Land and Water Boards of the
Mackenzie Valley

Box 2130 X1A 3Y6, Yellowknife NT
P: 867.669.0506
W: www.mvlwb.com

April 4, 2022

Lee Ross
Hazardous Waste Specialist
Department of Environment and Natural Resources
Government of the Northwest Territories

Sent by email

Dear Lee Ross,

Re: Review of the Government of the Northwest Territories Draft *Quarry Sampling and Testing Guidance for Identification of Acid Rock Drainage and Metal Leaching Potential*

The Land and Water Boards of the Mackenzie Valley (Gwich'in Land and Water Board, Mackenzie Valley Land and Water Board, Sahtu Land and Water Board, and Wek'èezhìi Land and Water Board (LWBs, the Boards) have reviewed and provided input on the Government of the Northwest Territories (GNWT) Draft *Quarry Sampling and Testing Guidance for Identification of Acid Rock Drainage and Metal Leaching Potential* (Guide) dated January 2022, as requested by the GNWT on March 15, 2022. The LWBs have reviewed the document with consideration of our role under the *Mackenzie Valley Resource Management Act* (MVRMA) and *Waters Act*.

LWB staff would be happy to discuss these comments and recommendations if any clarification is needed. Again, we would like to thank GNWT-ENR for the opportunity to provide these views. Please feel free to contact Shelagh Montgomery should you require more information or to initiate a meeting.

Sincerely,

Shelagh Montgomery, Executive Director, MVLWB

Ryan Fequet, Executive Director, WLWB

Leonard DeBastien, Executive Director, GLWB

Paul Dixon, Executive Director, SLWB

Appended: LWB Review Comments and Recommendations

LWB Review of the GNWT Draft *Quarry Sampling and Testing Guidance for Identification of Acid Rock Drainage and Metal Leaching Potential*

1.0 General Comments

Overall, the Boards appreciate the work of GNWT-ENR to develop the ARD/ML Guidance. The technical content from a sampling and evaluation perspective is very well done. The document mostly follows guidance provided in British Columbia and is therefore a sound and industry-standard approach. The summary and reasons for completing ARD/ML sampling and investigations will be of benefit to users of the Guide.

The Boards note that the applicability of the Guide is confusing and have thus recommended this be expanded to address all types of undertakings listed in Schedule B of the Waters Regulations, Schedule II of the Mackenzie Valley Federal Areas Waters Regulations, and Sections 4 and 5 of the Mackenzie Valley Land Use Regulations.

It would also be helpful to clarify the applicability of this Guide for a proponent that is seeking or holds a land use permit or water licence for quarry operations or other relevant activity. There is also limited information to say how this Guide might be used by regulators. Several recommendations are provided below to address these topics.

2.0 Specific Comments and Recommendations

Review Comment 1:

The Guide introduces many geologic concepts and vocabulary that may not be readily familiar to all users. Many quarry operators in the NWT are small, family-owned businesses that may not have the capacity to fully understand or carry out the screening requirements identified in this Guide. It is not clear if or how the GNWT may be able to assist existing quarry operators in meeting the requirements of this Guide. One place to start, however, would be to make this Guide more accessible and understandable by providing a list of definitions at the start of the document introducing the terms and concepts that may not be broadly understood to a wide audience (e.g., sulphide, sulphate, sulphuric acid, silicates, carbonate, kinetic, static, precipitate, ARD classifications, alteration products, rinse pH, paste pH, aqua regia method of digestion, crustal abundance). The document could also provide more direct links to external sources of information or assistance (e.g., GNWT Departments, websites, local laboratories, existing Northern Land Use Guidelines for Pits and Quarries). Finally, Section 3.1 states that "it may be possible to obtain this information by reviewing background geological information available from the Northwest Territories Geological Survey (NTGS) or other sources." It would be helpful for GNWT to start compiling information it has that operators might find useful and providing a link to where data can be found.

Recommendation:

1. Include a definitions section that introduces terminology and provides examples of terms and concepts used throughout the Guide.
2. Provide additional links to external resources so that users/operators can easily locate information that the GNWT or others may already have publicly available to inform geological assessments.
3. Provide a discussion on what types of geologic information the GNWT has available, what type information GNWT collects, including future plans of the NTGS, and where the data can be found.

Review comment 2:
Section reference - Section 1

The Guide states "In the Northwest Territories (NWT), contaminant release is prohibited." This statement is not consistent with the *Waters Act* or the *Mackenzie Valley Resource Management Act* (MVRMA), which would regulate the management of impacted waters. In this case, water that is impacted by ARD or metal leaching (ML) may require measures to ensure any discharges to the receiving environment are acceptable. Thus, release of impacted water is regulated in the NWT, not prohibited. Water impacted (change in quality or quantity) from a quarry could be considered a Waste as defined in the *Waters Act* or MVRMA and therefore a quarry may require a water licence to regulate how this Waste is managed (e.g., monitored, stored, discharge criteria to receiving environment, etc.).

Recommendation:

1. Update the wording to replace the word "prohibited" with "regulated".
2. Update Section 1 of the Guide to inform how ARD/ML can result in elevated water quality parameter concentrations which may be considered Waste as per the *Water Act* and MVRMA.
3. Update Section 1 to inform why a quarry site and its operations may require a land use permit or water licence within the NWT.

Review comment 3:
Section reference - Section 1

The Guide states that it is applicable to quarry sites. It is understood that many areas within the NWT require quarry activities to generate materials used in construction. It is unknown if this Guide can also be used for a borrow site (unconsolidated deposit which may or may not require drilling and blasting activities). Based on review of the technical content, the Boards suggest it may also be applicable to borrow sites. If applicable to borrow sites, in addition to quarries, it would be useful to include this language in Section 1 to avoid ambiguity in the application of the Guide. For context, some proponents seeking a land use permit or water licence use the terms quarry and borrow interchangeably and some proponents do not.

Recommendation:

1. If applicable, update Section 1.0 of the Guide (and throughout where needed) to indicate it covers quarries and borrow sites. A definition of a borrow and quarry site would also be beneficial.
2. If the Guide is not applicable to borrow sites, it would be beneficial if the Guide could be updated to be inclusive of both a borrow and a quarry.

Review comment 4:
Section reference - Section 1

The Guide states it is "applicable to current and potential quarry operations within the NWT, outside of mining/mineral exploration projects." It is not known why this Guide would not be applicable to mining or mineral exploration projects. It is unclear if this limitation is because of uniqueness in the activity or a means to narrow the scope of the Guide.

Note that quarry operations could occur throughout the NWT such as: construction, operation and/or maintenance activities within communities, to support road and infrastructure development/maintenance, reclamation of impacted sites, oil and gas exploration projects, and other industrial projects that may require granular material for construction, operation, maintenance, or closure and reclamation activities (including at mine sites). From a land use permit and water licence perspective, this Guide is applicable to a wide spectrum of activities. Based on the discussion provided in Section 2.2, a key item of concern was the use of ARD/ML materials for residential purposes, not other industrial or reclamation activities. Clarification on the types of projects this Guide can be applied towards is recommended.

More broadly, the Waters Regulations and Mackenzie Valley Federal Areas Waters Regulations define various types of “Undertakings” that occur within the NWT which may require a water licence. It would be useful for the Guide to utilize the Undertaking types as presented in Schedule B or Schedule II of these Regulations or Sections 4 and 5 of the Mackenzie Valley Land Use Regulations to identify the types of projects that this Guide can be applied towards. This approach would aid in ensuring correct application by proponents seeking a water licence or land use permit.

Recommendation:

1. Include mining and mineral exploration in the scope of this Guide or provide clarification why this Guide is not applicable to mining and mineral exploration projects.
2. Update the types of projects this Guide can be applied to be consistent with the types of Undertakings as listed in applicable regulations.

Review comment 5:
Section reference - Section 1 and 7

The Guide states it is “applicable to current and potential quarry operations within the NWT, outside of mining/mineral exploration projects” and Section 7 states that “if quarry material that has already been stockpiled is classified as PAG or found to have elevated potential for ML then the material should not be used and no further blasting of similar materials should be conducted.” As noted in comment 2, it is not known how this Guide might impact existing quarry operators, especially those that may not have the capacity to meet the requirements laid out in this Guide. For example, when this Guide is released, will it be immediately applied to existing stockpiles or will those be granted legacy status? Will there be assistance provided for existing operators to achieve the testing expectations of the Guide? It may be beneficial to clearly explain the implementation of this Guide under several scenarios.

Recommendation

1. Consider the implications on existing quarry operators and identify how the Guide and its requirements will be implemented and if there will be any assistance provided to the small businesses currently operating quarries throughout the NWT.

Review comment 6:
Section reference – 1 and 7

The Guide provides a good technical basis to inform ARD/ML quarry sampling programs with a focus on quarry operators. The Guide does not provide much context on how this information can be used by a quarry operator (proponent) seeking a land use permit or water licence and therefore how the Guide can be used by regulators. Board staff note there have been discussions with the GNWT regarding the introduction of the GNWT Granular Resources Quarry Development Plan Template and how this may be used by both the GNWT and the Boards to clarify information expectation for all quarry operators.

Section 7 of the Guide provides some introductory discussion regarding mitigation measures that a regulator may require to manage ARD/ML materials; however, specifics regarding typical or anticipated information that supports an application for a land use permit or water licence for a quarry operation are not provided. A cross reference to the development of the Granular Resources Quarry Development Plan Template and how it may be implemented through the regulatory system may be of benefit.

Recommendation:

1. Cross-reference the GNWT Granular Resources Quarry Development Plan Template.
2. Update the Guide to include details on how it may be used by a quarry operator (as the proponent) seeking a land use Permit and/or water licence and the type of information that may need to be submitted to the Land and Water Board. For example, and of potential relevance to ARD/ML, this may include:
    - A water management plan that considers any water diversion, storage and treatment for the quarry site;
    - An evaluation of anticipated changes in surface water and groundwater quality and quantity as a result of the quarry activity;
    - An evaluation of water quality and quantity released to the receiving environment and associated assessment of potential impacts; and,
    - Provision of factual data or reports that document the ARD/ML sampling, analysis and conclusions.

Review comment 7:

Section reference – 1.3

The Guide identifies that a qualified professional is required to evaluate ARD/ML potential. The qualified professional is listed to be a Professional Geoscientist registered with the Northwest Territories and Nunavut Association of Professional Engineers and Geoscientists (NAPEG). It is acknowledged that this type of evaluation is more commonly completed by a Professional Geoscientists; however, this type of evaluation can also be completed by a Professional Engineer, also registered with NAPEG, provided they have relevant qualifications and experience.

The Guide notes that the qualified professional is to be registered with NAPEG or equivalent professional organization. It is not clear what equivalent professional organization is contemplated as acceptable. Note that Professional Geoscientists and Professional Engineers practicing in the NWT must be registered with NAPEG. As such, an out of territory professional designation should not be considered an “equivalent” professional organization.

Recommendation:

1. Update the Guide to acknowledge that the qualified professional can be a Professional Geoscientist or a Professional Engineer.
2. Provide clarity on the professional organizations considered to be “equivalent” to NAPEG.

Review comment 8:
Section reference – 2.2

The Guide provides context as to the importance of ARD/ML with regards to impacts to infrastructure. This is useful information to include in the Guide. Bullet 2 on page 4 of the Guide (last sentence) is suggestive that the quarry operator has responsibility to determine the appropriate use of the quarried material. Although the quarry operator may have responsibility to inform on the characteristics of their product to a receiver (i.e., user), this responsibility should not be extended to the use of the quarried material by the 3rd party unless otherwise agreed to through a contractual type of relationship. The quarry operator is not responsible for the engineering or regulatory requirements by a user of the quarried material.

Recommendation:

1. Clarification required to limit the roles and responsibility of the quarry operator for use of the quarried material and note that the receiver of the quarried material is responsible for its use.

Review comment 9:
Section reference – 2.3

Section 2.3 introduces the idea of ARD classification (potentially acid generating, uncertain, and non-potentially acid generating). These classifications are not introduced in detail until Section 4.1. This could be addressed through the previously recommended definitions section (Review comment 1), internal cross-referencing, or through some reorganization of the Guide. Additionally, the concepts of static testing and kinetic testing are first introduced here. More descriptions are provided in this case explaining static and kinetic testing to the reader but the introduction of the steps seem to be out of order since the kinetic testing bullet refers to static testing which has not yet been described and because throughout the document, static testing is recommended to be carried out prior to kinetic testing.

Recommendation:
1. Either explain the ARD classification process earlier in the Guide or provide cross-references to appropriate subsections where the explanation of the ARD classification ratios are provided.
2. Include the description of static testing as bullet six before the kinetic testing discussion instead of after the kinetic testing information.

Review comment 10:

Sections 2.3 and 3.2 are fairly repetitive.

Recommendation:
1. Reorganize or consolidate information presented in Sections 2.3 and 3.2.

Review comment 11:
Section reference – 3.1

Section 3.1 states that "unsuitable geological characteristics for a potential quarry location that can be identified during a reconnaissance level assessment would include:
- Visible sulphide mineralization, or presence of oxidized (rusted) sulphides.

Note that iron oxide staining is not necessarily indicative of sulphide oxidation as it may result from benign weathering processes or groundwater movement." It is not clear what the difference is between oxidized sulphates and iron oxide staining and how that can be visually determined.

Recommendation:

1. Provide more context and background discussion on the information being presented in the excerpt noted and how it can be used by a quarry operator.

Review comment 12:

Section reference – 4.1.2.5

The Guide discusses screening solid phase element content against the Canadian Council of Ministers of the Environment (CCME) Soil Quality Guidelines for Protection of Environment and Human Health and average crustal abundance. It is not clear how this screening activity is used to understand metal leaching potential, for example, if solid phase element content is above the criteria, then there is increased potential for ML for these elements; however, further testing is necessary to confirm.

The discussion in the Guide regarding the use of quarried material that is above the CCME guide is relevant context regarding use of quarried material; however, this discussion does not appear to be sufficiently correlated with the topic of ML or ARD. Clarification would be beneficial.

Further, Bullet 4 on Page 15 informs that quarried material above the CCME guide should not be used "in the applications discussed above (or similar)". It is uncertain if this reference pertains to the use of quarried material as defined in Bullet 1 on Page 15. Clarification would be beneficial.

Recommendation:

1. Clarify how screening solid phase element content against specific criteria is relevant to informing ARD/ML.
2. Clarify the applications referenced in Bullet 4 on Page 15 of the Guide and why this CCME soil quality guide is included as an item within this Guide that is focused on ARD/ML.

Review comment 13:

It is not clear if or how this guide might affect current land tenure, such as leases, or if any changes resulting from the Public Lands Act might impact this Guide once implemented.

Recommendation:

1. Include a discussion on any impacts to land tenure or the Public Lands Act if applicable.

Review comment 14:

The LWBs recognize the Guide has been drafted from the GNWT perspective; however, throughout our comments we have added references to federal regulations as well. We are of the opinion that it would be helpful for operators to understand that the requirements laid out by this Guide should also apply to federal lands, for consistency and to make it clear for transboundary projects.

Recommendation:

1. Consider broadening the scope to include federal lands

Quarry Sampling and Testing Guidance for Identification of Acid Rock Drainage and Metal Leaching Potential

January 2022

Acknowledgements – This guidance document was developed by SRK Consulting Canada (Inc) with input from various GNWT departments, the City of Yellowknife and Quarry Operators in Yellowknife. It incorporates best practices, SRK's professional experience, and incorporates information from previous guides developed through the Mine Environment Neutral Drainage (MEND) program. Dr. Bill Price is thanked for reviewing a draft version of the document and providing input.

1 Table of Contents

1 INTRODUCTION

This Government of Northwest Territories (GNWT) quarry sampling and testing guidance document has been prepared to assist quarry operators to identify rock with potential for acid rock drainage (ARD) and/or metal leaching (ML). Rock that develops ARD and/or ML is at risk of releasing contaminants and negatively impacting the environment. In the Northwest Territories (NWT), contaminant release is prohibited. These guidelines aim to minimize the risk of contravening NWT legislation.

This guidance document is applicable to current and potential quarry operations within the NWT, outside of mining/mineral exploration projects. This guidance document replaces the GNWT Interim Quarry Sampling Program Guide dated June 2020.

1.1 Objectives

The primary objective of this guidance document is to enable rapid identification of rocks with potential for ML/ARD and thereby allow operators to avoid blasting and excavation of materials that may negatively impact the environment. The methods can also be applied to quarry materials that have already been excavated and stockpiled to determine suitability for use.

1.2 Layout of this Guidance Document

This document provides guidance on sampling, testing, and assessing quarry materials so that potential problems can be avoided. The following information is included:

- Section 2 provides background information on ML/ARD and associated issues, including causes and potential impacts. It also includes the rationale behind the testing methods used to predict ML/ARD potential.
- Section 3 includes guidance on reconnaissance and detailed field geological assessment and sampling for lab testing.
- Section 4 includes guidance on static testing (and mineralogy), including assessment criteria and items that should be considered in the interpretation of results. Two approaches for static testing are described including a simplified but more conservative approach (Level I) and a more comprehensive approach (Level II) that provides more context and detail in the results, for materials with marginal or uncertain outcomes.
- Section 5 includes guidance for follow-up static and kinetic testing, including when additional testing would be necessary to supplement previous results.
- Section 6 provides guidance on confirmatory sampling for blasted rock in quarry developments (assuming materials were tested prior to development for suitable use).
- Section 7 includes recommendations for materials identified as having elevated potential for ML/ARD.
- Appendix A provides a summary flow chart for assessing ML/ARD potential for quarries using the approach in this guidance document.

1.3 Use of Qualified Professionals

This guidance document provides background information for quarry owners and operators to increase awareness and understanding of ML/ARD and related processes, the potential impacts of ML/ARD, and the process by which rock with ML/ARD concerns can be identified. This context is important for owners and operators who will set terms of reference for ML/ARD assessment and act on the results. However, evaluation of ML/ARD potential should be conducted by a qualified professional (QP) with specific qualification and experience in ML/ARD characterization and geological field investigations. The QP should be responsible for the ML/ARD evaluation and therefore is required to be registered as a professional geoscientist with the Northwest Territories and Nunavut Association of Professional Engineers and Geoscientists (NAPEG), or equivalent professional organization.

It is appropriate that the reconnaissance level geological assessment described in Section 3.1, could be conducted by a trained geologist or quarry operator with a background in geology.

2 BACKGROUND

2.1 Rocks, Minerals and ML/ARD

Bedrock and surficial geological materials (e.g. overburden, till) are comprised of a wide range of minerals, each with characteristic physical and chemical properties that contribute to the overall characteristics of the resulting rock or surficial material. Most of the common rock forming minerals are either stable or weather very slowly in atmospheric conditions. However, some minerals are more reactive and can break down much more rapidly when they are exposed to air and water through physical disturbances such as mining and quarrying. In the context of this guidance document, sulphide minerals such as pyrite and pyrrhotite are the most important type of reactive minerals that can be found in quarries. Sulphide minerals can be present in any rock type at a range of abundances, and at higher abundance they may form mineral deposits. However, even at low abundances they have potential to cause environmental impacts when they are exposed to air and water.

Oxidation of sulphide minerals produces sulphuric acid on the scale of individual mineral grains. Acidic sulphate minerals are products of previous sulphide oxidation and if dissolved, also produce sulphuric acid. Sulphide minerals and their weathering products contain metals (e.g. iron, copper, zinc) and/or metalloids (e.g. arsenic and selenium[1]) that may be released and dissolve in water (metal leaching). ARD may develop if the acid is not neutralized and there is sufficient water to flush it from the rock. Even if the acid is neutralized, ML may occur at neutral pH conditions; however, ML is usually enhanced by acidic conditions.

Calcium and magnesium carbonate minerals, when present in sufficient amounts, may be capable of neutralizing acid from sulphide oxidation and reducing metal mobility. Carbonates are relatively fast reacting (like sulphide minerals) and typically occur at low abundances in many rock types. Carbonates are a major component of limestone and other calcareous rock types.

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[1] Metals and metalloids are both included throughout this guidance document in the term metal leaching.

Silicate minerals are the main component of many rock types and typically react too slowly to provide effective neutralization under field conditions, unless sulphide mineral abundance is very low.

Although ML/ARD is more commonly associated with mineralized rock, the potential for this process to occur is based on the mineralogy of the rock, the balance between the acid generating and acid neutralizing minerals, their reaction rates, and disturbance of the rock which exposes mineral surfaces to air and water. Rocks with very low sulphide content may generate ML/ARD if the neutralizing mineral content is low enough and the rock is exposed through excavation.

It can take many years for ML/ARD to develop, and it can last for decades or even centuries.

ML/ARD is a natural process, however excavation and crushing increase the surface area of the rock available for reaction with oxygen and water, which greatly enhances the likelihood of ML/ARD occurrence if sulphide minerals are present. In general, higher sulphide mineral concentrations are more likely to be present close to known mineralized areas or mineral deposits. For this reason, ML/ARD is more commonly associated with mining activities and there are well established guidelines for characterization and management of ML/ARD in the mining industry.

Widespread recognition of ML/ARD issues only occurred in the 1980's hence historically, characterization of ML/ARD potential was not required. There are numerous examples in Canada where community resources and aquatic environments have been impacted and expensive cleanup operations have been required (Section 2.4). ML/ARD is predictable and often preventable, and the testing required to do this is significantly cheaper than applying expensive mitigation measures if it develops.

2.2 Associated Issues

ML/ARD and the resulting impacts to the aquatic environment at mine sites, including sites in the NWT are often the most highlighted issues associated with the processes described above. However, there are other associated issues that may be prevalent outside of the mining industry in the NWT due to the common use of locally quarried aggregate in residential or other built-up areas, including:

- Metal concentrations in excess of soil quality guidelines in materials such as unscreened rock-based landscaping aggregate; and
- Impacts to infrastructure resulting from breakdown of aggregate in concrete, compacted fill, or pavement.

These stem in part from the climatic challenges present in the north, e.g. use of aggregate as a landscaping material on residential lots due to difficulties in growing a lawn; or leaving roads, parking lots and driveways unpaved due to challenges associated with frost heave, and the higher cost of repairing a paved road versus a gravel road. The potential issues are discussed further below.

Elevated concentrations of metals may be present in materials such as unscreened rock-based landscaping aggregate if sulphide minerals and alteration products are present. If used in residential areas, human interaction may occur, for example through children playing in such materials, or aggregate (intentionally or unintentionally) becoming a growth medium for plants with edible parts.

There are Canadian Council of Ministers of the Environment (CCME) soil quality guidelines for the protection of environment and human health which are applicable to such landscaping materials and these are discussed later in this guidance document.

Impacts to infrastructure from aggregate may occur in a variety of ways:

- Where there is insufficient drainage, sulphide oxidation reactions release sulphate and metals in situ, or close to in situ, when aggregate gets wet. These components are retained in porewater. Evaporation of water as aggregate dries leads to precipitation of secondary minerals. Secondary minerals may dissolve again each time the aggregate gets wet, and precipitate again as evaporation occurs.
- Certain rock types are prone to expansion caused by volume differences between sulphide minerals and secondary weathering products. The volume increase can cause heaving of compacted fill (pyrite heave, e.g. Hawkins, 2014). This can cause damage to foundation slabs and buildings built on such fill, and numerous examples exist in the literature where this has been observed (e.g., in Sainte-Foy and Trois-Rivières (QC), Ottawa (ON), and Ireland (UK)). The phenomenon is related to specific rock types (e.g. mudstones, shales, and muddy limestones) and stems from the same processes that cause ML/ARD. Identifying material containing these rock types, that have iron sulphide minerals present, provides an indication to quarry operators that engineering investigation is necessary to determine appropriate use of such aggregate as fill.
- Sulphide oxidation and associated reactions in aggregate fill may cause expansion and contraction, void formation, decreased cohesion, decreased particle size, and decreased strength of fill, which may result in settlement, with potential for damage to overlying material/structures if differential settlement occurs.
- ARD (including acidic porewater in aggregate) is capable of dissolving cement and concrete that it contacts, and therefore has the potential, over time, to impact anything built from these materials. The process involves sulphuric acid reacting with neutralizing components in concrete to form calcium sulphate which has been shown to occur within microcracks of affected concrete (Ekolu et al., 2021). The porosity and permeability of affected concrete increases with loss of compressive strength occurring (Fattuhi and Hughes, 1988), hence causing deterioration of concrete based materials and structures.
- Aggregate with a risk of ML/ARD used to manufacture concrete (or other cement mixtures), may impact the structural integrity of the concrete through oxidation of sulphides in the aggregate and the effect of acid generating and acid neutralizing reactions on the performance of the concrete. These processes may cause pop outs, rust stains, cracking of concrete, and sulphuric acid attack (ASTM C295/C295M-19).

While this guidance document does not address particular end uses of aggregate and does not provide guidance on requirements for using aggregate in manufactured or engineering design scenarios, the geological and geochemical methods that are included in this guidance document will help quarry operators and practitioners to determine whether sulphide minerals are present, so they can consider seeking additional specialized advice depending on the intended use of quarry materials. Further information on aggregate use in manufactured or engineering design scenarios is available in the references provided in the text.

2.3 Characterization Approach and Rationale

The typical approach and rational for characterization of ML/ARD potential is described as follows:

- Geological investigation is conducted to determine the rock types present, the presence of sulphide minerals (and/or alteration products), the presence of carbonate minerals, and the scale of variation. This is necessary to determine sampling requirements.
- Geochemical investigation, including mineralogy, acid base accounting and metal analyses (static tests) are conducted to determine current conditions and potential future conditions.
- Results from these types of lab tests are usually available in a few weeks. Mineralogy and geochemistry of rock or surficial material to be quarried (or already stockpiled), will indicate the balance of acid generating and acid neutralizing minerals (to classify ARD potential). The concentration of metals in the material to be quarried (or already stockpiled), combined with the potential for acidic conditions to develop, will inform ML potential. Coupled with geological investigations this stage of assessment should be sufficient to determine whether material has risk of ML/ARD so it can be avoided, and hence alternative and more suitable locations for quarries can be identified.
- Analysis of drainage samples in contact with or coming from previously exposed quarry faces, or stockpiled material, if these exist, will provide a more definitive indication of current pH and metal leaching conditions.
- Where geological material (e.g., rock units) with high and low ARD potential are interspersed and segregation is desired, then additional (more detailed) sampling and static testing is likely to be necessary to determine the manner and scale of variation, whether segregation is feasible, and segregation criteria and methods.
- Where the ARD potential of the material is classified as uncertain based on static results, then kinetic testing (combined with quantitative mineralogy on each kinetic sample) would be required to determine relative reaction rates of acid generating and acid neutralizing minerals, and more accurately determine the potential for ML/ARD.
- Kinetic testing measures solute release over time and involves weathering samples over an extended period of time (months to years) and monitoring the contact water that flushes through the sample (leachate). Lab-based kinetic testing provides some acceleration of weathering processes with aeration and weekly flushing of samples at room temperature. Field-based kinetic testing involves larger volumes of rock (typically 250 kg), conducted at the site being investigated, where the contact water is ambient snow melt and rainfall. Kinetic testing provides information that is used for predicting water quality so that potential impacts can be determined. Compared to static testing, kinetic testing is expensive and time consuming. It is commonly used in the mining industry where potential impacts from mine materials need to be

predicted. In the quarrying industry, static testing can be used to identify whether material is suitable for use. If it is not suitable, and avoidance of potentially problematic materials is not possible, then lengthy kinetic tests and data interpretation will be necessary to predict future pH and ML conditions, and therefore the monitoring and mitigation measures that may need to be incorporated to address those issues.

- Kinetic testing is a type of leach testing. There are also static leach tests, which measure the present solute content and are less expensive to conduct (e.g. shake flask extraction tests), that can be conducted on weathered material to provide valuable information on the existing ML potential. These should be conducted if there is already an abundance of alteration products (e.g., surface oxidized material (gossans) or crushed material that has been exposed/stockpiled for several years, if it exists). There is little value in performing these tests on fresh rock. If used on fresh rock where there is little to no build-up of soluble weathering products, they are likely to provide mis-leading information on ML potential. Data from leach tests require interpretation to indicate contact water quality, as the tests are dilute compared to rock to contact water ratios present in typical conditions of aggregate use in the NWT.

2.4 Other Sources of Information

Other sources of background information are available which may be of interest as follows (full references are provided in the reference list):

- Other ML/ARD guidance documents:
    - Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials (Price, 2009)
    - The Global Acid Rock Drainage Guide (INAP, 2012)
- British Columbia aggregate testing policies:
    - Evaluating the potential for ARD and ML at quarries, rock cut sites and from stockpiled rock and talus used by BC Ministry of Transportation and Infrastructure (MOTI, 2013)
    - Guide to preparing mine permit applications for aggregate pits and quarries in British Columbia (BC, 2010)
- Vancouver Island highway project ARD and mitigation case study:
    - Case Study of Non-Mining Prediction and Control of Acid Rock Drainage – The Vancouver Island Highway Project (Morin et al., 2003)
- Nova Scotia ARD information circular:
    - Acid Rock Drainage in Southwestern Nova Scotia (NS Dept of NR, 2013)
- Halifax International Airport ARD and mitigation case study:
    - Acidic Airport Drainage, Over 20 Years' Worth of Experience (Hicks, 2006)
- Glossary of terms related to ML/ARD:
    - Available at http://www.gardguide.com/index.php/Glossary

3 GEOLOGICAL INVESTIGATION AND SAMPLING

This section describes the sequential steps that should be taken when investigating an area as a potential quarry i.e. reconnaissance geological assessment, followed by detailed field geological assessment and then sampling for geochemical analysis. The detailed geological assessment and sampling for geochemical analysis are also applicable to existing quarries, where operators are considering a quarry expansion, and to operations with stockpiled material.

3.1 Reconnaissance Geological Assessment

A brief field visit to a proposed location to assess major rock types and presence of sulphide minerals or sulphide alteration products is valuable for identifying locations that are more likely to be prone to ML/ARD issues and hence can be ruled out of further consideration for a quarry location. It may be possible to obtain this information by reviewing background geological information available from the Northwest Territories Geological Survey (NTGS) or other sources. Key information for this level of assessment would be:

- Rock types present
- Carbonate content associated with each rock type
- Sulphide mineralization (minerals present, and abundance) associated with each rock type
- Presence of oxidized zones (oxidation products/staining/precipitates indicative of sulphide oxidation)

Unsuitable geological characteristics for a potential quarry location that can be identified during a reconnaissance level assessment would include:

- Visible sulphide mineralization, or presence of oxidized (rusted) sulphides.

Note that iron oxide staining is not necessarily indicative of sulphide oxidation as it may result from benign weathering processes or groundwater movement.

3.2 Detailed Field Geological Assessment

A more detailed geological field investigation to support characterization of ML/ARD potential at a proposed quarry location should include:

- Describing and identifying all geological units (bedrock and surficial) present, including the 3D distribution and thickness of each unit. This is typically conducted through geological mapping, including examining road cuts or other rock cuts or cliff faces where possible), and/or drilling.
- For each unit identified, the following information should be collected:
    - Occurrence (e.g. disseminated, vein) and estimated abundance of sulphide, sulphate and iron oxyhydroxide minerals, with field mineral identification if possible.
    - Occurrence and estimated abundance of carbonate minerals and intensity of reaction to cold dilute hydrochloric acid.
    - Distribution/variation in abundance of the above minerals within the unit.

  - If present, description of weathering features, oxidized zones, signs of leaching and precipitation of secondary minerals (e.g. rusty or white powdery stains).
  - Rinse and/or seepage pH, of contact water from weathered materials, measured with a pH probe or pH paper.
  - Record the methods used.
  - Take photographs (include a scale to infer the size of features in the photographs).
  - Identify areas that could not be accessed for investigation, and other information gaps or uncertainties.

3.3 Sampling for Lab Analysis

Sampling for mineralogical and geochemical analysis can be conducted during the same visit as the detailed field geological investigation. Sampling of solid materials should be designed to spatially cover (in 3D) the area to be excavated, and include all the geological units/rock types present. Samples should represent typical characteristics as well as the variability present in each unit, particularly for the key minerals that effect ML/ARD potential (i.e. sulphide and carbonate minerals). The information collected in the preceding detailed geological assessment is used to determine the number of samples required to represent the composition of each unit. Where information is scarce, geological information from equivalent geologic strata in nearby locations (outside of the proposed excavation area) may be used to inform likely variability within a particular unit to be sampled.

Water sampling is typically opportunistic and is most valuable when information can be recorded regarding origin of the water, particularly the geological characteristics (as identified for the detailed geological assessment) of the material that it may have been in contact with.

Maps of sampling locations should be provided as part of reporting results, including both plan and cross-section views to indicate 3D sampling. Sampling details are provided in the sections that follow.

3.3.1 Sampling of Bedrock, Surficial Materials and Stockpiles

3.3.1.1 Number of Samples

To ensure samples are spatially representative of the proposed excavation, samples should be collected at regular intervals in 3D space. In previously undisturbed areas (assuming a lack of drilling), sampling without mechanical equipment may be possible from surface outcrops, and the natural surface relief may be used to obtain samples from a variety of depths. Pre-existing road cuts, ravines, and trenches, if available, can be used to obtain samples from greater depths. In pre-existing quarries undergoing proposed expansion, sampling quarry walls and drill cuttings may provide the third dimension necessary for spatial coverage.

For stockpiled material, spatial coverage can be gained by collecting samples that represent different areas of a quarry. If stockpiles are composites of material from different areas of the quarry, then geological and mineralogical variation can guide sampling decisions.

Each identified geological unit should be sampled. If a unit is heterogeneous then more samples will be required, as the material may have variable ML/ARD potential. Heterogeneity of a unit should be determined based on variability of information identified in the geological assessment, particularly variation in occurrence and/or abundance of sulphide minerals (and their alteration products), and carbonate minerals.

Guidelines for minimum number of samples needed per geological unit are provided in Table 1 based on tonnage of unit to be excavated (or already stockpiled), assuming only minor heterogeneity in the unit. Sample number requirements will be higher for more heterogeneous units where the range of compositional variability will need to be represented. It is worth noting that collecting insufficient samples may lead to delays in use of material if additional testing is required for adequate characterization of ML/ARD potential. In addition, if low sampling frequency leads to failure to identify material that has elevated risk of ML/ARD, there may be unintended consequences of use of such material.

Table 1. Minimum Sampling Frequency per Geological Unit Based on Tonnage of Unit to be Excavated (adapted from Price, 2009)

Tonnage of Unit (metric tonnes)	Minimum Number of Samples Per Geological Unit
<10,000	3
10,000 to <100,000	4 to 8
100,000 to <1,000,000	9 to 26
1,000,000 to <10,000,000	27 to 80

Table note – Heterogeneity in a geological unit will require greater sampling frequency

3.3.1.2 Sample Size and Compositing

Sample size should typically be around 1 to 2 kg for static testing (including mineralogy). Collecting samples that are large enough for follow up kinetic testing (if required), may be wise if costs of returning to site are significant. One kg is used for lab kinetic testing of a sample (in addition to 300 g for particle size analysis). Every kinetic test sample requires mineralogical and static characterization, therefore sample size for combined static and lab kinetic testing should typically be around 2.5 to 3.5 kg.

In addition to these requirements, for oxidized or weathered material where static leach testing may be valuable to inform ML potential, 300 g would be required of <2 mm material for shake flask extraction testing. For larger scale static leach tests of weathered material, several kg of material could be needed if water quality predictions are required (but this is unlikely if the aim is simply to avoid using rock with elevated risk of ML/ARD).

Sample compositing should be avoided in heterogeneous material as it may mask natural variation that may affect ML/ARD potential. In homogenous material within a single geological unit, compositing should be limited to the height of a bench or the surface of an outcrop covering a few meters.

3.3.1.3 Information to Record at Sample Site

The following information should be collected/recorded for each sample and is either required for the chain of custody (COC) or is valuable for data interpretation:

- Sample number (needed for COC).
- Date and time of sample collection (needed for COC).
- Sample location (including depth).
- Material type (e.g. outcrop, till, drill cuttings, stockpile).
- Rock type and geological description.
- Location relative to key geological features within the unit (e.g. margin of dyke, top of flow, bottom of graded bed, proximity to structural features).
- Estimated abundance and occurrence (e.g. disseminated, vein) of sulphide, sulphate and iron oxyhydroxide minerals, with field mineral identification if possible.
- Estimated abundance and occurrence of carbonate minerals and intensity of reaction to cold dilute hydrochloric acid.
- Whether sample is typical of the unit it represents, or whether it represents the low or high end of a particular parameter (e.g. sulphide content, carbonate content, degree of oxidation) compared to the range identified for that unit.
- If present, description of weathering features, oxidized minerals, secondary mineral precipitates (e.g. rusty or white powdery stains).
- Rinse pH of <2 mm fraction of weathered samples (if being tested in the field – otherwise this can be tested by the lab).
- Photographs (include a scale to infer the size of features in the photographs).
- For stockpile samples, any available information on stockpile source location within the quarry, date of blasting and crushing, particle size, whether screened or unscreened stockpile.

3.3.1.4 Additional Guidance for Sample Collection

Unless samples are targeting an oxidized zone/unit, then the thin surface weathered rind (often partially lichen covered) should be removed in the field as much as possible from outcrop samples using a geology hammer.

There are additional considerations for sampling unconsolidated surficial material or previously stockpiled aggregate. For material that is heterogeneous in terms of particle size or rock type of the particles present, a larger than 2 kg sample size may be required to ensure a representative sample is collected. Additionally, these types of materials should be sieved to <2 mm and >2 mm particle size fractions for static testing. This can be conducted by the lab (with the weight of each size fraction reported); however, a larger than 2 kg sample size may be required if the proportion of <2 mm material appears to be low (a minimum of 500 g should be available for static testing of each size fraction).

Sieving is conducted primarily because the <2 mm fraction has the greatest surface area and is therefore considered to be most reactive and most influential over contact water chemistry. Related to this, depending upon length of exposure, the fine fraction of weathered material may be preferentially depleted in acid-generating (or acid neutralizing) minerals. Additionally, in blasted or crushed material sulphide minerals are often concentrated in the finer fraction if they were originally present in veins or along fractures. If collecting unconsolidated materials for kinetic testing, this portion should not be screened into <2 mm and >2mm fractions.

If samples are wet or damp, they should be dried at room temperature as soon as possible following collection to avoid mineral oxidation. This is especially true of finer fractions of unconsolidated or stockpiled material. If samples can't be dried in the field and delays are anticipated before samples can be shipped to the lab, samples could be frozen. If samples are shipped wet or damp, then the lab should be instructed to air dry samples (at room temperature) as soon as possible after receipt.

Lab sample preparation and analysis details are documented in Section 4.1.

3.3.2 Water Sampling

Water sampling is relevant to previously disturbed or quarried areas, or surface oxidized zones in/near proposed quarry sites. In such areas weathered material may be present in quarry walls, stockpiles, aggregate used for quarry access roads, or discarded material (or in outcrops for surface oxidized zones). Water that has been in contact with such materials (termed contact water) may have dissolved weathering/oxidation products that can provide information on:

- Current pH conditions
- Current metal leaching conditions
- Mineral weathering reactions that are occurring such as sulphide oxidation and carbonate dissolution

Contact water sampling should be conducted where possible. It is also valuable to sample water both upstream and downstream of the exposed/contacted rock so that change can be measured. Sampling water with high water to rock ratios (e.g. lakes or larger streams flowing next to a small quarry) should not be included.

Any available information should be recorded regarding origin of the water, particularly the geological characteristics (as identified for the detailed geological assessment) of the material that the water may have been in contact with. Photographs of the water seep/flow and the contact material should be taken including any stains/precipitates present, and information recorded on the flow rate. Ponded water may have been affected by evaporation or rainfall that may modify the original concentration of parameters present so flowing water is preferred. pH and conductivity should be measured in the field if possible as these parameters may change between time of sampling and laboratory analysis.

Water sampling is typically opportunistic but requires planning as sampling supplies must previously have been obtained from the lab. Water sampling protocols (i.e. how to collect a water sample) are beyond the scope of this guidance document however further information may be obtained from the BC Field Sampling Manual (Part E; BC, 2013), and from the labs providing sampling supplies. It is worth emphasizing that filtration of samples for dissolved parameters, and sample preservation, should be conducted in the field, due to changes that can occur in the water chemistry between sample collection and receipt at the lab.

Sample analysis details are provided in Section 4.2.

3.3.3 Quality Control Sampling

Quality control (QC) is performed by the labs and they have QC criteria that samples or batches of samples need to pass for data to be reported. Internal QC results are not routinely reported by all labs but can be requested.

In addition to internal lab QC, sampling programs typically include collection of blind QC samples to monitor for contamination (in water samples) and reproducibility (in water and solids samples). Sample heterogeneity in solid samples is a key reason for low reproducibility of results, particularly in samples with coarse particle sizes. Duplicate samples provide a valuable check on natural geological variability of key parameters that may affect ML/ARD potential.

Information on QC data analysis is provided in Section 4.3.

3.3.3.1 Solids

A blind duplicate sample should be collected for every 10 samples (or part thereof). It should be submitted under a different sample number to the sample it duplicates, and not identified to the lab as a QC sample.

3.3.3.2 Water

A blind duplicate sample and a field blank should be collected every tenth sample (or part thereof). For field blanks, deionized (DI) water is used (previously obtained from the lab). Duplicate samples and field blanks should be prepared (collected/filtered/preserved) using the same methods as used for samples. They should not be identified to the lab as QC samples and should be submitted with independent sample ID’s.

4 STATIC TESTING AND ASSESSMENT CRITERIA

In alignment with the primary objective of rapid identification and avoidance of rocks with potential for ML/ARD, a two-fold approach is provided for static testing and assessment: (i) a simplified but more conservative assessment, (ii) a more comprehensive (and expensive) approach to static testing that provides more context and detail in the results, for material with marginal or uncertain outcomes. Quarry operators can initially choose either level of static testing; however, the ARD assessment criteria are specific to each level of testing, therefore the more stringent Level I assessment criteria should be used if Level I testing is used. The more comprehensive Level II static testing is equivalent to that typically used for initial assessment of ML/ARD potential in exploration/mining projects.

The detailed geological assessment may provide insight into whether Level I testing may be sufficient; however, if Level I provides uncertainty in the ARD classification, then Level II analysis on the same samples used in the Level I tests will be required to reduce the uncertainty and provide further information on whether material is suitable for use. Sample preparation is the same regardless of the level of static testing. Labs can be instructed to analyze the reduced parameter list first and to save material in case further testing is required.

The ML/ARD testing and assessment approach is summarized in a flow chart in Appendix A.

4.1 Solids

4.1.1 Sample Preparation

Samples should be submitted to a certified laboratory that performs ARD testing. Some of these (e.g. Bureau Veritas (previously Maxxam Analytics) and ALS Minerals) have sample receiving locations in Yellowknife.

For unconsolidated material (e.g. till, stockpiled aggregate):

- Labs should be instructed to dry-sieve samples into <2 mm and >2 mm fractions (if not conducted in the field). The exception to this would be if sufficient sample has been collected for kinetic testing (in case it is required) then 1.3 kg should first be removed (prior to sieving) and reserved by the lab for potential kinetic testing and associated particle size analysis.
- Sample preparation for rinse pH and shake flask extraction leach testing (on weathered unconsolidated samples) requires splits of the <2 mm fraction to be separated so that this material is not pulverized.
- Pulverization is required for the other static tests on the <2mm fraction.

For outcrop samples, drill cuttings, rock chips, and >2mm fractions:

- Samples should first be crushed to <1/4 inch.
- If sufficient material has been collected for kinetic testing (in case it is required) then 1.3 kg of <1/4-inch material (the particle size required for standardized kinetic testing) should be removed and reserved by the lab for potential kinetic testing and associated particle size analysis.
- If samples are from oxidized zones, then a split should be removed (a few hundred grams) for dry sieving to generate a <2 mm sample for rinse pH.
- Pulverization is required for the other static tests.

4.1.2 Simplified Static Testing with More Conservative Assessment Criteria (Level I)

The simplified static testing approach may be sufficient to determine whether material has the potential to generate acid or has an elevated risk of metal leaching; however, there are sources of uncertainty inherent in the approach, therefore the ARD assessment criteria are more conservative than the Level II assessment criteria. Following Level I assessment the results may be clear cut with regard to ARD potential, however if they are not, then Level II static testing should be conducted.

The following parameters are needed for the minimum level of assessment (Level I):

- Rinse pH (if weathered material is available - conducted on uncrushed, sieved <2 mm fraction)
- Paste pH (if no weathered material for rinse pH)
- Total sulphur
- Total inorganic carbon (carbonate)
- Modified Sobek neutralization potential (or equivalent variations)
- Solid phase multi-element analysis (following aqua regia digestion)

From these parameters, the following calculations and assessments can be performed.

4.1.2.1 Rinse pH or Paste pH

The sample is already acid generating if rinse pH or paste pH are below pH 5.0[2]. No further analysis is required to determine whether a sample has potential for ARD; however, total sulphur can be used to provide an indication of whether rates of acid generation from sulphide oxidation are likely to be very low and no higher than background levels (e.g. if total sulphur is below detection limit).

4.1.2.2 Total Sulphur and Acid Potential

Total sulphur (by LECO analysis) can be used to calculate acid potential (AP). This is a simplification that assumes that all sulphur is present in minerals that have potential to generate acid. If the geological assessment indicates that this is not the case (e.g. non-acidic sulphate minerals such as anglesite, barite, or gypsum are present), then the Level II static testing should be conducted which includes mineralogy and sulphur speciation.

Acid potential is calculated from total sulphur as follows:

AP (kg $CaCO_3$/tonne) = total sulphur (%) x 31.25………………………………Equ 1

4.1.2.3 Carbonate and Bulk- Neutralization Potential

Neutralization potential (NP) needs to be interpreted from carbonate-NP and bulk-NP.

Carbonate-NP is calculated from lab measured total inorganic carbon (TIC), reported by the labs either in units of %C or %CO_2. The result should be converted to units of kg $CaCO_3$/t.

Bulk-NP should use a Modified Sobek method or similar variation (i.e. not the more aggressive Sobek method which includes boiling the sample).

Bulk-NP and carbonate-NP typically differ. If bulk-NP is higher than carbonate-NP this is likely due to dissolution of a portion of the silicate minerals in the bulk-NP tests (which are aggressive compared to typical field conditions and tend to overestimate field NP). If carbonate-NP is higher than bulk-NP this likely indicates that carbonate minerals are present which are not net-neutralizing (e.g. iron or manganese carbonates). The lowest of bulk-NP and carbonate-NP should be used for classifying ARD potential for Level I assessment.

4.1.2.4 ARD Potential Classification (From Level I Static Testing)

Using the appropriate measure of NP as discussed in the previous section, the following criteria are used to classify samples to estimate ARD potential based on the ratio of NP to AP, both in units of kg $CaCO_3$/tonne:

- NP/AP < 1 is potentially acid generating (PAG) and indicates that material should not be used/excavated

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[2] A caveat to this is that organic-rich surficial materials may be a source of organic acids, which are unrelated to acid generated from sulphide mineral oxidation.

- NP/AP of 1 to 3 indicates uncertain potential for ARD and requires further investigation to determine suitability for use
- NP/AP >3 is not potentially acid generating (non-PAG)

Use of less conservative classification criteria (i.e. using NP/AP >2 as non-PAG); or determining suitability of material that classifies as uncertain ARD potential, requires reducing the potential for errors in the estimation of effective NP and AP. This requires reducing the uncertainty in the mineral species used in the calculation. This should be done through Level II static testing (Section 4.1.3), so that the potential for errors in the classification can be reduced. Even following Level II static testing, samples that still had NP/AP between 1 and 2 would require kinetic testing to show whether the material was suitable for use, and significant project delays should be expected if there are no suitable alternatives for sourcing materials.

4.1.2.5 Metal Leaching Potential and Elevated Metals Content

Solid phase element content is typically assessed from results that used an aqua regia method of digestion which should fully digest sulphide and carbonate minerals, however, will only partially digest more resistant minerals such as silicates.

The results are typically interpreted by comparing them to soil quality guidelines and/or average crustal abundance data. Screening solid phase element contents against specific criteria has the following purpose:

- Screening against CCME Soil Quality Guidelines for the Protection of Environmental and Human Health (CCME 2021a) is important in the NWT due to the common use of locally quarried aggregate in residential or other built-up areas, in environments such as backyard landscaping and unpaved driveways and paths/roads, where direct human interaction is likely, or material may occur in an application comparable to soil.
- Screening against rock type specific average crustal abundances provided in Price (1997) to determine whether elements that have water quality guidelines are enriched in the samples.

The following assessment criteria are applicable:

- Exceedance of CCME Soil Quality Guidelines for the Protection of Environmental and Human Health indicates that material should not be used in the specific land uses identified in the guidelines (agricultural, residential/parkland, commercial, or industrial), in the applications discussed above (or similar). Use of material above the guidelines is unlikely to be protective of environmental or human health and if used, may require a site-specific risk assessment to determine whether remediation is recommended (CCME 1999, GNWT 2003[3]).
- Exceedance of 10 times the rock type specific average crustal abundances provided in Price (1997) indicates element enrichment (compared to the average for that rock type) and possible

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[3] Note that Yellowknife has a site-specific guideline for arsenic in soils due to elevated background levels. This is provided in GNWT (2003) however is currently under review by the GNWT.

elevated risk of ML potential. This does not provide a clear indication of ML potential as element mobility is often pH controlled.

- As most elements are more mobile under acidic conditions, any sample that is already acid generating, or classified as PAG, has elevated potential for ML regardless of the solid phase element concentration.
- Total sulphur contents >0.5%, may have increased potential for ML, regardless of the classification of ARD potential if the geological assessment showed that sulphides (or native sulphur or acidic sulphates) were the predominant sulphur minerals. Such material should not be used/excavated without further investigation of ML potential through mineralogy and sulphur speciation (Level II static testing).

Interpretation of ML potential requires professional judgment. Kinetic testing and interpretation of water quality effects may ultimately be required to determine rates of ML and if material is suitable for the intended use.

4.1.3 More Comprehensive Static Testing and Interpretation (Level II)

Level II static testing is used to reduce uncertainty and hence the potential for errors in the classification of ARD potential. It is recommended in the following situations to help inform whether material is suitable for use:

- Based on the geological assessment, the primary sulphur minerals are not sulphides.
- Based on the geological assessment or comparison of carbonate-NP to bulk-NP (as per Level I static testing), iron/manganese carbonates are thought to be present.
- Level I static testing provides an ARD classification of uncertain potential for ARD.
- Less conservative ARD classification criteria are preferred.

Level II static testing should be conducted on the same samples used in the Level I tests. The following parameters are needed for the more comprehensive level of static assessment in addition to those listed for Level I testing:

- Paste pH (if not tested in Level I)
- Sulphate (see below regarding methods)
- Sulphide by calculation
- Quantitative mineralogy (see below regarding methods)

Quantification of sulphate typically offered by ARD labs involves HCl dissolution (for relatively soluble sulphate species) or Na_2CO_3 extraction (for less soluble sulphate species). Price (2009) contains a discussion of these and other methods of sulphate analysis, the sulphate minerals they are likely to quantify, and whether they are also likely to dissolve certain sulphide minerals such as pyrrhotite. Sulphate results therefore need to be interpreted in combination with mineralogical results. For barite (barium sulphate) rich samples, a whole rock analysis method will be required to calculate barite content from measured barium.

Quantitative mineralogical testing is required on a subset of the samples used in Level I, to identify sulphur and carbonate minerals. Ten percent of samples with a minimum of two per rock type, should undergo mineralogical analysis (including those with typical and higher sulphur contents for each rock type). The mineralogical method should be determined by the geochemist/geoscientist (QP) working on the ML/ARD investigation. The geological assessment will provide information on the detection limits that are likely required to quantify sulphur and carbonate minerals. As a guide, QEMSCAN (quantitative evaluation of minerals by scanning electron microscope) and MLA (mineral liberation analysis) have significantly lower detection limits than XRD (x-ray diffraction) and optical petrography and are therefore more suitable for quantifying minerals where abundance is below 1%. The lab should be advised that identification of sulphur and carbonate minerals is the primary aim of the mineralogy, and therefore not to group different sulphur and carbonate phases together.

Using the combined Level I and II parameters, the following additional calculations and assessments can be performed to estimate ARD potential.

4.1.3.1 Sulphur Speciation

The presence of acidic sulphate minerals can be determined using mineralogy and by assessing the sulphate analysis results against paste pH and rinse pH. Non-acidic sulphate (as %S) can be subtracted from total sulphur, and the resulting sulphur content assumed to be sulphide. Sulphide (as %S) can then be used in equation 1 (in place of total sulphur) to calculate acid potential.

The calculation of acid potential may be refined further, as per the methods presented in Price (2009), if the mineralogical analysis indicates that the primary sulphide minerals are not iron sulphides.

4.1.3.2 Neutralizing Mineral Form

The mineralogical analysis will provide results on the carbonate mineralogy and whether iron or manganese-bearing carbonates are present. Any iron and manganese-bearing component of the carbonates should not be included in the estimate of carbonate-NP or in calculation of ARD potential as these carbonate forms are not net-neutralizing. The data should be interpreted to calculate a corrected carbonate-NP.

4.1.3.3 ARD Potential Classification (From Level II Static Testing)

Following interpretation from Level II testing, with consideration of the sulphur and carbonate mineral forms, the following ARD classification criteria may be used to estimate ARD potential based on the ratio of NP to AP. Corrected carbonate-NP should be used for classifying ARD potential.

- NP/AP < 1 is PAG and indicates that material should not be used/excavated
- NP/AP of 1 to 2 has uncertain potential for ARD and material should not be used or excavated without kinetic testing to determine suitability for use
- NP/AP >2 is non-PAG.

In addition, a low sulphur criterion for classifying non-PAG may be considered, if appropriate. A sample with total sulphur of less than 0.1% is likely to be non-PAG unless it contains no NP. At this sulphur content, acid generation rates are likely to be low enough for silicate minerals to provide effective neutralization; however, there are examples of quartz-rich sandstones with sulphur contents less than 0.1% that have generated acidic drainage indicating that a <0.1% sulphur criterion for non-PAG is not appropriate for rocks that are predominantly quartz.

If ARD potential classification is uncertain following Level II static testing, then relative reactivity of sulphide and carbonate minerals will need to be considered. This is done through kinetic testing and data interpretation and may lead to material being determined unsuitable for use. The work is time consuming and expensive therefore quarry operators may prefer to investigate alternative areas that may be more suitable for excavation.

4.1.3.4 Metal Leaching Potential (From Level II Static Testing)

Metal leaching potential was discussed in Section 4.1.2.5 and the same screening criteria are applicable for Level II static testing; however, ML potential can be revisited with mineralogical data and sulphur speciation results through interpretation of the likely mineral hosts of elements that are identified as enriched, along with the likely mineral reactivity and element release mechanisms. As such, interpretation of ML potential from static results requires professional judgment.

Kinetic testing to determine rates of ML, and interpretation of water quality effects under site specific conditions may ultimately be required to determine potential environmental impacts and if material is suitable for the intended use.

4.2 Water Analysis and Assessment

Water samples collected from sources discussed in Section 3.3.2, provide an indication of current pH and metal leaching conditions. Water sampling information was provided in Section 3.3.2. Samples should be submitted to an accredited laboratory for analysis of the following parameters:

- General parameters:
    - pH
    - Electrical conductivity
    - Hardness (calculation from measured parameters)
- Anions and nutrients
    - Total alkalinity
    - Sulphate
    - Chloride
    - Fluoride
    - Nitrogen species (nitrate, nitrite, ammonia)
- Dissolved metals
- Ion balance (calculation from measured parameters for QC)

The results should be considered in the following ways to provide an indication of current pH and metal leaching conditions:

- Compare contact water samples with upstream and downstream samples (if it was possible to collect these), to provide an indication of how contact water is influencing background water.
- Major ion concentrations, particularly sulphate, alkalinity, calcium, and magnesium, are valuable indicators of occurrence of sulphide oxidation and carbonate dissolution reactions.
- Trace ion concentrations, particularly arsenic, cadmium, copper, nickel, selenium, and zinc, (along with sulphate concentrations) may provide valuable information on leaching associated with sulphide oxidation.
- Compare concentrations of regulated parameters to CCME Water Quality Guidelines for the Protection of Freshwater Aquatic Life.
- Similarly, compare sulphate concentration to the BC water quality guideline (MOE 2013; calculated using receiving environment hardness).
- Exceedances of the guidelines should be interpreted in conjunction with the static results from the contact materials and may indicate that metal leaching is occurring and the potential effects of contact material on the down-gradient aquatic environment where the materials will be used will need to be further assessed to determine if material can be safely used. Lack of exceedances does not indicate that material does not have potential for future metal leaching as weathering proceeds.
- pH less than 5 indicates that contact material is acid generating and should not be used[4].

4.3 Quality Control Data Analysis

4.3.1 Solids

QC data analysis should consider:

- Consistency of lab QC results with lab QC criteria
- Reproducibility of duplicate samples and lab replicates
- Comparison of total sulphur to sulphate content
- Consistency of NP result with paste pH and fizz rating
- Comparison of bulk-NP to carbonate-NP

4.3.2 Water

QC data analysis should consider:

- Consistency of lab QC results with lab QC criteria
- Reproducibility of duplicate samples and lab replicates
- Ion balance
- Method blank concentrations
- Comparison of field and lab pH, and field and lab conductivity

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[4] A caveat to this is that waters may have naturally acidic pH (below pH 5) as a result of flow through organic rich surficial material such as tundra soils and bogs, therefore this should be considered in the interpretation.

5 FOLLOW UP SAMPLING AND TESTING

Additional sampling, additional testing, or both, may be required based on the Level I and Level II static results. The following subsections identify scenarios that would require additional work. This work is time consuming and expensive therefore quarry operators will need to decide whether the expense and project delays are worthwhile, or if another area should be investigated instead, with a view to finding a location more suitable for excavation (i.e. with material classified as non-PAG).

5.1 Uncertain Potential for ARD

If ARD potential classification is uncertain following Level II static testing and interpretation, then the relative reactivity of sulphide and carbonate minerals should be considered. This is done through kinetic testing and data interpretation of samples that have undergone Level II static testing. Without kinetic testing, material with uncertain potential for ARD is considered PAG.

5.2 Uncertain Potential for Metal Leaching

If ML potential has a high degree of uncertainty following static testing, then kinetic testing and data interpretation can be used to determine rates of ML and the potential for negative impacts.

5.3 Classification Varies (Material is Heterogeneous)

If samples with different ML/ARD characteristics occur together (based on static results) within a proposed excavation (e.g. non-PAG rock occurs with rock classified as PAG or uncertain potential for ARD, or material with low and elevated risk of ML occur together) then additional samples will need to be collected and undergo static testing to determine if the scale of variation is suitable to allow segregation into useable versus higher risk components. Operational segregation criteria will also need to be defined based on the results. This typically involves many samples (e.g. hundreds at mine sites) and close oversight by a QP. If the scale of intermixing is too fine to allow segregation, then excavation should be avoided.

5.4 Static Leach Testing

Material from oxidized zones or weathered stockpiles could undergo leach testing to supplement static testing and inform current ML conditions if the material contains an abundance of soluble alteration products. Samples should be splits of those that are/have undergone static testing. Rational and sampling information is provided in Section 2.3 and Section 3.3.1. Shake flask extraction tests are often used (however see limitations in Section 2.3). Data can be interpreted in the same way as for water samples (Section 4.2). Comparison to water quality guidelines is often used as a screening tool; however, this needs caution and data interpretation, as leach tests are often dilute compared to the dry conditions present in the NWT and are unlikely to represent contact water under field conditions.

5.5 Kinetic Testing

Kinetic testing provides information on ML that is used for predicting water chemistry so that potential impacts can be determined. Further background information is documented in Section 2.3. Kinetic testing is commonly used in the mining industry where potential impacts from mine materials need to be determined. In the quarrying industry, static testing can be used to identify whether material is suitable for use. If it is not suitable, and avoidance of potentially problematic materials is not possible, then kinetic testing and data interpretation will likely be necessary to predict future pH and ML conditions, and to determine the monitoring and potential mitigation measures that need to be incorporated into project designs. Kinetic testing recommendations are project specific and are dictated by the size of the project and the geological complexity of the material; however, as a general guide, testing would typically be conducted on all major rock types with sulphur content used as the primary variable to select "typical" and "worst case" samples. Minor rock types may also need testing dependent upon similarity to major units. Testing duration is for a minimum of 40 weeks and until stable test conditions are reached but may be necessary for a year or more. Further guidance is provided in Price (2009). Kinetic test programs should be developed, and kinetic data interpretation conducted, by QPs with experience in this field.

6 CONFIRMATORY SAMPLING FOR QUARRIED MATERIALS

For quarry sites that have undergone adequate characterization of ML/ARD potential prior to blasting, and material was classified as non-PAG and low potential for ML, inspection, sampling, and testing following blasting involves confirming that the developed area has similar characteristics to the discrete samples tested during the pre-development work (confirmatory sampling/testing). This helps to identify whether unanticipated materials are present that have not been characterized for ML/ARD potential, or if greater heterogeneity than expected is present. The frequency of monitoring and inspection will depend upon the degree of heterogeneity. Monitoring should typically include:

- Visual inspection of the blasted rock (ideally after each blast) for comparison to the geological information collected in the pre-development detailed geological assessment (Section 3.2), particularly that sulphide and carbonate characteristics are similar.
- Assuming geological characteristics are similar, Level I static testing (as per Section 4.1.2) of <2 mm and >2 mm size fractions on a minimum of one sample per 20,000 tonnes (with more frequent sampling with greater heterogeneity).

7 MATERIALS WITH RISK OF ML/ARD

For proposed quarry developments where PAG has been identified or material has elevated risk of ML, development should not proceed and more suitable locations for quarrying should be investigated.

If quarry material that has already been stockpiled is classified as PAG or found to have elevated potential for ML then the material should not be used and no further blasting of similar materials should be conducted. Excavated and crushed rock that has potential for ML/ARD may require further investigation (as documented in Section 4.1.3 and Section 5) depending upon the level of testing and assessment that has been conducted. Mitigation measures may be required, and the appropriate regulator should be informed of identification of such material through submission of an ML/ARD characterization report and supporting data. The quarry operator will be responsible for developing an ML/ARD mitigation plan based on the site-specific conditions, and for managing the waste materials.

As a general guide, short-term management measures that should be considered at a quarry site where stockpiled material has started to develop ARD or ML is occurring, include preventing or minimizing clean water contact with the material, adding neutralizing capacity to the material, and collecting and testing any contact water to determine suitability for release to the environment. Further guidance, including longer term management measures for problematic quarried material can be found in BC (1998).

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Appendix A: Summary flow chart for assessing ML/ARD potential for quarries using the approach in this guidance document.

Figure notes: See text for further explanation of flow chart. * = rinse pH or contact water pH of organic-rich surficial materials may be affected by organic acids, which are unrelated to acid generated from sulphide oxidation.