TERRASOIL SCIENCE

REPORT

WASTE CLASSIFICATION:

EESTECH POST PROCESS TAILINGS

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Declaration

I, Johan Hilgard van der Waals, declare that –

- I act as an independent specialist in this investigation;
- I have performed the work relating to the investigation in an objective manner;
- There are no circumstances that may compromise my objectivity in performing such work;
- I have expertise in conducting the specialist investigation relevant to this case;
- I will comply with the Act, regulations and all other applicable legislation;
- I have no, and will not engage in, conflicting interests in the undertaking of the investigation; and
- I undertake to disclose to the court and the competent authority all material information in my possession that reasonably has or may have the potential of influencing any decision by the court and or the competent authority.

J.H. VAN DER WAALS
TERRA SOIL SCIENCE

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WASTE CLASSIFICATION: EESTECH POST PROCESS TAILINGS

1. TERMS OF REFERENCE

Terra Soil Science was appointed by EESTech to conduct a waste classification investigation into the EESTech post process tailings (hereafter referred to "tailings") from Cr extraction and material stabilisation processes. The levels of pollutants are gauged against the relevant current legislation in terms of the National Environmental Management Waste Act (NEMWA) (Act 59 of 2008).

2. STATUTORY CONTEXT: WASTE CLASSIFICATION

The assessment and classification of waste for landfill disposal is conducted in accordance with the National Norms and Standards for the Assessment of Waste for Landfill Disposal (NSAWLD) (No. R. 635 of 2013) of the National Environmental Management Waste Act (NEMWA) (Act 59 of 2008).

2.1 RELEVANT DEFINITIONS IN THE NSAWLD

The following definitions are of relevance in this report:

"**Leachable Concentration (LC)**" means the leachable concentration of a particular element or chemical substance in a waste, expressed as mg/l

"**Leachable Concentration Threshold (LCT)**" means the leachable concentration threshold limit for particular elements and chemical substances in a waste, expressed as mg/l, prescribed in section 6 of the Norms and Standards

"**Total Concentration (TC)**" means the total concentration of a particular element or chemical substance in a waste, expressed as mg/kg

"**Total Concentration Threshold (TCT)**" means the total concentration threshold limit for particular elements or chemical substances in a waste, expressed as mg/kg, prescribed in section 6 of the Norms and Standards

2.2 PURPOSE, APPLICATION AND TECHNIQUES PRESCRIBED IN THE NSAWLD

The Norms and Standards prescribe the requirements for the assessment of waste prior to disposal to landfill in terms of Regulation 8(1)(a) of the Regulations.

The approach is summarised as follows:

1. Identify the chemical substances present in the waste;
2. Sample and analyse the waste to determine the TC and LC of the elements and substances that are specified in section 6 of the Norms and Standards; and
3. Determine the specific type of waste in terms of section 7 of the Norms and Standards.

The techniques stipulated in the NSAWLD are the following:

1. Total Concentration: techniques that are reliable, accurate and repeatable. In practice an Aqua Regia digestion is employed by most laboratories.
2. Leachable concentration: A standard leaching procedure – Australian Standard Leaching Procedure (AS 4439.1, 4439.2 and 4439.3) – is required.
3. Leachable concentration: the type of leaching fluid (solution) is selected as follows:
   a. Disposal with putrescible wastes – acetic solution;
   b. Disposal with non-putrescible wastes – sodium tetraborate decahydrate solution with acetic solution; or
   c. Non- putrescible to be disposed without any other wastes – reagent water.

2.3 LCT AND TCT LIMITS

The Total Concentration Threshold (TCT) Limits are listed in **Table 1**.

Table 1 Total Concentration Threshold (TCT) values (Section 6 of the Norms and Standards)

Element	TCT0	TCT1	TCT2
Metalloids	$mg.kg^{-1}$ (assumed to be aqua regia digestion)		
As, Arsenic	5.8	500	2000
B, Boron	150	15000	60000
Ba, Barium	62.5	62500	25000
Cd, Cadmium	7.5	260	1040
Co, Cobalt	50	5000	20000
Cr_{Total}, Chromium Total	46000	96000	790000
Cr(VI), Chromium (VI)	6.5	500	2000
Cu, Copper	16	19500	7800
Hg, Mercury	0.93	160	640
Mn, Manganese	1000	25000	10000
Mo, Molybdenum	40	1000	4000
Ni, Nickel	91	10600	42400
Pb, Lead	20	1900	7600
Sb, Antimony	10	75	300
Se, Selenium	10	50	200
V, Vanadium	150	2680	10720
Zn, Zinc	240	160000	640000
Inorganic Anions			
F, Fluoride	100	10000	40000
CN^- (Total), Cyanide Total	14	10500	42000

The Leachable Concentration Threshold (LCT) Limits are listed in **Table 2**.

Table 2 Leachable Concentration Threshold (TCT) values (Section 6 of the Norms and Standards)

Element	LCT0	LCT1	LCT2	LCT3
Metalloids	$mg.l^{-1}$			
As, Arsenic	0.01	0.5	1	4
B, Boron	0.5	25	50	200
Ba, Barium	0.7	35	70	280
Cd, Cadmium	0.003	0.15	50	200
Co, Cobalt	0.5	25	50	200
Cr_{Total}, Chromium Total	0.1	5	10	40
Cr(VI), Chromium (VI)	0.05	2.5	5	20
Cu, Copper	2	100	200	800
Hg, Mercury	0.006	0.3	0.6	2.4
Mn, Manganese	0.5	25	50	200
Mo, Molybdenum	0.07	3.5	7	28
Ni, Nickel	0.07	3.5	7	28
Pb, Lead	0.01	0.5	1	4
Sb, Antimony	0.02	1	2	8
Se, Selenium	0.01	0.5	1	4
V, Vanadium	0.2	10	20	80
Zn, Zinc	5	250	500	2000
Inorganic Anions	**Inorganic Anions**			
F, Fluoride	1.5	75	150	600
Cl, Chloride	300	15000	3000	120000
SO_4, Sulphate	250	12500	25000	100000
NO_3 as N, Nitrate-N	11	550	1100	4400
CN^- (Total), Cyanide Total	0.07	3.5	7	28

2.4 WASTE TYPE CLASSIFICATION

The following waste types are classified accordingly:

1. Type 0: LC > LCT3 <u>or</u> TC > TCT2
2. Type 1: LCT2 < LC ≤ LCT3 <u>or</u> TCT1 < TC ≤ TCT2
3. Type 2: LCT1 < LC ≤ LCT2 <u>and</u> TC ≤ TCT1
4. Type 3: LCT0 < LC ≤ LCT1 <u>and</u> TC ≤ TCT1
5. Type 4: LC ≤ LCT0 <u>and</u> TC ≤ TCT0
6. Special Provision – Type 1: If TC > TCT2 and cannot be reduced to below TCT2, but LC < LCT3

2.5 Waste Disposal Requirements

The waste disposal requirements are provided in **Table 3**.

Table 3 Waste disposal requirements according to waste type

Waste Risk Level	Disposal Requirements
Type 0: Very High Risk	Disposal **not allowed**. The waste must be treated first and then re-tested to determine the risk profile for disposal.
Type 1: High Risk	Disposal only allowed at a landfill with a Class A or Hh/HH containment barrier design.
Type 2: Moderate Risk	Disposal only allowed at a landfill with a Class B or GLB+ containment barrier design (or Class A).
Type 3: Low Risk	Disposal only allowed at a landfill with a Class C or GLB+ containment barrier design (or Class B or A).
Type 4: Inert Waste	Disposal only allowed at a landfill with a Cass D or GSB- containment barrier design.
Non-hazardous Waste (Pre-classified)	Disposal only allowed at a landfill with a Class B or GS/M/L B-/B+ containment barrier design.

3. METHOD OF INVESTIGATION

The investigation was conducted in two phases.

3.1 Phase 1: Waste Analysis

The tailings sample was submitted to WaterLab for 1) a water leach and 2) and aqua regia digestion procedure. In both cases the elements listed in the NSAWLD were determined in the solutions through ICP-MS.

3.2 Phase 2: Waste Classification

The sample analysis results were used to conduct a waste classification exercise in terms of the NSAWLD.

4. INVESTIGATION RESULTS

4.1 AQUA REGIA DIGESTION RESULTS

The aqua regia digestion metals, metalloid and inorganic anion determination results for the samples are provided in **Table 4**. The rows on the right indicate the TCT values as provided in the NSAWLD in colours for the purpose of indicating the analysis values that fall below the specified ranges.

The levels of As, Ba, Hg, Mn, V, CrVI and F exceed the TCT0 threshold levels but fall short of the TCT1 threshold values. The fraction of the determined value when compared to the TCT1 level is provided in Table 4. The data indicates that all the elements except Ba fall below 10 % of the TCT1 levels. The remainder of the elements fall below the TCT0 threshold levels.

Table 4 Aqua regia digestion metals, metalloid and inorganic anion determination results

Element	**mg/kg**	**TCT0**	**TCT1**	**TCT2**	**Fraction of TCT1**
As, Arsenic	47	5.8	500	2000	0.09
B, Boron	<10	150	15000	60000	
Ba, Barium	64	62.5	260	25000	0.25
Cd, Cadmium	3.2	7.5	260	1040	
Co, Cobalt	45	50	5000	20000	
Cr_{Total}, Chromium Total	28800	46000	800000	N/A	
Cu, Copper	<4.0	16	19500	78000	
Hg, Mercury	5.6	0.93	160	640	0.04
Mn, Manganese	1236	1000	25000	100000	0.05
Mo, Molybdenum	<10	40	1000	4000	
Ni, Nickel	656	91	10600	42400	0.06
Pb, Lead	8.8	20	1900	7500	
Sb, Antimony	9.6	10	75	300	
Se, Selenium	<4.0	10	50	200	
V, Vanadium	244	150	2680	10720	0.09
Zn, Zinc	102	240	160000	640000	
Inorganic Anions	**mg/kg**				
Cr(VI), Chromium (VI) Total [s]	28.3	6.5	500	2000	0.06
Total Fluoride [s]	114	100	10500	42000	0.01

4.2 WATER LEACH RESULTS

The water leach results are presented in **Table 5**. In the case of the water leach the total Cr levels exceed the LCT0 values but fall significantly short of the LCT1 values (fraction of 0.03). It is highly significant that the CrVI levels, as do the levels for most of the other elements, fall below the detection limits of the ICP-MS test procedure. These are all below the LCT0 threshold values.

Table 5 Water leach metals, metalloid and inorganic anion determination results

Element	mg/ℓ	LCT0	LCT1	LCT2	LCT3	Fraction of LCT1
As, Arsenic	<0.01	0.01	0.5	1	4	
B, Boron	<0.025	0.5	25	50	200	
Ba, Barium	<0.025	0.7	35	70	280	
Cd, Cadmium	<0.003	0.003	0.15	0.3	1.2	
Co, Cobalt	<0.025	0.5	25	50	200	
Cr_{Total}, Chromium Total	0.141	0.1	5	10	40	0.03
Cr(VI), Chromium (VI)	<0.01	0.05	2.5	5	20	
Cu, Copper	<0.025	2	100	200	800	
Hg, Mercury	0.001	0.006	0.3	0.6	2.4	
Mn, Manganese	0.034	0.5	25	50	200	
Mo, Molybdenum	<0.025	0.07	3.5	7	28	
Ni, Nickel	<0.025	0.07	3.5	7	28	
Pb, Lead	<0.01	0.01	0.5	1	4	
Sb, Antimony	<0.01	0.02	1	2	8	
Se, Selenium	<0.01	0.01	0.5	1	4	
V, Vanadium	<0.025	0.02	10	20	80	
Zn, Zinc	<0.025	5	250	500	2000	
Inorganic Anions	**mg/ℓ**					
Total Dissolved Solids at 180°C	220					
Chloride as Cl	<2	300	15000	30000	120000	
Sulphate as SO4	<2	250	12500	25000	100000	
Nitrate as N	<0.1	11	550	1100	4400	
Fluoride as F	<0.2	1.5	75	150	600	
pH	9.3					

4.3 WASTE CLASSIFICATION

All the elements that exceed the TCT0 threshold values (**Table 4**) fall below the LCT0 threshold values (**Table 5**). However, the total Cr levels, even though slightly exceeding the LCT0 threshold values, fall below the TCT0 levels. The water leach result is therefore considered to be an artefact of the lack of drying between the final tailings treatment and analysis. From several investigations conducted over the past 15 years on Cr stability in soil (unpublished data) it is evident that extractable (soluble) Cr levels decrease drastically once a soil/waste sample had undergone drying. From the above results it is stated with confidence that the tailings material fit the profile of a **Type 4 Waste**. This conclusion has implications for the beneficial use of the waste material. Should the waste material be used in the making of a range of concrete or cement products to extend the use of naturally mined sands any remaining risk will be much diminished. This is especially so due to the isolation of the material from water and atmospheric exposure through occlusion in the cement / concrete product.

5. CONCLUSIONS – BENEFICIAL USE CONSIDERATIONS

The EESTech post process tailings classification results indicate that the material is classified for all intents and purposes as a Type 4 Inert Waste material. This is the result of what is evident to be very efficient tailings stabilisation processes employed by EESTech. As such the temporary storage of the tailings in open ground should pose a very low risk, especially if storage is conducted in bunded areas with water runoff controls. As a stable clean fine sand product with a consistent particle size, the tailings would be a preferred product for use in geopolymer, Shot-Crete, cement, mortar, plastering, concrete based and brick-making products. Other applications where exposure to atmospheric conditions is limited can also be considered.

The use of the tailing as a sand replacement has numerous spin-off benefits. Sand materials that are suited for use as building and plaster sand are mined from wetlands and seepage zones within the South African land scape. The sand mining impacts are widely occurring in areas characterised by quartz dominated geology and as such coincide with extensive seepage wetland areas. The bleaching and low Fe content characteristics of these soils are directly attributed to the redox conditions that occur in the wetland areas. The extensive negative impacts of sand mining on wetlands leads to the conclusion that every ton of tailings that can be used to replace naturally occurring sandy soils for construction purposes will significantly decrease pressures on wetlands. The extensive use of the large volumes of tailings will have a significant impact in reducing the need for naturally occurring and mined sands of similar particle size and application.

An additional benefit of using the tailings is that it is a product with a very narrow range of properties and is consistent in its composition (size fraction, chemical properties, etc.). The consistency of the tailings is a distinct benefit in the sand supply industry as natural soils have variable clay and organic matter contents that may compromise sand quality.

Agricultural use of the tailings is possible and will depend on factors such as the pH neutralising and buffer capacity as well as labile Si fraction. These applications will have to be investigated in further detail within the specific regulatory framework as well as taking into account the long-term stability of the tailings and loading rates of specific elements within the context of the specific agricultural use parameters.

It is therefore recommended that the beneficial use of the tailings be explored in detail in order to maximise the spin-off benefits.