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APPENDIX S1
OVERVIEW OF ACID SULFATE SOILS ASSESSMENT BY PARSONS BRINKERHOFF, 2008-08-19

1. INTRODUCTION

1.1 PURPOSE

This report has been prepared as an appendix to the 2009 Happy Valley Environmental Review and Management Program (ERMP). The report is based on an earlier report prepared by Parsons Brinkerhoff (PB 2008b) and summarises the key information and findings of that report.

All citations to external documents are as per the references provided in the ERMP.

1.2 BACKGROUND

In 2008, Parsons Brinkerhoff (PB 2008b), were commissioned to conduct a series of investigations into the geology and hydrogeology of the Happy Valley deposits, with the objective of assessing the acid generating potential of lithologic units that would be disturbed (or dewatered) during the development of the deposits. The investigation was in response to:

- the Department of Environment (DoE) draft *Identification and Investigation of Acid Sulfate Soils* guideline (2006), that identifies mineral sands deposits and areas where iron minerals (such as laterite) and waterlogged conditions as areas with a high risk of acid sulfate soils being present and requiring investigation
- the results of a 2001 preliminary sampling program reported in the Environmental Scoping Document (Strategen 2007), which returned a sample result of 0.039% total sulfur and was considered by the DEC to be above the action criteria for loamy sands (0.03% oxidisable sulfur).

In brief, the PB investigations ascertained that there was a low risk of acid generation associated with the lithologies of the site. Lateritic gravels were encountered during the investigation but laboratory tests indicated they were not acid forming. The groundwater table was not intersected to the depth of mining but the potential for localised, seasonal perched water tables was acknowledged. The PB report on the acid sulfate soils investigation is summarised below. Both reports are available in full as attachments to the ERMP.

2. INVESTIGATION METHOD

Two separate guidelines are considered relevant to the soil investigation:

- the Department of Environment (DoE) draft Identification and Investigation of Acid Sulfate Soils guideline (2006)
- the Department of Industries and Resources (DoIR) environmental guidance on Acid Mine Drainage (2006).

Neither of the guidelines specify the appropriate distribution of acid sulfate soil sampling locations with respect to mining activities. The DoIR requirement for waste characterisation suggests that 10 samples should be collected for every 1 million tonnes of material that is excavated. For the Happy Valley deposit, this would equate to analysis of 30 samples, which is likely to be insufficient to assess the distribution of sulfides from acid sulfate soils. In contrast, DoE guidelines recommend the installation of 2 bores holes/ha and collection of samples at 0.25 m intervals. Strict adherence to the

DoE guidelines would have resulted in 170 bores installed over the 85 ha disturbance area and the analysis of over 3000 samples, which would have been considerably disproportionate to the preliminary risk indicators (e.g. Dent & Dawson 2002), including the elevated position of the site in the landscape, absence of a permanent standing water table and the minimal proportion of sampling results to date that point towards the presence of potentially acid sulfate soils.

Instead, PB utilised the extensive geological database developed during the exploration of the Happy Valley deposits (over 22,000 samples at 1 m intervals) to prepare a sampling strategy that targeted the highest risk samples in each lithology. This would be conducted in two stages: the first stage involving a broad drilling approach with subsequent stages (if required) involving an intense local drilling program to target hotspot areas identified during the first stage. Due to the absence of any hotspots arising from the first stage, the second stage was not conducted.

The first stage investigation program encompassed:

- the installation of 19 soil bores to depths up to 24 mBGL[1], both along strike and across strike of the ore body
- the field testing of 494 soil samples (including 21 QA/QC samples) at approximately 1 m intervals and at all lithological unit changes within the soil bores for field pH (pH_F) and field pH after oxidation (pH_{FOX})
- laboratory analyses of 92 soil samples (including 5 QA/QC) from representative lithological units and samples exhibiting high risk for acid generating potential based on field testing results using the Chromium Reducible Sulphur Suite (S_{Cr})
- SPOCAS[2] analysis was conducted on 11 selected samples (including 1 QA/QC) to determine the contribution from organic acidity
- the analyses of 19 soil samples (including 1 QA/QC) representative of the different lithologic units encountered for metals (Al, As, Cr, Cd, Co, Fe, Mn, Mo, Ni, Pb, Se and Zn).

3. ASSESSMENT CRITERIA

3.1 ACID GENERATING POTENTIAL

The action criteria for the assessment of environmental risk of acid sulfate soils, i.e. the levels at which an acid sulfate soil management plan will be required, are set by the DoE guidelines (2006) and are based on the sum of existing plus potential acidity, calculated as equivalent sulfur or equivalent acidity. As clay content tends to influence the soils natural pH buffering capacity, the action criteria are grouped by three broad texture categories — coarse, medium, and fine.

As the proposed mining activities are likely to result in the excavation of significant volumes of material, the DEC action criteria for “>1000 tonnes of material disturbed” (i.e. 0.03 %S, 18 mol H^+/tonne) has been used for the assessment. The highest laboratory result returned from the samples was used to assess against the action criteria.

[1] mBGL = metres below ground level, ie relative depth from surface.

[2] SPOCAS = Suspension Peroxide Oxidation Combined Acidity and Sulfur Method

In addition to the action criteria, the DEC guidelines (2006) define indicator pH values for field pH (pH_F) and peroxide pH (pH_{FOX}) to assist with identifying likely acid generating soils. The pH indicator values are defined as:

- pH_F <= 4 oxidation of sulfides probably occurred in past — presence of actual acid sulfate soils
- pH_{FOX} <3 and a significant reaction — strongly indicates presence of potential acid sulfate soils
- much lower pH_{FOX} than pH_F — the greater the difference (generally >2 pH units difference) the more indicative the presence of potential acid sulfate soils.

3.2 METALS

Samples analysed for metals were assessed against Ecological Investigation Levels (EILs) (PB 2008) to determine if they pose a risk to the environment and groundwater. The EILs are presented in Table 4.

4. INVESTIGATION RESULTS

4.1 GEOLOGY

The subsurface profile encountered during the investigation can be described as follows:

- **Topsoil** (0-1 mbgl[3]): black/grey fine-medium grained sand
- **Aeolian sand** (1-2 mbgl): yellow/orange/grey fine grained, well sorted sand
- **Ridge Hill Shelf** formation (1-25 mbgl): fine to coarse grained sand, interbedded with sandy clay and clay with intermittent calcareous sand layers. Lateritic gravel was also encountered within the Yoganup and consisted of well cemented clay, sand and gravel. Laterite was only observed in the Happy Valley North area during PB's field investigation and typically located at depths below 5 mbgl. A similar observation was made by Strategen (2007). Lateritic material was encountered only within a small percentage of soil samples obtained from the drill holes and were mostly restricted to >2 mbgl depth.

The top of the Leederville formation was intersected during drilling and comprised of sandy clay to clayey sand, low plasticity, orange-brown and was typically damp. A number of idealised cross-sections showing these formations are presented in the PB report. No groundwaters were encountered during the drilling program.

4.2 FIELD RESULTS

The full set of field results are provided in the PB (2008b) report. Table 1 below provides a statistical summary of the pH_F and PH_{FOX} results according to the lithologies encountered.

[3] mbgl = metres below ground level or surface

Table 1 Summary of pH_F and pH_{FOX} results by lithology (PB 2008b).

Lithology	No. of samples	pH_F range	pH_{FOX} range	No of samples with ΔpH > 2
Topsoil	18	4.4-8.5	5.4-8.3	8
Laterite	10	5.7-7.8	4.6-5.6	4
Aeolian sand	94	4.6-8.1	3.4-5.6	17
Ridge Hill Shelf	209	4.4-8.4	3.7-5.5	19
Leederville (Clay)	89	4.5-8.5	3.3-5.3	19

The following observations are drawn from the field test data:

- pH_F for all recorded lithologies at the site were greater than 4.5 indicating a likely absence of actual acidity.
- pH_F>7 was recorded for 56 samples (12%) reflecting the alkaline pH of the calcareous soils (possibly calcarenite) found over some of the site. These high pH values were in the shallower lithologies and concentrated towards the mid to southern portions of the site and in one bore in the northern portion of the site.
- All lithologies encountered at Happy Valley, at all depths generally exhibited high pH_{FOX} (>3). As these values are greater than the DEC criterion for potential acid sulfate soils (PASS), the pH_{FOX} results suggest a low risk of potential acidity associated with all lithologies.
- low pH_{FOX} values in the TOPSOIL unit (0 mbgl) are presumably due to the higher organic content of this material. There is a slight decrease in pH_{FOX} at approximately 22 mbgl, which may coincide with the Leederville formation, which is below the depth of mining.
- Although several samples in the lithologies exhibited differences in pH_F and pH_{FOX} of greater than 2 pH units, these large differences were mainly an artefact of the high pH_F (>7) in the soils at the site. As the final pH_{FOX} values were well above the DEC criterion indicative of PASS (pH_{FOX}<3), there is a low risk of potential acidity associated with the site.

4.3 LABORATORY RESULTS

Laboratory analysis using the Chromium reducible sulphur analysis (S_{Cr}) and SPOCAS methods were conducted for high risk and representative lithologic samples from each of the drill holes. The full set of laboratory results are provided in the PB report. Table 2 and Table 3 below provide statistical summaries of the laboratory results according to the lithologies encountered.

Table 2 Summary of SCr results by lithology (PB 2008b).

Lithology	No. of samples	TAA	S_{Cr}	Net Acidity (excl. ANC)	No. exceeding criteria
Topsoil	2	<0.02-0.03	<0.02	0.03	0
Laterite	3	<0.02	<0.02	<0.02	0
Aeolian sand	12	<0.02-0.03	<0.02	<0.02-0.03	0
Ridge Hill Shelf	40	<0.02-0.04	<0.02	<0.02-0.04	1
Leederville clay	10	<0.02-0.03	<0.02-0.02	<0.02-0.04	2

Table 3 Summary of SPOCAS results by lithology (PB 2008b).

Lithology	No. of samples	Total Actual Acidity	Total Sulfide Acidity	SPOS	Net acidity (excl. ANC)	No. exceeding criteria
Topsoil	1	<0.02	0.11	0.12	0.13	1
Laterite	-	-	-	-	-	-
Aeolian sand	3	<0.02-0.02	<0.02-0.04	0.12	0.12-0.14	3
Ridge Hill Shelf	6	<0.02-0.05	<0.02	0.11-0.12	0.13-0.17	6
Leederville clay	-	-	-	-	-	-

The following observations are drawn from the laboratory results:

- The majority of samples were at or below laboratory detection limits for most measures of acidity in the Chromium Reducible Sulfur (S_{Cr}) analytical suites and as such, may not be acid generating at all.
- All samples sent for SPOCAS returned significantly larger SPOS results (Table 3) than S_{Cr} (Table 2), indicating that an appreciable amount of organic acidity is present in association with the lithologies encountered at the site. Discrepancy between the SPOCAS, SPOS and S_{Cr} may also indicate the release of Fe and Al from organic sources. Where there is a discrepancy between the S_{Cr} and SPOS, Ahern et al. (2004, in PB 2008a) recommend that S_{Cr} results should take precedence[4].
- The topsoil exhibited a maximum net acidity value in one sample of 0.03 %S by S_{Cr} analysis and 0.13 %S by SPOCAS and thus may be acid generating. However, the majority of the acidity associated with the topsoil is present as potential acidity and is associated mainly with organic matter present in the topsoil (as demonstrated by the good correlation between TSA and SPOS, as well as the large SPOS and high net acidity by SPOCAS results in comparison with the low S_{Cr} results; a relatively high pH_{FOX} of 4.8 also indicates a low likelihood that acidity is actually associated with the sand).
- The laterite is not acid generating, with all of the laboratory samples below laboratory detection limits (<0.02%S). Note: no laterite samples were sent for SPOCAS analysis due to the very high iron content.
- The Ridge Hill Shelf formation is also considered to be predominantly non-acid generating with only one sample marginally exceeding the net acidity assessment criteria of 0.03%S (sample SH4_13.0 mBSL, 0.04%S). Acidity present in this sample was mainly a result of organic acidity, as indicated by the negligible (<LOR) S_{Cr} results and large SPOS values. A low pH_{FOX} of 3.8, but not exceeding the DEC criterion, may indicate that the purple gravelly clay associated with this sample presents a minor risk of acid generation.
- Soil samples for which lateritic material was specifically encountered within certain lithologies of the Ridge Hill Shelf formation were below LOR and therefore are unlikely to be acid generating.

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[4] The large Fe concentrations (up to 103000 mg/kg, see PB 2008a) associated with some of the soil samples may have produced the large false positive responses from the SPOS analysis. For example, in sample SH1 3_8.Om, large net acidity values were detected in the SPOCAS analysis but only a marginal exceedence of 0.03%S was detected in the same sample by the Chromium Reducible Sulfur method.

- The clay is considered to be predominantly non-acid generating with only two samples marginally exceeding the net acidity assessment criteria of 0.03%S (sample MB5_18.g and MB2_21 .0 mBGL). Note no SPOCAS results are available for this lithology.

Overall, the majority of exceedences were found in samples at depth (>8 m) with the exception of marginal exceedences by SPOCAS for two topsoil samples at 0.05 m and 0.0 m and one sand sample at 2.0 m. No exceedences in S_{Cr} for soils above 12 mbgl depths were detected. The SPOCAS net acidity exceedences were spread throughout the site. However, the net acidity exceedences detected by the S_{Cr} suite were only marginal (maximum 0.04 %S) with the majority of these samples at or below LOR for other measures of acidity. In light of the high pH_{FOX} measurements (all samples pH_{FOX}>3) associated with all soil types found on site, the likelihood of acid generation associated with the soil types found on site is considered to be relatively low.

Laboratory analysis for metals were conducted for a number of samples from each of the drill holes. The full set of laboratory results is provided in the PB report. Table 4 below provides a summary of the laboratory results. Note that these results are for total metals (i.e. acid digest and ICP-AES) and do not reflect lability or bioavailability.

Table 4 Summary of results for metals of ecological significance against assessment criteria.

Analyte	EIL (mg/kg)	Conc. Range (mg/kg)	No. of samples exceeding EIL
Aluminium (Al)	-	200-19400	N.A.
Arsenic (As)	20	<5-69	4
Cadmium (Cd)	3	<1-6	1
Chromium (Cr)	50	<2-104	3
Copper (Cu)		<5-46	-
Iron (Fe)	-	300-103000	N.A.
Manganese (Mn)	-	<5-31	0
Nickel (Ni)	60	<2	0
Selenium (Se)	-	<5-9	0
Zinc (Zn)	200	<5-50	0

The following observations are drawn from the laboratory results:

- Arsenic concentrations exceeded EILs in four samples taken from depth within the red/brown sand, sandy clay /clayey sand and lateritic dark purple gravel lithologies present in the north eastern portion of the investigation area.
- Cadmium concentrations exceeded EIL in one sample from SHS at 20 mbgl, in the compacted sandy clay lithology in the north east of the site.
- Chromium concentrations exceeded EIL in three samples at depth (>8 mbgl) from the orange/brown sandy clay lithology from the north west of the site and in the clayey sand and red/brown gravelly clay in the southwest.
- Iron was detected within most soil samples exhibiting concentrations up to 103,000 mg/kg, with the highest concentrations of iron observed within the medium grained red/brown clayey sand, suggesting that there is a high potential for iron mobilisation into the groundwater from this unit if the pH of the material drops below 3.5. Iron concentrations in the sandy lithologies were

generally at least one order of magnitude lower than other lithologies, although the more reactive nature of the sandy soils may result in substantial mobilisation of iron under acidic conditions.

- Aluminium was detected in most soil samples with concentrations ranging up to 19, 400 mg/kg. The highest concentrations of aluminium were observed within the medium grained sandy clay and the gravel lithologies suggesting that there is a high potential for aluminium mobilisation into the groundwater from these units under acidic conditions. Aluminium concentrations in the other lithologies, particularly the sand, were generally at least one order of magnitude lower, although the more reactive nature of the sandy soils may result in substantial mobilisation of aluminium under acidic conditions.

5. POTENTIAL IMPACTS

The environmental risks associated with acid sulfate soils (ASS) occur when mining disturbs these soils resulting in their oxidation. In a mineral sands mining environment, disturbance can generally be classified into three categories (from Palich 2008, cited in PB 2008b):

TYPE 1 -The direct disturbance of acid sulfate soils through excavation or dredging may result from the disturbance of overburden, interburden and/or the heavy mineral bearing units themselves. When these units are excavated and stockpiled, changes in compaction and saturation state can result in the introduction of oxygen to the soil profile catalysing the conversion of iron and metal sulfides to sulfates. Further, the process of separating the oversize material and clay fines from the heavy mineral fraction may result in the concentration of sulfides within the non-economic wastes.

TYPE 2 -When dewatering is required for the excavation of mineral sands, the area of potential oxidation of acid sulfate soils may extend anywhere within the dewatering drawdown cone including soil units below the excavation resulting in the acidification of the groundwater resource.

TYPE 3 - Mineral sands mining may impact upon shallow wetland and surface water body systems through either the drawdown of perched aquifer systems resulting from the dewatering of deeper aquifers or through the need to temporarily divert surface water features to enable mining to occur. The disturbance of acid generating surficial deposits may result in the acidification of these shallow ecosystems if inappropriately managed.

Based on the results of the field investigation and the proposed mine plan, the risk of acid generation for each of these soil types has been assessed and a relative risk ranking applied within the context of the mine plan.

5.1 RISK OF ACID GENERATION

The actual risk for acid generation to occur in soils as a result of soil disturbance, regardless of the nature of the project, is dependent on several factors including:

- soil type and texture
- depth of soil in the profile with relation to the water table
- volume of soil to be excavated
- pH_F and pH_{FOX}
- sulfide content and form in the soil

- metal content in the soil.

These risk factors apply to soils that exceed the DEC action criteria for sulfide content (O.O3%S or 18 mol H'/tonne) only (DoE 2006). Those soils with sulfide content less than the action criteria will be considered NO risk, regardless of their other soil parameters, and will therefore not require any special management.

The preliminary acid sulfate soil investigation identified three lithologies with an acid generating potential above DEC action criteria- the topsoil, Ridge Hill Shelf Formation and clay soils. Table 5 summarises the risk conditions of these soil types in the context of the mining proposal.

Table 5 Summary acid generation risk conditions

Parameter	Topsoil unit	Ridge Hill Shelf unit	Clay unit
Soil texture	Black/grey, fine-medium grained sand containing organics	Interbedded sands, clays, clayey sands and gravels	Mottled brown/ping/orange/grey, low to high plasticity
Depth in the soil profile	At the surface (0-1 mbgl)	Above the water table	Above the water table
Approx vol to be excavated	0.4 to 0.6 x 10^6 m^3	12 to 18 10^6 m^3	7 to 9 x10^6 m^3
Field pH indicators	pH_F 4.4-8.5; pH_{FOX} 5.4-8.3	pH_F 4.4-8.4; pH_{FOX} 3.7-5.5	pH_F 4.6-8.4; pH_{FOX} 3.4-5.6
Maximum sulfide concentration and type	0.13% S present predominantly as organic acidity; inorganic acidity <0.04%S	0.17% S present predominantly as organic acidity; inorganic acidity <0.04%S	0.14% S present predominantly as organic acidity; inorganic acidity <0.04%S
Metal concentrations	Metals concentrations <EILs; Fe and Al > 1000 mg/kg	As, Cd and Cr exceed EILs; Fe and Al > 1000 mg/kg	As exceeds EILs; Fe and Al >1000 mg/kg

(from PB 2008b)

Although exhibiting net acidity values greater than 0.13% S (based on SPOCAS analysis), the topsoil is only considered to have a LOW risk of acid generation on the following basis:

- this material is present at the surface therefore the oxidation processes associated with topsoil are already naturally occurring in this environment - supported by the observation that much of the acid generating potential is already present as actual acidity
- the majority of the potential acidity associated with this soil type is present as non-sulfidic acidity which is less reactive than sulfidic acidity under oxidising conditions
- the actual volume of topsoil is relatively small in the context of the total volume of soil (3%-5%) to be excavated within the 24 m deep pit.

Similarly, the Ridge Hill Shelf Formation soils are considered to have a LOW risk of acid generation as these soils were all found above the water table. The pH_F and pH_{FOX} of soils in this lithological class were all above DEC criteria for acid generating soils and the majority of acidity associated with this lithological unit is present as non-sulfidic acidity which is less reactive than sulfidic acidity under oxidising conditions. In addition, only a marginal exceedence above the DEC criterion was detected in one sample. However, since Cd, As and Cr associated with this lithology were detected above EILs, there is some risk of mobilising these metals if acidification of the soils occurs. A similar risk exists with regards to Fe and Al mobilisation as significant concentrations of Fe and Al were measured within this lithology.

The clay soils are also considered to have a LOW risk of acid generation, as only one sample was found to have exceeded DEC criterion but only exhibited marginally sulfidic acidity at 0.04%S.

Further, the acidity associated with this unit is predominantly non-sulfidic. Similarly, these soils are located above the water table and therefore are unlikely to release any acidity. The pH_F and pH_{FOX} of soils in this lithological class were above DEC criteria for acid generating soils. There is also some risk of mobilising arsenic from clay, which was detected above EILs, should the soil pH of this lithology decrease. A similar risk is associated with Al and Fe release, should soil pH decrease.

5.2 PROJECT RISK

The following aspects of project scope contribute to the overall risk for each disturbance type and have been considered in the assessment of project risk:

- proposed duration of project
- anticipated depth to groundwater
- presence of acid generating soils
- volume, area and depth of soil disturbance activities
- type and proximity of sensitive environmental receptors
- beneficial use of groundwater in the project area.

The project risks anticipated for each of the potential disturbance types based on the current mine plan are discussed below.

TYPE 1 disturbance is expected at the site as most of the ASS detected by laboratory measurements is found at depths >8 mBGL and the total depth of the mine pit will exceed this at 18 mBGL (Strategen, 2007). The relative risk associated with the TYPE 1 direct disturbance of ASS at the site is assessed as being LOW on the basis that most lithologies at the site are predominantly non-acid generating and located above the water table. The potentially acid generating units located between 8 - 12 mBGL exhibit a very low acid generating potential (0.04%S in low-reactive clayey materials) and represent approximately 29% - 48% of the total excavation volume. The excavation and stockpiling of these dry materials therefore is unlikely to create a pathway for acidity migration (in the unlikely case that acidity is generated) to either the underlying groundwater or nearby surface water receptors.

Risk of disturbance of TYPE 2 is LOW on the basis that groundwater is on average below the average mine depth (18 mBGL). There may however be some risk associated with dewatering of seasonally perched groundwater that may occur locally within the top 5 m of the soil profile in areas where significant clay layers are present. It is noted that hydrogeologic studies undertaken to date have not encountered any of these perched aquifers suggesting that if present, perched water is likely to be seasonal and inflows to the mine pit are likely to be minor and probably best managed by a sump pump. Further, acid generating lithologies have not been identified at these shallow depths, suggesting that if dewatering of any perched aquifers were to occur, the risk for oxidation and acidification would be low.

No risk of TYPE 3 disturbance is expected at the site as the existing creeks and streams will remain in-situ with at least a 30 m buffer for those on private land and 50 m for the northern creek through State Forest which crosses Gavins Rd.

5.3 RISK OVERVIEW

Based on the initial acid sulfate soil investigation, the soils at the site can be classified into the general lithological classes of topsoil, aeolian sands, Ridge Hill Shelf Formation consisting of clayey sand/ sandy clay/ gravelly clay/ gravelly sand. These soils were found to be spread throughout the site and at variable depths. Field pH tests of the soils indicated no risk of ASS associated with any of the lithologies. However, minor exceedences in laboratory tests by the Chromium reducible sulphur method were found for one sample in the Ridge Hill Shelf Formation and two samples in the Leederville Formation. All three exceedences were found at depths >12 mBGL. Most of this acidity is associated with non-sulfidic acidity. Acidity associated with organic acidity but not exceeding the DEC criterion was also measured in the topsoil.

Based on the results of field and laboratory investigations, there is a LOW risk of acid generation associated with the topsoil, Ridge Hill Shelf Formation and clay lithologies at the site. Although lateritic gravels were encountered within the Ridge Hill Shelf Formation of the northwestern portion of the site, laboratory results indicated that they were non-acid generating.

The groundwater table is on average situated below the anticipated average pit depth, 18 mBGL, and will not be intersected. However, there may be some risk associated with the dewatering of perched aquifers at the proposed mine site, although these were not intersected during PB's field investigation (PB 2008).

END