

CONTENTS

1.	Acknowledgement	1
2.	Purpose of Materials Characterisation Guidance	1
3.	Soils Characterisation	2
3.1	Soil characterisation outcomes.....	5
3.2	Soil sampling requirements.....	5
3.3	Recommended analyses.....	6
3.4	Collation and interpretation of soil analyses results.....	6
3.4.1	WA Soil Groups.....	6
3.4.2	Water holding capacity	6
3.4.3	Nutrient status.....	6
3.4.4	Salinity.....	6
3.4.5	Sodicity	6
3.4.6	Dispersion Risk and the evolution of soil stability EC vs ESP	6
3.4.7	Erodibility	7
4.	Subsurface Materials Characterisation.....	8
4.1	Subsurface materials characterisation outcomes.....	9
4.2	Subsurface materials sampling requirements.....	10
4.3	Recommended subsurface analyses.....	11
4.3.1	Materials with Acid Sulphate Soils Potential	14
4.3.2	Materials with AMD potential.....	14
4.3.3	Materials with Metalliferous Drainage Potential (associated with both sulphides and unrelated to sulphides)	17
4.3.4	Materials with Saline Drainage Potential	17
4.3.5	Materials with Sodic or Dispersive Potential	18
4.3.6	Fibrous and Silicate Materials	19
4.3.7	Radioactive Materials	19
5.	References	19
6.	Glossary	21
7.	Abbreviations	22
8.	Example suite for rock analysis.....	23
9.	Example suite for leachate analysis	24

Tables

Table 1	Baseline Soil Analysis.....	3
Table 2	Example Presentation of Soils Characterisation within a Mining Proposal.....	5
Table 3	Wind Erodibility Rating (Hazelton 2007)	7
Table 4	Suggested Phase 1 Characterisation Sampling Frequency Based on Tonnage When Sampled Without Prior Information.....	11
Table 5	Guidance for Initial Subsurface Materials Sampling and Analysis	11
Table 6	Guidance on Additional Characterisation Test Work for Materials Requiring Further Assessment	11
Table 7	Example Presentation of Subsurface Materials Characterisation Within a Mining Proposal	13

Figures

Figure 1	Phases of Materials Characterisation.....	8
Figure 2	Barren Non Acid Forming screening test decision tree for samples with Total S <0.05wt%	15
Figure 3	Acid and Metalliferous Drainage Decision Nodes and Acid and Metalliferous Drainage Classification Categories (adapted from AMIRA 2002)	16

1. Acknowledgement

The Department of Mines and Petroleum (DMP) would like to acknowledge the contribution of the following people to the development of this guidance.

- Marilena Stimpfl
- Russell Staines
- Steve Appleyard
- Evan Howard
- Adam Pratt
- Karen McKenzie
- Alison Turner.

All contributions have been made 'in kind'.

2. Purpose of Materials Characterisation Guidance

For the purposes of this guidance, 'materials' refers to all soils and subsurface material that has been disturbed or extracted by the mining activity, including material that has been physically or chemically processed on site. Materials characterisation identifies the physical and geochemical properties of materials and classifies them as to whether they have the potential to cause environmental harm, or contribute to, or detract from, success of rehabilitation and closure.

Materials characterisation is a critical component of mine planning due to the large-scale physical disturbance that is associated with most mining activities. It helps ensure that the risk assessment is appropriately informed, and aids in responsible mine closure planning. Given its importance to mine planning and closure planning, appropriate characterisation of materials assists in the cost-effective operation and closure of a mine. Materials characterisation provides a basis for preventative management, appropriate use of materials and improved environmental outcomes. Effective materials characterisation and scheduling can save on double handling and expensive remediation later in mine life. The proponent will use the materials characterisation baseline data to inform the Mining Proposal risk assessment.

Materials may include but are not limited to overburden, ore, heap leach piles, site derived construction materials, pit walls, waste material, processing waste, tailings, stockpiles, soil and rehabilitation substrates. Materials characterisation can be undertaken in association with exploration and resource definition drilling programs, however, it is important that materials characterisation is not biased towards the ore zone and that all materials are understood to the same level of detail. All types of materials proposed to be disturbed or impacted by the operation should be characterised. It should be noted that geochemical and physical stability of a material is dependent on site specific conditions such as climate and landform design, in addition to innate physical and chemical properties of the material.

Physical and chemical materials characterisation should address the following risk factors associated with proposed mining project activities:

- acidic and/or metalliferous drainage (AMD), including acidic drainage and metalliferous drainage (encompassing all metals/metalloids regardless of whether the conditions are acidic)
- saline materials and/or drainage
- sodic and/or dispersive material
- erosive material

- material with other chemical/physical properties that will affect stability of rehabilitation (eg. low pH, low fertility, poor structural integrity)
- fibrous minerals
- naturally occurring radioactive material (NORM).

This document is designed to provide additional guidance to proponents when completing a Mining Proposal. It covers all different types of materials characterisation that may be relevant to the different types of mining that occurs in Western Australia (WA).

This guidance is not intended to mandate set requirements for sampling, data collection and analysis for every mine site. Wherever a proponent can justify that various parts of this guidance are not relevant or necessary to be able to successfully determine the environmental risks, this can be accepted by DMP. On occasions DMP may ask proponents to justify why they haven't undertaken work that is recommended by this guidance document.

3. Soils Characterisation

Soil provides a growth medium for vegetation and habitat for soil organisms. Soil also influences the hydrological function of the land surface. The characteristics of the soil profile determine appropriate methods for soil stripping, handling and storage of topsoil and subsoil components, and soil profile reinstatement within post disturbance rehabilitation programs.

Soil characterisation can be undertaken prior to, or concurrent with, standard drilling programs.

3.1 Soil characterisation outcomes

Soil characterisation should be undertaken for the purposes of:

- Estimating the quantity and quality of the soil resource (topsoil and subsoil) including each major soil type.
- Characterising the baseline growth medium attributes of each major soil type including water holding capacity and nutrient status.
- Evaluating potential risks associated with salinity, wind erosion and water erosion.

3.2 Soil sampling requirements

A comprehensive sampling program must consider the following:

- the climate of the project area
- optimal timing of sampling
- soil landscape mapping completed by the Department of Agriculture and Food (DAFWA). This delineates broad scale landscape patterns, landforms and associated major soil groups and vegetation types. An example of relevant information is provided as follows:
 1. Collier land system (Pilbara) - undulating stoney uplands, low hills and ridges and stoney plains supporting mulga shrub lands. Upper landscape positions include stony soils, and shallow loams and sands. Lower landscape positions include clays and earths of variable depth.

- adequate spatial coverage and replication to identify and characterise major soil types. Soils can be classified in accordance with Soil Groups of Western Australia Resource Management Technical Report 380 Fourth Edition (Schoknecht N and Pathan S, 2013). Sampling should include surface and subsoil layers.

Physical soil measurements will have long-term value if they have an associated site and profile description that conforms to standards defined in the Australian Soil and Land Survey Field Handbook (McDonald et al. 2009).

3.3 Recommended analyses

Table 1 Baseline Soil Analysis outlines the recommended soils characterisation analysis for operations in WA (with the exception of any mining where minimal soil profile disturbance will occur or where the soil is the material being mined, e.g. river sand mining and some quarries.)

Table 1 Baseline Soil Analysis

Parameter	Relevance	Typical methodology (other methodologies may be used)	Standard Units or Descriptors
Bulk density	Required for estimation of water holding capacity and inference of plant available water capacity (PAWC).	McKenzie, Coughlan, Creswell (2002) Soil Physical Measurement and Interpretation for Land Evaluation, Commonwealth Scientific and Industrial Research Organisation (CSIRO) publishing.	kg/m ³
Particle Size Distribution for aggregates <2mm	Augments field texture classing. Defines the proportion of sands, silts and clays within the soil medium. Particle size distribution informs the assessment of erosion and sodicity risks (where there is a high Exchangeable sodium percentage (ESP) but % clay is <10%, then Sodicity is a low risk).	McKenzie, Coughlan, Creswell (2002) Soil Physical Measurement and Interpretation for Land Evaluation, CSIRO publishing.	Percentage of particle (e.g. clay, sand, silt) and description of the relative amount of a size fraction or particle in soil.
Coarse fragments	Proportion of a material with particles sizes >2mm.		%
Aggregate stability	Stability of the soil structure units when immersed in water. Instability may be indicated by slaking or dispersion. A soil with a low aggregate stability is likely to be compact and poorly structured or be susceptible to tunnelling erosion.*	Emerson Aggregate Test (Hazelton et al, 2007) (Note that the Emerson Test is a useful first approximation, but it can give misleading results in some circumstances).	Dispersion Very high High High to Moderate Moderate Slight Negligible/aggregated.

Parameter	Relevance	Typical methodology (other methodologies may be used)	Standard Units or Descriptors
Water repellence	<p>A natural condition of the soil preventing it from wetting up.* Water repellence results from waxy organic compounds coating soil particles.</p> <p>Sandy soils (<5 % clay) are most susceptible to water repellence.</p> <p>Claying sandy soils can help to alleviate water repellence.</p>	<p>The time taken for a droplet of water to penetrate the soil or interpretation of ethanol test</p> <p>McKenzie, Coughlan, Creswell (2002) Soil Physical Measurement and Interpretation for Land Evaluation, CSIRO publishing.</p>	<p>Low</p> <p>Moderate</p> <p>Severe</p> <p>Very Severe.</p>
pH	<p>pH characterises the chemical environment of the soil and guides the suitability of soils for growth of particular species.* The soil's pH affects the availability of various nutrients, toxic elements and chemical species to plant roots.*</p>	<p>pH 1:5 soil water ratio.</p>	<p>pH units.</p>
Electrical Conductivity (EC)	<p>The accumulation of water soluble salts. It is a measure of salinity.</p>	<p>EC 1:5 soil water ratio.</p>	<p>dS/m</p>
Exchangeable Cations	<p>The cation exchange capacity (CEC) of a soil is the measure of the soil's capacity to hold important cations such as calcium, magnesium, sodium and potassium ESP is used to calculate sodicity.</p> <p>$ESP = 100 \times \text{exchangeable sodium (cmol/kg)} / \text{CEC}$.</p> <p>If sodium makes up 6% or more of the total cations present, then the soil is classed as sodic. Susceptibility to dispersion will depend on ESP, but also be affected by EC, exchangeable Mg, and clay amount and mineralogy, so competent interpretation of data by a suitably qualified person is advisable.</p>		<p>CEC cmol/kg</p> <p>ESP %</p>

Parameter	Relevance	Typical methodology (other methodologies may be used)	Standard Units or Descriptors
Organic carbon	An indicator of soil nutrient store, it can also affect water retention and biological processes. Organic carbon supports microfauna and microflora in the soil.* Organic Carbon is only relevant to the topsoil.		% by weight.
Total N	Total nitrogen baseline information.		mg/kg
Available P (Colwell)	A measure of the phosphorous that is available for plant uptake. Phosphorous is required for photosynthesis and respiration.	Colwell.	mg/kg
Available K (Colwell)	A measure of the potassium that is available for plant uptake. Potassium is needed for a wide range of important processes within the plant including cell wall development, flowering and seed set.	Colwell.	mg/kg
Available S	A measure of the sulfur that is available for plant uptake	Potassium chloride (KCl 40 test.	mg/kg
Potentially hazardous compounds	Where there is prior knowledge or the suspected occurrence of these in the project area.	Specific elements or compounds to be targeted on a case by case basis, as informed by a site risk assessment.	Various.

* Hazelton et al (2007)

Table 2 Example Presentation of Soils Characterisation within a Mining Proposal

WA Soil Group	Percentage of project area (%)	Estimated Project Volume (m ³)	Baseline growth medium			Risk indicators				
			Baseline growth medium	Water holding capacity (mm)	Nutrient status	Salinity	Sodicity	Dispersion Risk Class	Erosion hazard for wind	Erosion hazard for water

3.4 Collation and interpretation of soil analyses results

Soils characterisation should be provided for each major soil type that is identified to occur in the project area. Commonly used methodologies are provided for guidance only, there may be other suitable methods.

3.4.1 WA Soil Groups

Soils can be classified according to the WA Soil groups outlined in Schoknecht and Pathan (2013).

3.4.2 Water holding capacity

The water holding capacity may be calculated using the bulk density value of the soil and the procedure explained in Appendix 3 of Burk and Dalgliesh (2013).

Soil water holding capacity provides an indication of the PAWC for a given soil type. PAWC is key to vegetation establishment and survival especially in arid environments.

3.4.3 Nutrient status

Different vegetation types require different amounts of nutrients. The minimum requirement is to report the baseline concentrations of nutrients in the soil, considering a profile depth to the base of the rooting zone.

3.4.4 Salinity

EC results can be interpreted to characterise the materials' suitability as a growth medium.

- 0 – 0.40 dS/m suitable for topsoil growth medium
- 0.40 -1.60 dS/m suitable for some salt tolerant species
- >1.60 dS/m, may not suitable as a growth medium (note exceptions in the Kalgoorlie region).

*(Based on Hunt, N. and Gilkes, B. (1992) Farm Monitoring Handbook. Published by University of Western Australia, Land Management Society, and National Dryland Salinity Program.)

3.4.5 Sodicty

Soil should be characterised as sodic when ESP >6. The high ESP of sodic soil causes it to be potentially dispersive. Note the ESP must be interpreted in conjunction with EC and also consider clay content and mineralogy and exchangeable magnesium.

3.4.6 Dispersion Risk and the evolution of soil stability EC vs ESP

When ESP >6 the material is sodic and potentially dispersive. The dispersion potential is quantified by the EC value.

The dispersive nature of material may be classified as follows (Hazelton, 2007):

- Class 1: Dispersive materials that disperse spontaneously in water. These are unstable, sodic soils that can have severe management and erosion problems.
- Class 2: Potentially dispersive materials that disperse after mechanical work eg. raindrops or earthworks.
- Class 2a: Materials that have few structural problems if there is no mechanical stress from earthworks.
- Class 2b: These materials become spontaneously dispersive when leached without the addition of calcium compounds and if there is no generation of electrolytes in the soil due to mineral weathering.
- Class 3: Flocculated soils that remain flocculated even with mechanical stress.

- Class 3a: Leaching with low electrolyte water may change saline sodic soil to class 2b or in extreme leaching to class 1. Soils may then disperse and cause severe crusting.
- Class 3b: These materials are saline but dominated by non-sodium salts. No physical problems.
- Class 3c: No dispersion and salinity problems occur where total cation concentration is greater than 20.

3.4.7 Erodibility

Wind erodibility

Where there are frequent high winds, soil erodibility for wind should be characterised. This can be based on aggregate size. The normal aggregate size of clays is such that they are not susceptible to wind erosion. However clays that are gypsiferous or highly saline can be composed of fine aggregates < 0.85mm and are susceptible to wind erosion. Sandy soils often have few aggregates >0.85mm and are the more vulnerable to wind erosion. (Hazelton, 2007). Wind erodibility based on aggregate size is described in Table 3 Wind Erodibility Rating (Hazelton 2007).

Table 3 Wind Erodibility Rating (Hazelton 2007)

Wind Erodibility Rating	Proportion of Aggregates >0.85mm
High	<10 % of soil mass
Moderate	10 – 30% of soil mass
Low	>30% of soil mass

This characterisation should be considered in conjunction with other factors affecting wind erosion eg.

- slope and exposure to wind
- wind fetch
- upstream wind conditions eg. presence of wind breaks
- soil moisture.

Water erodibility

Soil erodibility for water erosion is influenced by soil texture and the strength of the bonds between the soil particles (aggregate stability) (Hazelton et al 2007).

Materials with low infiltration rates, weak bonds between particles and an abundance of particles that are easily transported by water are very susceptible to erosion.

Typical materials with these properties include:

1. Materials high in silt and fine sand and having low organic matter levels
2. Self-mulching (eg. smectite) clays
3. Dispersible clay materials (usually sodic) (Hazelton et al, 2007).

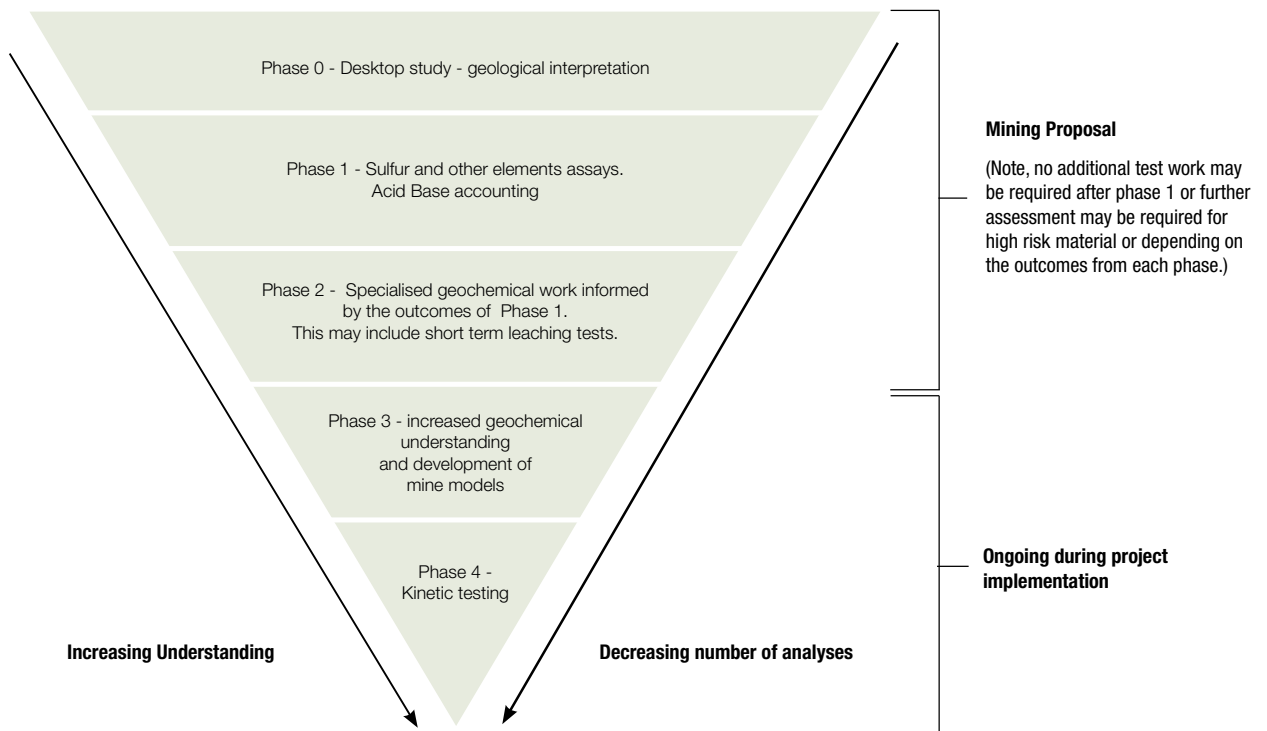
Mining often creates slopes that are higher, steeper or longer than exist in nature, and hence can be prone to erosion even when materials with low erodibility are present. Erodibility should be considered in conjunction with rainfall erosivity, slope length and degree, surface cover and land management practice, to determine the water erosion risk.

4. Subsurface Materials Characterisation

All material below the soil layers should be screened to determine suitability as a growth medium and for its potential to cause environmental impact when disturbed. The materials characterisation should aim to prove where material is benign and identify problematic material. The key is to understand where the issues are, have an understanding of the magnitude of the issue, and have sensible management options that can manage and mitigate that risk.

A phased approach can be applied to materials characterisation.

Figure 1 Phases of Materials Characterisation



Phase 0 – Pre-screening should provide a preliminary broad understanding of the geochemical properties of the deposit that will support the targeted sample selection required for Phase 1. This includes use of publically available data (eg. Geoscience Australia geological maps) to describe the geology of all materials to be disturbed. It may utilise drill hole assay data, and/or any field based analytical approach, background data, and examples of analogue systems.

Phase 1 – Sulfur and other elemental assays used to define the chemical variability within key representative lithologies and within the deposit. This Phase will also include standard static geochemical and tests to determine the physical properties of materials. Static geochemical tests can provide estimates of the total amount of acid generating and neutralising material present (Acid Base Accounting [ABA]). This provides the basis for identifying the underlying environmental risk and its associated geochemical properties.

Phase 2 - Specialised geochemical work informed by the outcomes of Phase 1. This Phase may include short term leaching tests. Short term leach tests can simulate the short term interaction of water with mine materials. These tests are beneficial for initial screening to identify which materials should be examined further for acid generation potential, metalliferous drainage potential and/or saline drainage potential. However, these tests should only be used in generating initial predictions. They should not be used in isolation to predict the long term ability of mined materials to generate problematic drainage.

Phase 3 – Long term kinetic tests. Kinetic tests are designed to estimate longer term geochemical behaviour and potential drainage quality of mined materials. Kinetic tests should start as early as possible if problematic units are identified, as they are time consuming.

The outcomes of each phase of characterisation will determine if additional test work is required. In general, information associated with Phases 0 to 2 will be required in the Mining Proposal. However, further assessment may be required for high risk material. This will be determined on a case by case basis. Phase 3 and Phase 4 characterisation may be included in the Mining Proposal if high risk materials are identified and should occur as the mine progresses. The information gathered from Phase 2 to Phase 4 will better define the geochemical behaviour of the material. This information must feedback into the live risk assessment and inform the appropriate design of waste landforms and scheduling of material placement. The number of samples will decrease from Phase 0 to Phase 4, with knowledge becoming more detailed for problematic lithologies.

Involvement of a person with an in depth understanding and experience in materials characterisation will help ensure correct interpretation of test results and result in a well-designed and implemented materials characterisation program (Maest et al, 2005).

4.1 Subsurface materials characterisation outcomes

Subsurface materials characterisation should be undertaken for the purposes of:

- Characterising the physical stability and potential growth medium attributes of each material type including:
 1. water holding capacity
 2. erosion hazard for wind
 3. erosion hazard for water
 4. risk of tunnelling
 5. potential for re-use eg. as armouring material.
- Evaluating potential risks associated with:
 1. sodic and/or dispersive material
 2. asbestiform material
 3. radioactive material
 4. acid sulphate soils
 5. acidic drainage
 6. metalliferous drainage under circum-neutral pH conditions related to sulphide oxidation
 7. metalliferous drainage under neutral to alkaline pH conditions unrelated to sulphides oxidation
 8. saline materials and/or drainage.

4.2 Subsurface materials sampling requirements

A comprehensive subsurface materials characterisation sampling program should consider the following:

- The level of information should be proportionate to the size of the operation.
- The type of information should be relevant to the deposit type and potential risks associated with the lithologies present and processes proposed for the site.
- Each material type to be excavated or exposed to oxidising conditions should be sampled and analysed.
- Sampling of tailings should consider the different tailings streams likely to be generated.
- The samples need to be spatially representative both horizontally and vertically of the deposit. The spatial representativeness of samples should be reassessed throughout operations as the mine plan changes (Global Acid Rock Drainage Guide – Chapter 4).
- The sampling should also be informed by the geological variability of the deposit and incorporate the sampling of each alteration within each lithology.
- Initial resource screening tests should be utilised to demonstrate the variability of all lithologies intercepted in the drilling. This early information can be utilised to provide information to inform the sampling and analysis plan.
- The number of samples should be sufficient to represent the variability within each geological unit and material type. A guide on the number of samples required for Phase 1 characterisation is listed in Table 4. This is a guide only and more or less samples may be required depending upon site specific issues.
- Sample selection must be carried out by someone familiar with the geological characteristics of the deposit, including rock types, structural characteristics, weathering, alteration, and mineralization (Global Acid Rock Drainage Guide – Chapter 4).
- Samples should be selected that are representative of the key material types in light of the geological factors that control the geochemical and physical attributes of the material. As a guide, each lithology, each alteration and each weathering profile within each lithology should be sampled. The weathering profiles may include oxidised, transition and fresh profiles.
- Compositing of samples should not generally be undertaken as it assumes a certain mixture of rock types will occur and in reality the different material types may not be combined in such a way. It may be appropriate for the sampling of tailings that is known to be from a consistent ore type and single process (Maest, A.S., Kuipers, J.R., Travers, C.L., and Atkins, D.A., 2005).
- Where there is potential for environmental risks associated with the mineralisation present, further detailed analyses should be considered based on the specific deposit characteristics.
- The Mining Proposal objectives to be achieved. ie. if a comparison is to be made with the pre-mining situation, the parameters to be compared must be determined in the baseline data.
- A suitably qualified expert should determine the complete sampling and analysis requirements.

Table 4 Suggested Phase 1 Characterisation Sampling Frequency Based on Tonnage When Sampled Without Prior Information

(Adapted from BCAMDTF, 1989, reproduced from MEND Report 1.20.1 (2009) Prediction Manual for drainage chemistry from sulphidic geologic materials)

Tonnes of Disturbed Rock	Minimum Number of Samples
<10,000	3
<100,000	3- 8
<1,000,000	8-26
<10,000,000	26-80
> 10,000,000	few hundred

4.3 Recommended subsurface analyses

Table 5 outlines the recommended subsurface materials screen testing to be undertaken and Table 6 Guidance on Additional Characterisation Test Work for Materials Requiring Further Assessment outlines potential additional characterisation test work for materials requiring further assessment. Table 7 provides an example of how this information could be summarised in a Mining Proposal.

Table 5 Guidance for Initial Subsurface Materials Sampling and Analysis

Mineralisation styles	Phase 1 and 2 subsurface materials sampling and analysis
All	<p>All samples from each alteration within each weathering profile within each lithology should be analysed for pH 1:2, EC 1:2, total Sulphur with a detection limit of 0.005 wt%, bulk density, dispersion risk class, fibrous material and radioactive minerals.</p> <p>If Total Sulphur is < 0.05 wt% S, then selected samples from each weathering profile within each lithology should be analysed for bulk chemistry, and leachate water quality (eg. shake flask extraction test).</p> <p>If Total Sulphur is >= 0.05 wt%S, then all samples from each alteration within each weathering profile within each lithology should be analysed for NAGpH, Acid Neutralising Capacity (ANC) and leachable materials.</p> <p>Regardless of Total Sulphur concentration, where there is concern for acid, metalliferous and/or saline drainage production advanced screening may be required.</p>
Tailings	Further to the analysis recommended for subsurface materials, added chemicals should be considered in determining appropriate tailings analysis.

Table 6 Guidance on Additional Characterisation Test Work for Materials Requiring Further Assessment

Potential Issue	Potential Further Analysis Required	Characterisation
Geochemical		
Acid Sulphate Soils	<p>Chemical analyses using methods outlined in the Department of Environment Regulation (DER) guidelines.</p> <p>In situations where unconsolidated sediments, peat or lignite are being dewatered or excavated from below the water table, the acid-base balance assessment should be carried out using ABA tests or the acid sulfate soil analytical methods outlined in the Department of Environmental Regulation guidelines (DEC, 2013).</p>	<p>Potential Acid Sulphate Soils (PASS).</p> <p>Actual Acid Sulphate Soils (AASS)</p> <p>Not Acid Sulphate Soils (NASS).</p>

Potential Issue	Potential Further Analysis Required	Characterisation
Acidic Drainage	Short term leach tests ABA ABCC (Acid Buffering Characteristics Curve) Mineralogy Multi element chemistry Sulfur speciation Carbon Speciation Sequential NAG Kinetic NAG Oxygen Consumption Tests.	Potentially Acid Forming (PAF) Non Acid Forming (NAF) NAF with potential for Neutral Mine Drainage (NMD)/ Saline Drainage (SD).
Metalliferous Drainage (associated with both sulphides and not associated with sulphides)	Leachable materials listed in Sections 8 and 9. The risk of mobilisation needs to be determined by a combination of methods suitable for the materials in question. These methods may include, but are not limited to, NAG liquor analysis, short-term individual and/or batch leach tests, and long term kinetic leach tests. Typical examples include; MEND shake flask, USEPA LEAF, Column leach, Humidity Cell.	Risk of metal ion and non-metal oxyanion mobilisation.
Saline Drainage	EC (mS/m) Total dissolved solids (TDS)	0 – 0.40 dS/m suitable for topsoil growth. medium 0.40 -1.60 dS/m suitable for some salt tolerant species >1.60 dS/m, may not be suitable as a growth medium (note exceptions in the Kalgoorlie region).
Physical		
Dispersive or sodic material	Exchangeable cations Emerson test.	ESP > 6 sodic and potentially dispersive** Emerson class ≤ 3 is dispersive.
Erosion Potential	Consideration of lithology, alteration, weathering profile, structural characteristics and mineralogy by a suitably qualified geologist.	Erosion potential under the site specific surface conditions.
Fibrous material and silicates	Typical techniques used include Scanning Electron Microscopy (SEM) and X-ray diffraction.	Classification and characterisation of the type of fibres present.
Radioactive material	Gamma activity by gamma spectroscopy. Alpha and beta counting to determine non-gamma constituents. Gross activity by sum of all.	Concentration and indicative volume of radioactive minerals.

* (Based on Hunt, N. and Gilkes, B. (1992) *Farm Monitoring Handbook*. Published by University of Western Australia, Land Management Society, and National Dryland Salinity Program.)

** ESP must be interpreted in conjunction with EC. If greater than 6 it is sodic and potentially dispersive. Dispersion potential is quantified by the EC value.

Table 7 Example Presentation of Subsurface Materials Characterisation Within a Mining Proposal

Weathering Zone	Rock type	Alteration	Amount of rock (Mt)	Percentage of total rock (%)	No Samples - Phase 1 static	Percentage of total samples (%)	Water Holding Capacity kg/m ³	Salinity grouping	Sodic/ Non Sodic	AMID Potential	Erosion hazard for wind	Erosion hazard for water	Risk of tunnelling	Fibrous	Radioactive	Growth medium suitability #	
Oxidised	A	x	10	8	6	7											
		y	4	3	2	2											
	B	x	15	12	10	12											
Transition	C	y	1	1	3	4											
		z	4	3	3	4											
	D	xx	7	6	5	6											
	E	z	2	2	3	4											
		y	0.2	0	-	-											
Fresh	D	w	3	2	3	4											
		x	8	7	5	6											
	E	y	30	25	20	24											
		z	1	1	3	4											
	F	w	15	12	10	12											
		x	20	17	12	14											
Total			120.2	100	85	100											

growth medium suitability can be categorised as i) suitable as topsoil growth medium, ii) suitable as subsoil growth medium or iii) not suitable.

4.3.1 Materials with Acid Sulphate Soils Potential

Recommended analyses

The analysis should include pH_F and pH_{FOX} , EC and nature of suspension (dispersion test).

Chemical analysis of unconsolidated sediments, peat or lignite should be conducted in accordance with DEC (2012) *Acid Sulfate Soil Guidelines Series, Investigation and Management of Acid Sulphate Soils Hazards Associated with Silica and Heavy Mineral Sand Mining Operations* and DEC (2013) *Identification and investigation of acid sulphate soils and acidic landscapes*. Department of Environment and Conservation management guidelines available at <http://www.der.wa.gov.au/images/documents/your-environment/acid-sulfate-soils/guidelines/identification-investigation-ass-acidic-landscapes.pdf>

Interpretation of results

Results should be interpreted as PASS, AASS or not acid sulphate soils in accordance with DEC (2012) and DEC (2013) from which the following information has been reproduced.

Material characteristics identifying PASS include:

- coffee rock horizons
- a sulphurous smell eg. hydrogen sulphide or rotten egg¹ gas
- soil $pH_F > 4$ and commonly neutral
- soil $pH_{FOX} < 3$, with large unit change from pH_F to pH_{FOX} , together with volcanic reaction to peroxide.

Material characteristics identifying AASS include:

- sulphurous smell eg. hydrogen sulphide or rotten egg¹ gas
- any jarositic horizons or substantial iron oxide mottling in surface
- encrustations or in any material dredged or excavated and left exposed
- field $pH_F < 4$ (when field $pH_F > 4$ but < 5 this may indicate some existing acidity and other indicators should be used to confirm presence or absence of AASS).

The AASS assessment should also take into account the water and vegetation characteristics as outlined in DEC (2012) and DEC (2013).

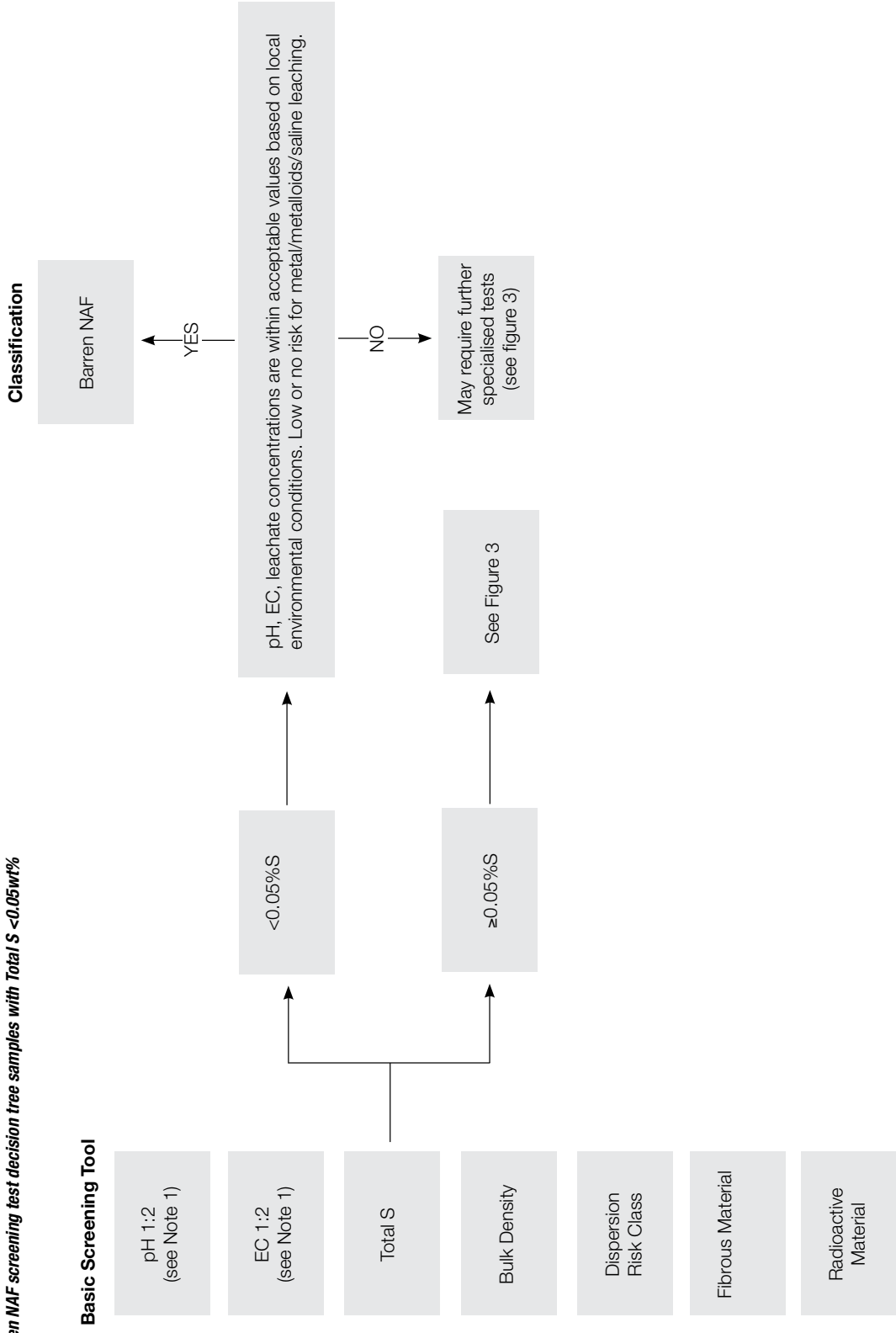
4.3.2 Materials with AMD potential

Recommended analyses

Where AMD is a potential issue, the modified AMIRA decision tree can be used to determine the screening and sample categorisation (Figure 2). The minimum analysis would include:

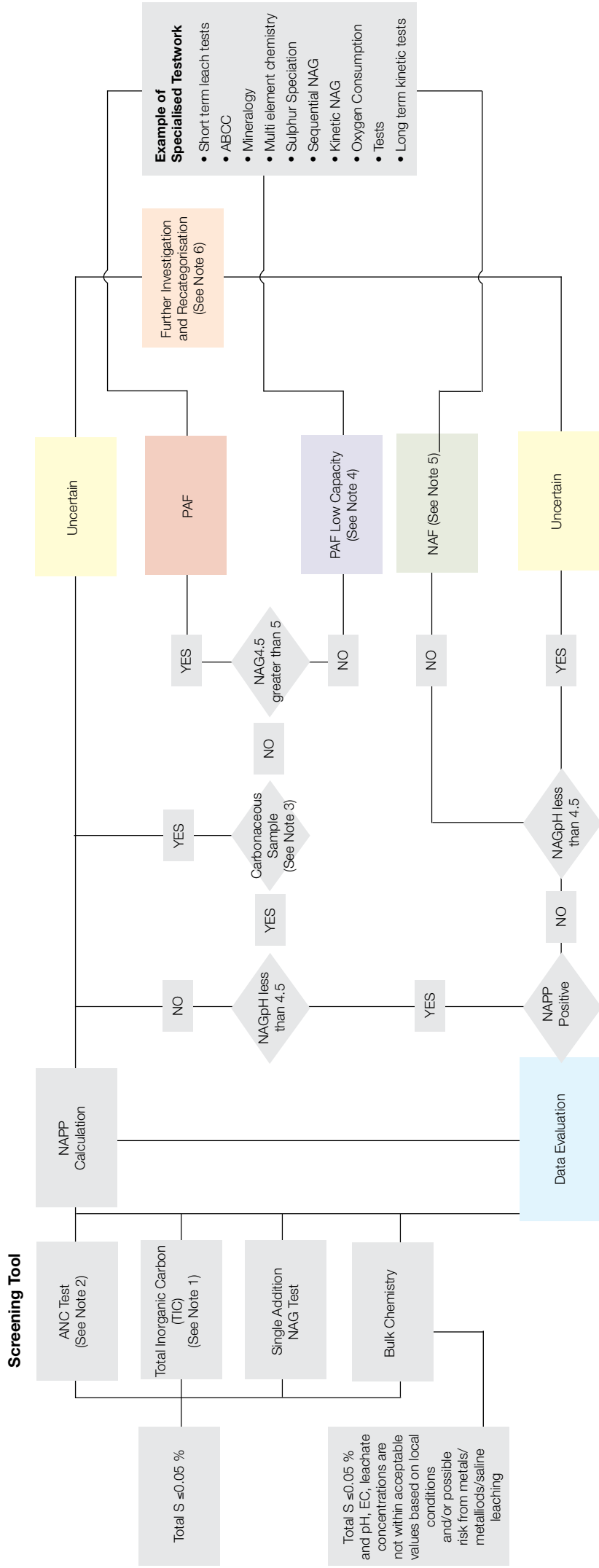
- bulk chemistry
- ANC
- total inorganic carbon (TIC)
- total Sulfur (TS)
- net acid generation (NAG)
- pH 1:2
- EC 1:2.

Figure 2 Barren NAF screening test decision tree samples with Total S <0.05wt%



Note 1: pH and EC measurements provide a measure of immediately available acidity and salinity. This information may influence the final categorisation of the sample due to potential short term effects of a given material on rehabilitation, drainage etc. Measurements are best carried out on the crushed sample rather than the pulverised sample where possible.

Figure 3 Acid and Metalliferous Drainage Decision Nodes and AMD Classification Categories (adapted from AMIRA 2002)



Note 3: The occurrence of organic compounds in some materials may interfere with NAG tests. In particular, samples from coal deposits with more than about 5% TOC.

Note 4: Further investigation is recommended to determine acid forming capacities of samples with high S values (>1% S) and low NAG/NAAPP ratios (<0.5). Low NAG/NAAPP ratios indicate either non-acid producing S forms or incomplete oxidation in the NAG test, and additional testing would be required to determine which applies in a particular case.

Note 5: Further evaluation is recommended to confirm classification of samples with High Sulphur and High ANC. There is a risk of incomplete sulphide oxidation during the NAG test on high sulphur samples. Selected samples of high S and High ANC material should be subjected to sequential NAG and ABCC determinations. Samples with more than 2% S and ANC/MPA ratios less than 2.5 should be evaluated.

Not all material classified as NAF will be low risk, as some NAF material may be at risk of metalliferous or saline drainage and should be further assessed.

Note 6: Further investigations are required to determine:

- Classification of samples with conflicting NAPP and NAG results.
- Magnitude of acid forming capacity for PAF samples with low NAG/NAAPP ratios.
- Availability of ANC for neutralisation of acid produced in samples with moderate to high S.
- Acid potential of samples with high contents of organic matter.
- Potential for metalliferous and saline drainage.

Interpretation of results

Preliminary interpretation of results can be interpreted following the adapted AMIRA decision tree (Figure 3). These classifications may be reassessed when more information becomes available. Maximum potential acidity (MPA) should be calculated from the sulphur content (ie. Total sulfur, or chromium reducible sulfur or other as applicable). MPA is then used in calculating the net acid producing potential (NAPP). The acid neutralising capacity (ANC, kg H₂SO₄/tonne) should be determined for all neutralising materials noted as ANC_(Total). The standard ANC_(Total) takes into account contributions to acid buffering from all potential neutralisation species, including silicate, which only act as a buffer when the pH <4. TIC provides an indication of the ANC associated with carbonates. However, TIC does not discriminate between Ca-Mg carbonate (ie. calcite and dolomite) which are most efficient acid buffering carbonates from other carbonate species, such as ferroan dolomite, ankerite, siderite, which provide partial or no acid buffering capacity. TIC results should be interpreted with caution and should be supported by mineralogical and ABCC testwork if TIC is used in lieu of ANC measured in the laboratory to assess the buffering potential of any given material.

The net acid producing potential should be calculated as:

$$\text{NAPP} = \text{MPA} - \text{ANC}$$

Where available, ANC_(TIC) and MPA_(S-CR) might be used to better refine the MPA and ANC.

$$\text{NAPP}_{(\text{Total})} = \text{MPA} - \text{ANC}_{(\text{Total})}$$

If NAPP is negative the sample may have enough ANC to prevent acid generation. If NAPP is positive the sample may be acid generating.

The S, ANC, NAG and NAPP are used to classify the acid generating potential of the material. Justification should be given as to why Total Sulfur, Cr reducible sulfur, ANC_(Total) or ANC_(TIC) have been used in the calculations.

The material should be categorised as non-acid forming NAF, potentially acid forming PAF or Uncertain (UC) as per Figure 3. The potential for metalliferous and saline drainage associated with NAF material will need to be assessed as per Figure 2. Where warranted, leachability of metallic oxyanions should be assessed.

4.3.3 Materials with Metalliferous Drainage Potential (associated with both sulphides and unrelated to sulphides)

Recommended analyses

The recommended analysis beyond that already undertaken to determine if the material has metalliferous drainage potential will include the leachable materials listed in Sections 7 and 8.

Interpretation of results

The risk of mobilisation can be determined in accordance with standard short-term leaching tests and/or kinetic testing, as applicable.

4.3.4 Materials with Saline Drainage Potential

Recommended analyses

The recommended analyses for materials with saline drainage potential are pH_F and pH_{F0x}, EC and nature of suspension (dispersion test) and TDS.

Interpretation of results

Results can be interpreted to characterise the materials suitability as a growth medium.

- 0 – 0.40 dS/m suitable for topsoil growth medium
- 0.40 -1.60 dS/m suitable for some salt tolerant species
- >1.60 dS/m, may not suitable as a growth medium (note exceptions in the Kalgoorlie region).

**(Based on Hunt, N. and Gilkes, B. (1992) Farm Monitoring Handbook. Published by University of Western Australia, Land Management Society, and National Dryland Salinity Program.)*

4.3.5 Materials with Sodic or Dispersive Potential

Recommended analyses

The recommended analysis for materials with sodic or dispersive potential is pH, pH_{FOX}, EC, exchangeable cations and the Emerson test.

Interpretation of results

If ESP is greater than 6 the material is sodic and potentially dispersive. Dispersion potential is quantified by the EC value and materials with ESP < 6 may disperse due to low EC and/or high magnesium.

The dispersive nature of material can be classified as follows (Hazelton, 2007):

Class 1: Dispersive materials that disperse spontaneously in water. These are unstable, sodic soils that can have severe management and erosion problems.

Class 2: Potentially dispersive materials that disperse after mechanical work eg. raindrops or earthworks.

Class 2a: Materials that have few structural problems if there is no mechanical stress from earthworks.

Class 2b: These materials become spontaneously dispersive when leached without the addition of calcium compounds and if there is no generation of electrolytes in the soil due to mineral weathering.

Class 3: Flocculated soils that remain flocculated even with mechanical stress.

Class 3a: Leaching with low electrolyte water may change saline sodic soil to class 2b or in extreme leaching to class 1. Soils may then disperse and cause severe crusting.

Class 3b: These materials are saline but dominated by non-sodium salts. No physical problems.

Class 3c: No dispersion and salinity problems occur where total cation concentration is greater than 20.

The risk of tunnelling should be characterised where the risk of dispersion is high. A combination of high dispersibility and high permeability indicates the most susceptible materials to tunnelling.

“Tunnelling susceptibility refers to the likelihood of tunnels forming in a body of material as a consequence of water flow through that material. There are three requirements for a tunnel to form in this way:

- A soil that is easily detached and transported by water flow through the material. This usually means the material has a highly dispersible clay or high levels of silt and fine sand.
- A head of water to provide a potential for water flow through the soil.
- A system of cracks or pores that provide relatively rapid flow path through the body of the soil” (Hazelton, 2007).

4.3.6 Fibrous and Silicate Materials

Recommended analyses

A generic fibrous assay should be conducted on each alteration of each lithology to identify the presence or absence of fibrous particles, unless a geologist or other suitably qualified professional can justify why this is not required. Typical methodologies include polarised microscopy. Where fibrous materials are identified the type and concentration of the fibre should be identified.

A generic silicates assay should be conducted on each alteration of each lithology to identify the presence or absence of silicates unless a geologist or other suitably qualified professional can justify why this is not required.

Interpretation of results

The type, concentration, location and indicative volume of fibrous material should be determined.

The indicative volume and location of material with silicates less than 16 microns should be provided.

4.3.7 Radioactive Materials

Recommended analyses

Each alteration of each lithology should be sampled for the presence or absence of radioactive elements such as uranium, thorium, potassium 40, radium, and rare earths unless a geologist or other suitably qualified professional can justify why this is not required. Where radioactive minerals are present their location, concentration, activity (ppm or Bq/g) and indicative volume of material should be provided.

Interpretation of results

The location, indicative volume and concentration of radioactive minerals should be provided. Consideration should be given to whether the mining process will concentrate the radioactive minerals and where these materials will eventually remain at mine closure.

5. References

References for further soils information

AS4133.0—1993 Australian Standard Methods of testing rocks for engineering purposes

Burk and Dalgliesh (2013) Estimating Plant Available Water Capacity –Grains Research and Development Corporation, CSIRO, The University of Adelaide.

Hamza MA (2008) Understanding soil analysis data Resource Management Technical Report 327, Department of Agriculture and Food Government of WA

Hazelton P, Murphy B (2007) Interpreting Soil Test Results – what do all the numbers mean? NSW Government Department of Natural Resources

Loch, R.J., Slater, B.K., and Devoil, C. (1998). Soil erodibility (K) values for some Australian soils. *Australian Journal of Soil Research* 36: 1045-1056.

McDonald R.C, Isbell R.F, Speight J.G, Walker J. and Hopkins M.S (2009) Australian soil and land survey field handbook, National Committee on Soil and Terrain, 3rd Edition.

McKenzie, Jacquier, Isbell Brown (2004) Australian Soils and Landscapes An Illustrated Compendium

McKenzie, Grundy, Webster 2008 Guidelines for Surveying Soil and Land Resources Second Edition, Australian Soil and Land Survey Handbooks Series 2

McKenzie, Coughland, Creswell (2002) Soil Physical Measurement and Interpretation for Land Evaluation, CSIRO publishing

Rosewell, C.J. and Loch, R.J. (2002). Estimation of the RUSLE Soil Erodibility Factor. In "Soil Physical Measurement and Interpretation for Land Evaluation", McKenzie, Coughlan, and Creswell (eds.), CSIRO Publishing, pp. 360-369.

Schoknecht N, Tille P, and Purdie B (2004) Soil- Landscape Mapping in South Western Australia – Overview of methodology and outputs. Resource Management Technical Report 280. Department of Agriculture WA.

Schoknecht N and Pathan S (2013) Soil Groups of Western Australia: edition 4, Resource Management Technical Report 380, Soil Physical Measurement and Interpretation for Land Evaluation, Australian Soil and Land Survey Handbooks Series 5 (This Handbook concentrates on soil physical measurement methods that are cost-effective and well suited to land resource survey.)

CIRIA (2007) The Rock Manual

<http://www.kennisbank-waterbouw.nl/DesignCodes/rockmanual/>
(This looks at rock tests in relation to durability).

Vacher, Cameron A. and Loch, Rob and Raine, Steven R. (2004) *Identification and management of dispersive mine spoils*. Technical Report. Australian Centre for Mining Environmental Research, Kenmore, Australia.

Van Vreeswyk A, Payne A, Leighton K & Hennig P 2004, An inventory and condition survey of the Pilbara Region, Western Australia, Technical Bulletin No. 92, Department of Agriculture, Perth

References for further subsurface materials characterisation information

AMIRA, 2002, ARD Test Handbook: Project P387A Prediction and Kinetic Control of Acid Mine Drainage, prepared by AMIRA International Limited.

DAFWA Soil-landscape units

DEC (2012) Acid Sulfate Soil Guidelines Series, Investigation and Management of Acid Sulphate Soils Hazards Associated with Silica and Heavy Mineral Sand Mining Operations

DEC (2013) Identification and investigation of acid sulfate soils and acidic landscapes, Department of Environment and Conservation, Government of Western Australia, Acid Sulfate Soils Guideline Series, March 2013 available at <http://www.der.wa.gov.au/images/documents/your-environment/acid-sulfate-soils/guidelines/identification-investigation-ass-acidic-landscapes.pdf>

Department of Industry Tourism and Resources (2007) Managing Acid and Metalliferous Drainage (soon to be updated).

Department of Mines and Petroleum (2010) Managing naturally occurring radioactive material (NORM) in mining and mineral processing – guideline. NORM 3.1 Monitoring NORM – preoperational monitoring requirements – guideline: Resources Safety , Department of Mines and Petroleum, Western Australia, 19pp www.dmp.wmaa.gov.au

DERM 1995 Technical guidelines for the environmental management of exploration and mining in Queensland. Part B Assessment and management of acid drainage, January 1995 Queensland Department of Environment and Resource Management

EPA (2010) Background Information for the Leaching Environmental Assessment Framework (LEAF) Test Methods. US Geological Survey.

GARD Guide <http://www.gardguide.com>

MEND (2004) Report 10.1 Review of water quality issues at neutral pH drainage: Examples and emerging priorities for the mining industry in Canada.

MEND Volume 2 Sampling and Analysis(<http://mend-nedem.org/publications/>)

MEND (2009) Report 1.20.1 Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials.

Maest, AS., Kuipers, JR., Travers, C.L., and Atkins, D.A., 2005. Predicting Water Quality at Hardrock Mines: Methods and Models, Uncertainties, and State of the Art.

National Environment Protection (Assessment of Site Contamination) Measure 1999.

6. Glossary

Acid Sulphate Soils	Naturally occurring soils, sediments and peats that contain iron sulfide minerals, predominantly as the mineral pyrite
AMD	Acidic and metalliferous drainage (AMD) is inclusive of: acidic drainage, metalliferous drainage (encompassing all metals/metalloids/non-metals which may be contaminants of concern) and saline materials and/or drainage.
Alteration	A mineralogical change at low pressures due to invading fluids or the influence of oxygen.
Asbestos	Crocidolite, chrysolite, grunerite (amosite) or the stiform of actinolite, tremolite or anthophyllite.
Bulk Chemistry	The chemical analysis of solids.
Dispersive material	Dispersive materials are structurally unstable. They disperse into basic particles sand, silt and clay in fresh water.
Fibrous material	A mineral with an aspect ratio of 5:1 (http://www.dmp.wa.gov.au/documents/Guidelines/MSH_G_ManagementOfFibrousMineralsInWaMiningOperations.pdf)
Kinetic Testing	Kinetic testing encompasses a group of tests where the acid generation characteristics of a sample are measured with respect to time.
Metalliferous drainage	Metalliferous drainage (encompassing all metals/metalloids/non-metals which may be contaminants of concern)
Mineralogy	The mineral assemblage of the rock. There are several methods for determining this including X-Ray powder diffraction.
Radioactive minerals	Minerals that include radioactive elements in their composition.
Silicate Material	A compound containing an anionic silicon compound.
Sodicity	A term given to the amount of sodium held in a soil.
Static geochemical testing	Static geochemical tests provide information on the bulk geochemical characteristics of material at a point in time. They do not provide information on rates of chemical processes or the rates of release of weathering products. Static tests include acid base accounting tests where measurements are made over a short fixed period of time.

7. Abbreviations

ABA	Acid Base Accounting
ABCC	Acid Buffering Characteristics Curve
AMD	Acid and Metalliferous Drainage
ANC	Acid Neutralising Capacity
CEC	Cation exchange capacity
EC	Electrical Conductivity
ESP	Exchangeable Sodium Percentage
MP	Mining Proposal
MPA	Maximum Potential Acidity
NAF	Non Acid Forming
NAG	Net Acid Generation
NAPP	Net Acid Producing Potential
NMD	Neutral Mine Drainage
PAF	Potentially Acid Forming
PAWC	Plant Available Water Capacity
pH	Negative algorithm of the concentration of hydrogen ions
SD	Saline Drainage
TC	Total Carbon
TIC	Total Inorganic Carbon
TS	Total Sulfur

8. Example suite for rock analysis

Parameter	Limit of Reporting	Units
Sulphate	100	mg/kg
Al	10	mg/kg
Sb	0.05	mg/kg
As	0.1	mg/kg
Ba	10	mg/kg
Be	0.05	mg/kg
Bi	0.01	mg/kg
B	10	mg/kg
Cd	0.01	mg/kg
Ca	10	mg/kg
Cr	1	mg/kg
Co	0.1	mg/kg
Cu	0.2	mg/kg
Fe	10	mg/kg
Pb	0.2	mg/kg
Mg	10	mg/kg
Mn	5	mg/kg
Hg	0.01	mg/kg
Mo	0.05	mg/kg
Ni	0.2	mg/kg
K	10	mg/kg
Se	0.2	mg/kg
Ag	0.01	mg/kg
Na	10	mg/kg
Tl	0.02	mg/kg
Sn	0.2	mg/kg
Ti	10	mg/kg
U	0.05	mg/kg
V	1	mg/kg
Zn	2	mg/kg

9. Example suite for leachate analysis

Parameter	Maximum Reporting Limit	Units
Inorganics		
pH	0.1	pH units
Eh	NA	mV
Conductivity	2	µmhos/cm
Acidity	1	mgCaCO ₃ /L
Alkalinity	1	mg/L
Chloride	0.2	mg/L
Fluoride	0.1	mg/L
Hardness	0.5	mg/L
Sulphate	0.2	mg/L
TDS	10	mg/L
Metals (dissolved)		
Al	1	µg/L
Sb	0.05	µg/L
As	0.1	µg/L
Ba	0.05	µg/L
Be	0.2	µg/L
Bi	0.5	µg/L
B	10	µg/L
Ca	50	µg/L
Cd	0.05	µg/L
Co	0.1	µg/L
Cr	0.5	µg/L
Cu	0.1	µg/L
Fe	30	µg/L
Pb	0.05	µg/L
Mg	5	µg/L
Mn	0.05	µg/L
Hg	0.01	µg/L
Mo	0.05	µg/L
Ni	0.5	µg/L
K	50	µg/L
Se	1	µg/L
Si	50	µg/L
Ag	0.01	µg/L
Na	2000	µg/L
Tl	0.05	µg/L
Sn	0.1	µg/L
V	0.5	µg/L
Zn	1	µg/L



Government of Western Australia
Department of Mines and Petroleum
Mineral House, 100 Plain Street
East Perth, Western Australia 6004

Tel: +61 8 9222 3333
Fax: +61 8 9222 3862
Email: dmp@dmp.wa.gov.au
Web: www.dmp.wa.gov.au

Published April 2015
DMPMAR15_3596