GLADSTONE NICKEL PROJECT ENVIRONMENTAL IMPACT STATEMENT SUPPLEMENT

Residue Geochemical Characterisation

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URS

Gladstone
Pacific Nickel LTD

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Appendix B Residue and Ore Geochemical Characterisation

B.1 Background

B.1.1 Residue Treatment

All material to be placed within the RSF will undergo initial treatment in the final neutralisation circuit. In this process, the pH is raised to 7.0[1], allowing most of the heavy metals to be precipitated. Limestone will be added as a reactant to the first stage, raising the pH of the slurry to approximately 5.5[1]. Lime slurry will be added as reactant to the second stage, raising the pH of the final slurry to 7.0. The neutralised slurry containing residues from ore and other process inputs, in addition to gypsum generated during neutralisation, will be pumped to the RSF thickeners located at the RSF.

B.2 Testing

A bulk residue sample was provided by GPN and geochemically tested in September 2007 by Australian Laboratory Services Pty Ltd (ALS). The residue sample analysed had been pre-neutralised to a pH of 7.0, in order to replicate the pH of residue material discharged to the RSF. The residue sample was derived from a pilot process utilising combined ore from Marlborough (Qld) and New Caledonia, and is representative of the final process.

In addition, an ore sample from Marlborough and an ore sample from New Caledonia (New Cal) also underwent geochemical testing by ALS in November 2007

B.2.1 Acid Generation and Prediction

Acid generation from the process residue is caused by the exposure of sulphide minerals, most commonly pyrite (FeS_2), to atmospheric oxygen and water. Sulphur assay results are used to calculate the maximum potential acid (MPA) that could be generated by the residue, either directly from pyritic sulphur content, or by assuming that all sulphur not present as sulphate occurs as pyrite. Pyrite oxidises to generate acid according to the following overall reaction:

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O \text{ ---> } Fe(OH)_3 + 2\ H_2SO_4$$

The chemical components of the acid generation process consist of the above sulphide oxidation reaction and acid neutralisation, which is mainly provided by inherent carbonates and to a lesser extent silicate materials. The amount and rate of acid generation is determined by the interaction and overall balance of the acid generation and neutralisation components.

The net acid producing potential (NAPP) is used as an indicator of materials that may be of concern with respect to acid generation and represents the balance between the MPA and the acid neutralising capacity (ANC) of the material, which is determined experimentally. By convention, the NAPP result is expressed in units of kg H_2SO_4/t sample. If the ANC exceeds the MPA, then the NAPP of the material is negative. Conversely, if the MPA exceeds the ANC, the NAPP of the material is positive.

The net acid generation (NAG) test involves direct hydrogen peroxide oxidation of a sample of a material to oxidise reactive sulphide, then measurement of pH and titration of any net acidity produced by the acid generation and neutralisation reactions occurring in the sample. A final NAGpH < 4 can confirm that the sample is Potentially Acid Forming (PAF), and a final NAGpH ≥ 4 can confirm that the sample is Non-Acid Forming (NAF).

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[1] Lisa Park (GPN) personal communication, July 2006.

B.2.2 Assessment of Element Enrichment and Solubility

Multi-element scans were carried out to identify any elements (particularly metals) that are present in the residue and ore at concentrations that may be of environmental concern with respect to surface water quality and revegetation. The assay result for each element is compared to relevant environmental investigation levels to determine any concerns related to the residue storage facility (RSF) operation and final rehabilitation. The assay result for ore is also compared to relevant environmental investigation levels to determine any concerns related to stockpiling of this material. Elements identified as enriched may not necessarily be a concern for revegetation, drainage water quality, or public health but their significance should be evaluated. Similarly, because an element is not enriched does not mean it will never be a concern, because under some conditions (*e.g.* low pH) the geochemical behaviour of common environmentally important elements such as Al, Cu, Cd, Fe and Zn increases.

Water extracts are used to determine the immediate solubility and potential mobility of elements under existing pH conditions. Soluble element concentrations have been compared with those recommended in relevant surface water and groundwater guidelines in order to determine their environmental significance.

The general water extract method involves mixing a 10g solid sample with 50 g of deionised water in a 100 mL bottle, tumbling end-over-end for 1 hour, then filtering the liquid to 0.45µm and analysing the filtrate. Soluble trace metals were analysed by ICP-AES. Soluble Hg was analysed by FIMS and soluble Cr VI was analysed by Discrete Analyser. Cr III is the calculated difference between Total Cr and Cr VI.

Total concentration in residue solids

There are no specific guidelines and/or regulatory criteria specifically related to total metal concentrations in process residue materials, apart from those associated with Queensland EPA acceptance criteria for hazardous dams (EPA, 2006). In the absence of directly relevant criteria, and to provide relevant context, the total concentration of each element reported in residue solids has been compared to QLD EPA (1998) environmental investigation levels (for soils) and NEPC (1999) health-based investigation levels (HILs) for parks and recreation (open spaces). The EPA (1998) guidelines are primarily aimed at soil investigations and provide a suitable guideline for an industrial facility, such as the RSF. The NEPC (1999) guidelines for ‘open spaces’ are less stringent than the EPA guidelines, however their applicability stems from the potential final land use of the RSF following closure (*e.g.* grass cover and low intensity livestock grazing). Geochemical results are also compared to EPA acceptance criteria for hazardous dams to provide additional context.

The total metals concentration for individual elements in residue materials can be relevant for revegetation activities and/or where the potential exists for human contact (*e.g.* if the material was to be used off-site). Of more relevance is the potential for residue material to leach soluble metals or metalloids at concentrations that may impact the environment or human health. The leaching tests go some way to addressing this issue.

Total concentration in ore solids

Similar to residue solids, there are no specific guidelines and/or regulatory criteria specifically related to total metal concentrations in ore materials. In the absence of directly relevant criteria, and to provide relevant context, the total concentration of each element reported in ore solids has been compared to QLD EPA (1998) environmental investigation levels (for soils) and NEPC (1999) health-based investigation levels (HILs) for parks and recreation (open spaces). Geochemical results are also compared to EPA acceptance criteria for hazardous dams to provide additional context.

The total metals concentration for individual elements in ore materials can be relevant for general stockpiling activities (or should some of this material report as waste) and/or where the potential exists for human contact (*e.g.* if the material was to be used off-site). Of more relevance is the potential for ore material to leach soluble metals or metalloids at concentrations that may impact the environment or human health. The water-extract tests go some way to addressing this issue, by providing an indication of the initial solubility of metals and metalloids.

Soluble concentration in residue liquor

The key regulatory tool for determining the water quality hazard criteria for dams (including tailing storage facilities) is the EPA acceptance criteria for hazardous dams (EPA, 2006). In addition to the solid residue (as stated above), the acceptance criterion also applies to the liquid contents in a dam generally available to the environment (for example, water available to birds and animals). As such, the concentration of elements and compounds in the residue liquor is compared to the acceptance criteria for determining dams containing hazardous waste (EPA, 2006). In addition, the concentration of elements and compounds in the residue liquor is also compared to ANZECC (2000) livestock drinking water guidelines.

Soluble concentration in residue leachate

Leaching tests are used to quantify solubility and potential mobility of elements and compounds under existing pH conditions. There are several leaching tests commonly used, depending on the waste type being tested and the likely disposal method and environment of disposal, *e.g.* municipal landfill waste, monofill industrial waste, *etc*. The leach test employed for the GNP process residue is the Australian Standard (AS4439.3-1997), "*Wastes, sediments and contaminated soils. Part 3: Preparation of leachates – Bottle leaching procedure*" (Standards Australia, 1997a). The water leachate used was de-ionised water. This leach method (and the selection of de-ionised water as the leaching fluid) is applicable for use with industrial solid waste proposed for monofil disposal. The general method for this test procedure is to combine a portion of process residue solid with de-ionised water in a 1:20 mass ratio (solid:water). The solution, within an enclosed 2 litre glass bottle, is mechanically tumbled end-over-end for 18 hours at room temperature. The fluid is then pressure filtered, and the filtrate analysed.

There are no specific Queensland guidelines and regulatory criteria specifically related to seepage from residue facilities, apart from those associated with EPA acceptance criteria for hazardous dams (EPA, 2006), however the applicability of various guidelines to seepage chemistry is related to the surrounding environment of the residue facility. The beneficial use of groundwater in the vicinity of the RSF is stock and domestic use. Therefore, to provide relevant context, the soluble concentrations of elements and compounds in the leachate have been compared to four key water quality references:

- NHMRC/ARMCANZ (1996) Australian Drinking Water Guidelines;
- ANZECC (2000) Livestock Drinking Water Guidelines;
- ANZECC (2000) Water Quality for Irrigation and General Use (Short- and Long-term trigger values); and
- Baseline groundwater quality from beneath the proposed RSF site and surrounding area.

Soluble concentration in water extracts from ore materials

Water extract tests are used to determine the immediate initial solubility of elements under existing pH conditions. Soluble element concentrations are compared with those listed in relevant marine water guideline criteria in order to determine their environmental significance.

There are no guidelines and regulatory criteria specifically related to seepage from ore materials since guidelines (and regulatory criteria) will depend upon the end-use and receiving environment of the seepage. Ore will only be handled, used or stored at the port facility and nearby processing plant, therefore, to provide relevant context, URS has compared the soluble concentration of each element extracted from ore materials to ANZECC (2000) Marine water quality guidelines.

B.2.3 Sodicity and Dispersion

The relative proportion of the various exchangeable cations (*e.g.* calcium, magnesium, potassium and sodium) in a material can have a significant effect on the physical properties of that material. Potential effects can be indicated by assessment of material sodicity, as measured by the Exchangeable Sodium Percentage (ESP[2]). ESP is calculated from the effective cation exchange capacity (eCEC) of the material. When the ESP is high or the calcium/magnesium ratio is low, the material is more likely to disperse upon wetting. As the percentage of sodium in the material increases, the tendency for dispersion increases, resulting in crusting, reduced infiltration and consequent reduced plant growth, high runoff and erosion. In general terms, ESP values of less than 6 indicate that a material has a low risk of dispersion and ESP values greater than 12 indicate that a material has a higher risk of dispersion. The effect of ESP on dispersion is also influenced by other soil properties such as organic matter content, clay mineralogy, cation composition, and particularly electrolyte concentration of the soil and of any applied irrigation water (Isbell, 2002). Materials with a high risk of dispersion generally require management strategies to be put in place to ensure that slopes are stabilised against erosion.

The structural stability of a soil aggregate upon wetting can have significant implications on the infiltration rate, hydraulic conductivity and soil strength of that particular material. Potential effects can be indicated by assessment of aggregate cohesion, as measured by the Emerson Class Number Test (Standards Australia, 1997b). Soils are generally divided into six classes on the basis of their coherence in water. The lower the Emerson Class Number, the greater the likelihood that the soil will readily disperse in water, resulting in crusting, reduced infiltration and consequent reduced plant growth, high runoff and erosion. The higher the Emerson Class number, the greater the likelihood that the soil will not disperse in water. Materials with a high risk of dispersion (*e.g.* ECN 1 or 2) generally require management strategies to be put in place to ensure that slopes are stabilised against erosion.

B.2.4 Organic Carbon and Nutrients

Total organic carbon in soil comprises a variety of carbonaceous materials including humus, soil micro-organisms, plant and animal residues, coal, charcoal, coke and graphite, and carbonate minerals such as calcite and dolomite. Australian soils generally contain less than 5% organic carbon but higher levels are common in some surface soils. The total organic carbon content of a soil (taken in context and in conjunction with a variety of other parameters) can provide an indication of its potential suitability as a growth medium.

Soil nutrients include nitrogen and phosphorous and deficiencies in these elements can also present a potential plant-growth issue, which may have implications for reduced vegetative cover, reduced plant species variability and erosion. Nitrogen and phosphorous deficiencies can generally be overcome in soils by fertiliser addition; however other soil characteristics (*e.g.* pH, salinity, sodicity, and metals) can impact soil fertility.

B.3 Geochemical Characteristics of Solid Residue

B.3.1 Acid Forming Potential

The results of the geochemical (acid-base) testing of the residue sample are provided in Table 1.3.1 and summarised below.

- The residue sample has a pH(1:5) of 7.4 and has a net alkalinity equivalent to 0.0021 kg H_2SO_4/t.
- The current Electrical Conductivity(1:5) (EC) of the sample is high (8,630 µS/cm) and the sample is classified as saline.
- Total sulphur concentration is relatively high (7.66%) and sulphate sulphur concentration is similarly high (7.34%) indicating that only a small amount of sulphur is present in the sulphidic (unoxidised)

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[2] ESP can be defined as the proportion of sodium adsorbed onto a material surface as a proportion of the total cation exchange capacity.

form. The relatively high sulphate sulphur concentration is likely due to the presence of gypsum in the final neutralised sample.

- The relatively low concentration of oxidisable sulphur (0.32%) within the residue material generates a Maximum Potential Acidity (MPA) of 9.7 kg H_2SO_4/t. Taking into account the high Acid Neutralising Capacity (ANC) of 54.4 kg H2SO4/t indicates that the material is unlikely to generate any significant amount of acidity.
- As the ANC significantly exceeds the MPA, the Net Acid Producing Potential (NAPP) for the sample is strongly negative (-44.7 kg H_2SO_4/t).
- The Net Acid Generation (NAG) capacity of the process residue sample is <0.1 kg H2SO4/t, with a NAGpH value of 8.1.

On the basis of these results the process residue material can be classified as Non-Acid Forming (NAF).

B.3.2 Multi-element Composition

Total metal and metalloid concentrations are generally within the applied EPA (1998) environmental investigation levels (EILs), NEPC (1999) health-based investigation levels (HILs) and EPA hazardous dam acceptance criteria. Exceptions are total nickel, manganese and sulphate concentrations.

- The total nickel concentration (182 mg/kg) is elevated compared to the EPA (1998) EILs (60 mg/L).
- The total manganese concentration (4,510 mg/kg) is elevated compared to the EPA (1998) EILs (500 mg/kg) and NEPC (1999) HILs (3,000 mg/kg). No EPA hazardous dam acceptance criteria exist for total manganese concentration.
- The total chromium concentration (3,100 mg/kg) is highly elevated compared to the EPA (1998) EILs (50 mg/kg) and NEPC (1999) HILs (200 mg/kg). No EPA hazardous dam acceptance criteria exist for total chromium concentration.

The total sulphate concentration (220,000 mg.kg) is highly elevated compared to the EPA (1998) EILs (2,000 mg/kg), most likely as a result of the gypsum present in the process residue. No NEPC (1999) HILs or EPA hazardous dam acceptance criteria exist for total sulphate concentration.

B.3.3 Cation Exchange Capacity, Sodicity, Organic Carbon and Nutrients

The results of the cation exchange capacity, sodicity, organic carbon and nutrient testing of the process residue sample are provided in Table 1.3.2 and summarised below.

- The effective CEC (eCEC) of the residue sample is moderate (52 meq/100g).
- The Exchangeable Sodium Percentage (ESP) of the residue sample is 7.3 %. This result indicates that the sodicity of the residue sample is marginally elevated (*i.e.* > 6 %).
- The Emerson Class Number of the sample is 6 (in distilled water). This indicates that the material is unlikely to disperse in water.
- The Total Organic Carbon (TOC) concentration in the process residue sample is low (0.08%).
- The total nitrogen concentration in the residue sample is low (30 mg/kg).
- The bicarbonate extractable phosphorus (extractable P) concentration in residue material is low (<2 mg/kg).

Appendix B Residue and Ore Geochemical Characterisation

B.4 Geochemical Characteristics of Solid Ore

B.4.1 Acid Forming Potential

The results of the geochemical (acid-base) testing of the ore samples are provided in Table 1.3.1 and summarised below.

- The Marlborough ore sample has a pH(1:5) of 7.6 and the New Cal ore sample has a pH(1:5) of 5.3. Both samples have no detectable alkalinity.
- The current Electrical Conductivity(1:5) (EC) of both samples is low (650 and 76 µS/cm for Marlborough and New Cal, respectively) and the samples are classified as non-saline.
- Total sulphur concentration is generally low (0.01 and 0.28% for Marlborough and New Cal, respectively), with all of the sulphur present as sulphate, indicating that almost no sulphur is present in the sulphidic (unoxidised) form.
- The low concentration of oxidisable sulphur (<0.01% for both samples) indicates that both ore samples are barren and can only generate an insignificant Maximum Potential Acidity (MPA) of approximately 0.3 kg H_2SO_4/t. The Marlborough ore sample has a moderate Acid Neutralising Capacity (ANC) of 25 kg H_2SO_4/t, whereas the New Cal ore sample has a low ANC of less than 1 kg H_2SO_4/t.
- As the ANC exceeds the MPA, the Net Acid Producing Potential (NAPP) for both samples is negative, more-so for the Marlborough ore due to a greater ANC.
- The Net Acid Generation (NAG) capacity of the ore samples is <0.1 kg H_2SO_4/t, with a NAGpH value of 8.3 for the Marlborough ore and 5.9 for the New Cal ore.

On the basis of the lack of oxidisable sulphur, negative NAPP and NAGpH values above 4.5, both ore samples can be classified as Non-Acid Forming (NAF).

B.4.2 Multi-element Composition

The results of the total metal concentrations in ore samples are provided in Table 1.3.2. Total metal and metalloid concentrations are elevated with respect to the applied EPA (1998) environmental investigation levels (EILs), NEPC (1999) health-based investigation levels (HILs) and EPA hazardous dam acceptance criteria for total chromium, cobalt, manganese, nickel and sulphate concentrations. This is to be expected, given that this is ore material and is supposed to be mineralised, particularly with respect to nickel.

B.5 Geochemical Characteristics of Residue Liquor

B.5.1 General Chemical Characteristics

Process residue liquor is pH neutral (pH 6.8), has moderate alkalinity (61 mg/L) and is highly saline. The total dissolved solids content of the liquor is 136,000 mg/L - approximately 4 times seawater concentration and significantly greater than the ANZECC (2000) livestock drinking water guidelines. Suspended solids content is 110 mg/L. Magnesium and sodium are the dominant cations (19,800 and 15,300 mg/L, respectively) and sulphate and chloride are the dominant anions (74,100 and 33,100 mg/L, respectively). The soluble sulphate and chloride concentrations were highly elevated with respect to the EPA hazardous dam acceptance criteria (and ANZECC livestock drinking water guidelines for sulphate), due to the highly saline nature of the process residue liquor.

B.5.2 Multi-element Composition

Soluble metal and metalloid concentrations are generally within the applied EPA hazardous dam acceptance criteria and ANZECC (2000) livestock drinking water guidelines. Exceptions are soluble nickel, cadmium and fluoride concentrations.

The soluble nickel and cadmium concentrations (1.92 mg/L and 0.198 mg/L, respectively) are elevated compared to the applied criteria of 1 mg/L and 0.01 mg/L, respectively.

The soluble fluoride concentration (3.3 mg/L) is elevated compared to the applied criteria of 2 mg/L.

B.5.3 Organic Carbon, Oxygen Demand and Nutrients

The results of the total organic carbon, chemical oxygen demand and nutrient testing of the process residue liquor are provided in Table 1.3.3 and summarised below.

- The Chemical Oxygen Demand (COD) of the residue liquor is 794 mg/L.
- The Total Organic Carbon (TOC) concentration in the residue liquor is 9%.
- The total nitrite and nitrate concentrations in the residue liquor are 0.044 and 1.39 mg/L, respectively and are below the applied criteria.
- The ammonia concentration in the residue liquor is 1.15 mg/L.

The total phosphorus concentration in residue liquor is 0.28 mg/L.

B.6 Leachate Characteristics of Residue Solid

The results of the leaching test of the process residue solid sample are provided in Table 1.3.4 and summarised below:

- Leachate is pH-neutral (7.22), brackish (3,170 mg/L TDS) with low alkalinity (16 mg/L).
- Dominant major soluble ions are calcium and sulphate, indicative of the gysum in the process residue solid.
- Leachate is generally low in soluble metals and metalloids.

The leachate results in Table 1.3.4 are compared to relevant applied guideline values and local groundwater quality results as follows:

- The salinity of the leachate is significantly elevated with respect to the Australian Drinking Water guideline value of 500 mg/L, and is almost twice the total dissolved solids concentration of local groundwater.
- Calcium and magnesium concentrations in leachate are greater than in local groundwater, but do not exceed applied water quality guideline values. Sulphate concentration in leachate exceeds all applied guideline sulphate values and local groundwater sulphate concentrations.
- With respect to metals and metalloids, leachate was:
  - marginally elevated in chromium and nickel compared to local groundwater; and
  - significantly elevated in manganese compared to local groundwater, the Australian drinking water guideline value and the irrigation (long-term) trigger value.

B.7 Multi-element Solubility in Water Extracts from Ore Solid

The results of the water-extract test of the ore solid samples are provided in Table 1.3.5 and summarised below:

- Leachate is pH-neutral (7.6) from Marlborough ore and slightly acidic (pH 5.3) from New Cal ore. Both ore samples are non-saline.
- Dominant major soluble ions are sodium and sulphate, although concentrations are low.
- Water extracts from both ore types is generally low in soluble metals and metalloids.

The water extract results in Table 1.3.5 are compared to relevant applied ANZECC Marine Water guideline values. The results indicate that despite the highly elevated total metal concentrations of some metals (Cr, Co, Mn and Ni) the initial solubility of these and other metals is generally low, as follows:

- Only soluble aluminium, chromium, nickel and sulphur were detectable (i.e. above the laboratory reporting limits (LOR)) in the water extract solutions from both ores. All other metals (excluding major cations) had soluble concentrations in water extracts below the LOR;
- Hexavalent chromium (Cr^{VI}) concentrations in both the Marlborough ore (0.26 mg/L) and New Caledonia ore (0.08 mg/L) were elevated with respect to the ANZECC Marine water quality guideline value of 0.0044 mg/L. Trivalent chromium (Cr III) concentrations in both ore samples were below applied guideline values;
- Cobalt, nickel and manganese concentrations, which were elevated in solid ore samples, were all less than the laboratory LOR in the water extracts.

The concentration of soluble metals in 1:5 water extracts from ore materials is likely to be greater than would be seen in leachate produced naturally from stockpile runoff. This is due to the agitation used in the water extract method and the greater dilution that would be seen with natural rainfall runoff.

B.8 Conclusions

Geochemical test results for process residue material likely to report to the RSF, and ore material, indicate that:

- The residue sample has a low TOS content, negative NAPP and NAGpH of 8.1; and is therefore classified as Non-Acid Forming (NAF). The ore samples also have a very low TOS content, negative NAPP and NAGpH greater than 4.5, and are therefore also classified as NAF.
- The concentration of metals in the residue sample solids is generally within applied environmental and health based investigation guideline levels for soils. However, elevated concentrations of chromium, manganese and nickel in solids are indicated. The concentration of some metals in ore solids (Ni, Mn, Co, Cr) is elevated, as expected in mineralised material.
- Leachate derived from residue is moderately saline and approximately double the salinity (TDS) of local groundwater. Water extract from ore material is non-saline.
- The concentrations of metals in leachate derived from residue solid are generally low and, with the exception of manganese, are comparable to or less than metals concentrations in local groundwater. Nickel and chromium concentrations in leachate are marginally above local groundwater concentrations, but below applied guideline values.
- The concentrations of metals in water extracts derived from ore solids are also low, despite the elevated total metals concentrations in the solid. Only hexavalent chromium (Cr VI) concentration in the water extract from both ore types is greater than the applied marine water quality guideline values, particularly in the Marlborough ore.

- The concentration of soluble metals in the residue liquor is generally low and within EPA hazardous dam acceptance criteria and ANZECC (2000) livestock drinking water criteria. However, the elevated concentrations of soluble cadmium, fluoride and nickel are indicated. The concentration of soluble salts in the residue liquor solution is generally high. The soluble sulphate concentration exceeds both the applied guideline criteria. Soluble chloride also exceeds the applied hazardous dam acceptance criteria.

- The residue solid has a moderate ESP indicating that the material is marginally sodic. However, the Emerson Class Test indicates that the material is generally cohesive and unlikely to disperse.

- The residue solid and the residue liquor contain low levels of total organic carbon, total extractable phosphorous and total nitrogen.

B.9 Summary and Recommendations

- The geochemical results indicate that the process residue material (following treatment in the final neutralisation circuit) is likely to be NAF. The source material (Marlborough ore and New Caledonia ore) is also NAF.

- The residue solids may contain elevated concentrations of chromium, manganese and nickel compared to applied guideline criteria. The ore solids are expected to contain elevated concentrations of chromium, manganese and nickel compared to applied guideline criteria.

- The salinity, soluble cadmium and nickel, and soluble sulphate and fluoride concentrations in the residue liquor are likely to be elevated compared to applied guideline criteria.

- The initial solubility of ore materials is unlikely to present a significant environmental hazard with respect to the applied ANZECC marine water quality guidelines, however hexavalent chromium concentration in both the Marlborough and New Caledonia ores is elevated with respect to the marine water quality guidelines. Therefore, ore material will need to be managed to minimise environmental release.

- The initial geochemical assessment results indicate that direct revegetation of the process residue material in the RSF (as part of final rehabilitation) is unlikely to be appropriate due to high salinity levels and low nutrient concentrations. Hence, a cover system may be required for final rehabilitation.

- It is recommended that GPN commence kinetic leach column testing of process residue material to confirm initial findings and investigate any potential issues associated with ongoing leachate quality. This will provide an indication of the timing and extent of any soluble metal/salt release, provide an indication of ongoing leachate quality, and facilitate optimisation of any required seepage monitoring program.

B.10 References

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Tables

Table 1.3.1 Acid-base chemistry of process residue neutralised solids and ore

	Units	Laboratory Detection Limit	Residue[6]	Marlborough Ore	New Caledonia Ore
pH[1]	pH units	0.1	7.4	7.6	5.3
Electrical Conductivity (EC)[1]	uS/cm	1	8,630	650	76
Alkalinity (to pH 5.5)[2]	kg H_2SO_4/t	0.0001	0.0021	<0.0001	<0.0001
Acidity (to pH 8.3)[2]	kg H_2SO_4/t	0.0001	0.00012	<0.0001	0.0026
Total Sulfur (as S)	%	0.01	7.66	0.01	0.28
Sulfate Sulfur (as S)[2]	%	0.01	7.34	0.01	0.28
Total Oxidisable Sulfur (TOS)[3]	%	0.01	0.32	<0.01	<0.01
Total Organic Carbon (TOC)	%	0.02	0.08	n/a	n/a
Maximum Potential Acidity (MPA)[4]	kg H_2SO_4/t	0.1	9.7	0.3	0.3
Acid Neutralising Capacity (ANC)	kg H_2SO_4/t	0.5	54.4	25.2	0.6
Net Acid Producing Potential (NAPP)	kg H_2SO_4/t	0.1	-44.7	-25	-0.3
Net Acid Generation (NAG)	kg H_2SO_4/t	0.1	<0.1	<0.1	<0.1
NAGpH	pH units	0.1	8.1	8.3	5.9
Sample Classification[5]			**Non-Acid Forming**	**Non-Acid Forming**	**Non-Acid Forming**

Notes:

1. Natural pH and EC provided for 1:5 sample:water extracts
2. Alkalinity and Acidity converted from meq/kg as $CaCO_3$ to kg H_2SO_4/t. Sulfate sulfur converted from mg/kg SO_4 to % S.
3. TOS concentration is calculated from the difference between total S and sulfate sulfur concentrations.
   It is assumed that the organic S concentration is negligible.
4. MPA calculated using TOS.
5. Sample has low TOS content, negative NAPP and NAGpH > 4.5 and is therefore classified as Non-Acid Forming (NAF).
6. Residue sample G200 NRS

Table 1.3.2 Chemistry of process residue neutralised solid and ore

Parameters	Laboratory detection limit	QLD-EPA[1] Environmnetal Investigation Level	NEPC[2] Health-Based Investigation Level	QLD-EPA Hazardous dam criteria[3]	Total concentrations in Residue Solid	Total concentrations in Marlborough Ore	Total concentrations in New Caledonia Ore
Elements and Major Ions	**mg/kg (unless indicated)**						
Aluminium (Al)	50	-	-	-	4,280	10,700	13,300
Antimony (Sb)	5	20	-	-	<5	<5	14
Arsenic (As)	5	20	200 (total)	500	<5	<5	<5
Barium (Ba)	10	-	-	-	-	450	60
Beryllium (Be)	1	-	40	-	<1	<1	<1
Boron (B)	50	-	6,000	15,000	<50	<50	<50
Cadmium (Cd)	1	3	40	100	2	<1	3
Calcium (Ca)	10	-	-	-	78,200	210	40
Chromium (Cr) (Total)	2	50[4]	200	-	3,100	1,340	4,070
Cobalt (Co)	2	-	200	500	26	577	1,160
Copper (Cu)	5	60	2,000	5,000	6	57	24
Fluoride (F)	40	-	-	-	<40	-	-
Iron (Fe)	50	-	-	-	110,000	92,500	298,000
Lead (Pb)	5	300	600	1,500	<5	<5	<5
Magnesium (Mg)	10	-	-	-	16,500	36,700	1,160
Manganese (Mn)	5	500	3,000	-	4,510	3,650	7,240
Mercury (Hg)	0.1	1	30 (inorganic)	75	<0.1	<0.1	0.1
Molybdenum (Mo)	2	-	-	-	<2	<2	<2
Nickel (Ni)	2	60	600	3,000	182	9,000	8,300
Phosphorus (P)	50	-	-	-	-	<50	<50
Potassium (K)	10	-	-	-	930	160	70
Sulphur (as S)	50	-	-	-	-	140	1,460
Selenium (Se)	5	-	-	-	<5	<5	<5
Silica (Si)	0.01%	-	-	-	13.9%	-	-
Silver (Ag)	2	-	-	-	<2	<2	<2
Sodium (Na)	10	-	-	-	8,220	1,580	70
Strontium (Sr)	2	-	-	-	66	14	9
Sulphate (SO_4)	100	2000	-	-	220,000	650	9,620
Thallium (Tl)	5	-	-	-	<5	<5	<5
Tin (Sn)	5	50	-	-	<5	<5	<5
Titanium (Ti)	10	-	-	-	-	80	30
Uranium (U)	0.1	-	-	-	0.2	-	-
Vanadium (V)	5	-	-	-	-	36	23
Zinc (Zn)	5	200	14,000	35,000	14	98	164
Exchangeable Cations & Emerson Class	meq/100g (except ESP)						
Exch. Calcium	0.1	-	-	-	39.1	-	-
Exch. Magnesium	0.1	-	-	-	8.9	-	-
Exch. Potassium	0.1	-	-	-	0.2	-	-
Exch. Sodium	0.1	-	-	-	3.8	-	-
Cation Exchange Capacity	0.1	-	-	-	52.0	-	-
Exchangeable Sodium Percentage	0.1%	-	-	-	7.3%	-	-
Emerson Class Number	-	-	-	-	6	-	-
Nutrients	mg/kg (unless indicated)						
Nitrite + Nitrate as N (sol.)	0.1	-	-	-	0.6	-	-
Total Kjeldahl Nitrogen as N	20	-	-	-	30	-	-
Total Nitrogen as N	20	-	-	-	30	-	-
Bicarbonate Extractable P (Colwell)	2	-	-	-	<2	-	-
Total Organic Carbon (TOC)	0.02%	-	-	-	0.08%	-	-

Notes:

< indicates less than the analytical detection limit.

Shaded cells indicate values which exceed one or more applied guideline values and/or hazardous dam acceptance criteria.

1. Queensland Government. Department of Environment. Draft Guidelines for the Assessment & Management of Contaminated Land in Queensland. May 1998.

2. NEPC (1999). National Environmental Protection Council (NEPC). National Environmental Protection (Assessment of Site Contamination) Measure (NEPM). Guideline on investigation levels for soil and groundwater. HIL(E); parks, recreation open space and playing fields.

3. Queensland Government - Environment Protection Agency. Determining dams containing hazardous waste. Information sheet 0302. Criteria for total solids.

4. Cr(III). No background or QLD-EPA EIL's available for Cr Total.

Table 1.3.3 Chemistry of process residue liquor

Parameters	Laboratory detection limit	QLD-EPA Hazardous dam criteria[1]	ANZECC Livestock drinking water (LDW) guideline levels[2]	Soluble concentrations in Residue Liquor
pH	0.01 pH unit	4 to 8	-	6.84
Electrical Conductivity	1 uS/cm	-	-	67,800
Total Dissolved Solids (TDS)	1 mg/L	-	4000 [3]	136,000
Suspended Solids (SS)	1 mg/L	-	-	110
Alkalinity as $CaCO_3$	1 mg/L	-	-	61
Acidity as $CaCO_3$	1 mg/L	-	-	61
Nutrients	mg/L			
Ammonia as N	0.010	-	-	1.15
Nitrite as N	0.010	-	30	0.044
Nitrate as N	0.010	-	400	1.39
Nitrite + Nitrate as N	0.010	-	-	1.44
Total Phosphorous as P	0.01	-	-	0.28
Total Organic Carbon	1	-	-	9
Chemical Oxygen Demand	5	-	-	794
Soluble Major Cations	mg/L			
Calcium (Ca)	1	-	1,000	528
Magnesium (Mg)	1	-	-	19,800
Sodium (Na)	1	-	-	15,300
Potassium (K)	1	-	-	476
Soluble Major Anions	mg/L			
Chloride (Cl)	1	2,500	-	33,100
Sulphate (SO_4)	1	1,000	1,000	74,100
Soluble Metals & Metalloids	mg/L			
Aluminium (Al)	0.01	-	5	<0.01
Antimony (Sb)	0.001	-	-	0.010
Arsenic (As)	0.001	1	0.5	0.023
Beryllium (Be)	0.001	-	-	<0.001
Boron (B)	0.1	5	5	2.8
Cadmium (Cd)	0.0001	0.01	0.01	0.198
Chromium (Cr)	0.001	-	1	0.166
Cobalt (Co)	0.001	1	1	0.421
Copper (Cu)	0.001	1	0.5	0.003
Fluoride (F)	0.1	2	2	3.3
Iron (Fe)	0.05	-	-	<0.05
Lead (Pb)	0.001	0.5	0.1	<0.001
Manganese (Mn)	0.001	-	-	800
Mercury (Hg)	0.0001	0.002	0.002	<0.0001
Molybdenum (Mo)	0.001	-	0.15	<0.001
Nickel (Ni)	0.001	1	1	1.92
Selenium (Se)	0.010	-	0.02	<0.010
Silica (Si)	0.1	-	-	32.1
Silver (Ag)	0.001	-	-	<0.001
Strontium (Sr)	0.001	-	-	6.55
Thallium (Tl)	0.001	-	-	<0.001
Tin (Sn)	0.001	-	-	<0.001
Uranium (U)	0.001	-	0.2	<0.001
Zinc (Zn)	0.005	20	20	0.021

Notes:

< indicates less than the analytical detection limit.

Shaded cells indicate values which exceed the applied guideline values and/or hazardous dam acceptance criteria.

1. Queensland Government - Environment Protection Agency. Determining dams containing hazardous waste. Information sheet 0302. Criteria for liquor.

2. ANZECC and ARMCANZ, Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, ACT (2000). Livestock drinking water (cattle).

3. TDS limit based on tolerance for beef cattle, sheep, horses and pigs.

Table 1.3.4 Chemistry of process residue leachate

		Water Quality Guidelines				Local Groundwater Quality [4]				
Parameters	**Laboratory detection limit for soluble analytes**	**NHMRC/ ARMCANZ Australian drinking water (ADW) guideline levels[1]**	**ANZECC Livestock drinking water (LDW) guideline levels[2]**	**ANZECC Irrigation water (LTV) guideline levels[3]**	**ANZECC Irrigation water (STV) guideline levels[3]**	**Groundwater bore RSF17[4] (alluvium)**	**Groundwater bore RSF14[4] (Mount Alma Fm quartzite + siltstones)**	**Groundwater bore RSF24[4] (Rockhampton Grp - Qzt siltstones)**	**Soluble concentrations in Residue leachate[5]**	**Exceedances***
pH (leachate)	0.01 pH unit	6.5 to 8.5 [6]	-	-	-	7.90	7.72	7.88	7.22	
Electrical Conductivity	1 uS/cm	-	-	crop dependent	crop dependent	3,150	1,980	2,380	3,710	local GW
Total Dissolved Solids (TDS)	1 mg/L	500 [6]	4000 [7]	crop dependent	crop dependent	1,920	1,520	1,430	3,170	ADW + local GW
Alkalinity as $CaCO_3$	1 mg/L	-	-	-	-	548	759	706	16	
Acidity as $CaCO_3$	1 mg/L	-	-	-	-	-	-	-	4	
Soluble Major Cations	mg/L									
Calcium (Ca)	1	-	1,000	-	-	86	102	71	556	local GW
Magnesium (Mg)	1	-	-	-	-	96	97	68	204	local GW
Sodium (Na)	1	180 [6]	-	crop dependent	crop dependent	432	236	352	153	
Potassium (K)	1	-	-	-	-	13	12	8	6	
Soluble Major Anions	mg/L									
Chloride (Cl)	1	250 [6]	-	crop dependent	crop dependent	627	272	338	240	
Sulphate (SO_4)	1	500	1,000	-	-	148	33	70	2,000	ADW + LDW + local GW
Soluble Metals & Metalloids	mg/L									
Aluminium (Al)	0.10	0.2 [6]	5	5	20	-	-	-	<0.10	
Antimony (Sb)	0.01	0.003	-	-	-	-	-	-	<0.01	
Arsenic (As)	0.01	0.007	0.5	0.1	2.0	0.001	0.002	0.002	<0.01	
Beryllium (Be)	0.01	-	-	0.1	0.5	<0.001	<0.001	<0.001	<0.01	
Boron (B)	0.1	0.3	5	0.5	crop dependent	-	-	-	<0.1	
Cadmium (Cd)	0.005	0.002	0.01	0.01	0.05	0.0003	<0.0001	<0.0001	<0.005	
Chromium (Cr)	0.01	0.05	1	0.1	1	0.001	<0.001	0.002	0.02	local GW
Cobalt (Co)	0.01	-	1	0.05	0.1	0.029	0.002	0.003	<0.01	
Copper (Cu)	0.01	2	0.5	0.2	5	0.013	<0.001	0.002	<0.01	
Fluoride (F)	0.1	1.5	2	1	42	-	-	-	0.5	
Iron (Fe)	0.05	0.3 [6]	-	0.2	10	-	-	-	<0.05	
Lead (Pb)	0.01	0.01	0.1	2	5	0.002	0.021	0.017	<0.01	
Manganese (Mn)	0.01	0.5	-	0.2	10	0.213	0.100	0.092	7.28	ADW + LTV + local GW
Mercury (Hg)	0.0001	0.001	0.002	0.002	0.002	<0.0001	<0.0001	<0.0001	<0.0001	
Molybdenum (Mo)	0.01	0.05	0.15	0.01	0.01	-	-	-	<0.01	
Nickel (Ni)	0.01	0.02	1	0.2	2	0.027	0.010	0.013	0.02	local GW
Selenium (Se)	0.01	0.01	0.02	0.02	0.05	-	-	-	<0.01	
Silica (Si)	0.1	-	-	-	-	-	-	-	20.7	
Silver (Ag)	0.01	0.1	-	-	-	-	-	-	<0.01	
Strontium (Sr)	0.1	-	-	-	-	-	-	-	0.6	
Thallium (Tl)	0.01	-	-	-	-	-	-	-	<0.01	
Tin (Sn)	0.01	-	-	-	-	-	-	-	<0.01	
Uranium (U)	0.001	-	0.2	0.01	0.1	-	-	-	<0.001	
Zinc (Zn)	0.01	3 [6]	20	2	5	0.041	0.010	0.042	<0.01	

Notes:

< indicates less than the analytical detection limit. * Result concentrations that exceed applied guideline values and/or local groundwater concentrations.

1. NHMRC & ARMCANZ, Australian Drinking Water Guidelines. National Health and Medical Research Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra, ACT (1996).
2. ANZECC and ARMCANZ, Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, ACT (2000). Livestock drinking water (cattle).
3. ANZECC and ARMCANZ. Water Quality for Irrigation and General Use. STV = short-term trigger value. LTV = long-term trigger value. STV assumes continuous irrigation for up to 20 years. LTV assumes 100 years of continuous irrigation.
4. Selected representative bores. Refer to URS report (2007) for full groundwater assessment.
5. Standards Australia (1997). AS4439.3-1997 Wastes, sediments and contaminated soils. Part 3: Preparation of leachates – Bottle leaching procedure. Homebush, NSW. Residue sample G200 NRS.
6. Aesthetic guideline value. No health-based guideline value.
7. TDS limit based on tolerance for beef cattle, sheep, horses and pigs.

Table 1.3.5 Multi-element solubility in water extracts from ore

Parameters	Laboratory detection limit for soluble analytes from Ore	ANZECC Marine water guideline levels (95%) [1]	Soluble concentrations in Marlborough Ore[2]	Soluble concentrations in New Caledonia Ore[2]
pH	0.01 pH unit	-	7.6	5.3
Electrical Conductivity	1 uS/cm	-	650	76
Total Dissolved Solids (TDS)	1 mg/L	-	-	-
Alkalinity as $CaCO_3$	1 mg/L	-	-	-
Acidity as $CaCO_3$	1 mg/L	-	-	-
Soluble Major Cations	mg/L			
Calcium (Ca)	2	-	<2	2
Magnesium (Mg)	2	-	6	2
Sodium (Na)	2	-	105	5
Potassium (K)	2	-	<2	<2
Soluble Major Anions	mg/L			
Chloride (Cl)	2	-	134	9
Sulphate (SO_4)	2	-	50	10
Soluble Metals & Metalloids	mg/L			
Aluminium (Al)	0.2	-	0.2	<0.2
Antimony (Sb)	0.02	-	<0.02	<0.02
Arsenic (As)	0.02	-	<0.02	<0.02
Barium (Ba)	0.2	-	<0.2	<0.2
Beryllium (Be)	0.02	-	<0.02	<0.02
Boron (B)	0.2	-	<0.2	<0.2
Cadmium (Cd)	0.02	0.0055	<0.02	<0.02
Chromium (Cr) (total soluble)	0.02	-	0.26	0.09
Chromium (Cr III)	0.02	0.0274	<0.02	<0.02
Chromium (Cr VI)	0.02	0.0044	0.26	0.08
Cobalt (Co)	0.02	0.001	<0.02	<0.02
Copper (Cu)	0.02	0.0013	<0.02	<0.02
Fluoride (F)	0.2	-	<0.2	<0.2
Iron (Fe)	0.2	-	<0.2	<0.2
Lead (Pb)	0.02	0.0044	<0.02	<0.02
Manganese (Mn)	0.02	-	<0.02	<0.02
Mercury (Hg)	0.0001	0.0004 (inorganic)	<0.0001	<0.0001
Molybdenum (Mo)	0.02	-	<0.02	<0.02
Nickel (Ni)	0.02	0.07	0.02	0.03
Phosphorous (P)	2	-	<2	<2
Sulphur (as S)	2	-	16	3
Selenium (Se)	0.02	-	<0.02	<0.02
Silver (Ag)	0.02	0.0014	<0.02	<0.02
Strontium (Sr)	0.2	-	<0.2	<0.2
Thallium (Tl)	0.2	-	<0.2	<0.2
Tin (Sn)	0.02	-	<0.02	<0.02
Titanium (Ti)	0.2	-	<0.2	<0.2
Vanadium (V)	0.02	0.1	<0.02	<0.02
Zinc (Zn)	0.02	0.015	<0.02	<0.02

Notes:

< indicates less than the analytical detection limit.

Shaded cells indicate result concentrations that exceed applied guideline values.

1. ANZECC and ARMCANZ, Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, ACT. Marine water quality guidelines (95% trigger values).

2. 1:5 solid:water extracts