# Weld Range Project
# Waste Rock Water Quality Estimates

**Report Prepared for**

Sinosteel Midwest Corporation Limited

**Report Prepared by**

srk consulting

**SMM004**

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# Waste Rock Seepage Water Quality Estimates

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# 1 Introduction

The proposed Sinosteel Midwest Weld Range Project (WRP) includes the development of open-cut pits and construction of waste material landforms. A prefeasibility study (PFS) was completed at the time of sample selection for geochemical characterisation. Since the sample selection a feasibility study (FS) (Value Improvement) based on a larger pit shell has been completed. The proposed mine plan includes development of open-cut pits, stockpiles and waste rock dumps. Ore will be stockpiled on site and, blended before direct shipping for processing.

SRK Consulting (Australasia) Pty Ltd (SRK) carried out a geochemical characterisation programme to assess the potential for acid and metalliferous drainage (AMD) from waste rock that will be mined from the open pits. The results from that programme is reported elsewhere (SRK, 2009; SRK 2011) and indicated that some proportion of the waste rock is likely to be net acid generating. This report utilises the results from the static and kinetic tests to estimate potential seepage water quality that may be formed by the waste rock piles.

# 2 Background

## 2.1 Location

WRP is located 600 km NNE of Perth, 65 km southwest of Meekatharra and 50 km northwest of Cue in the Mid West region of Western Australia. A location map is provided in Figure 2-1.

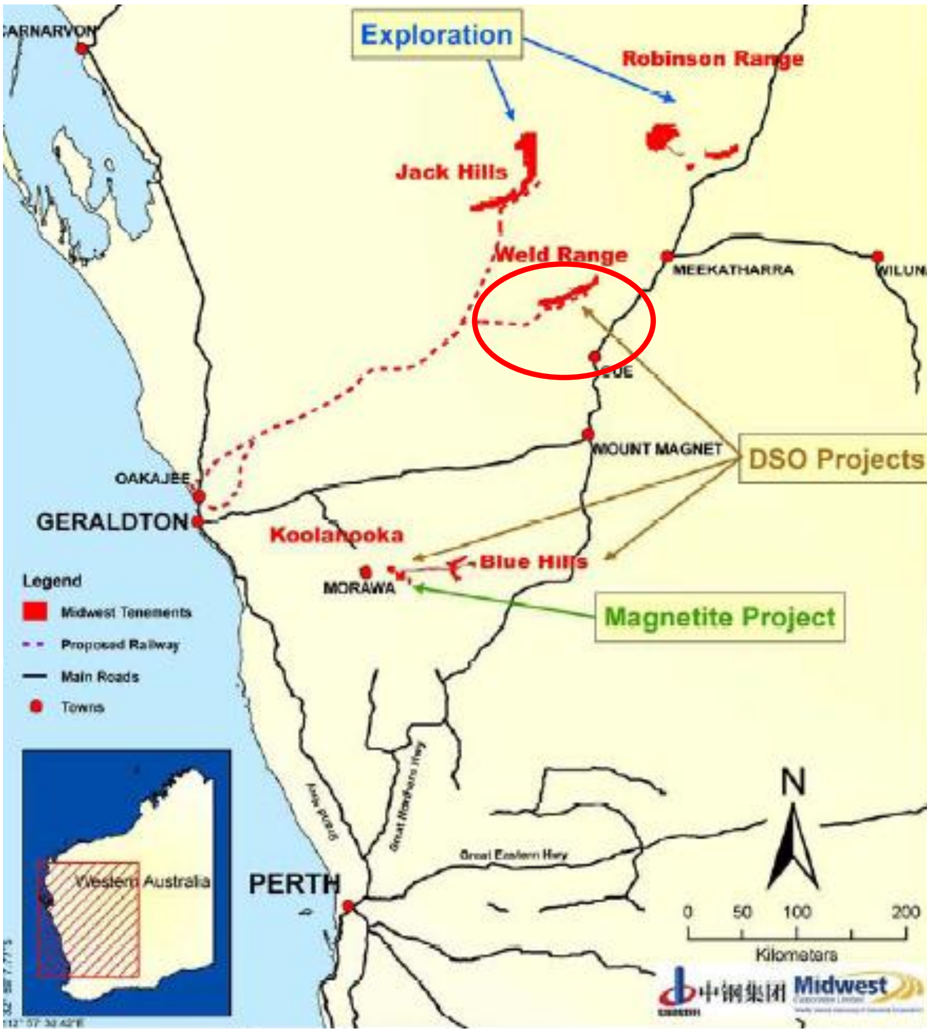


**Figure 2-1: General location of the Weld Range Project**

## 2.2 Geological setting

The Weld Range Project includes the Madoonga and Beebyn iron ore deposits. Both deposits consist of rock sequences steeply dipping to SE at Beebyn and to the SSE at Madoonga. The rock sequences include banded iron formations (BIFs) and dolerite.

At Madoonga, the local rock sequence from north to south comprises a package of felsic (FEL) sedimentary rocks overlain by BIF approximately 60 to 250 m thick. The lower part of the BIF contains a shale unit 5 to 10 m thick. A zone of deeply weathered and altered rocks within which the iron mineralisation is hosted, occurs in the hanging wall of the BIF and is between 20 to 50 m thick. Mafic igneous rocks including dolerite and basalt occur in the hanging-wall.

The Beebyn deposit contains numerous BIFs interlayered with dolerite. The main BIF at the north is approximately 40 m thick. BIF layers to the south range from about 2 to 10 m. Least altered and un-weathered BIFs contain millimetre to centimetre-thick iron-, silica-, Fe-silicate- and locally carbonate-rich bands (SRK, 2008).

## 2.3 Landscape

Arid shrub lands make up the vast majority of vegetation encountered. The arid shrub lands host a number of native plant species, which do not occur in many other bioregions. There are few or no trees or perennial grasses across much of the landscape.

## 2.4 Climate

The summers are characterised by hot, dry days and mild to warm dewless nights. At Meekatharra maximum daily temperatures during the summer range from 29 to 38°C and the minimum daily temperatures range from 14 to 22°C. Winter is characterised by mild days and cool to cold nights. Winter average daily temperatures range between 6 and 19°C in July and rise to 13 and 29°C in October (Department of Agriculture, WA).

At Cue the average daily temperature ranges from 7 to 18°C in July to 23 to 38°C in January.

The rainfall records for Meekatharra and Cue are summarised in Table 2-1. Mean annual rainfall is 232 mm at Meekatharra with the wettest months being January to July. Average annual open pan evaporation is in excess of 3 m per year. Whilst cyclones are not regarded as regular events in the Meekatharra district, they do cause widespread heavy rainfall. Cyclones usually occur between November and April when intense low pressure disturbances develop off the north-west coast of Western Australia and high daily rainfall events can occur.

**Table 2-1 Summary of Rainfall Records for Meekatharra and Cue**

| | Meekatharra | | | Cue | |
|---|---|---|---|---|---|
| | Mean | Highest Daily | Pan Evap. (2009) | Mean | Highest Daily |
| Month | mm | mm | mm | mm | mm |
| Jan | 27.1 | 103.13 | 512.4 | 26.6 | 117.6 |
| Feb | 35.3 | 69.42 | 374.4 | 29.2 | 119 |
| Mar | 28.1 | 106 | 366.4 | 23.5 | 90.2 |
| Apr | 20.7 | 39.6 | 250.4 | 19.4 | 82 |
| May | 23.2 | 44.2 | 193.2 | 25.1 | 57.9 |
| Jun | 30.6 | 114.4 | 111.2 | 28.3 | 53.8 |
| Jul | 21.7 | 62.1 | 104.6 | 25.7 | 56.2 |
| Aug | 11.3 | 23.6 | 174.4 | 17.2 | 36.3 |
| Sep | 4.6 | 21.4 | 216.2 | 6.8 | 29 |
| Oct | 6.3 | 33.42 | 328.6 | 6.6 | 30 |
| Nov | 11.6 | 81.8 | 345 | 8.9 | 39.9 |
| Dec | 12.1 | 55.6 | 492.2 | 13.9 | 58.2 |
| Total | **232.6** | **-** | **3469** | **231.2** | - |

## 2.5 Waste Production

The waste rock production estimated for the proposed developments were obtained from the block model developed for the Feasibility Study, and is shown in Table 2-2. The waste rock is expected to be produced over a 12 year period.

**Table 2-2 Summary of Estimated Waste Production at Madoonga and Beebyn**

| Domain | Description | Mass (resource model) (tonnes) | Distrib. (% mass) |
|---|---|---|---|
| **Madoonga** | | | |
| DID | Detrital | 9,684,594 | 2.8 |
| FEL | Felsic volcanic | 32,411,073 | 9.2 |
| BIF | BIF sedimentary sequence | 111,946,972 | 31.9 |
| HYD | BIF Hydrated sequence | 43,310,909 | 12.3 |
| SHL | Shale | 20,774,898 | 5.9 |
| MAF | Mafics | 132,933,534 | 37.9 |
| **Total** | | **351,061,979** | **100.0** |
| **Beebyn** | | | |
| BIF | Banded Iron Formation | 32,524,388 | 8.4 |
| SHL | Shale | - | - |
| MAF | Mafics | 355,894,175 | 91.6 |
| **Total** | | **388,418,564** | **100.0** |

# 3 Summary of Geochemical Results

## 3.1 Investigations

The mass of waste rock to be produced at the Madoonga and Beebyn deposits was estimated to be approximately 364 Mt based on the PFS. The pit shell derived for the FS (VI) is substantially larger and would result in a total production of 739 Mt of waste rock. For the purpose of this assessment it was assumed that the waste materials for the larger pit are reasonably represented by the samples assessed as part of the PFS investigation.

The geochemical investigation was carried out in two phases.

- Phase 1 comprised a scoping level study to assess the overall magnitude of the potential for acid generation based primarily on static test procedures.
- Phase 2 was designed to establish the net potential for acid generation and determine metal leach rates using kinetic tests procedures and supplemental static tests. Materials for testing were selected based on the outcomes of Phase 1.

The objectives of kinetic testing were to obtain estimates of:

- rates of oxidation from sulphate release;
- release of metals; and,
- lag time to the onset of acidic conditions.

An outcome of the evaluation is the assessment of the maximum sulphur content below which acid generation is unlikely to occur and which may serve as a cut-off for classifying materials as potentially acid forming (PAF) or non-acid forming (NAF) during mining.

The initial geochemical results were reported in October 2009 (SRK, 2009) and the results from the second phase were reported in March 2011 (SRK, 2011).

## 3.2 Summary of Results and Conclusions

A total of 427 samples were characterised using static and kinetic testing procedures. The results and observations are summarised as follows:

### 3.2.1 Paste Parameters

The paste pH and conductivity results for core samples stored in core trays for up to 18 months indicated that net acid generating materials are likely to be present in the waste rock materials. Low pH samples were sourced from the shale (SHL), hydrated (HYD) and banded iron formation (BIF).

### 3.2.2 Acid Base Accounting

In general the waste rock is expected to have a relatively low sulphide content. Nevertheless there are lithological units present at both deposits that are likely to be net acid forming. The results from the acid base accounting testing, including the NAG testing, indicate the following:

For Madoonga:

- 83 to 90% of the waste is likely to be non acid forming (NAF);
- 10% of the waste is likely to be potentially acid forming (PAF) comprising portions of the banded iron formation (BIF), hydrated (HYD), mafic (MAF) and shale (SHL);
- up to 6% of the waste is likely to be classified as uncertain (UC).

For Beebyn:

- 99% of the waste is likely to be NAF;
- about 1% of the waste is likely to be PAF, primarily from the mafic domain (MAF).

Using the average properties of each of the lithological units (as inferred from the static geochemical dataset), overall average geochemical properties of waste rock dumps at each site can be calculated on the basis of the estimated production schedules. The results are shown in Table 3-1. Based on the results shown in the table it is expected that the Madoonga waste rock dump could be net acid generating, albeit at a low capacity. These calculations assume that waste rock will be intermixed as it is produced, i.e. potential acid generation from hydrated BIF (HYD) and the shales (SHL) will be neutralised by nearby ANC within well mixed materials. However, inter-mixing may not be effective, in which case the hydrated BIF (HYD) and the shales (SHL) will require specific handling and disposal to ensure that they do not generate acid.

In the case of the Beebyn dump, it is almost certain that no acid generation would occur.

**Table 3-1 Summary of Average Waste Rock Dump Compositions**

| Domain | Mass | Tot S | MPA | ANC | NAPP | NPR |
|---|---|---|---|---|---|---|
| | (t) | (%) | ( kg(H2SO4)/t) | | | |
| **Madoonga** | | | | | | |
| BIF | 111,946,972 | 0.075 | 2.3 | 3.0 | -0.7 | 1.3 |
| DID | 9,684,594 | 0.037 | 1.1 | 1.5 | -0.4 | 1.3 |
| FEL | 32,411,073 | 0.015 | 0.5 | 3.9 | -3.4 | 8.3 |
| HYD | 43,310,909 | 0.333 | 10.2 | 2.1 | 8.1 | 0.2 |
| MAF | 132,933,534 | 0.039 | 1.2 | 4.1 | -2.9 | 3.4 |
| SHL | 20,774,898 | 0.82 | 25.0 | 24.0 | 0.9 | 1.0 |
| **Total** | **351,061,979** | 0.131 | 4.0 | 4.6 | -0.6 | 1.2 |
| **Beebyn** | | | | | | |
| BIF | 32,524,388 | 0.03 | 0.8 | 23.1 | -22.3 | 29.8 |
| MAF | 355,894,175 | 0.01 | 0.4 | 10.9 | -10.6 | 29.5 |
| SHL | - | 0.82 | 25 | 3.9 | 3.4 | 0.5 |
| **Total** | **388,418,564** | **0.01** | **0.4** | **11.9** | **-11.5** | **29.5** |

## 3.3 Kinetic Test Results

A total of 13 kinetic tests were completed on samples representing each of the lithological units from each of the deposits. The results were used to estimate oxidation rates and solute release rates from the various material types. A summary of the estimated steady state sulphate generation rates and release rates for selected metals is provided in Table 3-2. As shown in the table, some of the materials were net acid generating. Notably the sulphate generation rate for similar rock types is higher for acidic conditions than for neutral pH conditions. The shale is shown to most reactive, followed by the hydrated BIF sample. Both these samples had elevated sulphide sulphur contents. The Mafic (MAF) and the BIF samples also were found to be net acid generating and had sulphide sulphur contents of 0.3% and 0.51% respectively. These results clearly indicate that even the low sulphur materials have a potential to generate acid.

**Table 3-2 Summary of Kinetic Test Results**

| Column ID | Domain | pH | Sulphate mg/kg/wk | Al mg/kg/wk | Cu mg/kg/wk | Fe mg/kg/wk | Se mg/kg/wk | Zn mg/kg/wk |
|---|---|---|---|---|---|---|---|---|
| A13050 | BIF | 6.5 | 0.75 | 3.8E-03 | 3.8E-03 | 7.5E-03 | 1.9E-04 | 7.5E-03 |
| SRK13059 | BIF | 4.3 | 7.78 | 4.1E-02 | 6.9E-03 | 7.5E-01 | 0.0E+00 | 5.0E-02 |
| A13019 | DID | 6.5 | 3.24 | 3.6E-03 | 3.6E-03 | 3.6E-03 | 1.8E-04 | 7.2E-03 |
| SRK5 | DID | 6.6 | 0.40 | 4.0E-03 | 4.0E-03 | 4.0E-03 | 0.0E+00 | 1.7E-02 |
| A13035 | HYD | 6.5 | 3.25 | 3.0E-03 | 3.0E-03 | 3.0E-03 | 2.7E-03 | 8.9E-03 |
| SRK24 | HYD | 7.9 | 4.92 | 4.7E-03 | 3.1E-03 | 5.2E-03 | 0.0E+00 | 8.6E-03 |
| SRK25 | HYD | 2.8 | 161 | 2.3E+00 | 3.8E-02 | 8.1E+01 | 1.3E-04 | 3.7E-02 |
| A13017 | MAF | 7 | 1.07 | 1.1E-02 | 3.6E-03 | 1.4E-02 | 1.8E-04 | 7.1E-03 |
| SRK15 | MAF | 4.3 | 2.31 | 5.0E-02 | 4.2E-03 | 3.5E-03 | 0.0E+00 | 2.3E-02 |
| SRK330 | SHL | 2.7 | 381 | 1.3E+01 | 3.5E-01 | 1.6E+02 | 0.0E+00 | 4.8E-02 |

# 4 Water Quality Estimation Approach and Assumptions

## 4.1 Introduction

This section describes the approach and assumptions adopted to estimate the potential water quality that may occur within the waste rock dumps. Since the waste characterization has shown that some proportion of the waste material has a potential to generate acid, waste management practices will need to be implemented to manage or prevent acid generation.

Consequently, the waste management strategy (i.e. what will be done to prevent acid generation) will dictate the resultant water quality. Therefore to develop the water quality predictions it is necessary to understand the waste management strategy that will be implemented. Ideally several iterations would need to be carried out during which a waste management strategy would be proposed, the success of implementation of that strategy would be assessed and then the resultant water quality would be estimated. The water quality would then be assessed against accepted or proposed water quality criteria and/or potential surface and groundwater water quality impacts, and if the impacts are unacceptable, an alternate strategy would need to be developed and assessed.

However, to be able to develop a suitable waste management strategy requires a good understanding of the quantity of each lithological unit that will be produced, when it will be produced and where it will be placed (i.e. schedule of waste production to understand spatial placement in the waste material landforms). This allows an assessment of interaction between, for example, acid generating and acid consuming waste material. Such waste production and placement schedules were not available. Therefore for the purpose of this assessment only a base-case evaluation will be completed in which it is assumed that the waste rock is intermixed. Each material type will be assumed to react according the reaction kinetics inferred from the kinetic tests and the outflow or percolate water would represent a weighted average of these leach rates.

To estimate the water quality it is also necessary to understand how the flows (from meteoric waters) that will pass through the dump. Again, these flows may be influenced by mitigation measures such as covers and so on. Another factor that will need to be evaluated is the ingress of oxygen to support the oxidation reactions. Modelling of all of these aspects require detailed physical and geochemical properties of the waste material. At least from a physical perspective, it is difficult to determine, for example, factors that will impact oxygen ingress to the waste material landform on the basis of core samples alone. Fracturing during blasting will determine mineral exposure and size distribution and cannot be determined accurately without the benefit of actual operational waste material data. Therefore, for the current assessment, simplified but conservative assumptions will be adopted in the assessment.

## 4.2 Landform Development

The waste rock dumps would be developed at 10 m lifts throughout. At Beebyn, the north dump would be constructed to an overall height of 70 m (i.e. 7 lifts) with a maximum footprint of 112 ha, and the south dump to an overall height of 80 m (i.e. 8 lifts) with a maximum footprint of 285 ha. The Madoonga dump would be constructed to a height of 80 m (8 lifts) and a maximum footprint of 310 ha.

## 4.3 Infiltration and Oxygen Entry

Factors that may influence net infiltration into waste material landforms, although numerous, may be categorized broadly as follows:

- atmospheric boundary conditions, i.e. climate,
- waste material physical, hydraulic and chemical properties, and
- pile construction technique, which in turn relates to internal pile structure.

The project is located in an area where evaporation greatly exceeds rainfall. Rainfall can also vary significantly. Recharge to the waste material landforms is expected to vary over the life of the dump. Initial infiltration rates are expected to be high due to the coarse nature of the waste material. With compaction (trafficking by heavy vehicles) and as the waste material weathers and slakes net infiltration is expected to decrease overtime.

In arid and semi-arid areas, the natural recharge (i.e. the amount of precipitation that enters the ground profile and contributes towards replenishing of the groundwater) may be an indicator of the potential net infiltration to the waste material landform. Scanlon et al. (2006) carried out an extensive international review of recharge rates in arid and semi-arid environments and concluded that on average recharge rates in these regions, if undisturbed, range between 0.1 and 5% of the long-term annual precipitation. This observation is supported by data presented by Xu and Beekmann (2003), which suggest that in arid and semi-arid regions of South Africa and Botswana the annual recharge is between 0.1 and 18%, but closer to about 1% or less for areas with mean annual precipitation close to the 230 mm experienced at the project site. The magnitude of the natural recharge is expected to be less than 1% (e.g. in some areas near Kalgoorlie estimates of recharge have been in the order of 0.5% or less (Source: Bureau of Rural Sciences).

Although for most part available data reported in the literature as referenced above are: i) anecdotal, ii) indirectly derived, or iii) theoretically estimated, net infiltration as a fraction of annual precipitation decreases significantly as the site precipitation decreases.

The waste material landforms will consist of run-of-mine waste, which will consist of overburden sedimentary and basement material. Actual grain size distribution will vary according to material type. Considering the range of geological regimes within the proposed pits, as well as the mine sequencing, the waste material landform is expected to be heterogeneous, which in turn means that net infiltration would not be constant over the entire area of the waste landform. In some areas the infiltration both during operations and after closure could be managed through the selective placement of material or material blending.

The internal structure of a waste material landform is to a large extent defined by the method of construction. Conventional truck end-dumping results in physical material segregation and layering, which in turn will result in preferential flow within the waste landform (i.e. not all of the waste will be contacted by the infiltrating water (Hockley et al., 1996)).

For the most part the in-situ moisture content of waste material when placed will be at a gravimetric moisture content of about 2 to 5%. With field moisture capacities ranging up to 15% this means that the waste material will have a large capacity to take up water before it will actually release seepage water at the base. Considering the low rainfall and low recharge expected for the area, this could mean a delay of decades to centuries before the seepage would enter the groundwater system. However it is possible that some seepage could occur due to selective flowpaths (Williams and Rhode, 2008).

Actual data for infiltration rates into waste landforms are extremely scarce, and when data are published it is often very difficult to determine the accuracy of the data. None of these case studies are, however, in a climate regime similar to the proposed project, i.e. they were all located in higher precipitation zones, with lower evaporation rates. Data from uncovered heap leach pads in Nevada, USA, suggest net infiltration rates range from 12 to 21% (Rykaart et al, 2006). The precipitation regime at these sites was, however, still higher, and the evaporation lower, than that at project location. The actual infiltration at the site is therefore likely to be much less and anticipated to approach levels of regional infiltration.

In the light of the above, it will be assumed that the net average recharge will be 5% of mean annual precipitation, as a base case.

Oxygen is supplied to sulphidic material in the dump interior via transport from external surfaces. Gas transport can be controlled by diffusive processes, or through more rapid gas convection or advection. With end dumped waste material, typically the coarse waste accumulates at the base of a lift and the fines nearer the top. This results in layering of coarse and fine material that may provide ‘channels’ for advective oxygen transport. Advective oxygen entry can be constrained by the placement of covers, or through compaction, that extends down the sideslopes. For the purpose of the base case assessment it was assumed that there would be no constraints on oxygen entry, and the dumps would be fully oxygenated.

## 4.4 Assignment of Oxidation and Leach Rates

Since a detailed schedule of the waste rock production and associated geochemical properties is not available, for the purposes of this assessment the waste rock dump is assumed to be fully mixed. Reaction kinetics were assigned according to the make-up of the waste rock dump (i.e. the relative abundance of each material type). Furthermore, since the distribution of the acid generation properties are not known, interaction that may lead to acid neutralisation (i.e. where acid generated near the surface flows down and is neutralised by alkaline materials at depth) will not be considered herein.

While oxidation rates and solute release rates are available for both acidic and neutral pH conditions for the BIF, HYD and MAF materials, the detailed schedule of acid generation properties is not known. Therefore for simplicity, to obtain the average oxidation rate for each rock unit, the oxidation and solute rates were apportioned according to the proportion of net acid generating materials as estimated in the static testing program. This will lead to conservative estimates of oxidation rates and solute release considering that the sulphur content of the SHL and HYD samples were well above the average sulphur content for these units.

## 4.5 Scaling Factors

In order to calculate the potential solute concentrations in the water passing through a full scale dump it is necessary to consider the differences between the kinetic tests and the field conditions. First, the kinetic tests are performed at small particle sizes (constrained both in sampling, i.e. core samples and physical test conditions, i.e. size of testing apparatus) whereas the waste rock dump will contain run of mine materials. Most of the surface area, and therefore reactive area, is associated with the fines fraction of waste material (< 10 mm). The actual proportion of fines will depend on the blasting intensity and frequency as well as the friability of the waste. The proportion of fines can range from as low as 5% in very competent material to as high as 30 to 40% for very friable material, and is expected to vary according to the lithological unit. An example plot is provided in Figure 2-1 showing a typical size distribution for blasted run of mine waste rock and comparing the particle size distribution for the materials tested in the column tests. Based on these size distribution curves it can be shown that the surface area ratio of run of mine waste rock to test material ranges from about 0.06 to 0.08. For the purpose of this assessment it was conservatively assumed that the ratio is about 0.1.

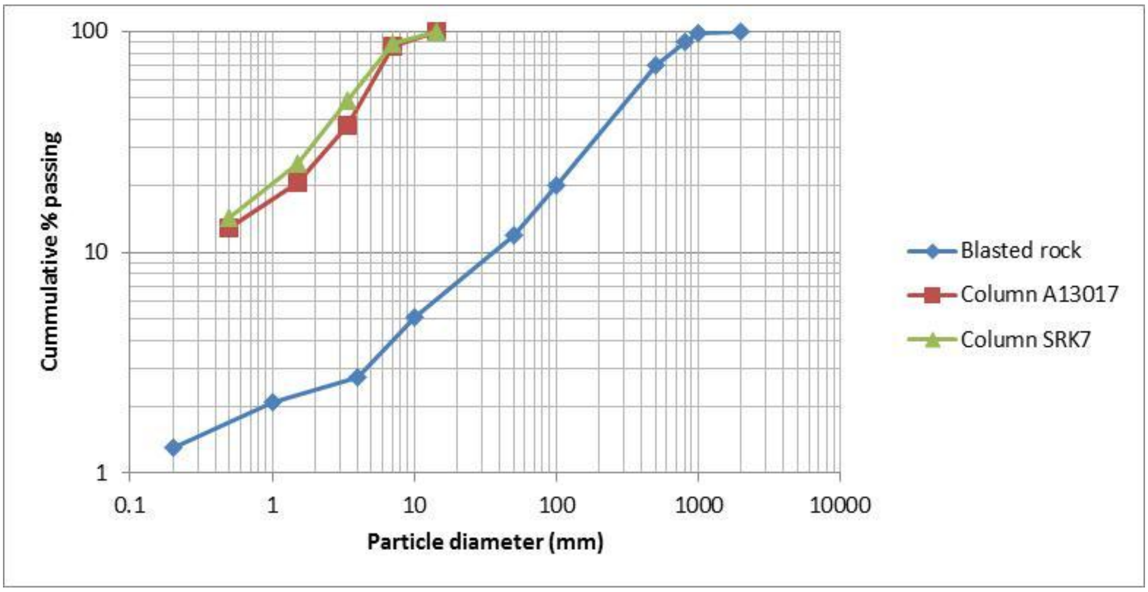


**Figure 4-1 Comparison of Test Sample and Run of Mine Waste Rock Particle Size Distributions**

The kinetic tests are designed to maximise flushing so that all the solutes that are generated can be recovered and used for assessing release rates. However, selective flow paths are expected to form within the waste rock dump so that only a portion of the waste landform will be contacted by meteoric water that infiltrates the landform. The proportion of waste that would be contacted would vary depending on the final particle size distribution, the dumping method, segregation and layering and so on. Typical fractions of waste contacted by infiltration reported in the literature range from about 5% to as high as 50%, ranging from dry to wet climates. The project location is arid and recharge is expected to be very low. Therefore, for the purpose of this assessment, it was assumed that about 10% of the waste would be contacted by water that passes through the dump.

A final consideration is the availability of oxygen. As already mentioned, oxygen entry is assumed to be unconstrained and the dump fully oxygenated.

# 5 Results and Discussion

## 5.1 Water Quality Development

The column test results indicated that there is an initial release of salinity, predominantly in the form of sodium chloride. This release may be from saline porewater or from drilling fluids that were used during the drilling and recovery of the core. In the event the primary source of the salinity is saline porewater (groundwater) then a similar release of salinity would be expected during the early phases of seepage from the waste rock dumps. Since the source of the salinity is unknown, the initial flush cannot be determined and is not quantified herein. Should the groundwater quality be available, it may be possible to estimate the initial flush. A similar initial flush in surface runoff would be expected. However, estimation of the initial flush is beyond the scope of this assessment.

In the following sections the longer term water quality, which would result from the oxidation and neutralisation reactions within the dump, are determined and discussed. Since the dumps are being considered as fully mixed, the water quality estimates derived below are for steady state conditions only, i.e. for conditions where the reactions have fully developed and seepage rates have stabilised.

## 5.2 Madoonga Waste Rock Dump

### 5.2.1 Madoonga Base Case

The estimated base case water quality for the seepage from the Madoonga waste rock dump is shown in Table 5-1. These estimates do not consider that some solutes may exceed solubility limits of secondary mineral phases that may form within the dump. Therefore the concentrations were assessed in the geochemical speciation model MINTEQA2 (developed by the USGS). The results of the equilibrated solutions (following precipitation of the relevant secondary mineral phases) are included in the table as shown. The secondary minerals that may form to reduce the relevant solute concentrations are identified in the last column of the table.

**Table 5-1 Summary of Base Case Madoonga Seepage Water Quality**

| Parameter | Base Case Water Quality mg/L | Equilibrated mg/L | Phase |
|---|---|---|---|
| pH | - | 1.6 | |
| Sulphate | 31968 | 28722 | Gypsum, Jarosite |
| Al | 1785 | 1785 | |
| Sb | 1.0 | 1.0 | |
| As | 18.5 | 18.5 | |
| Ba | 3.40 | 0.004 | Barite |
| Ca | 2626 | 322 | Gypsum |
| Co | 46.8 | 46.8 | |
| Cu | 58.3 | 58.3 | |
| Fe | 23401 | 19532 | Jarosite |
| Pb | 0.94 | 0.94 | |
| Mg | 4119 | 4119 | |
| Mn | 88 | 88 | |
| Mo | 0.79 | 0.79 | |
| Ni | 119 | 119 | |
| P | 115 | 0.62 | Strengite |
| K | 855 | 0.05 | Jarosite |
| Si | 881 | 42 | $SiO_2$(am) |
| Sr | 8.5 | 8.5 | |
| U | 0.171 | 0.171 | |
| V | 29 | 29 | |
| Zn | 37 | 37 | |

As shown, in general the seepage water is expected to be acidic and generally would have elevated concentrations of sulphate and various metals. The seepage may report to surface water or groundwater and in general would not be considered acceptable for discharge.

### 5.2.2 Madoonga Mitigated Case

Mitigation of the Madoonga Dump may include various strategies that are implemented either during operations or after operations cease, or both, as the operational strategies may be combined with the closure strategy. The operational strategies may include selective placement of the sulphide materials within the dump, to limit oxygen entry to the material and thus minimise the overall rate of oxidation, or backfilling the material to an open pit to below the long term water level after the water table recovers. Post closure strategies generally comprise placement of covers to reduce oxygen and water entry to the dump.

The most effective strategy for preventing long term oxidation and acid generation is placement of the sulphide materials below the water table. This in general would preclude future oxidation and water quality impacts would be minimised.

The effectiveness of selective placement of the sulphide materials within the waste rock dump will depend on the success of identifying the sulphidic materials, accurate placement of these materials, as well as the depth at which it would be placed and the properties of the materials placed around it. Assessment of this option would require a good understanding of the schedule of when the sulphide and non-sulphidic material would be produced. Since the schedule is not yet available, such an assessment cannot be included in the current scope. Therefore, only a post closure option will be considered herein. It is assumed that a soil cover would be placed after closure that would constrain oxygen ingress to a diffusional process. This would require a sufficiently thick fine grained compacted soil type cover that would extend down the sideslopes of the waste rock dump. The actual configuration of the cover would need to be assessed based on the actual properties of the soils and materials that would be available for the construction of the cover. Typically the cover system would also lower the rate of infiltration, but for the purpose of this assessment it was assumed that net recharge would remain at 5% of mean annual precipitation.

Assuming a diffusion control on oxygen ingress, the depth of oxygen entry can be calculated from the oxidation rate using the following formulation:

$$x = (2*D_e * C_o / S')^{0.5}$$

Where:

$D_e$ is the effective diffusion coefficient

$C_o$ is the oxygen concentration in air and,

$S'$ is the oxygen consumption rate (calculated from the oxidation rate)

The depth of oxygen entry is estimated to range from 2 m to 6 m from surface, depending on the rate of oxidation and the effective diffusion coefficient. For the calculations below a depth of 6 m was assumed.

The results of the calculations are shown in Table 5-2. The results show first the percolate from the oxidation zone (i.e. the concentration in water that exists oxidation zone) in the columns **"Mitigated (oxidation zone)"**. As shown, the percolate from the oxidation would be expected to be acidic, at a pH of about 2.5. As before, solubility constraints were determined for these concentrations, and the results for equilibrated solutions are shown in the next column in the table.

**Table 5-2 Summary of Madoonga Mitigated Dump**

| | Mitigated (oxidation zone) | | | Mitigated Seepage | |
|---|---|---|---|---|---|
| Parameter | Water Quality mg/L | Equilibrated mg/L | Phase | Equilibrated mg/L | Phase |
| pH | | 2.5 | | 5.9 | |
| Alkalinity | - | - | - | 418 | Dolomite |
| Sulphate | 2398 | 2292 | Jarosite, Barite | 1793 | Gypsum |
| Al | 134 | 134 | | 27 | |
| Sb | 0.07 | 0.07 | | 0.07 | |
| As | 1.4 | 1.4 | | 1.4 | |
| Ba | 0.255 | 0.001 | Barite | 0.001 | Barite |
| Ca | 197 | 197 | | 436 | Gypsum |
| Co | 3.5 | 3.5 | | 3.5 | |
| Cu | 4.4 | 4.4 | | 3.7 | $CuCO_3(s)$ |
| Fe | 1755 | 1162 | | 1755 | |
| Pb | 0.07 | 0.07 | | 0.07 | |
| Mg | 309 | 309 | | 476 | |
| Mn | 6.6 | 6.6 | | 4.4 | |
| Mo | 0.06 | 0.06 | | 0.06 | |
| Ni | 9.0 | 9.0 | | 4.6 | $NiCO_3(s)$ |
| P | 8.61 | 0.01 | Strengite | 4.97 | Strengite |
| K | 64 | 64 | | 64 | |
| Si | 66 | 50 | $SiO_2(am)$ | 43 | |
| Sr | 0.6 | 0.6 | | 0.6 | |
| U | 0.013 | 0.013 | | 0.013 | |
| V | 2.2 | 2.2 | | 0.4 | |
| Zn | 2.8 | 2.8 | | 2.8 | |

The percolate from the oxidation zone would then flow down through the rest of the waste rock in the dump. Because the oxidation is limited to a narrow zone on the outside of the dump, the rest of the waste rock would not be oxidising and therefore would not be acid generating. The acidic flow would be neutralised by the available ANC that remains in the waste rock at depth. Because of the high ratio of the oxidation zone to the balance of the dump (6 m vs. 80 m) a large excess of ANC is available. Water that would report as seepage would therefore be neutralised. The resultant water quality is shown in the second set of columns **"Mitigated Seepage".** As shown the seepage would be near neutral in pH and the concentrations of metals in general would decrease. The slightly acidic pH would result from excess carbon dioxide that would be generated due to the reaction of the acidic water with the carbonate minerals.

## 5.3 Beebyn Waste Rock Dumps

The North and South Beebyn waste rock dumps are expected to be similar in composition and similar in height (North 70 m and South 80 m). Therefore the seepage water quality is expected to be similar for both dumps. The estimated seepage quality is summarised in Table 5-3. As before the solute release equivalent concentrations and the corresponding equilibrated seepage water quality estimates are presented. As shown, the seepage from the Beebyn dumps is expected to be neutral in pH. As a result, most metals are at relatively low concentrations and it may be possible that no mitigation of the dumps would be required. The requirements for mitigation would need to be assessed based on the potential impacts on receiving water quality.

**Table 5-3 Estimated Beebyn North and South Dump Seepage Water Quality**

| | Water Quality | Equilibrated | |
|---|---|---|---|
| Parameter | mg/L | Concentration mg/L | Phase |
| pH | - | 6.3 | |
| Alkalinity | - | 33 | Dolomite |
| Sulphate | 3929 | 3396 | Gypsum |
| Al | 71 | 1 | |
| Sb | 0.54 | 0.54 | |
| As | 4.3 | 4.3 | |
| Ba | 1.801 | 0.005 | Barite |
| Ca | 2808 | 450 | Gypsum |
| Co | 1.1 | 1.1 | |
| Cu | 12.5 | 3.5 | $CuCO_3(s)$ |
| Fe | 508 | 508 | Ferrihydrite |
| Pb | 0.58 | 0.58 | |
| Mg | 2796 | 1769 | |
| Mn | 12.1 | 5.2 | Rhodochrosite |
| Mo | 0.46 | 0.46 | |
| Ni | 13.8 | 4.2 | $NiCO_3(s)$ |
| P | 114.56 | 18.51 | Strengite |
| Se | 0.57 | 0.57 | |
| Si | 50 | 48 | $SiO_2$ (am,ppt) |
| Sr | 9.5 | 9.5 | |
| U | 0.292 | 0.292 | |
| V | 42.6 | 0.2 | $V(OH)_3(s)$ |
| Zn | 23.6 | 11.2 | Smithsonite |

# 6 Conclusions and Recommendations

Water quality estimates have been prepared for the proposed Madoonga and Beebyn waste rock dumps and are presented herein.

The results indicated that the Madoonga dump is likely to be net acid generating and percolate is likely to contain elevated concentrations of sulphate and metals. The seepage water is likely to be unacceptable for direct discharge and will require mitigation. Whilst various options are available for managing the waste rock during operations, evaluation of this options would require the development of a detailed waste production schedule that provides a clear indication of the waste properties (sulphide content, ANC). This would allow an assessment of the potential for acid generating waste to be segregated and placed strategically within the waste rock dump, or backfilling into an open pit where it might be inundated.

In the absence of a detailed schedule, potential benefits for restricting oxygen ingress into the Madoonga dump to diffusion alone were assessed. The results suggest that, if oxygen ingress can be limited to diffusion, while the percolate in the oxidation zone would remain acidic, the percolate from the dump base would be near neutral in pH and metal concentrations should decrease significantly.

The results for the Beebyn dumps indicate that the seepage from these dumps should remain neutral in pH. Whilst sulphate concentrations are likely to be elevated, metal concentrations are expected to comparatively low. It may be possible that the impacts from an unmitigated dump may be acceptable for discharge. However, an impact assessment would be required to evaluate the requirements for mitigation.

SRK recommends that:

- A detailed waste production schedule be developed that would provide an indication the waste properties over time. The schedule should then be used to evaluate the feasibility of selective and strategic placement of acid generating waste to limit oxidation and to assess if this can be effective in limiting acidic seepage.
- An impact assessment be completed to evaluate the minimum requirements for oxidation control acid generation mitigation to identify applicable and evaluate feasible control measures that may be considered both during operations and after closure.

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All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.

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