ZITHOLELE CONSULTING

WASTE ASSESSMENT OF ASH AND FLUE GAS DESULPHURISATION WASTES FOR THE MEDUPI POWER STATION

REPORT

Report No.: JW197/14/E173 – REV 02

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EXECUTIVE SUMMARY

Eskom's Medupi Power Station will be fitted with a Flue Gas Desulphurisation (FGD) Plant to manage sulphur dioxide emissions from the Power Station. Currently the FGD Plant is being designed and authorised under the National Environmental Management Act (NEMA, Act 107 of 1998). The FGD Plant and the FGD Waste Water Treatment Plant operation will generate three waste streams that required assessment in terms of the "*National Norms and Standards for the Assessment of Waste for Landfill Disposal*" (National Norms and Standards) of the Department of Environmental Affairs (DEA) (DEA, 2013a). As it is proposed to dispose some of these wastes on the same landfill as the ash from the power station, the ash was also assessed in terms of the National Norms and Standards.

The three waste streams to be generated by the FGD Plant and the FGD Waste Water Treatment Plant operation are:

- **FGD Gypsum**: The FGD process uses finely ground limestone mixed with water to form a slurry. The slurry is sprayed into an absorber tank where it reacts with the flue gas. The calcium carbonate in the lime slurry reacts with sulphur dioxide in the flue gas and gypsum is precipitated as per the following reactions:
  - $CaCO_{3\ (aq)} + SO_{2\ (g)} \rightarrow CaSO_{3\ (aq)} + CO_2$
  - $CaSO_{3\ (aq)} + ½\ O_{2\ (g)} \rightarrow CaSO_4.2H_2O_{\ (s)}$ (gypsum).

  In the case of the Medupi Power Station two limestone qualities are considered for usage, namely an 85% limestone and a 96% limestone.
- **FGD Waste Water Treatment Plant Sludge**: The wastewater from the absorber tank is flocculated in a clarifier. The underflow from the clarifier is fed through a filter press to recover the sludge. The sludge from the process is referred to as the FGD Waste Water Treatment Plant (WWTP) Sludge.
- **FGD Waste Water Treatment Plant Crystalliser Solids**: The crystalliser uses evaporation to cause precipitation of salts from the wastewater (brine) after flocculation and the clarifier process. The liquid from the crystalliser is of a high enough quality to be re-used in the process, resulting in a Zero Liquid Discharge (ZLD) system, but the FGD Waste Water Treatment Plant Crystalliser Solids (FGD WWTP Crystalliser Solids) require disposal.

The FGD Waste Water Treatment Plant process is illustrated in **Figure A**.

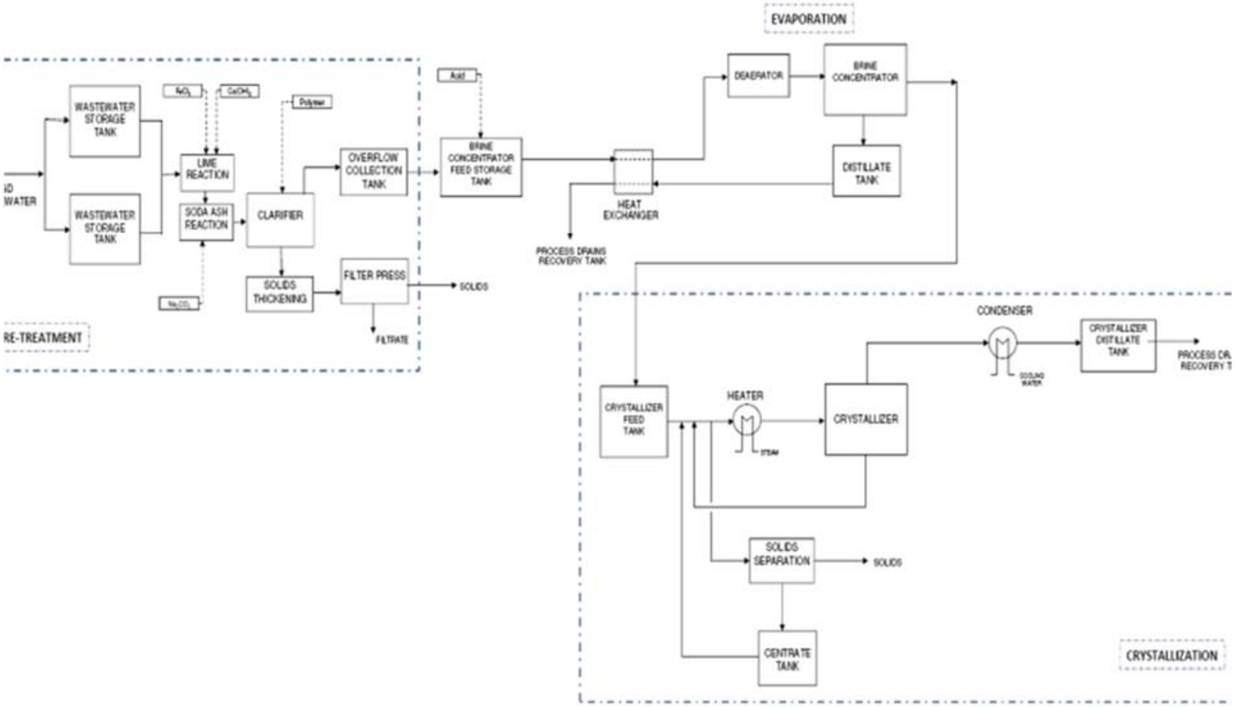

Figure A: Process Flow Diagram of the FGD Waste Water Treatment Plant

Jones & Wagener (Pty) Ltd (J&W) was requested to undertake the waste assessments for the disposal of the above wastes and the Power Station's ash in order to determine the classes of landfills required for the safe disposal of the various wastes.

The ash, FGD gypsum, FGD WWTP Sludge and FGD WWTP Crystalliser Solids were assessed for disposal according to the National Norms and Standards as per Government Notice Regulations 635 of the National Environmental Management: Waste Act, Act 59 of 2008, as amended. For this project, samples of the Matimba Power Station ash, which also contain some brine from the water treatment plant facility, was used for the assessment of the coal derived waste. For the assessment of the FGD gypsum, FGD WWTP Sludge and Crystalliser Solids information was obtained from Eskom, Black & Veatch and other sources, notable the VGD Powertech Journal published by VGD Powertech, the European Technical Association for power and heat generation, and the Electric Power Research Institute (USA) and L. Chen and co-workers/authors, who did significant research work on FGD derived gypsum in the United States of America. Reliance was also made on information obtained from work carried out by J&W and En-Chem for the Kusile Power Station. It is noted that the assessments for especially the FGD WWTP Sludge and FGD WWTP Crystalliser Solids should be regarded as provisional as such wastes are not yet generated in South Africa.

The Matimba Power Station ash was assessed as a Type 3 waste requiring disposal on a Class C landfill. The ash to be generated by the Medupi Power Station should have similar characteristics as that of the Matimba Power Station as the coal for both power stations are obtained from the same coal field. The assessment was based on chemical analyses and leach tests carried out on ash samples obtained from the Matimba Power Station.

The FGD Gypsum was assessed as a Type 3 waste and may be disposed of on a Class C landfill. The assessment was based on chemical analyses of FGD Gypsum generated elsewhere in the world, such as the USA.

The FGD WWTP sludge was classified as either a Type 1 or Type 2 waste and would require disposal in a Class A or Class B landfill for material produced using the 96% calcium carbonate limestone and the 85% calcium carbonate limestone respectively. As there is a considerable amount of uncertainty regarding the composition of the two sludges and their assessments for disposal, it is proposed that the 85% calcium carbonate limestone sludge also be disposed of in a Class A landfill as a Class A landfill provides the highest level of environmental protection.

The FGD WWTP Crystalliser Solids was assessed as a Type 1 waste due to the likely leachable TDS concentrations as a result of the high concentration of sodium chloride in the solid material, and will need to be disposed of in a Class A landfill. The 85% and 96% limestone derived FGD WWTP Sludges and FGD WWTP Crystalliser Solids are waste materials generated from the treatment of FGD wastewater and as such should have similar chemical characteristics.

The Class A landfill offers the highest level of environmental protection of any landfill barrier system used in South Africa taking this into account and given the similar chemical characteristics of the 85% and 96% limestone derived FGD WWTP Sludges and Crystalliser Solids, it is proposed that these waste materials be disposed of in a single newly designed and constructed Class A landfill at the Medupi Power Station.

Table 1: Summary of waste assessment results and

Waste	Assessment and Class of Landfill required for disposal	Percentage of waste (%)
Ash	Type 3 waste – Class C Landfill	79 or 68
FGD Gypsum	Type 3 waste – Class C Landfill	19 or 29
FGD WWTP Sludge 85% Limestone	Type 2 waste – Class A landfill*	2.4
FGD WWTP Sludge 96% Limestone	Type 1 waste – Class A landfill	1.4
FGD WWTP Crystalliser Solids	Type 1 waste – Class A landfill	0.72 or 0.62
*** The Type 2 assessment was based on theoretical values and therefore a conservative approach should be followed and the 85% Limestone FGD WWTP Sludge should be disposed of on a Class A landfill until the assessments can be confirmed on actual waste samples.**		

Based on the outcome of the assessments, it is recommended that:

- The Medupi Power Station ash and the FGD Gypsum be disposed of on a waste disposal facility of which the barrier system complies with the performance requirements of a Class C landfill.
- The 85% limestone derived FGD WWTP Sludge is provisionally assessed as a Type 2 waste but should be disposed of on a waste disposal facility of which the barrier system complies with the performance requirements of a Class A landfill due to the considerable amount of uncertainty regarding the composition of the sludge at this point in time.
- The 96% limestone derived FGD WWTP Sludge is provisionally assessed as a Type 1 waste and should be disposed of on a waste disposal facility of which the barrier system complies with the performance requirements of a Class A landfill.
- The FGD WWTP Crystalliser Solids should be disposed of on a waste disposal facility of which the barrier system complies with the performance requirements of a Class A landfill. The FGD WWTP Sludge and the FGD WWTP Crystalliser Solids may be disposed of on the same Class A landfill.

- The three FGD waste streams should be re-assessed once generated in order to confirm the theoretical assessments.
- Once the wastes are generated, leach tests should be conducted on various percentage combinations of the wastes. J&W recommends that column leach tests be conducted. The outcome of the column leach tests can then be used to motivate for the combined disposal of all three wastes or combinations thereof on a Class C landfill or other suitable class of landfill.

Marius van Zyl

Acronyms and abbreviations used in this document:

ASLP	Australian Standard Leaching Procedure
DEA	Department of Environmental Affairs
DWS	Department of Water and Sanitation
DWAF	Department of Water Affairs and Forestry
MFA	Medupi Fly Ash
ℓ	litre
landfill	Waste disposal facility
HDPE	High Density Poly-Ethylene
LC	Leach concentration in mg/ℓ
LCT	Leach concentration threshold in mg/ℓ
mg/kg	Milligram per kilogram
mg/ℓ	Milligram per litre
SPLP	Synthetic Precipitation Leaching Procedure
TC	Total concentration in mg/kg
TCLP	Toxicity Concentration Leach Procedure
TCT	Total concentration threshold in mg/kg
TDS	Total dissolved salts
µS/cm	Micro Siemens per centimetre

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1. INTRODUCTION

1.1 Background

Eskom's Medupi Power Station, currently being constructed, will be fitted with a Flue Gas Desulphurisation (FGD) Plant to manage sulphur dioxide emissions from the Power Station. Currently the FGD Plant is being designed and authorised under the National Environmental Management Act (NEMA, Act 107 of 1998). The FGD Plant and the FGD Waste Water Treatment Plant operation will generate three waste streams that required assessment in terms of the "*National Norms and Standards for the Assessment of Waste for Landfill Disposal*" (National Norms and Standards) of the Department of Environmental Affairs (DEA) (DEA, 2013a). As it is proposed to dispose some of these wastes with the ash from the power station, the ash also needed to be assessed in terms of the National Norms and Standards.

The waste streams to be generated in the FGD Plant will be treated in a FGD Waste Water Treatment Plant – see **Figure 1-1**. The three waste streams to be generated by the FGD Plant and the FGD Waste Water Treatment Plant operation are:

- **FGD Gypsum**: The FGD process uses finely ground limestone mixed with water to form a slurry. The slurry is sprayed into an absorber tank where it reacts with the flue gas. The calcium carbonate in the lime slurry reacts with sulphur dioxide in the flue gas and gypsum is precipitated as per the following reactions:
  - $CaCO_3{}_{(aq)} + SO_2{}_{(g)} \rightarrow CaSO_3{}_{(aq)} + CO_2$
  - $CaSO_3{}_{(aq)} + ½ O_2{}_{(g)} \rightarrow CaSO_4.2H_2O_{(s)}$ (gypsum).

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- **FGD Waste Water Treatment Plant Sludge**: The wastewater from the absorber tank is flocculated in a clarifier. The underflow from the clarifier is fed through a filter press to recover the sludge. The sludge from the process is referred to as the FGD Waste Water Treatment Plant (WWTP) Sludge.
- **FGD Waste Water Treatment Plant Crystalliser Solids**: The crystalliser uses evaporation to cause precipitation of salts from the wastewater (brine) after flocculation and the clarifier process. The liquid from the crystalliser is of a high

enough quality to be re-used in the process, resulting in a Zero Liquid Discharge (ZLD) system, but the FGD Waste Water Treatment Plant Crystalliser Solids (FGD WWTP Crystalliser Solids) require disposal.

1.2 Objectives of the Project

Jones & Wagener (Pty) Ltd (J&W) was requested to undertake the waste assessments for the disposal of the FGD wastes and the power station ash in order to determine the class of landfill the wastes require disposal onto.

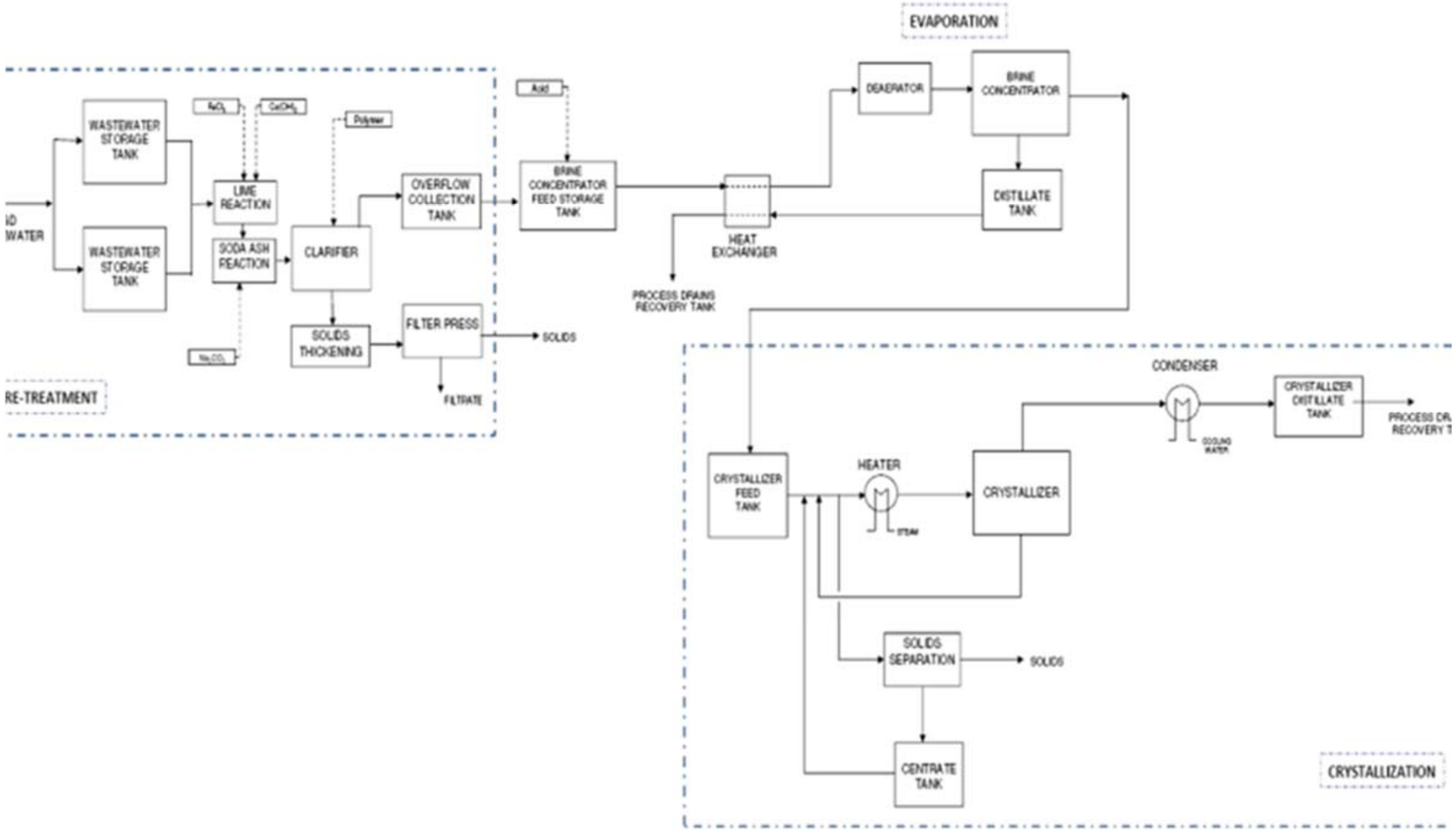

Figure 1-1: FGD Waste Water Treatment Plant Flow Diagram

2. WASTE ASSESSMENT SYSTEM

2.1 Background

The management of waste in South Africa is governed under the National Environmental Management: Waste Act, Act 59 of 2008, as amended (NEM:WA). On 23 August 2013 the "*Norms and Standards for the Assessment of Waste for Landfill Disposal*" (National Norms and Standards) were promulgated in the form of Government Notice Regulations (GNR) 635 (DEA, 2013a). These regulations are used to assess the potential impacts that a waste may have on the receiving water environment and the outcome of the assessment is used to determine the barrier (liner) system required for the waste disposal facility. The barrier systems are prescribed in GNR 636 of August 2013, the "*National Norms and Standards for Disposal of Waste to Landfill*" (DEA, 2013b)

2.2 Waste Assessment for Disposal to Landfill

The South African waste assessment system is based on the Australian State of Victoria's waste classification system for disposal, which uses total concentrations (TCs) of a range of elements in the solid waste and the Australian Standard Leaching Procedure (ASLP) to determine the leachable concentrations (LCs) of pollutants (DEA, 2013a).

The TCs can be determined by suitable and accredited methods for assessing the total concentration of the elements and/or organic compounds listed in Section 6 of the regulations.

With respect to Leachable Concentrations (LCs) a number of leach solutions can be used. For waste to be disposed with putrescible organic matter, an acetic acid leach solution is used. This leach solution is very similar to the US EPA Toxicity Characteristic Leaching Procedure (TCLP) leach solution used in the now outdated Minimum Requirements, except that the pH is 5.0, instead of pH 4.93.

In cases where non-organic wastes, such as the FGD gypsum, is to be co-disposed with other non-organic wastes, a basic 0.10 M sodium tetraborate decahydrate (borax) solution of pH 9.2 ± 0.10 should be used in addition to the acetic acid leach (DEA, 2013a). The objective of the sodium tetraborate test is to identify contaminants that are leached above the various leachable concentration thresholds (LCTs) trigger values at a high pH.

For non-putrescible inorganic waste, such as the coal derived ash, to be disposed of without any other wastes (mono- disposal scenario), reagent water (distilled water) is used as a leach reagent.

Once the total concentration and leachable concentrations have been determined they are compared to total concentration thresholds (TCTs) and leachable concentrations thresholds (LCTs) to assess the waste as either Type 0, Type 1, Type 2, Type 3 or Type 4 wastes according to the following:

- Wastes with any element or chemical substance concentration above the LCT3 or TCT2 values ($LC > LCT3$ or $TC > TCT2$) are Type 0 Wastes. Type 0 wastes require treatment/stabilisation before disposal;
- Wastes with any element or chemical substance concentration above the LCT2 but below LCT3 values, or above the TCT1 but below TCT2 values ($LCT2 < LC \leq LCT3$ or $TCT1 < TC \leq TCT2$), are Type 1 Wastes must be disposed of in a Class A landfill constructed with the most conservative barrier system.

- Wastes with any element or chemical substance concentration above the LCT1 but below the LCT2 values and all concentrations below the TCT1 values (LCT1 < LC ≤ LCT2 and TC ≤ TCT1) are Type 2 Wastes, which must be disposed of on a Class B landfill.
- Wastes with any element or chemical substance concentration above the LCT0 but below or equal to the LCT1 limits and all TC concentrations below or equal to the TCT1 limits (LCT0 < LC < LCT1 and TC < TCT1) are Type 3 Wastes and must be disposed of in a Class C landfill.
- Wastes with all element and chemical substance concentration levels for metal ions and inorganic anions below or equal to the LCT0 and TCT0 limits (LC < LCT0 and TC < TCT0), and with all chemical substance concentration levels also below the total concentration limits for organics and pesticides presented in **Table 2-1**, are Type 4 Wastes.

Table 2-1: Organic compounds and Pesticides Total concentration limits for Type 4 Wastes

Chemical Substances in Waste	Total Concentration (mg/kg)
Organics	
Total Organic Carbon	30 000 (35)
BTEX	6
PCBs	1
Mineral Oil (C10 to C40)	500
Pesticides	
Aldrin + Dieldrin	0.05
DDT+DDD+DDE	0.05
2,4-D	0.05
Chlordane	0.05
Heptachlor	0.05

- Wastes with all element or chemical substance leachable concentration levels for metal ions and inorganic anions below or equal to the LCT0 limits are considered to be Type 3 waste, irrespective of the total concentration of elements or chemical substances in the waste, provided that:
  - All chemical substance concentration levels are below the total concentration limits for organics and pesticides in **Table 2-1**;
  - The inherent physical and chemical character of the waste is stable and will not change over time; and,
  - The waste is disposed of to landfill without any other waste.
- Wastes with the TC of an element or chemical substance above the TCT2 limit, and where the concentration cannot be reduced to below the TCT2 limit, but the LC for the particular element or chemical substance is below the LCT3 limit, the waste is considered to be a Type 1 Waste.

2.3 Containment Barrier Designs

The barrier systems for waste disposal facilities were published in GNR 636 of August 2013 (DEA, 2013b). Apart from specifying the barrier systems, the GNR 636 regulations also list a number of important technical aspects which must be considered in the design of waste disposal barrier systems, such as:

- Total solute seepage (inorganic and organic) must be calculated in determining acceptable leakage rates and action leakage rates;

- Alternative elements of the barrier of proven equivalent performance may be considered in the design, such as the replacement of:-
  - granular filters or drains with geosynthetic filters or drains;
  - protective soil layers with geotextiles; or
  - clay components with geomembranes or geosynthetic clay liners;
- All drainage layers must contain drainage pipes of adequate size, spacing and strength to ensure atmospheric pressure within the drainage application for the service life of the waste disposal facility in order to prevent build-up of leachate on the barrier system.

2.3.1 Class A Landfill

The Class A landfill barrier system is presented in **Figure 2-1**. This type of landfill barrier is required for Type 1 wastes and consists of a double composite barrier system and is very similar to that of H:H landfills as specified in the *Minimum Requirements for Waste Disposal by Landfill* (2nd Ed., Department of Water Affairs and Forestry, 1998).

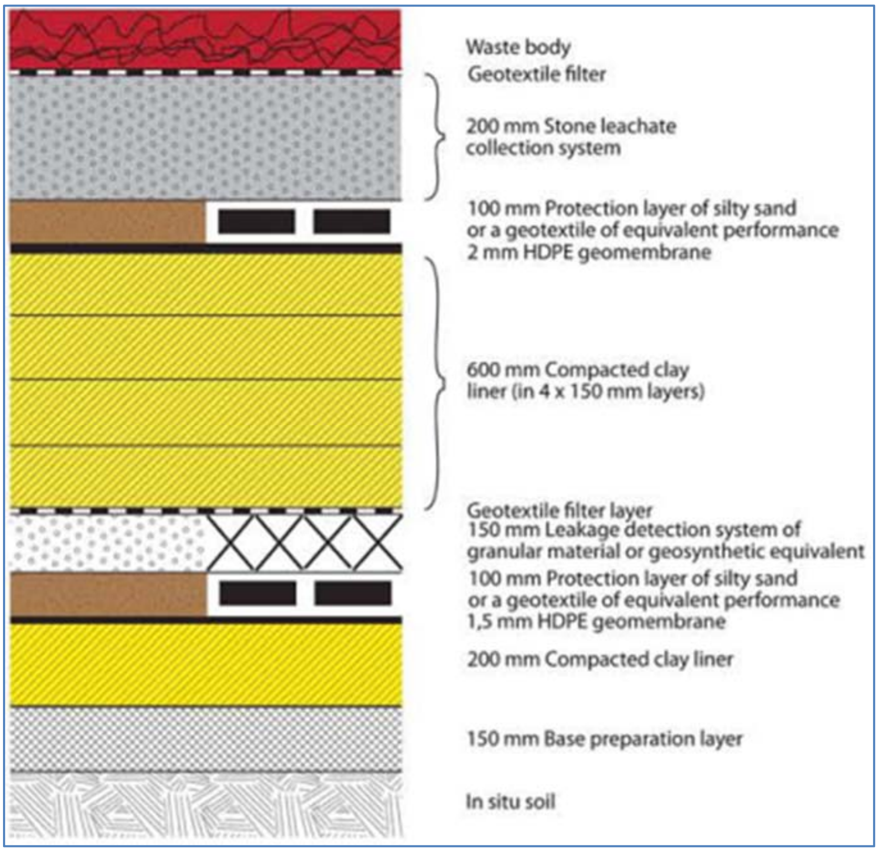

Figure 2-1: Class A Landfill Barrier System (DEA, 2013b)

2.3.2 Class B Landfill

The Class B landfill barrier system is presented in **Figure 2-2**. This type of landfill is required for Type 2 wastes and consists of a single composite barrier system of which the clay component consists of 4 x 150 mm layers.

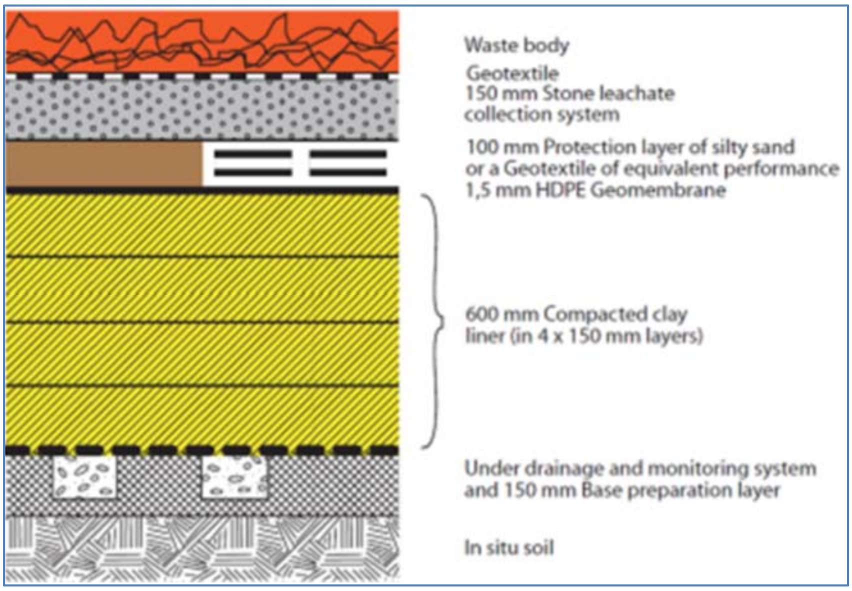

Figure 2-2: Class B Landfill Barrier System (DEA, 2013b)

2.3.3 Class C Landfill

The Class C landfill barrier system is presented in **Figure 2-3.** This type of landfill is required for the disposal Type 3 wastes to landfill and also consists of a one single composite barrier system. In this case the clay component of the barrier system is only 300 mm thick.

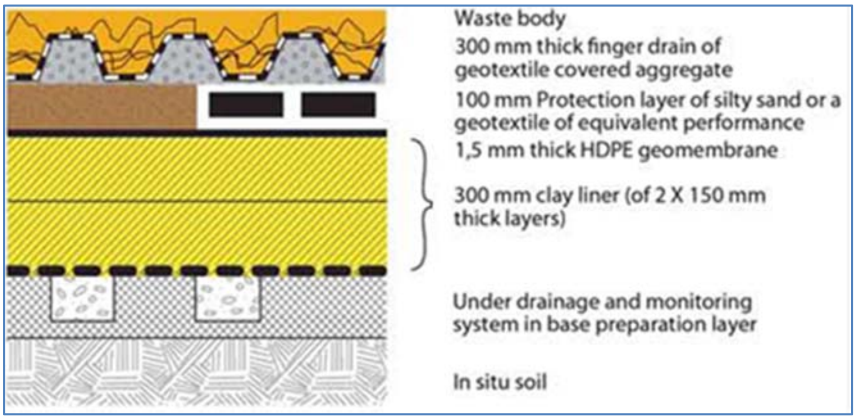

Figure 2-3: Class C Landfill Barrier System (DEA, 2013b)

2.3.4 Class D Landfill

The Class D landfill barrier system is presented in **Figure 2-4.** This type of landfill is required for the disposal of Type 4 wastes (or inert wastes) and consist of in-situ compacted material. This landfill class does not have a formal barrier system.

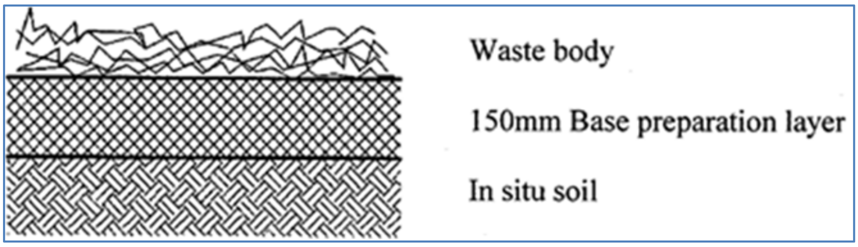

Figure 2-4: Class D Landfill Barrier System (DEA, 2013b)

3. WASTE ASSESSMENT METHODOLOGY

3.1 Ash Assessment

As the Medupi Power Station is not yet operational, ash generated from Eskom's Matimba Power Station was sampled and analysed. The Medupi Power Station will also burn coal from the Grootegeluk mine and the Matimba Power Station ash was therefore selected as a suitable analogue for testing.

Three ash samples from the Matimba Power Station's load out discharge point were collected and analysed in the following way:

- Aqua Regia digestion with analysis of relevant elements by ICP-MS to determine the total concentrations of elements in the ash. The total inorganic elemental concentrations (TCs) were compared to the total concentration threshold (TCT) limits in the norms and standards (DEA, 2013a). As the ash is a product of full combustion it was not considered necessary to determine the concentrations of organic compounds in the ash as their concentrations would be negligible.
- Deionised water leach of the samples at a 1:20 Solid:Liquid ratio as per the Australian Standards AS 4439.1 to AS 4439.3 (Standards Australia, 1997 and 1999). The total leachable concentrations of inorganic constituents were compared to the leachable concentration threshold limits (LCTs) in the Norms and Standards (DEA, 2013a). As the ash will generate an alkaline leach solution and will not turn acidic in the field neither the alkaline nor acidic leach procedures in the Australian Leach procedure are appropriate for assessment of the ash. A deionised water leach was specified instead of the TCLP or borax leachates because the waste is alkaline in nature and if other wastes are co-disposed with it such as the FGD gypsum, which is also alkaline, the waste body will not become acidic and a high pH leach will not add any value as the wastes are already alkaline.

As the ash was taken at the ash load-out point at the ash disposal facility, the ash also contained demineraliser plant effluent, which is added for dust suppression purposes.

3.2 Flue Gas Desulphurisation Gypsum

As the FGD plant is not currently operational it was not possible to undertake laboratory analysis on the actual FGD Gypsum that will be produced. Therefore the assessment was undertaken using literature values from the USA and Europe. The following data sources were used for the assessment.

Total elemental concentrations and summary data from analysis of a total of 53 FGD gypsum samples:

- Four samples of FGD Gypsum analysed and presented by Chen et al. 2012;
- The maximum values from the summary data for the analysis of 32 FGD gypsum samples presented in the Electric Power Research Institute of the USA's technical report on mixed and FGD gypsum composition (EPRI, 2011);
- The total elemental concentrations for 15 FGD gypsum samples presented by VGB (1990): Technical Scientific Report on the comparison of natural and FGD gypsum.
- One sample of FGD gypsum presented by En-Chem, 2008.
- Leachable concentrations were obtained from the following sources:
    - ♦ Synthetic precipitation leachate procedure concentrations for trace elements from the summary data for the analysis of 32 FGD gypsum

samples presented in the Electric Power Research Institute (EPRI, 2011)) USA's technical report on mixed and FGD gypsum composition. The SPLP test used a deionised water adjusted to pH 4.2 using a combination of sulphuric and nitric acids and is therefore a more conservative test than the deionised water leach test that would have been carried out under the DEA's National Norms and Standards.

- ♦ Toxicity Concentration Leach Procedure (TCLP) results for trace elements of one sample of FGD gypsum presented in En-Chem 2008. The TCLP procedure is similar to the acetic acid leach procedure in the Australian standards. Given that leaching of FGD Gypsum will result in a neutral to mildly alkaline solution this acidic leach result is considered a more conservative measure of leaching concentrations than what is required by the standard.
- ♦ The concentrations of leachable major ions were calculated based on the estimated concentrations (provided by Eskom and Black & Veatch) of gypsum and other salts in the solids. For gypsum and calcium carbonate literature solubility limits were used to predict leachable concentrations while for other salts it was assumed that 100% solubility would occur in the leach test.
- ♦ The concentration of TDS was calculated by summing the predicted leachable concentrations of major soluble components.

3.3 FGD WWTP Sludge

As with the FGD Gypsum no measured data was available for the Medupi FGD WWTP Sludge as the facility is not yet operational. In addition, no relevant sources of literature data could be found as the waste streams are not analysed by the industry as frequently as the FGD gypsum. Therefore the following approach was used for the FGD WWTP sludge:

- The total elemental concentrations of the FGD WWTP Sludge were calculated by the design engineers (Eskom and Black & Veatch, see **Appendix A**). These estimates were based on previous experience of the concentrations of total elements in the wastewater and the likely removal into the filter cake and crystalliser solids.
- The leachable concentrations of metals were calculated from the total fraction assuming full dissolution of 1 mg of solid material into 20 mℓ of water to simulate a 1:20 solid to liquid ratio used in the Australian Leach method.
- The solubility limits for calcium carbonate, gypsum and magnesium carbonate were used to predict leachable concentrations of major ions.
- The TDS concentrations were calculated using the sum of major leachable concentrations.

3.4 FGD WWTP Crystalliser Solids

As with the FGD WWTP sludge, no measured or literature data was available for the FGD WWTP crystalliser solids as the facility is not operational. Therefore the following approach was used for the FGD WWTP Crystalliser Solids:

- The TCs of elements and major ions in the FGD WWTP crystalliser solids were calculated by the design engineers (Eskom and Black & Veatch, **see Appendix A**). These estimates were based on previous experience of the concentrations of total elements in the wastewater and the likely removal into the filter cake and crystalliser solids.

- The LCs of all parameters were calculated from the total fraction assuming full dissolution of 1 mg of solid material into 20 mℓ of water to simulate a 1:20 solid to liquid ratio used in the Australian Leach method.
- The TDS concentrations were calculated using the sum of leachable concentrations.

4. ASSESSMENTS

4.1 Ash

4.1.1 Total Concentrations

The results for the total concentrations from the laboratory analysis of the three Matimba Fly Ash samples are provided in **Table 4-1** (the laboratory analytical certificates are provided in **Appendix B**).

- The TCT0 threshold concentrations were exceeded for barium and fluoride in all three samples, and mercury in one of the three samples.
- Most values were below the detection limits of the analytical method.
- There were no exceedances of the TCT1 or TCT2 thresholds in any samples.

Table 4-1: TCs of metal ions and inorganic anions in Matimba Fly Ash

Total Concentration	Total Concentration Thresholds (mg/kg)			Matimba Fly Ash Total concentrations by the Aqua Regia test (mg/kg)		
	TCT0	TCT1	TCT2	MFA-1	MFA-2	MFA-2
Metal Ions						
Arsenic	5.8	500	2 000	<4	<4	<4
Boron	150	15 000	60 000	42	38	34
Barium	62.5	6 250	25 000	388	346	356
Cadmium	7.5	260	1040	3.2	4.4	2
Cobalt	50	5 000	20 000	<10	<10	<10
Chromium (Total)	46 000	800 000	NA	54	38	33
Chromium (VI)	6.5	500	2000	<5	<5	<5
Copper	16	19 500	78 000	<10	<10	<10
Mercury	0.93	160	640	<0.4	<0.4	4.4
Manganese	1 000	25 000	100 000	357	339	312
Molybdenum	40	1 000	4 000	<10	<10	<10
Nickel	91	10 600	42 400	20	16	15
Lead	20	1 900	7 600	<4	<4	<4
Antimony	10	75	300	<4	<4	<4
Selenium	10	50	200	<4	<4	<4
Vanadium	150	2 680	10 720	27	16	<10
Zinc	240	160 000	640 000	50	42	37

Total Concentration	Total Concentration Thresholds (mg/kg)			Matimba Fly Ash Total concentrations by the Aqua Regia test (mg/kg)		
	TCT0	TCT1	TCT2	MFA-1	MFA-2	MFA-2
Inorganic anions						
Fluoride	100	10 000	40 000	296	285	346
Note – Blue shading indicates above the TC0 threshold						

4.1.2 Leachable concentrations

The results for the leachable concentrations from the laboratory analysis of three Matimba Fly Ash samples are provided in **Table 4-2**.

- The LCT0 threshold concentrations were exceeded for boron, chromium (VI) and molybdenum in all samples.
- There were no exceedances of LCT1, LCT2 or LCT3 thresholds in any samples.

Table 4-2: LCs for Matimba Fly Ash (DI Water Leach)

Elements & Chemical Substances in Waste	LCs thresholds (mg/ℓ)				Matimba Fly Ash (MFA) DI water leach (mg/ℓ)		
	LCT0	LCT1	LCT2	LCT3	MFA-1	MFA-2	MFA-3
Metal ions							
Arsenic	0.01	0.5	1	4	<0.005	<0.005	<0.005
Boron	0.5	25	50	200	0.535	0.501	0.515
Barium	0.7	35	70	280	0.062	0.08	0.067
Cadmium	0.003	0.15	0.3	1.2	<0.003	<0.003	<0.003
Cobalt	0.5	25	50	200	<0.025	<0.025	<0.025
Chromium (Total)	0.1	5	10	40	0.079	0.061	0.062
Chromium (VI)	0.05	2.5	5	20	0.073	0.061	0.060
Copper	2	100	200	800	<0.025	<0.025	<0.025
Mercury	0.006	0.3	0.6	2	<0.001	<0.001	<0.001
Manganese	0.6	25	50	200	<0.025	<0.025	<0.025
Molybdenum	0.07	3.5	7	28	0.095	0.089	0.091
Nickel	0.07	3.5	7	28	<0.025	<0.025	<0.025
Lead	0.01	0.5	1	4	<0.01	<0.01	<0.01
Antimony	0.02	1	2	8	<0.01	<0.01	<0.01
Selenium	0.01	0.5	1	4	<0.01	<0.01	<0.01
Vanadium	0.2	10	20	80	0.16	0.16	0.157
Zinc	5	250	500	2000	<0.025	<0.025	<0.025
Inorganic Anions							
TDS	1000	12 500	25 000	100 000	146	120	122
Chloride	300	15 000	30 000	120 000	<5	<5	<5
Sulfate	250	12 500	25 000	100 000	64	74	60
NO3 as N, Nitrate-N	11	550	1 100	4 400	<0.2	<0.2	<0.2

Elements & Chemical Substances in Waste	LCs thresholds (mg/ℓ)				Matimba Fly Ash (MFA) DI water leach (mg/ℓ)		
	LCT0	LCT1	LCT2	LCT3	MFA-1	MFA-2	MFA-3
F, Fluoride	1.5	75	150	600	<0.2	<0.2	<0.2
Note – Blue shading indicates above the LCT0 threshold							

4.1.3 Waste Assessment

As only TC0 and LTC0 thresholds were exceeded, it is predicted that the Medupi Ash will be a Type 3 waste requiring a Class C landfill barrier system **Figure 2-3** for disposal purposes.

The following assumptions have been made with regard to the assessment of the ash:

- The Matimba Power Station Ash has the same chemical properties as the ash that will be produced at the Medupi Power Station.
- The concentrations of any organic compounds in the ash will be negligible and therefore organic components have not been analysed.

4.2 FGD Gypsum

4.2.1 Total Concentrations

The full set of literature results for the total concentrations of trace elements in the FGD gypsum compared to the Total Concentration Thresholds (TCTs) are presented in **Appendix C**. The total concentrations of elements in the FGD gypsum at times exceeded the TCT0 concentrations but at no time were the TCT1 or TCT2 thresholds exceeded. The exceedances of the TCT0 thresholds are summarised below:

- **Arsenic**: The EPRI (2011) maximum value and Chen et al 2008 exceeded the TCT0 value.
- **Chromium (VI)**: Assuming total Chromium was equal to Chromium (VI) the total concentrations exceeded the TCT0 value for the maximum value of the EPRI dataset, one sample of the VGB dataset, and two of the values from Chen et al (2012) (Indiana and Alabama).
- **Lead**: One of the VGB samples and the En-Chem sample exceeded the TCT0 for lead.
- **Antimony**: The concentration of total antimony in the Indiana sample (Chen et al, 2012) exceeded the TCT0 for antimony.
- **Selenium**: The maximum value in the EPRI dataset, the sample from En-Chem and 2 samples from the VGB data set exceeded the TCT0 for selenium.
- **Fluoride**: Only the En-Chem dataset contained total concentration for fluoride, this value exceeded the TCT0 for fluoride.

The predicted total concentrations of salts in the gypsum (calculated by Eskom and Black & Veatch) are presented in **Table 4-3** along with the assumptions used to predict the leachable concentrations of the salts in the gypsum.

Table 4-3: Predicted total concentrations of salts and inert material in the FGD Gypsum solids and assumptions regarding their solubility

Component	Concentration (% dry weight)	Concentration mg/kg (dry weight)	Assumed solubility for prediction of leachable fraction (mg/ℓ)	Assumption
Gypsum	88.9	889 000	2 050	Literature solubility limit (CRC, 2005)
$CaCO_3$	2.8	28 000	6.6	Literature solubility limit (CRC, 2005)
$CaSO_3$	0.1	1 000	70	Total solubility 1 mg of FGD gypsum in 20 mℓ water
$MgCO_3$	0.3	3 000	150	Total solubility 1 mg of FGD gypsum in 20 mℓ water
Inert Material	7.9	79 000	0	Completely insoluble.
TDS	NA	NA	2 276.6	Sum of assumed solubility for major soluble components: gypsum, $CaCO_3$, $CaSO_3$, $MgCO_3$
Note: Values calculated by Eskom				

4.2.2 Leachable concentrations

The leachable concentrations are summarised in **Table 4-4** and **Table 4-5** for trace elements and inorganic ions respectively. The following summarises the results:

- The maximum values for boron, manganese and selenium in the EPRI dataset exceeded the LTC0s for those elements.
- The concentration of selenium in the TCLP leach test results (En-Chem, 2008) exceeded the LTC0 threshold.
- The predicted concentrations of sulphate and TDS exceed the LCT0 threshold.
- No exceedances of the LCT1, LCT2 or LCT3 thresholds were measured or predicted.

Table 4-4: Measured LCs in SPLP and TCLP tests on FGD Gypsum

Elements & Chemical Substances in Waste	Leachable Threshold (mg/L)				EPRI 2011 Maximum from SPLP (N=32) (mg/ℓ)	En-Chem 2008 TCLP (N=1) (mg/ℓ)
	LCT0	LCT1	LCT2	LCT3		
Arsenic	0.01	0.5	1	4	<0.005	<0.02
Boron	0.5	25	50	200	20.1	0.09
Barium	0.7	35	70	280	0.048	0.07
Cadmium	0.003	0.15	0.3	1.2	0.0019	<0.001
Cobalt	0.5	25	50	200	0.0106	0.25
Chromium Total	0.1	5	10	40	0.00109	<0.003
Chromium (VI)	0.05	2.5	5	20	0.00109	<0.01
Copper	2	100	200	800	0.0025	0.02
Mercury	0.006	0.3	0.6	2	-	<0.001
Manganese	0.6	25	50	200	7.52	0.04
Molybdenum	0.07	3.5	7	28	0.0289	0.007
Nickel	0.07	3.5	7	28	0.0094	0.007
Lead	0.01	0.5	1	4	0.00128	<0.01

Antimony	0.02	1	2	8	0.00142	<0.01
Selenium	0.01	0.5	1	4	0.47	0.06
Vanadium	0.2	10	20	80	0.00662	-
Zinc	5	250	500	2 000	0.0847	-
Note: Blue shading indicates above the LCT0 threshold						

Table 4-5: LCs of inorganic anions used for the assessment (measured and calculated)

Inorganic Anions	Leachable Thresholds (mg/L)				Calculated values Refer Table 4-1 (mg/ℓ)	EPRI 2011 DI water leach Measured values (mg/ℓ)	En-Chem 2008 TCLP Results Measured values (mg/ℓ)
	LCT0	LCT1	LCT2	LCT3			
TDS	1 000	12 500	25 000	100 000	2 277[1]	-	-
Chloride	300	15 000	30 000	120 000	-	76.9	5.2
Sulfate	250	12 500	25 000	100 000	1 481[1]	1 550	2 387
Fluoride	1.5	75	150	600	-	13.7	7.5
Note: 1: Refer to Table 4-3 assumptions regarding calculations. Blue shading indicates exceedance of the TCT0 threshold							

4.2.3 Waste assessment

Based on the assessment described above, the FGD gypsum is predicted to be a Class 3 waste and could therefore be disposed of in a landfill with a Class C barrier system (**Figure 2-3**).

The following assumptions have been made with regard to the assessment of the FGD gypsum:

- The ranges of values identified in the literature are representative of those that will be obtained from analysis of the Medupi Power Station FGD gypsum.
- Due to the inorganic nature of the gypsum, the concentrations of organic compounds in the gypsum would be negligible and were not assessed.
- The solubility limit for gypsum was assumed to be 2 050 mg/ℓ (CRC Handbook of Chemistry and Physics, 2005).
- The solubility limit for $CaCO_3$ was assumed to be 6.6 mg/ℓ (CRC Handbook of Chemistry and Physics, 2005)
- The calculated leachable concentration of sulphate was based on the assumed solubility limit of gypsum, complete solubility of $CaSO_3$ and total conversion of SO_3 to SO_4 in solution.
- The leachable TDS concentration was calculated by summing of the assumed solubility limits for gypsum and $CaCO_3$ and complete solubility of $CaSO_3$ and $MgCO_3$. It was assumed that trace element contribution to TDS was negligible.

4.3 FGD WWTP Sludge

Two scenarios were assessed for the FGD WWTP sludge that is using a limestone of 85% calcium carbonate and one of 96% calcium carbonate. The results of the calculations are presented in **Table 4-6** for TCs and Table 4-7 and **Table 4-8** for LCs. The predicted values from the Kusile project (En-Chem, 2008) are also presented in the tables, these values were generated using the same method that was used in this study.

4.3.1 Total concentrations

The estimated TCs, based on an 85% grade of limestone exceeded the TCT0 thresholds for barium, chromium (VI) (assuming all Chromium is in the +VI oxidation state) and mercury.

The estimated total concentrations based on a 96% grade of limestone exceeded the TCT0 thresholds for a larger range of elements than the 85% limestone grade. These elements were: barium, chromium (VI) (assuming all Chromium is in the VI oxidation state), cadmium, copper, mercury, lead, selenium and fluoride.

The TCs predicted in the Kusile project were typically lower than those predicted for the Medupi project with the exception of boron, which was predicted to be considerably higher than in the Medupi waste. TCT0 thresholds were exceeded for arsenic, boron and fluoride in the Kusile study (M-Tech, 2012).

Table 4-6: Predicted total concentrations of metal ions and inorganic anions in the FGD WWTP Sludge

Elements & Chemical Substances in Waste	Total concentration thresholds (mg/kg)			FGD WWTP Sludge – Medupi Estimates (mg/kg)		FGD WWTP Sludge – Kusile Estimates (M-Tech, 2012) (mg/kg)
	TCT0	TCT1	TCT2	96% limestone	85% limestone	
Metal Ions						
Arsenic	5.8	500	2 000	6.9	2.4	6.9
Boron	150	15 000	60 000	25	<1	405
Barium	62.5	6 250	25 000	582	282	
Cadmium	7.5	260	1040	11	5.0	0.57
Cobalt	50	5000	20 000	15	6.7	2.9
Chromium (Total)	46000	800 000	NA	46	22	6.9
Chromium (VI)[1]	6.5	500	2000	46	22	6.9
Copper	16	19 500	78 000	29	13	5.1
Mercury	0.93	160	640	3.7	1.8	0.11
Manganese	1 000	25 000	100 000	586	284	-
Molybdenum	40	1 000	4 000	<1	<1	-
Nickel	91	10 600	42 400	46	21	8.9
Lead	20	1 900	7 600	26	12	8.9
Antimony	10	75	300	<1	<1	-
Selenium	10	50	200	14	6.7	2.9
Vanadium	150	2 680	10 720	5.5	1.9	67
Zinc	240	160 000	640 000	86	40.6	6.9
Inorganic Anions						
Fluoride	100	10 000	40 000	212	74	743

Note – Data provided by Eskom, calculated values based on previous projects carried out by the design engineers. Blue shading indicates above the TCT0 threshold. [1]Chromium (VI) concentration based on assumption that all Chromium is in the +VI oxidation state

Table 4-7: Predicted concentrations of salts and inert material in the FGD WWTP Sludge and assumptions regarding their solubility

Component	FGD WWTP Sludge 96% Grade (mg/kg dry wt)	Assumed solubility (mg/ℓ)	FGD WWTP Sludge 85% Grade (mg/kg dry wt)	Assumed solubility (mg/ℓ)	Assumption regarding solubility
Inert material	217 000	-	365 000	-	Insoluble
Gypsum	58 000	2 900	22 000	1 100	Completely soluble: 1 mg of FGD WWTP sludge in 20 mℓ water
$CaCO_3$	714 000	13	409 000	13	Based on solubility limit (CRC, 2005)
$CaSO_3$	11 000	550	4 000	200	Completely soluble: 1 mg of FGD WWTP sludge in 20 mℓ water
$Mg(OH)_2$	0	-	199 000	6.4	Based on solubility limit (CRC, 2005)

4.3.2 Leachable concentrations

The estimated total concentrations based on a 96% grade of limestone exceeded the LCT thresholds as follows:

- The LCT2 thresholds were predicted to be exceeded for cadmium and lead.
- The LCT1 thresholds were predicted to be exceeded for manganese and selenium.
- The LCT0 thresholds were predicted to be exceeded for TDS, sulphate, fluoride, arsenic barium, boron, cobalt, chromium, chromium VI, mercury, nickel and vanadium.

The estimated total concentrations based on an 85% grade of limestone exceeded the LCT thresholds as follows:

- The LCT1 concentrations were exceeded for cadmium and lead.
- The LCT0 threshold was exceeded for TDS, sulphate, fluoride, arsenic, barium, chromium, mercury, molybdenum, nickel and selenium.
- No exceedances of the LCT2 or LCT3 thresholds.

The LCT0 thresholds for arsenic, boron, cadmium, chromium, nickel, lead, selenium and vanadium were predicted to be exceeded in the Kusile study (M-Tech, 2012).

Table 4-8: Calculated leachable concentrations of metals ions and major ions for FGD WWTP Sludge

Elements & Chemical Substances in Waste	Leachable thresholds (mg/ℓ)				FGD WWTP Sludge – Medupi Estimates (mg/ℓ)		FGD WWTP Sludge – Kusile Estimates (mg/kg) (M-Tech, 2012)
	LCT0	LCT1	LCT2	LCT3	96% limestone	85% limestone	
Metal ions[1]							
Arsenic	0.01	0.5	1	4	0.35	0.12	0.34
Boron	0.5	25	50	200	1.2	<0.5	20
Barium	0.7	35	70	280	29	14	-
Cadmium	0.003	0.15	0.3	1.2	0.53	0.25	0.029
Cobalt	0.5	25	50	200	0.73	0.33	0.14
Chromium Total	0.1	5	10	40	2.3	1.1	0.34
Chromium (VI)	0.05	2.5	5	20	2.3	1.1	-
Copper	2	100	200	800	1.5	0.67	0.26
Mercury	0.006	0.3	0.6	2	0.18	0.088	0.006
Manganese	0.6	25	50	200	29	14	-
Molybdenum	0.07	3.5	7	28	<0.07	<0.07	-
Nickel	0.07	3.5	7	28	2.3	1.1	0.34
Lead	0.01	0.5	1	4	1.3	0.59	0.34
Antimony	0.02	1	2	8	<0.02	<0.02	-
Selenium	0.01	0.5	1	4	0.73	0.33	0.14
Vanadium	0.2	10	20	80	0.28	0.096	3.4
Zinc	5	250	500	2 000	4.3	2.0	0.34
Inorganic Anions							
TDS[2]	1 000	12 500	25 000	100 000	3 500	1 300	-
Sulfate[3]	250	12 500	25 000	100 000	1 600	1 800	-
Fluoride[1]	1.5	75	150	600	11	3.7	-

Notes: 1: Predicted leachable concentrations of metals/metalloids assume complete solubility of estimated total metal/metalloid concentrations presented in Table 4-6. 2: TDS concentration calculated as the sum of major soluble components summarised in Table 4-7. 3: Concentration based solubility assumptions for gypsum and $CaSO_3$ described in Table 4-7 and assuming all SO_3 converts to SO_4 in solution. Blue shaded values exceed LCT0 threshold. Purple shaded values exceed LCT1 thresholds. Orange Shaded values exceed the LCT2 thresholds

4.3.3 Waste assessment: FGD WWTP Sludge

The 96% limestone generated FGD WWTP Sludge is predicted to have exceedances of the TCT0 for a number of elements and exceedances of the LCT2 thresholds for cadmium and lead and would therefore be assessed as a Type 1 waste and would therefore require a Class A landfill barrier system for disposal (**Figure 2-1**).

The 85% limestone generated FGD WWTP sludge is predicted to have exceedances of the TCT0 and LCT1 thresholds for cadmium and lead and would therefore be assessed as a Type 2 waste requiring a Class B landfill barrier system for disposal **Figure 2-2**.

It should be noted that the predicted leachable concentrations are driving the assessment for both the 85% and 96% limestone and that those leachable concentrations are based on a highly conservative assumption that the trace element components of the FGD WWTP sludge are completely soluble. In reality trace elements that have been removed from the raw water by the treatment process are likely to be largely insoluble and the actual leachable concentrations considerably lower.

However, as the speciation of the elements in the FGD WWTP sludge is unknown, the leachable concentration of these elements cannot currently be predicted and therefore a conservative approach in the assessment should be followed. Based on this approach the 85% limestone generated FGD WWTP sludge should be disposed of on a Class A landfill until an assessment of the actual waste can be confirmed.

The following assumptions have been made regarding the assessment of the FGD WWTP Sludge:

- The Medupi Site will generate WWTP Sludge with similar chemical characteristics to the previous sites studied by Black & Veatch (see **Appendix C**).
- The designed removal efficiencies are achieved in the FGD WWTP clarifier
- All chromium is present in the +VI oxidation state.
- All metal ions in the solids are 100% soluble at the solids to liquid ratio of the test method (1 mg/ℓ solid to 20 mℓ of water). This is a highly conservative assumption as it is likely that a considerably fraction of metal constituents such as lead and cadmium will not be leachable from the solids.
- The solubility of calcium carbonate was assumed to be 6.6 mg/ℓ (CRC Handbook of Chemistry and Physics, 2005).
- The solubility of $Mg(OH)_2$ was assumed to be 64 mg/ℓ (CRC Handbook of Chemistry and Physics, 2005)
- The gypsum and $CaSO_3$ in the solids was 100% soluble when subjected to a 1:20 distilled water leach.
- All SO_3 from the $CaSO_3$ dissociates and converts to SO_4 in solution.
- The leachable TDS concentration was calculated by summing of the assumed solubility limits for $CaCO_3$ and $Mg(OH)_2$ and complete solubility of $CaSO_3$ and gypsum. It was assumed that trace element contribution to TDS was negligible.

4.4 FGD WWTP Crystalliser Solids

As with the WWTP two scenarios were assessed for the FGD WWTP Crystalliser Solids that is using a limestone of 85% calcium carbonate and one of 96% calcium carbonate, the results of the calculations are presented in **Table 4-9** for TCs and **Table 4-10** for LCs.

The predicted values from the Kusile project are also presented in the tables, these values were generated using the same method that was used in this study.

4.4.1 Total concentrations

The total concentration assessment results for the 96% and 85% limestone scenarios are the same and discussed together below:

- The TCT0 thresholds were exceeded for arsenic, boron, chromium (VI), antimony and fluoride.
- There were no predicted exceedances of TCT1 or TCT2 thresholds.

There were no predicted exceedances of total concentration thresholds in the Kusile study.

Table 4-9: Predicted total concentrations of metal ions and inorganic anions in the FGD WWTP Crystalliser Solids

Elements & Chemical Substances in Waste	Total concentration thresholds (mg/kg)			WWTP Crystalliser Solids Medupi estimates (mg/kg)		WWTP Crystalliser solids Kusile estimates (M-Tech, 2012)
	TCT0	TCT1	TCT2	96% limestone	85% limestone	
Metal Ions						
Arsenic	5.8	500	2000	10.25	11.62	0.08
Boron	150	15 000	60 000	615.24	620	51.8
Barium	62.5	6250	25000	4.1	4.65	-
Cadmium	7.5	260	1040	1.03	1.16	0.07
Cobalt	50	5 000	20 000	4.1	4.65	0.37
Chromium (Total)	46 000	800 000	NA	10.25	11.62	-
Chromium (VI)[1]	6.5	500	2000	10.25	11.62	-
Copper	16	19 500	78 000	8.2	9.3	0.66
Mercury	0.93	160	640	0.21	0.23	0.01
Manganese	1 000	25 000	100 000	1.03	1.16	-
Molybdenum	40	1 000	4 000	31.76	31.04	-
Nickel	91	10 600	42 400	10.25	11.62	0.87
Lead	20	1 900	7 600	10.25	11.62	0.87
Antimony	10	75	300	15.88	15.52	-
Selenium	10	50	200	4.1	4.65	0.37
Vanadium	150	2 680	10 720	8.2	9.31	8.62
Zinc	240	160 000	640 000	10.25	11.62	0.87
Inorganic Anions						
Fluoride	100	10 000	40 000	307.62	348.59	

Note – Data provided by Eskom, calculated values based on previous projects carried out by the design engineers. Blue shading indicates above the TC1 threshold. [1]Chromium (VI) concentration based on assumption that all Chromium is in the +VI oxidation state

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Table 4-10: Predicted major ion concentrations in FGD WWTP Crystalliser Solids

Major ion	Predicted Concentration in FGD WWTP Crystalliser Solid 96% Limestone (mg/kg dry wt)	Predicted leachable Concentration 96% Limestone (mg/ℓ)	Predicted Concentration in solid 85% Limestone (mg/kg dry wt)	Predicted leachable Concentration 85% Limestone (mg/ℓ)	Assumption regarding solubility
Calcium	29 800	1 490	27 000	1 350	Completely soluble: 1 mg of FGD WWTP crystalliser solids in 20 ml water
Magnesium	6 400	320	5 800	290	
Sodium	354 800	17 740	351 900	17 595	
Chloride	489 300	24 465	443 800	22 190	
Sulphate	119 700	5 985	177 000	8 850	
Note – Data provided by Eskom					

4.4.2 Leachable concentrations

The leachable concentration assessment results for the 96% and 85% limestone scenarios are the same and discussed together below:

- The LCT2 threshold was predicted to be exceeded for TDS.
- The LCT1 thresholds were predicted to be exceeded for arsenic, boron, lead and chloride.
- The LCT0 thresholds were predicted to be exceeded for cadmium, chromium, manganese, molybdenum, nickel, antimony, selenium, vanadium, fluoride and sulphate.

The Kusile study predicted exceedances of the LCT0 thresholds for lead, selenium and vanadium and as with the current study predicted the leachable TDS would exceed the LCT2 threshold (M-Tech, 2012).

Table 4-11: Predicted LCs from FGD WWTP Crystalliser Solids

Elements & Chemical Substances in Waste	Leachable concentration thresholds (mg/ℓ)				WWTP Crystalliser Solids – Medupi estimates (mg/ℓ)		WWTP Crystalliser Solids – Kusile estimates (mgℓ)
	LCT0	LCT1	LCT2	LCT3	95% Limestone	85% Limestone	
Metal ions[1]							
Arsenic	0.01	0.5	1	4	0.51	0.58	0
Boron	0.5	25	50	200	31	31	2.59
Barium	0.7	35	70	280	0.21	0.23	
Cadmium	0.003	0.15	0.3	1.2	0.052	0.058	0
Cobalt	0.5	25	50	200	0.21	0.23	0.02
Chromium (Total)	0.1	5	10	40	0.51	0.58	0.04
Chromium (VI)[2]	0.05	2.5	5	20	0.51	0.58	
Copper	2	100	200	800	0.41	0.47	0.03
Mercury	0.006	0.3	0.6	2	0.011	0.012	0
Manganese	0.6	25	50	200	0.052	0.058	
Molybdenum	0.07	3.5	7	28	1.6	1.6	
Nickel	0.07	3.5	7	28	0.51	0.58	0.04
Lead	0.01	0.5	1	4	0.51	0.58	0.04
Antimony	0.02	1	2	8	0.79	0.78	
Selenium	0.01	0.5	1	4	0.21	0.23	0.02
Vanadium	0.2	10	20	80	0.41	0.47	0.43
Zinc	5	250	500	2 000	0.51	0.58	0.04
Inorganic Anions							
TDS[3]	1 000	12 500	25 000	100 000	50 000	50 300	48 400
Chloride[1]	300	15 000	30 000	120 000	24 500	22 200	-
Sulphate[1]	250	12500	25 000	100 000	5 990	8 850	-
Fluoride[1]	1.5	75	150	600	15	17	-

Note: 1: Predicted leachable concentrations of these parameters assume complete solubility of estimated total concentrations presented in Table 4-9 and Table 4-10. 2: Assumes all chromium in the +VI oxidation state. 3: TDS concentration calculated by summing of predicted leachable major ion concentrations presented in Table 4-10. Blue shaded values exceed LCT0 threshold. Purple shaded values exceed LCT1 thresholds. Orange Shaded values exceed the LCT2 thresholds.

4.4.3 Waste Assessment of FGD WWTP Crystalliser Solids

The FGD WWTP Crystalliser Solids have a number of exceedances of the TCT0, LCT1 and LCT0 thresholds. In addition the LCT2 threshold is predicted to be exceeded for TDS and the waste is assessed as a Type 1 waste based on the predicted highly elevated TDS. Given that a large proportion of the crystalliser solids are likely to be highly soluble sodium chloride ions this result is logical. The predicted TDS calculated from only sodium and chloride would still exceed 40 000 mg/ℓ LCT2 threshold and the waste would remain Type 1 waste requiring a Class A landfill (**Figure 2-1**). The same result was predicted in the Kusile study (M-Tech, 2012).

The following assumptions have been made regarding the assessment of the FGD WWTP Sludge and the Crystalliser Solids:

- The Medupi Site will generate Crystalliser Solids with similar chemical characteristics to the previous sites studied by Black and Vetch (see **Appendix C**).
- The designed removal efficiencies are achieved in the Crystalliser Plant.
- All constituents of the solids are 100% soluble. This is a highly conservative assumption as it is likely that a considerably fraction of metal constituents such as lead and cadmium may not be leachable from the solids.
- All chromium is present in the +VI oxidation state.
- The TDS of the leachable fraction was calculated by summing of all the major ion components summarised in **Table 4-10**.

5. COMBINED DISPOSAL OF SIMILAR WASTE STREAMS

5.1 Ash and FGD Gypsum

The Ash and the FGD gypsum are both assessed as Type 3 wastes that can be disposed of on a disposal facility of which the performance of the barrier system complies with that of a Class C landfill. The gypsum is likely to result in near neutral to alkaline leachate (see **Table 5-1**) while the ash has an alkaline pH leachate. Neither of these wastes are likely to contain organic matter that could decompose to result in a pH change of the leachate and both wastes are likely to be stable with respect to oxidation.

Table 5-1: FGD Gypsum and Ash leachable pH

Parameter	pH
FGD Gypsum (EPRI, 2008)	
Minimum	6.6
Median	8.0
Maximum	10.1
Ash (De ionised water leach test)	
MFA - 1	8.8
MFA – 2	9.0
MFA – 3	9.1

Given that both wastes are likely to generate alkaline leachate and will be stable with respect to oxidation, the leaching characteristics of the wastes are unlikely to be significantly altered should the wastes be disposed of in the same facility and the combined waste would be suitable for disposal on a facility of which the performance of the barrier system complies with that of a Class C landfill.

5.2 85 and 96% FGD WWTP Sludge and Crystalliser Solids

The WWTP Sludge and Crystalliser Solids are both produced by treatment of the wastewater from the FGD process. The sludge is produced in the first cycle of treatment via clarification. The solids are then dewatered using a filter press and the liquid from the clarifier is transferred to the crystalliser where water is evaporated to generate a solid material (salt cake) and treated water for re-use. As such, the composition of both these waste steams is influenced by the type of coal burnt, efficiency of the fly ash removal and the type of limestone used and should have similar chemical properties.

The FGD WWTP Sludge was assessed as a Type 1 waste when using 96% limestone, and a Type 2 waste when using an 85% limestone, while the FGD WWTP Crystalliser Solids was assessed as Type 1 waste. As was stated above, the Sludge when using an 85% limestone should be disposed of on a Class B landfill, but as the assessment was based on theoretical values a conservative approach should be followed and it is recommended that the 85% FGD WWTP Sludge also be disposed of on a Class A landfill until an assessment on the actual waste can be performed.

The Class A landfill barrier system is the most conservative barrier system used in South Africa and currently offers the highest level of protection for the environment. It is normal procedure for Class A landfills in South Africa to contain a number of different wastes as it is assumed that the level of protection is sufficient to manage combined hazardous waste streams. A prime example of such a landfill is that of EnviroServ's Holfontein hazardous waste disposal facility.

Once the FGD Plant and FGD WWTP wastes are generated, assessments should be made on the actual results and a decision then made with regards to the barrier systems required for the safe disposal of these wastes. Combinations of these wastes should be blended with the ash and FGD Gypsum and assessments on these combinations carried out to verify whether or not they can be disposed of on a Class C landfill.

6. SUMMARY

The ash, FGD gypsum, FGD WWTP Sludge and FGD WWTP Crystalliser Solids were assessed for disposal according to the National Norms and Standards as per Regulation 635 of NEM:WA, 2008. The results are summarised in **Table 6-1**.

The ash and gypsum are assessed as Type 3 wastes and can be disposed of on a disposal facility of which the performance of the barrier system complies with that of a Class C landfill. These wastes would produce neutral to alkaline leachate and are chemically and biologically stable and compatible.

The 96% limestone derived FGD WWTP Sludge was assessed as a Type 1 and would require disposal in a Class A landfill. The 96% limestone derived limestone may be disposed with the FGD WWTP Crystalliser Solids on a Class A landfill, as the Crystalliser Solids was also assessed as a Type 1 waste. The 85% limestone generated FGD WWTP Sludge, which was assessed as a Type 2, but as the assessment was based purely on theoretical values, it is recommended that the 85% limestone generated FGD WWTP Sludge also be disposed of on a Class A landfill until the actual waste can be assessed and a decision then made on the way forward.

The FGD WWTP Crystalliser Solids is assessed as a Type 1 waste due to the likely leachable TDS concentrations as a result of high concentration of sodium chloride in the solid material and will need to be disposed of in a Class A landfill.

The 85% and 96% limestone derived FGD WWTP Sludge and FGD WWTP Crystalliser Solids are waste materials generated from the treatment of FGD wastewater and as such should have similar chemical characteristics. The Class A landfill offers the highest level of environmental protection of any landfill barrier system used in South Africa and taking this into account and given the similar chemical characteristics of the 85% and 96% limestone derived FGD WWTP Sludges and Crystalliser Solids, it is proposed that these waste materials be disposed of on site in a newly designed and constructed Class A landfill at the Medupi Power Station site.

Table 6-1: Summary of waste assessment results

Waste	Assessment and Class of Landfill required for disposal	Percentage of waste (%)
Ash	Type 3 waste – Class C Landfill	79 or 68
FGD Gypsum	Type 3 waste – Class C Landfill	19 or 29
FGD WWTP Sludge 85% Limestone	Type 2 waste – Class A landfill*l	2.4
FGD WWTP Sludge 96% Limestone	Type 1 waste – Class A landfill	1.4
FGD WWTP Crystalliser Solids	Type 1 waste – Class A landfill	0.72 or 0.62
*** The Type 2 assessment was based on theoretical values and therefore a conservative approach should be followed and the 85% Limestone FGD WWTP Sludge should be disposed of on a Class A landfill until the assessments can be confirmed on actual waste samples.**		

7. RECOMMENDATIONS

Based on the outcome of the assessments made, it is recommended that:

- The Medupi Power Station ash and the FGD Gypsum be disposed of on a landfill of which the barrier system complies with the performance requirements of a Class C landfill.
- The 85% limestone derived FGD WWTP Sludge, provisionally assessed as a Type 2 waste, should be disposed of on a landfill of which the barrier system complies with the performance requirements of a Class A landfill due to the considerable amount of uncertainty regarding the composition of the sludge.
- The 96% limestone derived FGD WWTP Sludge, provisionally assessed as a Type 1 waste, should be disposed of on landfill of which the barrier system complies with the performance of a Class A landfill.
- The FGD WWTP Crystalliser Solids should be disposed of on landfill of which the barrier system complies with the performance requirements of a Class A landfill. The FGD WWTP Sludge and FGD WWTP Crystalliser Solids may be disposed of on the same Class A landfill.
- The FGD process and FGD Waste Water Treatment Plant operation waste streams should be re-assessed once being generated by Medupi, in order to confirm the theoretical assessments.
- Once the wastes are generated, leach tests should be conducted on various percentage combinations of the wastes. J&W recommends that column leach tests

be conducted. The outcome of the column leach tests can then be used to motivate for the combined disposal of all four wastes or combinations thereof on a Class C landfill or other suitable landfill class.

8. REFERENCES

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Appendix A

CALCULATIONS OF TOTAL CONCENTRATIONS IN FGD WWTP SLUDGE AND FGD WWTP CRYSTALLISER SOLIDS

Project Name	Medupi Power Station	**Preparer**	**Abigail Melanie**
Calculation No.	56.6405.1204	**Date**	2014/03/14
SPF No.		**Verifier**	
Title	FGD ZLD Treatment Solids Quality Estimate	**Date**	

Purpose:

To estimate the quality of the solids generated in the the FGD WWTP.

References:

1. Medupi FGD,56.6405.1201,FGD ZLD Water Mass Balance, 20 November 2013
2. Medupi FGD,56.6405.1212,FGD ZLD Water Mass Balance, 20 November 2013
3. e-mail "AW: 131027 56.6607 Medupi FGD - Chloride Bleed Stream Flow Solids Quality", Sven Kaiser (Steinmueller), 2013/11/04 (Attached)
4. email " AW: 130816 56.6405 Medupi FGD - Chloride Bleed stream - with attachment", Stefan Binkowski (Steinmueller), 2013/08/19 (Attached)
5. Medupi FGD, 56.3202.1201, Cooling Tower Cycles of Concentration and Acid Feed Estimate, 25 October 2013

Definition of Units and Constants:

Units

1. Mass =	kg	5. 1 m^3 =	1000 L	9. 1 mass % =	10,000 ppm for solution with a specific gravity ~ 1
2. Length =	m	6. Pressure =	N/m^2		
3. Area =	m^2	7. Temperature =	deg C	10. Vol. Flow =	Lpm or m^3/hr
4. Volume =	m^3 or L	8. Density =	kg/L		

Constants

Design Conditions

	85% Limestone	**Reference**	96% Limestone	**Reference**
TSS Mass Flow in the Cooling Tower Blowdown	1 kg/hr	1	1 kg/hr	2
TSS Mass Flow in FGD Wastewater	2 773 kg/hr	1	1 170 kg/hr	2
TSS Mass Flow in the TOC Scavenger Regen Waste	0 kg/hr	1	0 kg/hr	2
$Mg(OH)_2$ formed in Mg Removal	7 972 ppm	1	0 ppm	2
$CaCO_3$ formed in Mg Removal	13 685 ppm	1	0 ppm	2
$CaCO_3$ formed in Ca Removal	2 365 ppm	1	20 134 ppm	2
Lime Inerts	1 652 ppm	1	3 ppm	2
Soda ash Inerts	86 ppm	1	107 ppm	2
SA Tank Effluent Prior to Softening Rxns	194 684 kg/hr	1	141 402 kg/hr	2
TSS Mass Flow in Clarifier Outlet	6 kg/hr	1	5 kg/hr	2
Cooling Tower Blowdown Mass Flowrate	14 515 kg/hr	1	14 515 kg/hr	2
FGD Waste Water Mass Flowrate	77 253 kg/hr	1	79 246 kg/hr	2
TOC Scavenger Regen Waste Mass Flowrate	13 769 kg/hr	1	13 769 kg/hr	2
Clarifier Outlet Mass Flowrate	115 684 kg/hr	1	102 336 kg/hr	2
TSS Mass Flow Clarifier in Solids for Disposal (Filter Cake)	8 132 kg/hr	1	4 053 kg/hr	2
Clarifier Solids for Disposal (Filter Cake) Mass Flowrate	20 330 kg/hr	1	10 132 kg/hr	2
BC after Chemical Addition and Steam Mass Flowrate	93 457 kg/hr	1	103 045 kg/hr	2
Moisture content of crystalliser filter cake	6.00%	Design Basis	6.00%	Design Basis
Moisture content of clarifier filter cake	60.00%	Design Basis	60.00%	Design Basis
Crystalliser Feed Mass Flowrate	25590.7 kg/hr	1	25 655.60	2
Sodium Added due to Caustic Addition	29.4 kg/hr	1	29.5 kg/hr	2

Project Name	Medupi Power Station
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SPF No.	
Title	FGD ZLD Treatment Solids Quality Estimate

Preparer	**Abigail Melanie**
Date	2014/03/14
Verifier	
Date	

Maximum Concentrations in clarifier effluent

Ag	2.00	ppm	Design Basis	2.00	ppm	Design Basis
Al	50.00	ppm	Design Basis	50.00	ppm	Design Basis
As	0.50	ppm	Design Basis	0.50	ppm	Design Basis
B	30.00	ppm	Design Basis	30.00	ppm	Design Basis
Ba	0.20	ppm	Design Basis	0.20	ppm	Design Basis
Be	0.05	ppm	Design Basis	0.05	ppm	Design Basis
Cd	0.05	ppm	Design Basis	0.05	ppm	Design Basis
Co	0.20	ppm	Design Basis	0.20	ppm	Design Basis
Cr	0.50	ppm	Design Basis	0.50	ppm	Design Basis
Cu	0.40	ppm	Design Basis	0.40	ppm	Design Basis
F	15.00	ppm	Design Basis	15.00	ppm	Design Basis
Fe	1.00	ppm	Design Basis	1.00	ppm	Design Basis
Hg	0.01	ppm	Design Basis	0.01	ppm	Design Basis
Mn	0.05	ppm	Design Basis	0.05	ppm	Design Basis
Mo	2.00	ppm	Design Basis	2.00	ppm	Design Basis
Ni	0.50	ppm	Design Basis	0.50	ppm	Design Basis
Pb	0.50	ppm	Design Basis	0.50	ppm	Design Basis
Sb	1.00	ppm	Design Basis	1.00	ppm	Design Basis
Se	0.20	ppm	Design Basis	0.20	ppm	Design Basis
Sr	0.48	ppm	Design Basis	0.48	ppm	Design Basis
Ti	0.60	ppm	Design Basis	0.60	ppm	Design Basis
V	50%	reduction	Design Basis	50%	reduction	Design Basis
Zn	0.50	ppm	Design Basis	0.50	ppm	Design Basis

Inerts	90.36%	3	73.20%	3
$CaSO_4 \cdot 2H_2O$	6.23%	3	20.10%	3
$CaCO_3$	2.28%	3	2.84%	3
$CaSO_3 \cdot 1/2\ H_2O$	1.13%	3	3.74%	3

Clarifier Inlet Concentration

Converting from ppm to kg/hr

$$\text{Mass of Component, kg/hr} = \frac{\text{Component, ppm x Total Mass Flowrate, m}^3\text{/hr}}{1\ 000\ 000}$$

$$Mg(OH)_2\ \text{(85\% Limestone), as an example, kg/hr} = \frac{7\ 972 \quad \text{x} \quad 194\ 684}{1\ 000\ 000}$$

$Mg(OH)_2$ = 1 552 kg/hr

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Table 1: TSS Formed in Reaction Tank

	85% Limestone		96% Limestone	
	PPM	kg/hr	PPM	kg/hr
$Mg(OH)_2$ formed in Mg Removal,kg/hr	7 972	1 552	0	0
$CaCO_3$ formed in Mg Removal, kg/hr	13 685	2 664	0	0
$CaCO_3$ formed in Ca Removal, kg/hr	2 365	460	20 134	2847
Lime Inerts, kg/hr	1 652	322	3	0
Soda ash inerts, kg/hr	86	17	107	15
Total, kg/hr		**5 015**		**2 863**

	85% Limestone	96% Limestone
solids in cooling tower blowdown	1 kg/hr	1 kg/hr
+ solids in TOC regenerant	0 kg/hr	0 kg/hr
+ solids in FGD blowdown	2 773 kg/hr	1 170 kg/hr
+ solids created in softener	5 015 kg/hr	2 863 kg/hr
- solids in clarifier effluent	6 kg/hr	5 kg/hr
Precipitated solids in clarifier sludge =	7 784 kg/hr	4 029 kg/hr

Trace Metals in Clarifier

Data extracted from Reference 1 and Reference 2

Project Name	Medupi Power Station	Preparer	Abigail Melanie
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Table 2: Trace Metals into the Clarifier							
Heavy Metal Components	Cooling Tower Blowdown stream	TOC Scavenger Regen wastewater stream	FGD Chloride bleedstream 85% limestone, worst coal	FGD Chloride bleedstream 96% limestone, worst coal	Maximum Clarifier Effluent	Maximum Clarifier Effluent 85% Limestone	Maximum Clarifier Effluent 96% Limestone
	ppm	ppm	ppm	ppm	ppm	kg/hr	kg/hr
Ag			2.0000	2.0000	2.0000	0.2314	0.2047
Al	0.0800		50.0000	50.0000	50.0000	5.7842	5.1168
As			1.0000	1.0000	0.5000	0.0578	0.0512
B			40.0000	40.0000	30.0000	3.4705	3.0701
Ba	0.2000		30.0000	30.0000	0.2000	0.0231	0.0205
Be			2.0000	2.0000	0.0500	0.0058	0.0051
Cd	0.0200		0.6000	0.6000	0.0500	0.0058	0.0051
Co			1.0000	1.0000	0.2000	0.0231	0.0205
Cr	0.0600		3.0000	3.0000	0.5000	0.0578	0.0512
Cu	0.0200		2.0000	2.0000	0.4000	0.0463	0.0409
F	1.2800		30.0000	30.0000	15.0000	1.7353	1.5350
Fe	0.4800		40.0000	40.0000	1.0000	0.1157	0.1023
Hg			0.2000	0.2000	0.0100	0.0012	0.0010
Mn	0.0400		30.0000	30.0000	0.0500	0.0058	0.0051
Mo			2.0000	2.0000	2.0000	0.2314	0.2047
Ni	0.0200		3.0000	3.0000	0.5000	0.0578	0.0512
Pb			2.0000	2.0000	0.5000	0.0578	0.0512
Sb			1.0000	1.0000	1.0000	0.1157	0.1023
Se			1.0000	1.0000	0.2000	0.0231	0.0205
Sr	0.4800		120.0000	120.0000	0.4800	0.0555	0.0491
Ti			0.6000	0.6000	0.6000	0.0694	0.0614
V			0.8000	0.8000	0.4000	0.0463	0.0409
Zn	0.1000		5.0000	5.0000	0.5000	0.0578	0.0512

Converting from ppm to kg/hr

$$\text{Mass of Componentl, kg/hr} = \frac{\text{Component, ppm x Total Mass Flowrate,kg/hr}}{1000000}$$

$$\text{Aluminum in FGD Bleedstream (85\% Limestone), as an example, kg/hr} = \frac{50.00 \quad \text{x} \quad 77\,253}{1000000}$$

$$= \quad 3.86 \quad \text{kg/hr}$$

Clarifier influent = CT Blowdown (kg/hr) + TOC Scavenger Regen (kg/hr) +FGD Chloride Bleedstream (kg/hr)

Aluminum in FGD Bleedstream (85% Limestone), as an example, kg/hr = 0.00 + 0.00 + 3.86

= 3.86 kg/hr

Clarifier effluent = the lower value of the clarifier influent or the maximum clarifier effluent except vanadium which = 1/2 influent value.

Project Name	Medupi Power Station	**Preparer**	**Abigail Melanie**
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Table 3: Trace Metals exiting the Clarifier

Heavy Metal Components	Cooling Tower Blowdown stream	TOC Scavenger Regen wastewater stream	FGD Chloride bleedstream 85% limestone, worst coal	FGD Chloride bleedstream 96% limestone, worst coal	Clarifier Influent 85% Limestone	Clarifier Effluent 85% Limestone	Clarifier Influent 96% Limestone	Clarifier Effluent 96% Limestone
	kg/hr	kg/hr	kg/hr	kg/hr	kg/hr	kg/hr	kg/hr	kg/hr
Ag	0.00000	0.00000	0.15451	0.15849	0.15451	0.15451	0.15849	0.15849
Al	0.00116	0.00000	3.86266	3.96231	3.86382	3.86382	3.96347	3.96347
As	0.00000	0.00000	0.07725	0.07925	0.07725	0.05784	0.07925	0.05117
B	0.00000	0.00000	3.09013	3.16985	3.09013	3.09013	3.16985	3.07008
Ba	0.00290	0.00000	2.31759	2.37738	2.32050	0.02314	2.38029	0.02047
Be	0.00000	0.00000	0.15451	0.15849	0.15451	0.00578	0.15849	0.00512
Cd	0.00029	0.00000	0.04635	0.04755	0.04664	0.00578	0.04784	0.00512
Co	0.00000	0.00000	0.07725	0.07925	0.07725	0.02314	0.07925	0.02047
Cr	0.00087	0.00000	0.23176	0.23774	0.23263	0.05784	0.23861	0.05117
Cu	0.00029	0.00000	0.15451	0.15849	0.15480	0.04627	0.15878	0.04093
F	0.01858	0.00000	2.31759	2.37738	2.33617	1.73526	2.39596	1.53504
Fe	0.00697	0.00000	3.09013	3.16985	3.09709	0.11568	3.17681	0.10234
Hg	0.00000	0.00000	0.01545	0.01585	0.01545	0.00116	0.01585	0.00102
Mn	0.00058	0.00000	2.31759	2.37738	2.31817	0.00578	2.37796	0.00512
Mo	0.00000	0.00000	0.15451	0.15849	0.15451	0.15451	0.15849	0.15849
Ni	0.00029	0.00000	0.23176	0.23774	0.23205	0.05784	0.23803	0.05117
Pb	0.00000	0.00000	0.15451	0.15849	0.15451	0.05784	0.15849	0.05117
Sb	0.00000	0.00000	0.07725	0.07925	0.07725	0.07725	0.07925	0.07925
Se	0.00000	0.00000	0.07725	0.07925	0.07725	0.02314	0.07925	0.02047
Sr	0.00697	0.00000	9.27038	9.50954	9.27734	0.05553	9.51650	0.04912
Ti	0.00000	0.00000	0.04635	0.04755	0.04635	0.04635	0.04755	0.04755
V	0.00000	0.00000	0.06180	0.06340	0.06180	0.04627	0.06340	0.04093
Zn	0.00145	0.00000	0.38627	0.39623	0.38772	0.05784	0.39768	0.05117
Total						**9.76**		**9.58**

Determine Heavy Metals in Clarifier Solids

Heavy metals in clarifier solids = the sum of the heavy metals into the system - the heavy metals in the clarifier effluent.

Barium in clarifier solids (85% limestone) for example =	0.00	kg/h (cooling tower blowdown)
+	0.00	kg/h (TOC regeneration wastewater)
+	2.32	kg/h (FGD blowdown)
-	0.02	kg/h (Clarifier effluent)
	2.30	kg/h (Total)

Project Name	Medupi Power Station	**Preparer**	**Abigail Melanie**
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Converting from kg/hr to ppm

$$\text{Concentration of dry basis component, ppm} = \frac{\text{Component, kg/hr} \times 10^6}{\text{Mass Flowrate of filter cake TSS, kg/hr}}$$

$$\text{Barium (in 85\% limestone), as an example} = \frac{2.30 \quad \times \quad 1\,000\,000}{8132}$$

$$= 282.5 \text{ ppm}$$

$$\text{Concentration of wet basis component, ppm} = \frac{\text{Component, kg/hr} \times 10^6}{\text{Total Mass Flowrate of filter cake, kg/hr}}$$

(Based on 40% solids in filter cake)

$$\text{Barium (in 85\% limestone), as an example} = \frac{2.30 \quad \times \quad 1\,000\,000}{20330}$$

$$= 113.00 \text{ ppm}$$

Table 4: Clarifier filter cake trace components

Heavy Metal Components	85% Limestone Clarifier Solids Dry Basis kg/hr	85% Limestone Clarifier Solids Dry ppm	85% Limestone Clarifier Solids Wet ppm	96% Limestone Clarifier Solids Dry Basis kg/hr	96% Limestone Clarifier Solids Dry ppm	96% Limestone Clarifier Solids Wet ppm
Ag	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Al	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
As	0.019411	2.386948	0.954779	0.028078	6.928368	2.771347
B	0.000000	0.000000	0.000000	0.099764	24.617020	9.846808
Ba	2.297360	282.502096	113.000839	2.359820	582.293576	232.917431
Be	0.148722	18.288075	7.315230	0.153375	37.845918	15.138367
Cd	0.040858	5.024230	2.009692	0.042721	10.541597	4.216639
Co	0.054116	6.654584	2.661833	0.058779	14.503899	5.801560
Cr	0.174788	21.493389	8.597356	0.187441	46.251774	18.500710
Cu	0.108523	13.344865	5.337946	0.117848	29.079432	11.631773
F	0.600913	73.893120	29.557248	0.860923	212.435561	84.974224
Fe	2.981409	366.618243	146.647297	3.074477	758.637556	303.455023
Hg	0.014294	1.757680	0.703072	0.014826	3.658333	1.463333
Mn	2.312390	284.350330	113.740132	2.372848	585.508277	234.203311
Mo	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ni	0.174208	21.421993	8.568797	0.186861	46.108508	18.443403
Pb	0.096664	11.886622	4.754649	0.107324	26.482621	10.593049
Sb	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Se	0.054116	6.654584	2.661833	0.058779	14.503899	5.801560
Sr	9.221815	1133.989363	453.595745	9.467382	2336.108743	934.443497
Ti	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
V	0.015529	1.909559	0.763823	0.022462	5.542694	2.217078
Zn	0.329875	40.564132	16.225653	0.346514	85.503547	34.201419
Total	18.64			19.56		

Project Name	Medupi Power Station	**Preparer**	**Abigail Melanie**
Calculation No.	56.6405.1204	**Date**	2014/03/14
SPF No.		**Verifier**	
Title	FGD ZLD Treatment Solids Quality Estimate	**Date**	

Determine Major Components in Clarifier Solids

Mass flow of solids in FGD solids = Mass percent X TSS Mass Flow in FGD Wastewater

$CaCO_3$ (85% Limestone) for example = 2.28% X 2773
= 63.23 kg/hr

Mass flow of precipitated solids = Sum of the precipitates from lime and soda ash addition

$CaCO_3$ (85% Limestone) for example = 2664 + 460 = 3125 kg/hr

Percent dry solids = $\frac{\text{component solids (kg/hr) X 100}}{\text{Total dry solids (kg/hr)}}$

$CaCO_3$ (85% Limestone) for example = $\frac{3188 \text{ kg/hr} \times 100}{7790 \text{ kg/hr}}$ = 41%

Determine Wet basis

The wet solids are based on 60.00%

Total filter cake = Dry solids / (1-% moisture in solids)

For 85% Limestone, total filter cake = 7 790 / (1 - 60.00%)

= 19 474 kg/hr

Water in filter cake = Total filter cake - dry solids

Water in filter cake = 11684 kg/hr

Solids in % = dry solids(kg/h)/total wet solids

Wet inerts for 85% limestone = 7790 kg/h / 19474 kg/h = 40.0%

Project Name	Medupi Power Station	**Preparer**	**Abigail Melanie**
Calculation No.	56.6405.1204	**Date**	2014/03/14
SPF No.		**Verifier**	
Title	FGD ZLD Treatment Solids Quality Estimate	**Date**	

Table 5: Clarifier filter cake major components

85% Limestone

Major Components	Precipitated Solids	FGD Solids	Cooling Tower Solids	Total Solids	Total Solids	Clarifier Solids	Clarifier Solids
	Dry Basis	Dry	Dry	Dry	Dry	Wet	Wet
	kg/hr	kg/hr	kg/hr	kg/hr	%	kg/hr	%
Inerts	338	2506	1	2845	36.5	2845	14.6
$CaSO_4 \cdot 2H_2O$	0	173	0	173	2.2	173	0.9
$CaCO_3$	3125	63	0	3188	40.9	3188	16.4
$CaSO_3 \cdot 1/2\ H_2O$	0	31	0	31	0.4	31	0.2
$Mg(OH)_2$	1552	0	0	1552	19.9	1552	8.0
H_2O	0	0	0	0	0	11684	60
Total				**7790**		**19474**	

Table 6: Clarifier filter cake major components

96% Limestone

Major Components	Precipitated Solids	FGD Solids	Cooling Tower Solids	Total Solids	Total Solids	Clarifier Solids	Clarifier Solids
	Dry Basis	Dry	Dry	Dry	Dry	Wet	Wet
	kg/hr	kg/hr	kg/hr	kg/hr	%	kg/hr	%
Inerts	16	857	1	873	21.7	873	8.7
$CaSO_4 \cdot 2H_2O$	0	235	0	235	5.8	235	2.3
$CaCO_3$	2847	33	0	2880	71.4	2880	28.6
$CaSO_3 \cdot 1/2\ H_2O$	0	44	0	44	1.1	44	0.4
$Mg(OH)_2$	0	0	0	0	0.0	0	0.0
H_2O	0	0	0	0	0.0	6049	60
Total				**4032**		**10081**	

NOTE:

Water component will have high concentrations of dissolved solids including chlorides, sulfates, sodium, magnesium, and calcium.
There will be trace amounts of heavy metals in the liquid fraction.

Project Name	Medupi Power Station	**Preparer**	**Abigail Melanie**
Calculation No.	56.6405.1204	**Date**	2014/03/14
SPF No.		**Verifier**	
Title	FGD ZLD Treatment Solids Quality Estimate	**Date**	

Determining the Mass of solids formed in the Crystalliser

Converting from ppm to kg/hr

$$\text{Mass of Componentl, kg/hr} = \frac{\text{Component, ppm x Total Mass Flowrate,kg/hr}}{1\ 000\ 000}$$

$$\text{Sodium in 85\% limestone, as an example, kg/hr} = \frac{18431 \quad x \quad 93\ 457}{1\ 000\ 000}$$

= 1723 kg/hr

Sodium in crystalliser feed = Sodium content in BC inlet (kg/h) + caustic feed (kg/hr)

Sodium in crystalliser feed (85% Limestone) = 1723 + 29.4 = 1752 kg/hr

	Table 7: Crystalliser input Data					
	85% Limestone			96% Limestone		
	BC After Chem and Steam Addition	BC After Chem and Steam Addition	Crystalliser Feed	BC After Chem and Steam Addition	BC After Chem and Steam Addition	Crystalliser Feed
	ppm	kg/hr	kg/hr	ppm	kg/hr	kg/hr
Calcium	1 440	135	135	1 442	149	149
Magnesium	307	29	29	308	32	32
Sodium	18 431	1 723	1 752	16 897	1 741	1 771
Chloride	23 640	2 209	2 209	23 695	2 442	2 442
Sulfate	9 132	853	853	5 798	597	597
Total		4 949	4 978		4 961	4 990

BC Inlet concentrations and Crystalliser Feed concentration extracted from Reference 1 and Reference 2

Determine wet basis

Assume heavy metals do not impact bulk concentrations.

Based on 6.00% moisture in the crystalliser solids, the wet solids = Dry solids / (1-% moisture in solids)

Wet solids for 85% limestone = 4 978 x (1 - 6.00%)

= 5296 kg/h

Wet solids for 96% limestone = 4 990 x (1 - 6.00%)

= 5 309 kg/h

Project Name	Medupi Power Station	**Preparer**	**Abigail Melanie**
Calculation No.	56.6405.1204	**Date**	2014/03/14
SPF No.		**Verifier**	
Title	FGD ZLD Treatment Solids Quality Estimate	**Date**	

Table 8: Crystalliser product (trace metals)

Heavy Metal Components	85% Limestone			96% Limestone		
	Crystalliser	Crystalliser	Crystalliser	Crystalliser	Crystalliser	Crystalliser
	Dry Basis	Dry	Wet	Dry Basis	Dry	Wet
	kg/hr	ppm	ppm	kg/hr	ppm	ppm
Ag	0.15	31.04	29.18	0.16	31.76	29.86
Al	3.86	776.19	729.62	3.96	794.27	746.61
As	0.06	11.62	10.92	0.05	10.25	9.64
B	3.09	620.76	583.52	3.07	615.24	578.32
Ba	0.02	4.65	4.37	0.02	4.10	3.86
Be	0.01	1.16	1.09	0.01	1.03	0.96
Cd	0.01	1.16	1.09	0.01	1.03	0.96
Co	0.02	4.65	4.37	0.02	4.10	3.86
Cr	0.06	11.62	10.92	0.05	10.25	9.64
Cu	0.05	9.30	8.74	0.04	8.20	7.71
F	1.74	348.59	327.67	1.54	307.62	289.16
Fe	0.12	23.24	21.84	0.10	20.51	19.28
Hg	0.00	0.23	0.22	0.00	0.21	0.19
Mn	0.01	1.16	1.09	0.01	1.03	0.96
Mo	0.15	31.04	29.18	0.16	31.76	29.86
Ni	0.06	11.62	10.92	0.05	10.25	9.64
Pb	0.06	11.62	10.92	0.05	10.25	9.64
Sb	0.08	15.52	14.59	0.08	15.88	14.93
Se	0.02	4.65	4.37	0.02	4.10	3.86
Sr	0.06	11.15	10.49	0.05	9.84	9.25
Ti	0.05	9.31	8.75	0.05	9.53	8.96
V	0.05	9.30	8.74	0.04	8.20	7.71
Zn	0.06	11.62	10.92	0.05	10.25	9.64

Solids in % = dry solids(kg/h)/total wet solids

Wet calcium for 85% limestone = 135 kg/h / 5296 kg/h = 2.5%

Table 9: Crystalliser Product (Major Components)

Major Components	85% Limestone			96% Limestone		
	Crystalliser	Crystalliser	Crystalliser	Crystalliser	Crystalliser	Crystalliser
	Dry Basis	Dry	Wet	Dry Basis	Dry	Wet
	kg/hr	%	%	kg/hr	%	%
Calcium	134.58	2.70	2.54	148.59	2.98	2.80
Magnesium	28.69	0.58	0.54	31.74	0.64	0.60
Sodium	1 751.90	35.19	33.08	1 770.65	35.48	33.35
Chloride	2 209.32	44.38	41.72	2 441.65	48.93	45.99
Sulfate	853.45	17.14	16.12	597.45	11.97	11.25
H_2O	0.00	0.00	6.00	0.00	0.00	6.00
Total	4978	100	100	4990	100	100

			Preparer	**Abigail Melanie**
Project Name	Medupi Power Station		**Date**	2014/03/14
Calculation No.	56.6405.1204		**Verifier**	
SPF No.			**Date**	
Title	FGD ZLD Treatment Solids Quality Estimate			

Conclusion:

	85%	96%
Clarifier Product: Trace Metals	Table 4	Table 4
Clarifier Product: Major Components	Table 5	Table 6
Crystalliser Product: Trace Metals	Table 8	Table 8
Crystalliser Product: Major Component	Table 9	Table 10

Appendix B

LABORATORY RESULTS FOR MATIMBA ASH

WATERLAB (PTY) LTD

WATERLAB

Building D, The Woods,
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Meiring Naudé Road,
Pretoria

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES

Digestion AS 4439.3

Date received:	02/09/2014		**Date completed:**	26/09/2014
Project number:	132	**Report number:** 47779	**Order number:**	GMS/E173/140902

Client name:	Groundwater Monitoring Services (Pty) Ltd.	**Contact person:**	Steven Gumbi
Address:	PO Box 1811, Rivonia, 2128	**Email:**	steve@gwms.co.za
Telephone:	011 234 1550	**Cell:**	---

Analyses	MFY-1		MFA-2		MFA-3		
Sample Number	15079		15080		15081		TCT0 mg/kg
Digestion	Aqua Regia		Aqua Regia		Aqua Regia		
Dry Mass Used (g)	0.25		0.25		0.25		
Volume Used (mℓ)	100		100		100		
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	
Al, Aluminium	57	22800	35	14000	34	13600	
As, Arsenic	<0.010	<4.00	<0.010	<4.00	<0.010	<4.00	5.8
B, Boron	0.106	42	0.095	38	0.085	34	150
Ba, Barium	0.971	388	0.864	346	0.889	356	62.5
Ca, Calcium	45	18000	43	17200	41	16400	
Cd, Cadmium	0.008	3.20	0.011	4.40	0.005	2.00	7.5
Co, Cobalt	<0.025	<10	<0.025	<10	<0.025	<10	50
$Cr_{Total,}$ Chromium Total [s]	0.134	54	0.094	38	0.082	33	46000
Cr(VI), Chromium (VI) Total [s]	---	<5	---	<5	---	<5	6.5
Cu, Copper	<0.025	<10	<0.025	<10	<0.025	<10	16
Hg, Mercury	<0.001	<0.4	<0.001	<0.4	0.011	4.4	0.93
K, Potassium	1.6	640	0.9	360	0.5	200	
Mg, Magnesium	9.00	3600	9.00	3600	8.00	3200	
Mn, Manganese	0.893	357	0.848	339	0.781	312	1000
Mo, Molybdenum	<0.025	<10	<0.025	<10	<0.025	<10	40
Na, Sodium	<2.00	<800	<2.00	<800	<2.00	<800	
Ni, Nickel	0.051	20	0.041	16	0.037	15	91
Pb, Lead	<0.010	<4.00	<0.010	<4.00	<0.010	<4.00	20
Sb, Antimony	<0.010	<4.00	<0.010	<4.00	<0.010	<4.00	10
Se, Selenium	<0.010	<4.00	<0.010	<4.00	<0.010	<4.00	10
V, Vanadium	0.067	27	0.039	16	<0.025	<10	150
Zn, Zinc	0.125	50	0.106	42	0.093	37	240
Inorganic Anions	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	
Total Dissolved Solids at 180°C	---	---	---	---	---	---	N/A
Chloride as Cl	---	---	---	---	---	---	N/A
Sulphate as SO_4	---	---	---	---	---	---	N/A
Nitrate as N	---	---	---	---	---	---	N/A
Total Fluoride [s] mg/kg	---	296	---	285	---	346	100

UTD = Unable to determine

Appendix C

LITERATURE VALUES FOR FGD GYPSUM TOTAL ELEMENTAL CONCENTRATIONS

Table 1: FGD Gypsum Total Concentration Results

Elements & Chemical Substances in Waste (all units mg/kg)	Total Concentration Thresholds (mg/kg)			FGD Gypsum	FGD Gypsum	FGD Gypsum	FGD Gypsum	FGD Gypsum	FGD Gypsum
Reference				Chen et al 2012	Chen et al 2012	Chen et al 2012	Chen et al 2012	EPRI 2011	Chen 2008
	TCT0	TCT1	TCT2	Ohio	Indiana	Alabama	Wisconsin	Max (N=32)	
Metal Ions									
Arsenic	5.8	500	2000	<1.28	1.35	<1.28	<1.28	11.1	<11
Boron	150	15000	60000	-	-	-	-	387	5.8
Barium	62.5	6250	25000	31.3	21.3	43	19.6	55.2	5.5
Cadmium	7.5	260	1040	0.158	0.472	0.549	0.079	0.369	<1
Cobalt	50	5000	20000	<0.146	0.21	<0.146	<0.146	0.716	-
Chromium Total	46000	800000	NA	1.8	7.04	7.58	3.81	14.5	<1
Chromium (VI)	6.5	500	2000	1.8	7.04	7.58	3.81	14.8	<1
Copper	16	19500	78000	3.25	<0.378	<0.378	7.02	3.17	<3
Mercury	0.93	160	640	0.376	0.198	0.589	1.33	1.41	-
Manganese	1000	25000	100000	-	-	-	-	129	1.3
Molybdenum	40	1000	4000	0.7	1.46	1.32	0.97	4	<3
Nickel	91	10600	42400	0.88	2.22	2.68	1.61	2.86	<3
Lead	20	1900	7600	<0.774	<0.774	1.33	<0.774	8.3	<5
Antimony	10	75	300	4.58	10.4	7.34	9.55	4.97	-
Selenium	10	50	200	<2.32	2.92	<2.32	8.36	32	<25
Vanadium	150	2680	10720	2.42	7.24	5.72	1.38	8.57	-
Zn, Zinc	240	160000	640000	4.7	27.4	29	11.5	23.3	4.8
Inorganic Anions									
F, Fluoride	100	10000	40000	-	-	-	-	-	-

Table 1: FGD Gypsum Total Concentration Results

Elements & Chemical Substances in Waste (all units mg/kg)	Total Concentration Thresholds (mg/kg)			FGD Gypsum	FGD Gypsum	FGD Gypsum	FGD Gypsum	FGD Gypsum	FGD Gypsum
Reference				En-Chem 2008	VGB -TW-707e	VGB -TW-707e	VGB -TW-707e	VGB -TW-707e	VGB -TW-707e
	TCT0	TCT1	TCT2		G 4/88/R	G 5/88/R	G 6/88R	9/88/R	G 10/88/R
Metal Ions									
Arsenic	5.8	500	2000	2	1.15	1.34	0.48	0.72	1.96
Boron	150	15000	60000	-	-	-	-	-	-
Barium	62.5	6250	25000	17	0.32	0.15	0.05	0.04	0.16
Cadmium	7.5	260	1040	<0.1	0.29	0.03	0.06	<0.02	0.21
Cobalt	50	5000	20000	8.2	1.36	0.4	0.25	0.22	2.2
Chromium Total	46000	800000	NA	7.8	4.61	3.88	1.02	9.72	1.18
Chromium (VI)	6.5	500	2000	<1	4.61	3.88	1.02	9.72	1.18
Copper	16	19500	78000	2.8	8.56	5.44	1.25	1.2	5.83
Mercury	0.93	160	640	<1	1.32	0.66	0.03	0.87	1.02
Manganese	1000	25000	100000	7.1	-	36.3	3.67	9.74	196
Molybdenum	40	1000	4000	0.79	-	-	-	-	-
Nickel	91	10600	42400	6.8	5.2	0.85	0.55	0.55	12.9
Lead	20	1900	7600	93	22	8.96	0.49	<2.5	2.04
Antimony	10	75	300	<1	-	-	-	-	-
Selenium	10	50	200	22	8.9	1.03	2.69	2	13.3
Vanadium	150	2680	10720	-	7.7	3.48	1.22	2.67	5.09
Zn, Zinc	240	160000	640000	-	53.2	22.8	<3	<3	22
Inorganic Anions									
F, Fluoride	100	10000	40000	355	-	-	-	-	-

Table 1: FGD Gypsum Total Concentration Results

Elements & Chemical Substances in Waste (all units mg/kg)	Total Concentration Thresholds (mg/kg)			FGD Gypsum	FGD Gypsum	FGD Gypsum	FGD Gypsum	FGD Gypsum	FGD Gypsum
Reference				VGB -TW-707e	VGB -TW-707e	VGB -TW-707e	VGB -TW-707e	VGB -TW-707e	VGB -TW-707e
	TCT0	TCT1	TCT2	G 11/88/R	G 12/88/R	G13/88/R	G 14/88/R	G 22/88/R	G 23/88/R
Metal Ions									
Arsenic	5.8	500	2000	0.67	1.04	1.13	0.21	2.7	0.49
Boron	150	15000	60000	-	-	-	-	-	-
Barium	62.5	6250	25000	<0.05	0.09	<0.1	<0.1	<0.1	0.65
Cadmium	7.5	260	1040	0.02	0.03	0.02	0.02	0.02	0.01
Cobalt	50	5000	20000	0.2	0.27	0.24	0.06	0.17	0.09
Chromium Total	46000	800000	NA	1.68	3.32	4.3	3.16	2.31	2.18
Chromium (VI)	6.5	500	2000	1.68	3.32	4.3	3.16	2.31	2.18
Copper	16	19500	78000	1.3	1.9	1.65	2.38	2.3	2.37
Mercury	0.93	160	640	0.3	0.96	0.1	0.23	0.6	0.33
Manganese	1000	25000	100000	9.17	106	15.8	28.9	8.3	29
Molybdenum	40	1000	4000	-	-	-	-	-	-
Nickel	91	10600	42400	0.3	1.02	1.2	1.27	1.1	1.36
Lead	20	1900	7600	3.98	<2.5	3.1	1.19	12.2	0.27
Antimony	10	75	300	-	-	-	-	-	-
Selenium	10	50	200	0.88	6.2	15.7	1.61	1.1	2.27
Vanadium	150	2680	10720	1.49	4.23	2.9	3.57	3.3	2.62
Zn, Zinc	240	160000	640000	<3	7	3	3	1.7	4.6
Inorganic Anions									
F, Fluoride	100	10000	40000	-	-	-	-	-	-

Table 1: FGD Gypsum Total Concentration Results

Elements & Chemical Substances in Waste (all units mg/kg)	Total Concentration Thresholds (mg/kg)			FGD Gypsum	FGD Gypsum	FGD Gypsum	FGD Gypsum
Reference				VGB -TW-707e	VGB -TW-707e	VGB -TW-707e	VGB -TW-707e
	TCT0	TCT1	TCT2	G 24/88/R	G 25/88/R/B1	G 26/88/R/B2	G 27/88/R/B3
Metal Ions							
Arsenic	5.8	500	2000	0.42	2.04	2.2	2.6
Boron	150	15000	60000	-	-	-	-
Barium	62.5	6250	25000	0.03	0.24	0.42	0.1
Cadmium	7.5	260	1040	0.003	0.14	0.15	<0.02
Cobalt	50	5000	20000	0.04	0.49	0.53	0.49
Chromium Total	46000	800000	NA	1.8	3.64	2.75	4.8
Chromium (VI)	6.5	500	2000	1.8	3.64	2.75	4.8
Copper	16	19500	78000	3.99	4.65	2.38	1.1
Mercury	0.93	160	640	0.27	0.76	0.66	0.9
Manganese	1000	25000	100000	2.04	64.9	52.7	41.7
Molybdenum	40	1000	4000	-	-	-	-
Nickel	91	10600	42400	0.6	1.63	3.12	3.2
Lead	20	1900	7600	<2.5	<3	11.1	6.41
Antimony	10	75	300	-	-	-	-
Selenium	10	50	200	DL	DL	2.3	0.7
Vanadium	150	2680	10720	4	3.55	3.92	5.4
Zn, Zinc	240	160000	640000	DL	DL	43	24.3
Inorganic Anions							
F, Fluoride	100	10000	40000	-	-	-	-