					Type 4
Mn, Manganese					Type 4
Mo, Molybdenum				Type 3	Type 4
Ni, Nickel					Type 4
Pb, Lead					Type 4
Sb, Antimony					Type 4
Se, Selenium				Type 3	Type 4
V, Vanadium				Type 3	Type 4
Zn, Zinc					Type 4
<i>Inorganic Anions</i>					
Sulphate				Type 3	

6.3.1 Discussion

The four ash samples that were taken at Hendrina ash dam can all be classified as a **Type 3** waste according to the Waste Disposal Risk Rating. **Type 3 waste are low risk waste with a low potential for contaminant release and requires some level of control and ongoing management to protect health and the environment.** Note that not all the chemical substances that are specified in paragraph 6 of the notice 433 of 2011- 1 July 2011 were analysed for. Some of these specified chemicals substances are only for areas that can be affected by pesticide and organic chemical substances like benzene and oil.

The chemical substance aluminium (Al) that was leached from the ash samples has no guideline or standard to compare too. Thus Al cannot be classified. The Al content of these ash samples is very high. It is suggested that further investigation must be done to determine the Aluminium impact on the environment. It is also suggested that the waste disposal risk rating must be updated to include Al in their calculations.

6.4 Classification according to dwaf water quality guidelines.

Table 18. Quality of Domestic Water Supplies, DWAF, Second Edition 1998.

Site No.	Quality Class	pH	Na mg/L	Ca mg/L	Mg mg/L	K mg/L	Fe mg/L	Mn mg/L	Cd mg/L	Pb mg/L	Cr mg/L	Ba mg/l	B mg/l	Cu mg/l	Al mg/l	As mg/l	Co mg/l	Li mg/l	Mo mg/l	Ni mg/l	Se mg/l	V mg/l
HD01	Class 1	8.48	2	7	2	1.39	0.1287	0.0073	0.0017	0.0090	0.00	0.02	1.164	0.003	0.3717	0.0342	0.0019	0.0179	0.0115	0.0047	0.0079	0.0644
HD02	Class 1	8.80	3	7	2	0.73	0.0287	0.0082	0.0031	0.0084	0.01	0.02	1.012	0.003	0.1640	0.1009	0.0019	0.0279	0.0134	0.0040	0.0200	0.1613
HD03	Class 1	9.46	2	13	4	1.22	0.0111	0.0094	0.0021	0.0078	0.04	0.02	0.935	0.004	0.1255	0.0509	0.0019	0.0600	0.0294	0.0051	0.0192	0.3018
HD04	Class 3	10.62	10	110	2	4.64	0.0042	0.0126	0.0010	0.0062	0.32	0.15	2.173	0.006	0.1372	0.0000	0.0018	0.2358	0.1635	0.0037	0.0213	0.1690

Acid (H2SO4) soluble constituents in mg/l

Site No.	Quality Class	pH	Na mg/L	Ca mg/L	Mg mg/L	K mg/L	Fe mg/L	Mn mg/L	Cd mg/L	Pb mg/L	Cr mg/L	Ba mg/l	B mg/l	Cu mg/l	Al mg/l	As mg/l	Co mg/l	Li mg/l	Mo mg/l	Ni mg/l	Se mg/l	V mg/l
HD01 Acid	Class 4	1.82	16	255	193	12.90	18.9903	5.9150	0.0166	0.0667	0.36	0.02	4.309	0.292	388.1367	0.1499	0.1948	0.3375	0.0000	0.2549	0.0089	1.1892
HD02 Acid	Class 4	1.72	16	254	174	11.69	41.3253	4.5364	0.0213	0.0718	0.41	0.02	3.125	0.371	378.6579	0.3325	0.2097	0.3643	0.0000	0.3368	0.0077	1.4392
HD03 Acid	Class 4	2.21	15	252	263	18.00	41.3519	8.2290	0.0121	0.0492	0.57	0.03	3.521	0.466	451.9215	0.0000	0.1589	0.5471	0.0000	0.2531	0.0014	1.6450
HD04 Acid	Class 4	2.16	25	241	218	15.95	24.6731	5.7488	0.0172	0.0520	1.09	0.03	9.072	0.651	359.9102	0.0390	0.1400	0.6395	0.0112	0.2743	0.0190	2.6810

Quality of Domestic Water Supplies, DWAF, Second Edition 1998

Class 0	- Ideal water quality - Suitable for lifetime use.
Class 1	- Good water quality - Suitable for use, rare instances of negative effects.
Class 2	- Marginal water quality - Conditionally acceptable. Negative effects may occur in some sensitive groups
Class 3	- Poor water quality - Unsuitable for use without treatment. Chronic effects may occur.
Class 4	- Dangerous water quality - Totally unsuitable for use. Acute effects may occur.

South Africa Water Quality Guidelines, Volume 1: Domestic Use, DWA&F, First Edition 1993 & Second Edition 1996

NR	- Target water quality range - No risk.
IR	- Good water quality - Insignificant risk. Suitable for use, rare instances of negative effects.
LR	- Marginal water quality - Allowable low risk. Negative effects may occur in some sensitive groups
HR	- Poor water quality - Unsuitable for use without treatment. Chronic effects may occur.

6.4.1 Discussion

The water quality of the water leached ash from samples HD01, HD02 and HD03 are classified as good (Class 1). Good water quality is suitable for use and negative effects are rare. The leached water from ash sample HD04 can be classified as poor (Class 3). HD04 is classified as poor possibly due to the very high pH and the occurrence of Cr and B. Poor water quality water is unsuitable for use without treatment. Chronic effects may occur.

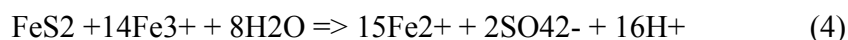
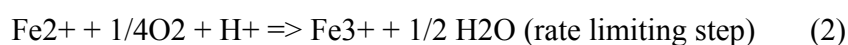
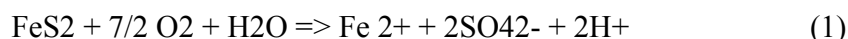
When acid was leached through the ash all the sampled sites are classified as dangerous (Class 4). Very high Al, Fe, B, Mn and Cr concentration and very low pH levels are observed. The possibility if the environment can turn into an acid generator are explained in section 7. If the possibility is high that the environment can be an acid generator, these high concentration of elements can leach from the ash dam.

7 ACID BASE ACCOUNTING (ABA)

7.1 Theory

In most mining environments the onset of acid mine drainage (AMD) is as a result of the oxidation of sulphide minerals present. In waste rock dumps it is often these sulphides that react with water and oxygen, usually assisted by microbiological catalysis, to generate low pH waters, with high sulphates and often associated heavy metal mobilization.

The reactions involved are usually written with pyrite regarded as the sulphide of interest. Pyrite (FeS) is a common mineral often occurring as a gangue mineral associated with deposits of interest. The principal reactions involved are the following:



Reaction 1 shows oxidation of the disulphide, thus releasing ferrous iron (Fe²⁺) and two protons. In Reaction 2 the ferrous iron is oxidised to ferric iron (Fe³⁺) which hydrolyses to form ferric hydroxide (an insoluble compound at pH greater than 3.5) and in the process as shown in Reaction 3, three more protons are released. Thus for every mole of pyrite five protons are released. However, since one proton is consumed for the oxidation of ferrous to ferric, only four protons are actually produced. Upon initiation of pyrite oxidation, the ferric iron can be reduced by the pyrite itself as shown in Reaction 4.

Acid-Base Accounting (ABA) usually refers to the so-called static methods that provide no information on the speed (or kinetic rate) with which acid generation or neutralisation will proceed, but simply determine the acid-neutralising potential (assets) and acid-generating potential (liabilities) of rock samples, and calculates the difference or net neutralising potential (equity). The net neutralising potential (NNP), and/or the ratio of neutralising potential to acid-generation potential (the neutralising potential ratio, NPR), is compared with a predetermined value, or set of values, to divide samples into categories that either require, or do not require, further determinative acid potential generation test work.

The potential for a given rock to generate and neutralize acid is determined by its mineralogical composition. This includes not only the quantitative mineralogical composition, but also individual mineral grain size, shape, texture and spatial relationship with other mineral grains. The term "potential" is used because even the most detailed mineralogical analysis, when combined with ABA, can give only a "worst case" value for potential acid production and, depending upon the NP procedure used, a "worst case", "most likely case" or "best case" value for potential neutralisation capability. The field generation and neutralisation of AMD represents the degree to which these potential values are realised in practice.

Neutralisation potential measures the sum total of carbonates, alkaline earths, and bases available to neutralize acidity and represents the most favourable condition. Calculations of maximum potential acidity and neutralisation potential are structured to equate the two measurements to a common basis for comparison. The resulting values, expressed as calcium carbonate equivalent, are compared to compute a net acid-producing or neutralising potential. Material exhibiting a

net acid production potential of 5 tons/1000 tons of overburden material or more as calcium carbonate equivalent are classed as toxic or potentially toxic.

In its simplest form then Acid-Base Accounting is a way of determining via a set of procedures whether a particular sample has the potential for acid generation. Just as different methods of accounting present different sets of books to an auditor, so different methods of conducting ABA test work will generate different sets of sample data for evaluation. Three methods commonly used to interpret ABA data are described below:

7.2 pH

A sample from the waste rock is subjected to ultra oxidizing conditions by the addition of a strong oxidizing agent, such as hydrogen peroxide. This agent oxidizes all the sulphides in the sample to sulphates, liberating protons in the process. This test therefore gives a worst-case end member that could arise from oxidation. The criteria used to assess acid-generation potential are:

Final pH > 5.5, sample is considered to be non acid-generating,

$3.5 < \text{Final pH} < 5.5$, sample has a low risk of acid generation,

Final pH < 3.5, sample has a high acid generation risk.

7.3 Net neutralising potential (NNP)

The NNP is simply the difference between the neutralising potential (NP) and the acid-generation potential (AP). The following criteria are used to evaluate the potential of the sample to generate acid:

If $\text{NNP} = \text{NP} - \text{AP} < 0$, the sample has the potential to generate acid,

If $\text{NNP} = \text{NP} - \text{AP} > 0$, the sample has the potential to neutralise acid produced.

More specifically, any sample with an $\text{NNP} < -20$ is potentially acid generating, while any sample with $\text{NNP} > 20$ is likely not to generate acid. The acid generation potential of samples with NNP values between -20 and 20 is usually considered as uncertain and other static and/or kinematic tests are performed to obtain more certainty.

7.4 Neutralising potential ratio (NPR)

The NPR is calculated from NP/AP. The following criteria are used to evaluate the potential for Acid Mine Drainage (AMD):

$\text{NPR} < 1$, likely AMD generating,

$1 < \text{NPR} < 2$, possibly AMD generating if NP is sufficiently reactive or is depleted at a faster rate than sulphides,

$2 < \text{NPR} < 4$, not potentially AMD generating, unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP,

$\text{NPR} > 4$, high neutralising potential, AMD very unlikely.

7.5 ABA Results

The ash samples taken from Hendrina ash dam were submitted to the laboratory of the Institute for Groundwater Studies (UFS) for Acid-Base Accounting (ABA).

To interpret the results of the analyses, the analysed chemical variables (pH, Acid Potential, Neutralisation Potential) were entered into the spreadsheet ABACUS, Acid Base Accounting Cumulative Screening, developed by Dr Brent Usher. This spreadsheet makes use of various accepted approaches to interpret ABA data and allows a comparison of the results from each approach. These approaches include assessments made on the basis of pH values, Net Neutralising Potential (NNP) values and Neutralising Potential Ratios (NPR) for both open and closed systems. In open systems O₂ and CO₂ are able to freely enter and leave the solution. However, in closed systems, such as positions below the water table, no gas phase is present to supply CO₂ to the system. This reduces the solubility of calcite/calcrete causing the system to have an overall higher acid potential. The sample and comparative interpretations of the ABA data for the discards is presented in Table 19.

Table 19. Sample interpretation of the Acid/Base Accounting (ABA) results.

Acid Generating Potential											
Sample nr	pH			NNP open system		NNP closed system		NPR open system		NPR closed system	
	Initial pH	Final pH	Interpretation	Value	Interpretation	Value	Interpretation	Value	Interpretation	Value	Interpretation
HD01	8.48	5.63	Lower Acid Risk	67.03	Probably Excess Neutralising Minerals	66.87	Probably Excess Neutralising Minerals	424.36	No Acid Potential	212.18	No Acid Potential
HD02	8.8	5.74	Lower Acid Risk	63.47	Probably Excess Neutralising Minerals	63.27	Probably Excess Neutralising Minerals	321.67	No Acid Potential	160.84	No Acid Potential
HD03	9.46	6	Lower Acid Risk	75.55	Probably Excess Neutralising Minerals	74.69	Probably Excess Neutralising Minerals	88.18	No Acid Potential	44.09	No Acid Potential
HD04	10.62	7.03	Lower Acid Risk	66.20	Probably Excess Neutralising Minerals	55.24	Probably Excess Neutralising Minerals	7.04	No Acid Potential	3.52	Acid under certain conditions

Table 20. Sample interpretation of the Acid/Base Accounting (ABA) results for the samples from Leeuw Mining discards.

Sample nr	pH values	Net Neutralising Potential	NPR (Open System)	NPR (Closed System)	%S and NPR Method(Soregali and Lawrence,1997)	ABA INDEX	ABA INDEX	VERDICT
HD01	Lower Acid Risk	Probably Excess Neutralising Minerals	No Acid Potential	No Acid Potential	Too little S to create sustained acidity	0	-11	Very Low Risk
HD02	Lower Acid Risk	Probably Excess Neutralising Minerals	No Acid Potential	No Acid Potential	Too little S to create sustained acidity	0	-11	Very Low Risk
HD03	Lower Acid Risk	Probably Excess Neutralising Minerals	No Acid Potential	No Acid Potential	Too little S to create sustained acidity	0	-13	Very Low Risk
HD04	Lower Acid Risk	Probably Excess Neutralising Minerals	No Acid Potential	Acid under certain conditions	Confirm with other testing	1	-1	Do Further Testing

Table 20 and Figure 6 and Figure 7 are graphs of the initial and final pH values of the ash samples from the ash dam and it's plotted against the NNP values calculated for an open and closed system, respectively. It can be seen that all the final pH values are all above the 5.5 and are likely to not be acid generating in both the open and closed systems. However, one sample (HD04) have NPR between 2 and 4 and are potentially AMD generating, if significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP.

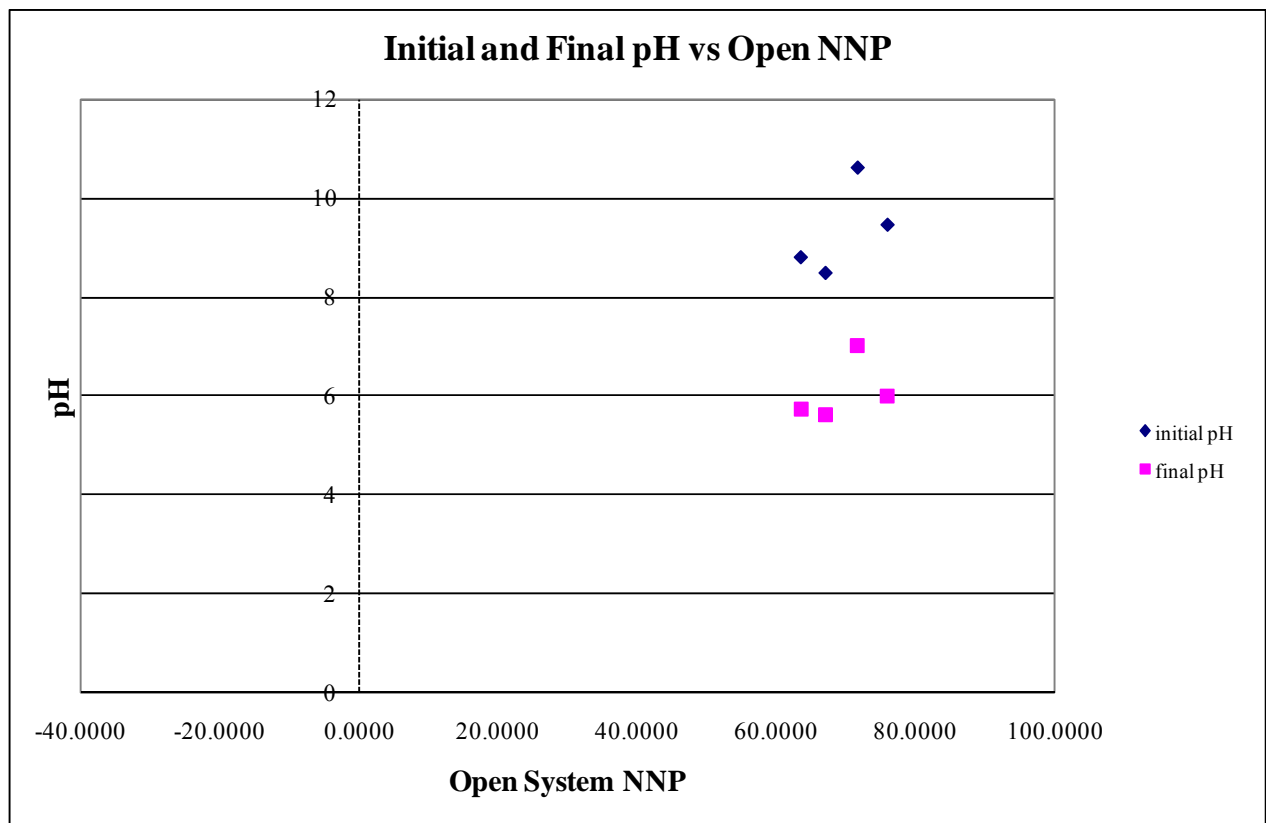


Figure 6. Initial and final pH values plotted versus NNP values (open system) for the samples.

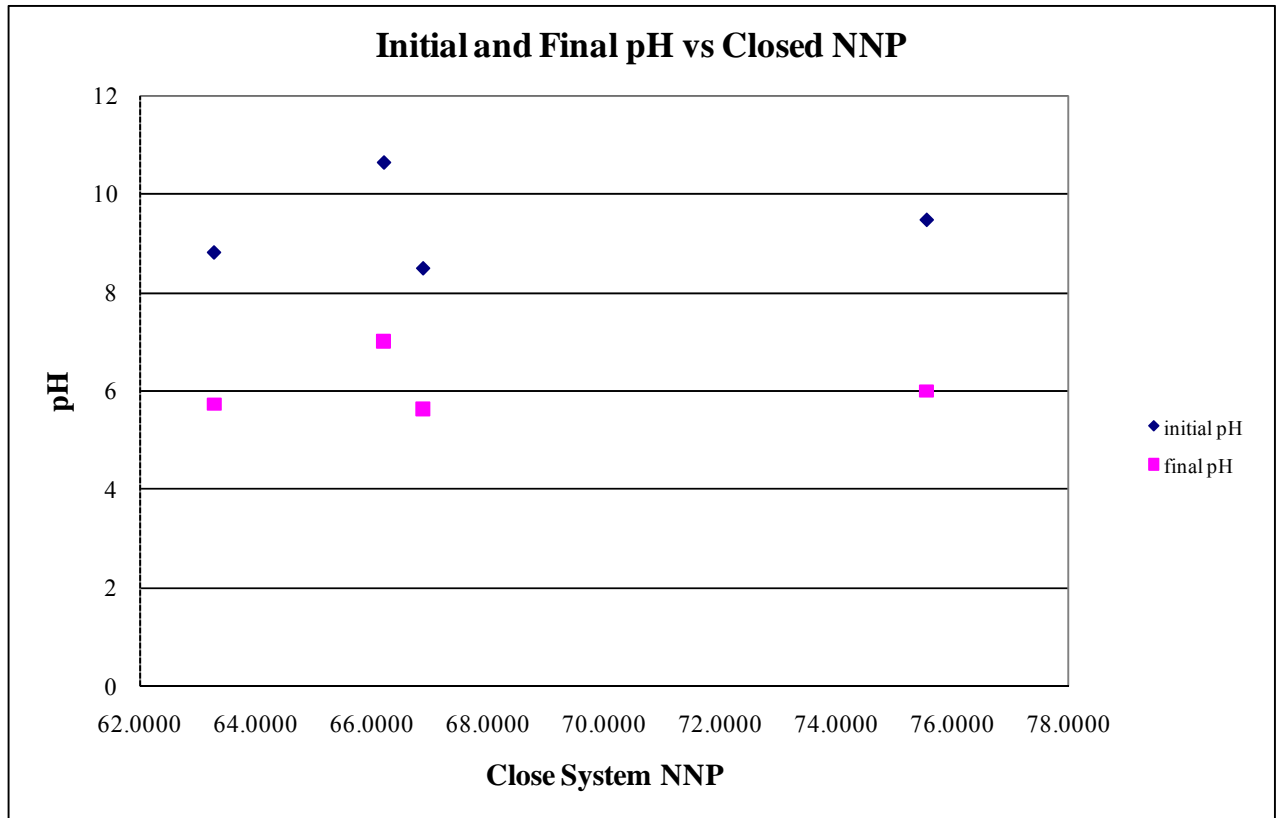


Figure 7. Initial and final pH values plotted versus NNP values (closed system).

Figure 8 is a graph of the acid potential (AP) plotted against neutralising potential (NP) for samples for both open and closed systems. Most of the samples plot below the 4:1 line (blue dashed line) and are therefore unlikely to be acid generating. This observation holds true for both the open and closed systems.

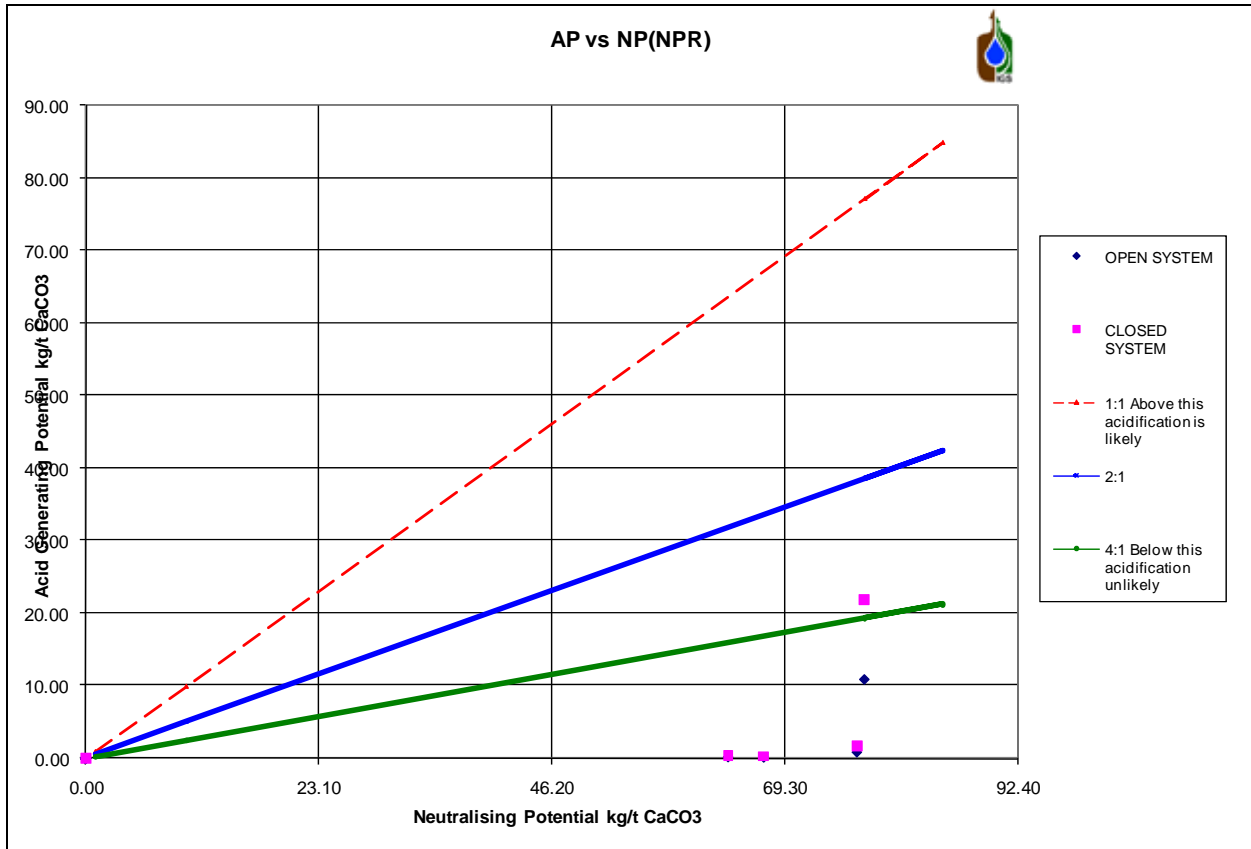


Figure 8. Acid potential (AP) plotted versus neutralising potential (NP).

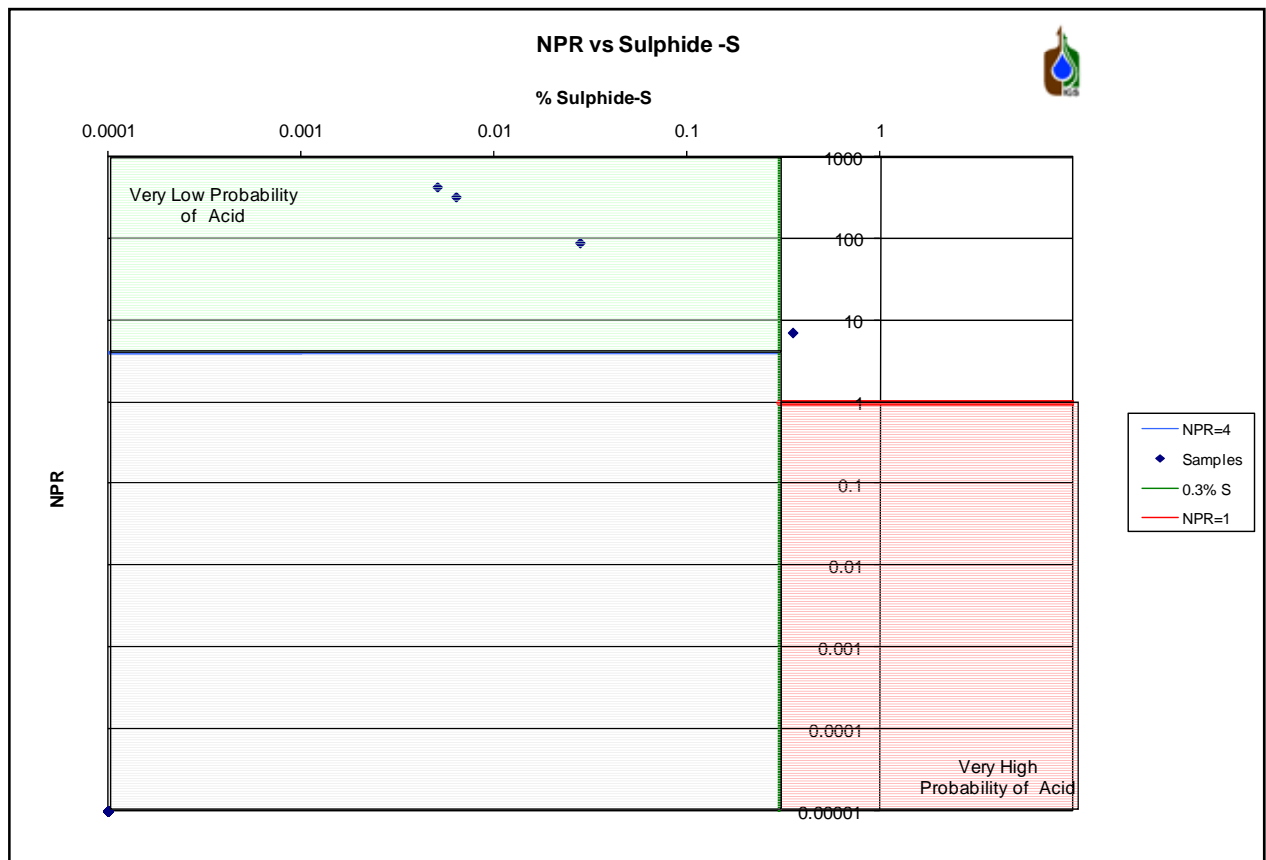


Figure 9. Neutralising Potential Ratios (NPR) plotted versus %S

8 CONCLUSION

The four ash samples that were taken at Hendrina ash dam can all be classified as a **Type 3** waste according to the Waste Disposal Risk Rating. **Type 3 waste are low risk waste with a low potential for contaminant release and requires some level of control and ongoing management to protect health and the environment.** Note that not all the chemical substances that are specified in paragraph 6 of the notice 433 of 2011- 1 July 2011 were analysed for. Some of these specified chemicals substances are only for areas that can be affected by pesticide and organic chemical substances like benzene and oil.

The chemical substance aluminium (Al) that was leached from the ash samples has no guideline or standard to compare too. Thus Al cannot be classified. The Al content of these ash samples is very high. It is suggested that further investigation must be done to determine the Aluminium impact on the environment. It is also suggested that the waste disposal risk rating must be updated to include Al in their calculations.