

MEMORANDUM

Attention:	Piers Goodman	From:	Thomas Robson
Company:	Venturex Resources Limited	Date:	28 January 2020
Subject:	ERD: Tailings Geochemistry	Project:	Sulphur Springs ERD

1. INTRODUCTION

This memorandum has been prepared to address specific queries arising from an Environmental Scoping Document (ESD) prepared by the West Australian Environmental Protection Authority (EPA) to address impact assessment requirements for the Sulphur Springs Zinc-Copper Project (Sulphur Springs), owned by Venturex Resources Limited (Venturex). The project, which consists of a small open pit, subsequent underground mine, sulfide concentrator and valley-fill tailings storage facility (TSF), was referred to the EPA by the proponent on 14 December 2016. On 13 July 2017, the level of assessment was set as Environmental Review - no public review and the ESD was released as final by the EPA on 2 October 2017.

This document addresses the following ESD items, specifically concerning Sulphur Springs tailings:

- ESD Item 30 - Conduct chemical and physical characterisation of the waste materials, including characterisation of tailings pore water.
- ESD Item 33 - For each tailings stream, identify geochemical properties.
- ESD Item 39 - Determine and document if the TSF is likely to be listed as a contaminated site under the *Contaminated Sites Act 2003 (WA)*.
- ESD Item 50 - Characterise wastes, including intermediate processing wastes, effluents and tailings according to contaminant and leachable concentrations including base metals present in the deposits to allow for waste processing and tailings seepage issues to be addressed. Leach test studies should include the use of onsite water and the characterisation of the leaching potential.

Venturex submitted a draft Environmental Review Document (ERD) for review by the EPA and other government agencies in June 2018. This document was revised to address comments received from EPA Services and resubmitted (as Revision 1) in November 2018. Review of the ERD by the EPA identified several aspects of the proposed project requiring further information to assess specific project risks, including hydrological and geochemical risks arising from acid and metalliferous drainage (AMD) reporting to the receiving environment. Venturex subsequently requested an independent review of these project risks by Preston Consulting, supported by a review of geochemical aspects by Grant Douglas, Senior Principal Research Scientist, CSIRO Land and Water (CSIRO 2019).

This memorandum provides an update to an earlier report, dated 11 June 2019, prepared for Venturex that was included as an Appendix to the Revision 5 ERD, summarising tailings geochemistry. This updated report specifically addresses:

- Predicted tailings seepage quality to be used as source terms for contaminant dispersion modelling, undertaken by AECOM Pty Ltd (AECOM 2020), in the Sulphur Springs Creek catchment downgradient from the proposed TSF.

- A comparison of hydrated lime ($\text{Ca}(\text{OH})_2$) and calcined caustic magnesia (MgO , CCM) for neutralising acidity and attenuating contaminants in tailings and sulfidic waste rock seepage. The CSIRO report (CSIRO 2019) strongly advocated use of CCM.

2. PREVIOUS TAILINGS STUDIES

Previous studies concerning geochemical assessment of tailings for the Sulphur Springs project are detailed in Table 1. Data and findings of GCA (2002), URS (2007a) and Knight Piésold (KP 2018) were incorporated into this report as these assessed tailings best reflecting those of the operation currently proposed by Venturex.

Table 1: Previous Tailings Characterisation Studies for Sulphur Springs Project

Author	Year	Study	Tailings Sample Details	Testwork
Roger Townsend and Associates	2002	Mineralogical Examination of one Tailings Sample. (Panorama Deposit).	Tailings produced using conventional sulfide flotation, producing copper concentrate, zinc concentrate and final tailings slurry. Tailings sample considered analogous to material proposed by Venturex.	Static (acid-base testwork) and multi-element analysis on solids and supernatant.
Graeme Campbell and Associates (GCA)	2002	Geochemical Assessment of Panorama Tailings.		
URS	2007a	Geochemical Assessment of Waste Rock and Tailings Materials.	A bulk tailings sample generated from Sulphur Springs ore. Conventional sulfide flotation producing copper concentrate, zinc concentrate and final tailings slurry. Tailings sample considered analogous to material proposed by Venturex.	Static (acid-base testwork) and multi-element analysis on solids and supernatant. Kinetic testwork (saturated and unsaturated conditions) for 159 days of leaching.
RGS	2009	Geochemical Assessment of Tailing: Letter Report. Depyritised Tailing Samples GS3412 and GS3696.	Two samples of 'depyritised' tailings generated from metallurgical testwork. These samples are not considered to be representative of tailings likely to be generated from currently proposed operation.	Static multi-element analysis on solids and supernatant. Kinetic –unsaturated conditions.
Knight Piésold Consulting (KP)	2018	Tailings Management Definitive Feasibility Study	Two samples of composite copper and zinc tailings included for assessment of geotechnical and geochemical properties.	Static (acid-base testwork) and multi-element analysis on solids and supernatant.

3. SUMMARY OF GEOCHEMICAL CHARACTERISATION OF TAILINGS

Based on the previous studies outlined in Section 2, the studies conducted by GCA (2002), URS (2007a) and KP (2018) are considered applicable to current assessments. These tailings were produced from metallurgical investigations by conventional sulfide flotation and are considered representative of the fresh process-tailings likely to be produced at Sulphur Springs. Both samples were subjected to static acid-base accounting (ABA) testwork to determine their likely acid-formation risk, and the later sample (URS 2007a) was also subjected to kinetic leaching tests to evaluate sulfide-oxidation reaction rates and to predict leachate chemistry under saturated and saturated conditions.

3.1 ACID FORMING WASTE CLASSIFICATION METHODOLOGY

A combined acid generation classification scheme based on Net Acid Producing Potential (NAPP) and Net Acid Generation pH (NAG pH) determinations is presented in Table 2 and is applied by MBS Environmental (MBS) in assessment of mine waste. A glossary of technical terms is provided in Section 8.

Table 2: Waste Classification Criteria

Primary Geochemical Waste Type Class	NAPP Value kg H ₂ SO ₄ /t	NAG pH	Sulfide S Content
Potentially Acid Forming –High Capacity (PAF-HC)	≥10	< 4.5	≥ 0.3%
Potentially Acid Forming – Low Capacity (PAF-LC)	0 to 10	< 4.5	0.16 to 0.3%
Uncertain (UC)	0 to 5	> 4.5	Not important
Uncertain (UC)	-10 to 0	< 4.5	Not important
Non Acid Forming (NAF)	-100 to 0	> 4.5	Not important
NAF and Acid Consuming (AC)	< -100	>4.5	Not important

Table 2 is based on the Australian Government's Guidelines on Managing Acidic and Metalliferous Drainage (DIIS 2016) and is in turn based on an earlier classification system included within the AMIRA ARD Test Handbook (AMIRA 2002), which is advocated by the Global Acid Rock Drainage Guidelines (GARD) published by the International Network for Acid Prevention (INAP 2009). This classification system, based on static acid base accounting procedures and used in conjunction with geological, geochemical and mineralogical analysis can still leave materials classified as 'uncertain' where there is conflicting NAG pH and NAPP results. Uncertain materials demonstrating a NAG pH above 4.5 may be tentatively assigned as potentially NAF and those below pH 4.5 as potentially PAF. In such cases further assessment, such as the use of kinetic leaching columns, may be required to provide a definitive classification.

3.2 ACID-BASE ACCOUNTING

The static acid-base accounting characterisation data for tailings samples generated from three previous studies are summarised in Table 3.

Table 3: Static Acid Base Accounting Data for Tailings Samples

Source	pH	Total-S	SO ₄ -S	TOS	MPA	ANC	NAPP	NAG	NAG pH	Class
		%			kg H ₂ SO ₄ /t					
GCA (2002)	7.20	27.8	0.3	27.5	841	4.5	837	400	2.5	PAF-HC
URS (2007a)	6.30	25.8	0.16	25.6	785	7	778	378	1.9	PAF-HC
KP (2018)	4.9	30.5	0.63	29.9	915	8	907	511	2.0	PAF-HC
	3.8	27.9	0.49	27.4	838	10	828	354	2.1	PAF-HC

In terms of acid-formation risk, the four previous sulfide flotation tailings samples assessed were consistent. All samples contained high total-S concentrations (26-30%), the vast majority of which (98%) was present as unoxidised sulfides. Previous mineralogy work (Roger Townend and Associates 2002) indicates the dominant sulfide mineral is pyrite plus the orebody mineralised sulfides (chalcopyrite, sphalerite and galena). All samples yielded high Maximum Potential Acidity (MPA) (785-915 kg H₂SO₄/t) values, low Acid Neutralising Capacity (ANC) (4.5-10 kg H₂SO₄/t) and low NAG pH (1.9-2.5), resulting in their classification as PAF-HC.

3.3 ELEMENTAL ENRICHMENT

Environmentally significant metals and metalloids were measured (Graeme Campbell and Associates 2002), following digestion of a finely ground sample with a mixture of four acids (hydrochloric, nitric, perchloric and hydrofluoric acids) which is a near-total determination for the elements measured. From this data, the global abundance index (GAI) for each element was calculated by comparison to a reference value, in this case the average earth crustal abundance (Bowen 1979, AIMM 2001 and Smith and Huyck 1999). The main purpose of the GAI is to provide an indication of any elemental enrichment that could be of environmental significance. The GAI (based on a log-2 scale) is expressed in integer increments from zero to six (INAP 2009). A GAI of zero indicates that the content of the element is less than or up to three times the average crustal abundance; a GAI of one corresponds to a three to six fold enrichment; a GAI of two corresponds to a six to 12 fold enrichment and so forth, up to a GAI of six which corresponds to a 96-fold, or greater, enrichment above average crustal abundances. A GAI of more than three is considered significant and may warrant further investigation.

Examination of results from URS (2007a) indicates that sample (A10634) was digested using a milder digestion for total environmentally available metals which are considered capable of release under extreme acid conditions, but where the silicate minerals themselves are not destroyed. These differences (slightly lower results for otherwise similar samples) can be seen in Table 4. On the basis of total four acid digestion results (GCA 2002), tailings samples were enriched in silver, arsenic, bismuth, cadmium, chromium, copper, mercury, molybdenum, nickel, lead, antimony, selenium, thallium and zinc. Elemental enrichment profiles based on results in KP (2018) were generally consistent with those of GCA (2002).

Table 4: Elemental Composition and GAI Values for Tailings Samples

Element	GCA 2002		URS 2007a		KP 2018		GAI Reference Value (mg/kg)
	Concentration (mg/kg)	GAI	Concentration (mg/kg)	GAI	Concentration (mg/kg)	GAI	
Ag	12	6	N.D.		2.9 – 20.4	4 - 6	0.070
Al	15,000	0	3,000	0	9,800 – 37,000	0	82,000
As	636	4	467	4	519 - 1301	6	25
B	N.D.		N.D.		50	1	10
Ba	973	1	N.D.		165 - 221	0	425
Be	N.D.		N.D.		0.2 – 0.4	0	2.6
Bi	69	6	N.D.		20.6 - 128	6	0.17
Cd	7.2	5	4.0	4	2 - 155	3 - 6	0.20
Co	65	1	42	0	62 - 113	1	25
Cr	1,025	3	N.D.		710 – 1,305	2 - 3	100
Cu	1,122	4	594	3	1,213 – 3,048	4 - 5	55
F	N.D.		N.D.		93 - 319	0	950
Fe	273,400		160,000		255,600 – 259,800	2	31,000 - 65,000
Hg	1.9	4	4.4	5	1.6 – 22.2	4 - 6	0.080
Mn	441	0	408	0	224 - 489	0	950
Mo	136	6	N.D. ¹		83 - 10	5	1.5
Ni	763	3	425	2	569 – 1,085	2 - 3	75
P	69	0	N.D.	0	51 - 217	0	1,000
Pb	1,749	6	1,140	6	214 – 2,527	3 - 6	12.5
Sb	41	6	N.D.		16 - 77	5 - 6	0.20
Se	116	6	110	6	36 - 225	6	0.20
Sn	N.D.		N.D.		4.7 – 10.7	0 - 1	2.2
Sr	13	0	N.D.		6 - 7	0	500
Th	1.3	0	N.D.		0.8 – 4.2	0	10
Tl	20	5	N.D.		N.D.		0.45
U	0.88	0	N.D.		0.4 – 1.6	0	2.7
V	13	0	N.D.		5 - 10	0	135
Zn	3,101	5	1,550		513 – 50,000	2 - 6	70

¹ N.D. Not determined.

3.4 KINETIC TESTING

Previous tailings characterisation work URS (2007a) conducted kinetic leach column testing to assess the possible oxidation kinetics and leachate chemistry of the material, both under unsaturated (exposed) and saturated (flooded) conditions. On the basis that the tailings will be maintained at or near to saturation during operations and closure, the results of the kinetic testing under unsaturated conditions likely apply only to exposed surficial tailings beaches, whereas the kinetic results under saturated conditions provide more relevant information on likely seepage characteristics (i.e. from saturated tailings deeper in the TSF). The main objective of kinetic tests is to inform management strategies by supporting estimates of acid-generating and acid-neutralising reactions under controlled conditions, and also concentrations of potentially environmentally significant elements in leachate that may impact groundwater quality if seepage is not managed appropriately.

3.4.1 Unsaturated (Oxidising) Conditions

The unsaturated kinetic test method used by URS was adapted from the AMIRA Free Draining Leach Column Test (AMIRA 2002) and data were presented for a 159 day leaching period. The study was conducted on a 3 kg sample of tailings, which was placed in a reaction column and leached with 400 mL/kg of deionised water (added on a weekly basis) for the first 6 weeks (9 Feb – 16 March 2007). After week 6, further leaches were conducted one month later (Leach 7, 18 April) and four months later (leach 8, 18 July). This provided a total of eight leaching events (Table 5). The column was placed under heat lamps to allow the sample to dry between deionised water additions and to ensure adequate oxygen ingress into the sample, maintaining the sample surface temperature at about 30°C throughout the experiment. Leachates were collected and analysed for pH and electrical conductivity EC (conducted in-house), and acidity, alkalinity, soluble metals and sulfate (NATA-accredited analyses by ALS Environmental Division, Brisbane). MBS notes that due to the apparent lack of applied water between collection events and drying conditions between leaches 7 and 8, the degree of oxidation in this time may have been limited by dry conditions and not proportional to exposure time, as per previous leaches.

Table 5: Kinetic Leach Testing Parameters From URS (2007a), Unsaturated Conditions

Date	9 Feb	16 Feb	23 Feb	2 Mar	9 Mar	16 Mar	18 Apr	18 Jul
Leach number	1	2	3	4	5	6	7	8
Volume collected (L)	0.70	0.246	0.300	0.283	0.400	0.360	0.270	0.275
Cum. Volume (L)	0.70	0.946	1.246	1.529	1.929	2.289	2.559	2.834
Pore volumes	0.5	0.7	0.9	1.1	1.4	1.7	1.9	2.1
pH	5.9	2.80	2.76	2.36	2.4	2.3	2.40	2.44
EC ($\mu\text{S}/\text{cm}$)	420	40,750	14,500	18,000	12,900	12,400	12,400	21,800
Acidity (mg CaCO_3/L)	10	N.D.	8,110	18,000	12,200	12,700	16,400	33,500
Alkalinity (mg CaCO_3/L)	8	N.D.	<1	<1	<1	<1	<1	<1
Sulfate (mg/L)	146	35,900	13,300	23,500	17,400	17,400	29,600	34,400
SO_4 Release (kg $\text{H}_2\text{SO}_4/\text{t}$ per flush)	0.03	3.01	1.36	2.26	2.37	2.13	2.72	3.22
Cumulative SO_4 Release (kg $\text{H}_2\text{SO}_4/\text{t}$)	0.03	3.04	4.40	6.66	9.03	11.2	13.9	17.1
Residual ANC (%)	99.6	78	67	59	50	47	42	34

The initial (leach one, week 0) leachate was circum-neutral (pH 5.9); consistent with pH values from the static acid-base accounting leaching tests (Table 3). From the second leach (week 1) onwards, solution pH was consistently below pH 2.8 (2.3 - 2.8) and EC values were 12,400 – 40,750 $\mu\text{S}/\text{cm}$. These basic parameters, together with high dissolved sulfate concentrations (13,000 - 36,000 mg/L from the second leach), are indicative of sulfide-oxidation reactions and suggest that unsaturated tailings are likely to become acidic within a short period (order of weeks)

after exposure to air. This finding is consistent with the low ANC (4.5 - 7.0 kg H₂SO₄/t), acidic NAG pH (1.9 - 2.5) and PAF-HC classifications assigned to the tailings (Table 3).

The proportion (% mass) of each element leached from the tailings sample over the 159 day period was calculated, based on the cumulative mass of each element extracted (leachate volume multiplied by leachate concentration) and the total concentrations of each element in the tailings (Table 6). As mentioned previously, the digestion method applied to the sample from URS (2007a) is likely to underrepresent the true total concentrations and yield inflated values for the proportion leached. Consequently, leached proportions were calculated based on compositional data from both the previous studies, with results based on GCA (2002) being more conservative. It is important to note that in calculating leached proportion values based on compositional data from GCA (2002), it was assumed that the two tailings samples were comparable. This is considered reasonable, based on their consistent ABA characterisation data (Table 3).

The results demonstrate that in particular cadmium, copper, zinc and manganese rapidly became mobile under the leaching conditions, with a total of at least 32, 27, 38 and 34% of the total tailings content leached for these elements, respectively. The leachate analysis indicates that many elements of potential environmental concern (chromium, mercury, lead - Table 4) were particularly immobile, yielding <0.1% of the total tailings content over the leaching period. Nickel, antimony, arsenic and selenium were released in the order of 0.5 - 5% over the leaching period.

Table 6: Cumulative Leaching of Tailings During Kinetic Leaching

Element	Total Concentrations in Tailings (mg/kg)		Cumulative Mass Leached (mg)	Total Mass Leached (%)	
	URS	GCA		URS	GCA
Al	3,000	15,000	709	7.9	1.6
As	467	636	14	1.0	0.8
Ca		2,040	987		16
Cd	4.0	7.2	6.8	57	32
Co	42	65	8.6	6.8	4.4
Cr		1,025	0.11		<0.01
Cu	594	1,122	910	51	27
Fe	160,000	273,400	11,693	2.4	1.4
Hg	4.4	1.9	0.0006	<0.01	<0.01
K		5,826	5.3		<0.01
Mg		4,001	2,788		23
Mn	408	441	445	36	34
Na		187	66		12
Ni	425	763	63	5.0	2.8
Pb	1,140	1,749	2.3	<0.1	<0.1
SO ₄	772,914	832,830	50,250	2.2	2.0
Se	110	116	2.7	0.81	0.77
Sb		41	0.72		0.59
Zn	1,550	3,101	3,571	77	38

Leachate concentrations from the fourth leaching event (2 March) were selected for comparison with applicable guideline values for groundwater, since these represent the leachates with the highest (i.e. worst case) concentrations of cadmium, copper and zinc. Concentrations from the eighth event (18 July) were also selected as these represent the final leaching event for which data were collected (Table 7). Based on the volume of leachate collected and the tailings sample mass, the kinetic column leachates represent a solid/solution ratio of 1:10, which is broadly indicative of seepage, but is unlikely to reflect the tailings pore-water geochemistry, which would typically be presented by a solid/solution ratio of 1:2. Leachate mercury and chromium concentrations were low, suggesting that these elements were present in the tailings in forms that were geochemically stable under the leaching conditions and represent a low contamination risk under similar environmental conditions. Cadmium, copper, zinc, selenium and arsenic in particular represent metals which may pose a risk to the environment if uncontrolled seepage from exposed tailings were to occur.

Table 7: Leachate Concentrations vs Water Quality Guideline Values (mg/L)

Element	Leachate Concentration		Guideline Value ²
	2 Mar	18 Jul	
Al	342	854	5
As	8.7	39	0.5
Ca	428	423	1,000
Cd	5.1	1.4	0.01
Cl	136	<1	250
Co	3.5	4.1	1
Cr	0.02	0.02	1
Cu	847	124	1
Fe	7,090	10,800	N/A
Hg	0.0007	0.0002	0.002
K	1	<1	N/A
Mg	1,280	1,100	N/A
Mn	285	51	5
Na	3	4	N/A
Ni	30	15	1
Pb	2.4	0.1	0.1
SO ₄	23,500	34,400	1,000
Se	1.2	1.9	0.02
Sb	0.83	0.21	0.03
Zn	3,600	611	20

3.4.2 Saturated (Reducing) Conditions

The saturated kinetic test method used by URS was adapted from the AMIRA Free Draining Leach Column Test (AMIRA 2002) but involved maintenance of the tailings sample under relatively saturated conditions throughout the test period. The study was conducted on a 1.18 kg sample of tailings, which was placed in a reaction column and leached with approximately 0.75 L of deionised water (added on a weekly basis) for the first 6 weeks (9 Mar –

² ANZECC (2000): Livestock Drinking Water; NEPC (1999): Investigation levels for livestock; DER (2014) Non-potable groundwater use.

13 April 2007). After Week 6, further leaches were conducted one month later (Leach 7, 23 May) and two months later (Leach 8, 18 July). This provided a total of eight leaching events (Table 8).

Table 8: Kinetic Leach Testing Parameters From URS (2007a), Saturated Conditions

Date	9 Mar	16 Mar	23 Mar	30 Mar	6 Apr	13 Apr	23 May	18 Jul
Leach number	1	2	3	4	5	6	7	8
Volume collected (L)	0.75	0.765	0.79	0.78	0.76	0.76	0.745	0.75
Cum. Volume (L)	0.75	1.515	2.305	3.085	3.845	4.605	5.35	6.10
Pore volumes	0.6	1.1	1.7	2.3	2.8	3.4	3.9	4.4
pH	3.99	4.06	4.16	4.06	4.26	5.10	4.39	3.30
EC ($\mu\text{S}/\text{cm}$)	3,600	1,220	1,842	1,310	1,860	1,870	2,300	1,170
Acidity (mg CaCO_3/L)	591	160	142	87	151	141	318	399
Alkalinity (mg CaCO_3/L)	<1	<1	<1	<1	<1	<1	<1	<1
Copper (mg/L)	15.6	0.6	0.2	0.2	0.2	0.1	1.4	20.8
Iron (mg/L)	20	10	7	6	12	24	43	61
Nickel (mg/L)	10	2	3	2	2	1.8	3.3	1.8
Zinc (mg/L)	290	47	48	34	50	41	106	82
Sulfate (mg/L)	3,260	685	1,040	824	1,150	1,360	1,530	489
SO ₄ Release (kg H ₂ SO ₄ /t per flush)	2.12	0.45	0.71	0.56	0.76	0.89	0.99	0.32
Cumulative SO ₄ Release (kg H ₂ SO ₄ /t)	2.12	2.57	3.28	3.84	4.59	5.49	6.47	6.79
Residual ANC (%)	77.2	71.3	62.0	54.9	45.2	33.3	33.6	30.0

Comparison of results presented in Table 8 for saturated conditions with those in Table 5 for unsaturated conditions indicates:

- Less acidic leachate under saturated conditions (pH generally greater than 4 and titratable acidity up to 600 mg/L, compared with typical pH 2.3 to 2.8 and acidity up to 34,000 mg/L under unsaturated conditions).
- Slightly brackish seepage produced under saturated conditions (EC typically less than 2,000 $\mu\text{S}/\text{cm}$ following the "first flush" leachate).
- The concentration of soluble sulfate in column leachate is higher for the unsaturated tailings column (ranges from about 13,000 to 36,000 mg/L) compared to the saturated tailings column (ranges from about 700 to 3,300 mg/L). Comparing cumulative sulfate release for the saturated tailings (6.79 kg H₂SO₄/t) and unsaturated tailings (17.1 kg H₂SO₄/t), the testing demonstrate that sulfide oxidation is occurring in both tailings columns, but at a relatively faster rate (by a factor of more than three) in the unsaturated tailings column.
- The concentration of soluble metals in leachate from the tailings samples is initially low, but increases relatively quickly after exposure to oxidising conditions. Soluble metal concentrations in tailings leachate from the saturated concentrations are generally much lower, but more variable (increasing with decreasing leachate pH values) in comparison to those obtained under unsaturated conditions.

4. SEEPAGE QUALITY SOURCE TERMS FOR CONTAMINANT DISPERSION MODELLING

Tailings seepage source terms were characterised by MBS to inform contaminant dispersion modelling (conducted by AECOM) in the Sulphur Springs Creek catchment. The aim of this modelling was to provide one of the source terms for prediction of water quality within the pit lake, located downgradient from the main TSF embankment.

Composition of the tailings seepage source terms considered the following:

- Fresh (unoxidised) tailings porewater, as indicated by analysis of fresh tailings slurry supernatant solution. Fresh tailings supernatant water quality data comprised:
 - One sample assessed in 2002 (GCA 2002)
 - One sample assessed in 2007 (A10634 supernatant, URS 2007a).
 - Two samples assessed in 2018 (Knight Piesold Consulting 2018)
- Leachates from kinetic column leach tests under unsaturated conditions, Section 3.4.1.
- Leachates from kinetic column leach tests under saturated conditions, Section 3.4.2.
- Results from metallurgical tailings samples (supernatant and kinetic leachate columns), TSF decant water quality and TSF groundwater monitoring bores established at the Savannah Nickel Mine (URS 2009). Despite the TSF at Savannah being an unlined valley fill style containing reactive, sulfidic nickel tailings (as indicated by kinetic column tests), monitoring during operations has shown that leachate impacted groundwater contained elevated sulphate concentrations (2,000 to 3,000 mg/L), but only slightly elevated concentrations of metals (mainly nickel) and metalloids (selenium). Seepage pH values also indicated circum-neutral to moderately alkaline conditions. Knowledge gained from comparison of predicted versus actual tailings behaviour over time, from an operation with similar tailings geochemistry, provides confidence in the assumptions included in development of the source terms outlined in this document.

Two sets of tailings seepage source terms were provided for contaminant dispersion modelling:

- An 'expected case', based on tailings supernatant fluid composition. Although some oxidation of exposed tailings beaches may result in surface tailings porewater composition, similar to that predicted by unsaturated kinetic column tests (Section 3.4.1), most of the soluble oxidation productions will return to the decant pond following high rainfall events, from where acidic constituents will be neutralised by alkali addition when the decant return water is recycled through the process plant.
- A 'worst case', based on evapo-concentration of tailings supernatant until calcium sulphate (as either gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) or basanite ($\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$)) saturation occurs, as indicated by geochemical speciation modelling using PHREEQC (USGS 2019). Further oxidation of surficial tailings from this point will result in precipitation of calcium sulfate with minimal increases in seepage salinity.

Nominal 'expected case' and 'worst case' source term tailings seepage composition values are presented in Table 9, along with tailings supernatant composition from metallurgical trials (GCA 2002, URS 2007a and KP 2018) and kinetic column leach tests under saturated conditions (mean values for Leach 1 to Leach 8, URS 2007a).

Table 9: Tailings Seepage Source Terms and Input Values

Constituent	Units	Tailings Supernatant				Kinetic Column (Saturated)	Predicted Tailings Seepage	
		GCA 2002	URS 2007a	KP 2018			Expected Case	Worst Case
				Bulk #1	Bulk #2			
pH	pH units	7.2	7.48	7.1	6.7	4.17	7.34	7.34
TDS	mg/L	1,800	N.D	2,106	1,944	1,138	1,800	6,100
Bicarbonate	mg HCO ₃ /L	50	N.D	N.D	N.D	1.0	50	50
Aluminium	mg/L	<0.01	<0.01	0.01	0.1	1.4	<0.01	<0.05
Arsenic	mg/L	0.0087	<0.001	0.004	0.005	0.002	0.005	0.022
Calcium	mg/L	220	233	60	215	164	227	650
Cadmium	mg/L	0.0029	0.0062	0.002	0.037	0.153	0.005	0.02
Chloride	mg/L	150	129	325	244	13	140	620
Cobalt	mg/L	0.0072	0.017	0.003	0.042	0.26	0.012	0.05
Chromium	mg/L	<0.01	<1	0.01	0.01	0.01	<0.01	<0.05
Copper	mg/L	0.02	0.02	0.01	0.08	4.9	0.02	0.09
Iron	mg/L	<0.01	0.68	0.01	0.02	23	0.34	1.51
Mercury	mg/L	0.0006	<0.0001	0.0001	0.0001	0.0001	0.0003	0.001
Potassium	mg/L	16	15	N.D	N.D	3.0	16	69
Magnesium	mg/L	32	42	19	29	175	37	460
Manganese	mg/L	5.7	7.2	4.5	4.2	32	6.5	29
Sodium	mg/L	170	194	569	338	8.0	182	810
Nickel	mg/L	0.19	0.243	0.08	0.4	3.2	0.22	0.96
Lead	mg/L	0.026	0.01	0.085	0.02	1.6	0.02	0.08
Antimony	mg/L	N.D	0.006	0.019	0.008	0.003	0.006	0.027
Selenium	mg/L	0.09	0.32	0.1	0.24	0.08	0.2	0.91
Sulfate	mg/L	620	943	1,264	1,156	1,292	782	3,470
Zinc	mg/L	1.6	0.5	2.3	0.7	87	1.1	4.7

N.D – Not determined or not reported.

Although single source term concentrations were provided for both 'expected case' and 'worst case' tailings seepage quality, tailings seepage composition is expected to change over time. As discussed above, the source terms provided relate to seepage from largely 'fresh' tailings that have been largely predicted from significant oxidation during operations and covered by a low permeability engineered cover at mine closure to maintain low (but not zero) potential for ingress of oxygen. Tailings oxidation is expected to occur over time following mine closure, albeit at a slow reaction rate and under low redox conditions, as indicated by increased concentrations of soluble iron in the saturated kinetic column test (Table 8). Geochemical speciation modelling using PHREEQC (USGS 2019) indicated dissolved iron to be present as the reduced (ferrous form), which in turn produces very low (anoxic) redox (pE below 3) conditions. Under these redox conditions, selenium was predicted to be mainly present as insoluble metal selenide minerals and elemental selenium, rather than soluble selenite and selenate anions. This prediction is consistent with very low selenium concentrations (0.01 to 0.03 mg/L, Table 10) recorded in leachates from the saturated kinetic column test (URS 2007a) from Month 2 onwards. Based on these results and predictions, slightly elevated selenium concentrations (0.2 to 0.91 mg/L) are predicted to occur in the "first flush" tailings seepage as a result of soluble selenium produced by oxidation of selenium minerals in the flotation process. In the longer term (several years after mine closure), selenium concentrations are expected to stabilise at substantially lower (<0.1 mg/L) concentrations that those provided as source terms for hydrological modelling by AECOM.

Table 10: Selenium Concentrations in Tailings Leachates Under Saturated Kinetic Leach Column Conditions (URS 2007a)

Leach Number	1	2	3	4	5	6	7	8
Selenium (mg/L)	0.48	0.02	0.02	0.01	0.02	0.02	0.03	0.02

5. ENVIRONMENTAL SCOPING DOCUMENT QUERIES

This document addresses the following ESD items, specifically concerning tailings:

- ESD Item 30 - Conduct chemical and physical characterisation of the waste materials, including characterisation of tailings pore water.
- ESD Item 33 - For each tailings stream, identify geochemical properties.
- ESD Item 39 - Determine and document if the TSF is likely to be listed as a contaminated site under the *Contaminated Sites Act 2003 (WA)*.
- ESD Item 50 - Characterise wastes, including intermediate processing wastes, effluents and tailings according to contaminant and leachable concentrations including base metals present in the deposits to allow for waste processing and tailings seepage issues to be addressed. Leach test studies should include the use of onsite water and the characterisation of the leaching potential.

The following subsection summarises the available information with respect to each query.

5.1 GEOCHEMICAL CHARACTERISATION OF WASTE MATERIALS

The geochemical characterisation data summarised in this report largely addresses the requirements of ESD items 30, 33 and 50 in relation to tailings. Waste rock characterisation is addressed in a separate waste rock characterisation conducted by MBS Environmental in 2018. Key geochemical findings for Sulphur Springs tailings are as follows:

- The tailings (produced as a single stream), can be classified as PAF-HC and kinetic leaching tests demonstrated that acidic drainage (pH typically less than three) conditions developed rapidly (order of weeks) under unsaturated conditions (ESD Items 30, 33 and 50). Kinetic testing predicted mildly acidic (pH typically between four and five) drainage under saturated storage conditions.
- Elemental compositional data showed that the tailings were substantially enriched in various elements of potential environmental concern, namely arsenic, bismuth, cadmium, chromium, copper, mercury, molybdenum, nickel, lead, antimony, selenium and zinc (ESD Items 30, 33 and 50).
- Kinetic leaching test data demonstrated that several elements (especially cadmium, copper and zinc) were readily leached from the tailings under unsaturated, acidic storage conditions (pH 2.3 – 2.8) and that leachates contained concentrations of numerous elements (aluminium, arsenic, cadmium, cobalt, copper, manganese, nickel, lead, selenium, antimony, zinc) and sulfate at levels substantially exceeding groundwater quality guideline levels (ESD Item 50). Under saturated conditions, kinetic leach tests demonstrated comparatively low concentrations of these elements, although still elevated with respect to livestock drinking water quality guidelines levels (ANZECC 2000).
- Kinetic leaching test data indicated that slightly elevated selenium concentrations (similar to those in fresh tailings supernatant) were present in the “first flush” (Month 1) leachate, but decreased substantially (0.01 to 0.03 mg/L) thereafter. This result suggests that the source of soluble selenium in tailings supernatant is produced by oxidation of selenium minerals in the process plant. Under low (anoxic) redox conditions of tailings in a covered TSF, tailings seepage is expected to contain lower selenium concentrations in the post-closure period than those provided as source terms for hydrological modelling by AECOM.
- Kinetic leaching test data demonstrated that mercury, chromium and lead, although enriched in the tailings samples, were not significantly leached following oxidation under saturated conditions.

Some knowledge gaps remain with respect to ESD Items 30 and 50:

- There is currently no data available to directly characterise tailings pore-water geochemistry (ESD Item 30). This is normally assessed at a solid:solution ratio of 1:2 in order to evaluate contaminant solubility. Whilst such analyses have not been performed, it is considered that tailings kinetic leach data under exposed or saturated (depending on final management options) at approximately 1:10 ratio is more representative and informative for field conditions. Static leaching of fresh tailings at different ratios does not reflect the potential for slight-to-moderate oxidation. If tailings are to be kept saturated, then saturated kinetic column leach results available in URS (2007a) are likewise considered more field-representative. As concentrations in a 1:2 porewater extract are often solubility-limited, adjustment of available kinetic leach data down to this ratio as an estimate is considered a conservative approach, should this be required.
- In line with standard practise, the kinetic leaching studies conducted to date used deionised water as opposed to on-site water (ESD Item 50). Use of site-water for static leaches is not common practice due to the issues of:
 - Background concentrations of metals which vary with location taken at site.
 - Interferences or higher limits of laboratory reporting if site water has high salinity.For example, it is noted that copper, which is naturally enriched in site groundwater, can vary in concentration from 0.002 to 3.0 mg/L, based on baseline monitoring (URS 2007b).

5.2 SITE CLASSIFICATION UNDER CONTAMINATED SITES ACT 2003 (WA)

ESD Item 39 states, “Determine and document if the TSF is likely to be listed as a contaminated site under the *Contaminated Sites Act 2003 (WA)*”.

The *Contaminated Site Act 2003 (WA)* defines ‘contaminated’ as, “in relation to land, water or a site, means having a substance present in or on that land, water or site at above background concentrations that presents, or has the potential to present, a risk of harm to human health, the environment or any environmental value.” In brief it should be considered that classification requires a presence above background concentrations and that it has a pathway or potential pathway for release to receptors in order to pose a risk.

In relation to current assessment of the TSF post closure under the *Contaminated Sites Act* the following key points are considered relevant:

- The tailings, although significantly enriched in various metals and metalloids, exist in a naturally mineralised and enriched (surface and subsurface) area. Levels of metals and metalloids are only primarily of significance in the TSF (which have been moved from depth to nearer surface), if they have a potential pathway for release to receptors in the groundwater or soil.
- Therefore, classification of the TSF post closure under the Act as ‘contaminated’ is not expected if:
 - Cover material at the surface meets site specific derived criteria for soils (allowing for ambient background concentrations and in consideration of the post-mining land use) in relation to metal and metalloid concentrations.
 - It can be demonstrated that no upward migration of contamination from the tailings material itself will occur (e.g. into any overlying vegetation) by means of a suitable cover design/capping.
- The other primary means/potential pathway is via seepage to groundwater, which could result in impacts to downgradient groundwater or surface water receptors. If found to be occurring, this would be a trigger for classification under the Act. This risk would be mitigated and controlled by suitable TSF design, intended to restrict the potential for seepage to a level that would not present a risk of harm to human health, the environment or any environmental value. Groundwater monitoring would be a suitable means to establish evidence and management requirements for the TSF, and should be conducted prior to, during and for a suitable period (a few years) post mining.

The TSF location and provisional closure design (Knight Piésold Consulting 2020) is considered to meet the requirements outlined above to avoid migration of contaminants. Seepage is predicted to remain within the pit catchment area, percolating vertically from the tailings mass to mix with local groundwater. This groundwater, mixed with small volumes of seepage will then be intercepted by the cone of depression formed by the final pit lake. Sections of the pit lake catchment will be recontoured to limit inflows to the pit, thus ensuring it remains a terminal hydraulic sink. Additional control measures intended to restrict seepage rates and reduce the potential for tailings oxidation include:

- A partial basin underdrainage system comprising main collector drains along part of the basin spine designed to drain by gravity to a collection sump located at the toe of the main embankment.
- Cycling of tailings deposition to ensure exposed beaches are re-wetted at least every two weeks to assist in maintaining tailings high saturation levels.
- Monitoring bores installed to monitor the phreatic surface within the embankments and groundwater levels/quality downgradient of the embankments. Select bores will be sized such that they can be converted into recovery bores to abstract water if required.
- Covering the final tailings surface with a low permeability capping and NAF waste rock that minimises infiltration and is contoured to shed surface runoff to the south into the adjacent Six Mile Creek and Minnieritchie Creek catchments.
- Covering the final tailings surface with a crushed limestone (or other suitable alkali) layer, low permeability capping and NAF waste rock that minimises infiltration and is contoured to shed surface runoff to the south into the adjacent Six Mile Creek and Minnieritchie Creek catchments.

To conclude, although mining activities are regarded as a 'potentially contaminating activity' under WA guidelines (DER 2014), appropriate design, management and closure of the TSF are considered capable of controlling the potential contaminant migration pathways and, subject to appropriate cover design, is unlikely to result in a default classification of the TSF as a contaminated site under the *Contaminated Sites Act 2003* (WA).

6. ENVIRONMENTAL REVIEW DOCUMENT QUERIES

This document addresses the following ERD items (including those identified from peer review), specifically concerning tailings:

- A comparison of hydrated lime ($\text{Ca}(\text{OH})_2$) and caustic calcined magnesia (MgO , CCM) for neutralising acidity and attenuating contaminants in tailings and sulfidic waste rock seepage.

6.1 COMPARISON OF HYDRATED LIME AND CAUSTIC CALCINED MAGNESIA (CCM)

The ERD peer review (CSIRO 2019) advocated use of CCM as a means of controlling acidity and attenuating soluble metal and metalloid contaminants. In this respect, CCM has similar properties to those of the most widely used alkali in mining metallurgy and AMD management; hydrated lime (calcium hydroxide, $\text{Ca}(\text{OH})_2$). Advantages of CCM over hydrated lime include:

- An inherent pH of 9 to 10 pH units, which is significantly less alkaline (and corrosive) than that of hydrated lime (approximately 12 pH units).
- Despite lower inherent pH values, CCM has a higher acid neutralising capacity than hydrated lime. One tonne of pure CCM can theoretically neutralise 2.43 tonnes of H_2SO_4 , whereas a tonne of hydrated lime can only neutralise 1.32 tonnes of H_2SO_4 (not accounting for actual reaction efficiency). CCM also has the advantage of having higher density (3.6 tonnes/m^3) compared with hydrated lime (2.2 tonnes/m^3).
- Acid neutralising by CCM produces mainly soluble reaction products (magnesium and sulfate ions), unlike hydrated lime which is subject to coating of particles by reaction products such as calcium sulfate. This process, known as 'armouring', reduces the effectiveness of hydrated lime for neutralising acidity (i.e. actual reaction efficiency).

- In the presence of soluble aluminium (which is expected in highly acidic AMD), acid neutralisation by CCM forms a double hydroxide material known as hydrotalcite. Research by CSIRO has demonstrated hydrotalcite provides a very high assimilation capacity for dissolved metals and metalloids in AMD.

Disadvantages of CCM include:

- Substantially higher cost, with only two suppliers of bulk materials in Australia (located in New South Wales and Queensland).
- Neutralisation of acidity in AMD increases salinity.
- The “armouring” reaction of hydrated lime discussed earlier can be used to advantage when the product is blended with potentially acid forming tailings as the sparingly soluble reaction products (gypsum and/or basanite) act as a cementing material, thereby decreasing the permeability of treated tailings, which in turn reduces ingress of water and oxygen into underlying fresh tailings. CCM does not create such an armouring effect.

The use of CCM when blended with coarse sand during the construction of the TSF, as suggested in the CSIRO peer review report, is supported for:

- Encapsulation of drainage coils in seepage recovery systems.
- A protective sand blanket layer between the HDPE liner and underlying compacted earth layer.

Other uses of CCM suggested in the CSIRO peer review report should be further evaluated (by comparison with hydrated lime) in trials to be set up during operations to further inform the Mine Closure Plan. Suggested comparative trials include:

- Use of alkali in the TSF cover.
- High rate alkali dosing of tailings during the final stages of tailings deposition to provide a permanent alkaline cover over sulfidic tailings prior to construction of the TSF cover. Laboratory kinetic column trials should be conducted in the early stages of the project to validate use of either alkali reagents.

Yours sincerely

MBS Environmental



Thomas Robson
Environmental Geochemist

7. REFERENCES

- AECOM 2020. Sulphur Springs Project Groundwater Assessment. Unpublished report prepared for Venturex Sulphur Springs Pty Ltd.
- AIMM 2001. Field Geologists' Manual. Australasian Institute of Mining and Metallurgy Monograph 9. Fourth Edition. Carlton, Victoria.
- AMIRA 2002. *ARD Test Handbook: Project 387A Prediction and Kinetic Control of Acid Mine Drainage*. Australian Minerals Industry Research Association, Ian Wark Research Institute and Environmental Geochemistry International Pty Ltd, May 2002.
- ANZECC. 2000. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality: Livestock Drinking Water*. Canberra, ACT.
- Bowen, H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London; New York.
- CSIRO. 2019. Venturex Sulphur Springs Project: High Level Peer Review of Aspects of Mine operation and Closure Planning - May 2019. Unpublished peer review report prepared for Venturex Pty Ltd by CSIRO Land and Water.
- Department of Environment Regulation (DER). 2014. *Assessment and Management of Contaminated Sites - Contaminated Sites Guidelines December 2014*. Department of Environment Regulation, Perth, Western Australia.
- Graeme Campbell and Associates (GCA). 2002. *Geochemical Characterisation of Process- Sample(Static Test work): Implications for Process-Tailings Management - Panorama Project*. Unpublished report prepared for Outokumpu Zinc Australia Pty Ltd.
- International Network for Acid Prevention (INAP). 2009. *Global Acid Rock Drainage (GARD) Guide*. International Network for Acid Prevention, <http://www.gardguide.com> (accessed 21 June 2017).
- Knight Piésold Consulting. 2020. Sulphur Springs Zinc-Copper Project – Tailings Storage Facility Preliminary Concept Design Rev 1. Unpublished report prepared for Venturex Resources Ltd.
- NEPC. 1999. *Guideline on investigation levels for soil and groundwater: Groundwater Investigations Levels (Agricultural: Livestock)*.
- NEPC. 2013. *National Environment Protection (Assessment of Site Contamination) Measure - Guideline on Investigation Levels for Soil and Groundwater*. National Environment Protection Council, May 2013.
- O'Kane Consultants Pty Ltd (OKC) 2019. Sulphur Springs TSF Conceptual Cover Design Performance Modelling and Geochemical Amendments Review. Unpublished memorandum report prepared for Venturex Resources Limited, May 2019.
- Roger Townend and Associates. 2002. Mineralogical examination of one tailing (Panorama deposit). Unpublished report prepared for Graeme Campbell and Associates.
- Smith, K.D. and Huyck, H.L.O. 1999. An Overview of the Abundance, Relative Mobility, Bioavailability, and Human Toxicity of Metals. In *The Environmental Geochemistry of Mineral Deposits Part A: Processes, Techniques and Health Issues*. *Reviews in Economic Geology* 6: 29-70.
- URS. 2007a. *Geochemical Assessment of Waste Rock and Tailings Materials. Conceptual WRD Design and TSF Cover Design Strategy*. Unpublished Report Prepared for CBH Sulphur Springs Pty Ltd.
- URS. 2007b. *Panorama Project – Groundwater Resources Assessment*. Unpublished report prepared for CBH Sulphur Springs Pty Ltd.
- URS. 2009. *Hydrogeological Assessments. Savannah Project TSF*. Unpublished report prepared for Savannah Nickel Mines Pty Ltd, September 2009.

8. GLOSSARY OF TECHNICAL TERMS

Term	Explanation
AC	Acid consuming material. Defined as NAF material which has a NAPP value in excess of -100 kg H ₂ SO ₄ /t
ANC	Acid Neutralising Capacity. A process where a sample is reacted with excess 0.5 m HCl at a pH of about 1.5, for 2-3 hours at 80-90°C followed by back-titration to pH=7 with sodium hydroxide. This determines the acid consumed by soluble materials in the sample.
Circum-neutral pH	pH value near 7.
EC	Electrical conductivity. A measurement of solution salinity. Conversion: 1,000 µS/cm = 1 dS/m = 1 mS/cm
MPA	Maximum Potential Acidity. A calculation where the total sulfur in the sample is assumed to all be present as pyrite. This value is multiplied by 30.6 to produce a value known as the Maximum Potential Acidity reported in units of kg H ₂ SO ₄ /t.
NAF	Non Acid Forming.
NAG	Net Acid Generation. A process where a sample is reacted with 15% hydrogen peroxide solution at pH = 4.5 to oxidise all sulfides and then time allowed for the solution to react with acid soluble materials. This is a direct measure of the acid generating capacity of the sample but can be affected by the presence of organic materials.
NAG pH	The pH after the NAG test with hydrogen peroxide and heating is completed i.e. oxidation of all sulfides.
NAPP	Net Acid Producing Potential. $NAPP (kg H_2SO_4/t) = AP - ANC$.
PAF	Potentially Acid Forming.
PAF-LC	Potentially Acid Forming – Low Capacity. Waste rock classification for samples with NAPP values less than or equal to 10 kg H ₂ SO ₄ /t.
PAF-HC	Potentially Acid Forming – High Capacity. Waste rock classification for samples with NAPP values greater than 10 kg H ₂ SO ₄ /t.
TOS	Total oxidisable sulfur. Determined by the difference between total-sulfur and sulfate-sulfur, to provide an indication of the proportion of unoxidised sulfides present in solid materials.