Effective Assessment of ARD/ML Potential for Non-Mining Infrastructure Projects

Amber Blackwell

Knight Piésold Ltd., North Bay, ON, CANADA, ablackwell@knightpiesold.com

ABSTRACT

The risks associated with inadequate and/or improper Acid Rock Drainage (ARD) and Metal Leaching (ML) characterization and subsequent management are front and center in mine development. The long legacy of ARD/ML risks in mining means that today's mining community understands that ARD/ML issues can result in some of the most expensive and longest-lasting environmental impacts that could arise during the life of a mine. Within the mining community, it is commonly understood that ARD/ML can occur from the oxidation of disturbed (excavated) sulphide-bearing rock because of exposure to air and water over time. However, it is not only mining activities that can expose potentially acid-generating and/or ML rock. Bedrock excavation is also a common activity associated with the development of non-mining infrastructure projects, such as hydroelectric dams, highways, and tunnels. The potential risks and impacts associated with ARD/ML are both less well-known and understood in the infrastructure space. As such, the development of infrastructure projects can result in negative environmental and financial impacts because of the unexpected formation of ARD/ML. We review several high-profile infrastructure projects that did not effectively characterize the potential ARD/ML risks during project development, resulting in an expensive legacy. We consider some of the reasons this may be happening, and what is being done about it. Historically, many jurisdictions have not provided industry standard guidelines, nor have they required any ARD/ML characterization ahead of/during/or even after the construction of infrastructure projects. Awareness of the risks associated with ARD/ML from infrastructure project development has become more widely understood over time. In the absence of industry-specific standards, proponents within the infrastructure space have relied upon existing ARD/ML characterization frameworks developed for the mining industry to evaluate the potential ARD/ML risks associated with their projects. In recent years, efforts have been made to develop infrastructure-specific ARD/ML prediction programs, with most of them building upon the existing ARD/ML characterization frameworks used in the mining industry. This is a step in the right direction for non-mining related projects to evaluate ARD/ML related risks. However, we must consider the applicability of utilizing these mining industry-related geochemical characterization frameworks to assess infrastructure projects. Several differences exist between these industries, such as the availability of baseline information, the complexity and understanding of geological settings, and the strictness of construction timelines. This discussion focuses on tailoring existing ARD/ML characterization frameworks to effectively characterize the geochemistry of materials from infrastructure projects. Successful ARD/ML prediction at the conceptual phase will minimize the potential for environmental impacts and escalated project costs associated with unexpected or improperly characterized ARD/ML materials.

Key Words: acid rock drainage, metal leaching, guidelines, non-mining, characterization, prediction

INTRODUCTION

Non-Mining Projects Can Cause ARD/ML Too

Any disturbance of sulphide-bearing bedrock to air (oxygen) and water has the potential to cause Acid Rock Drainage (ARD) and Metal Leaching (ML), which may not be well-known or understood in other industries, such as with infrastructure projects. Bedrock excavation is a component of many infrastructure projects including the development and construction of hydroelectric dams, highways, and tunnels, which could result in the exposure of sulphide-rich bedrock. Within the last decade, some jurisdictions have developed guidance documents that are designed to increase the awareness and understanding of ARD/ML for non-mining proponents. These documents provide recommendations for evaluating the potential for ARD/ML from non-mining projects based on the existing ARD/ML characterization frameworks from the mining industry. This increased awareness and understanding of ARD/ML is critical to avoiding and/or mitigating the potential impacts associated with infrastructure projects.

While bedrock excavation is akin to both mining and infrastructure projects, several differences must be considered when applying similar ARD/ML characterization frameworks to both developments. Blackmore et al. (2022) describe that linear projects, such as roadways and pipelines, face challenges due to diverse geology, limited data, and tight construction schedules.

This paper discusses the implications of inadequate and/or improper geochemical characterization on historic infrastructure projects, the variables to consider to tailor ARD/ML characterization frameworks developed for the mining industry to infrastructure projects, as well as how these can be adapted to effectively characterize the geochemical nature of materials from non-mining projects.

DISCUSSION

Inadequate ARD/ML Characterization from Infrastructure Projects

Case Study – Halifax International Airport

During the construction of a taxiway at the Halifax International Airport (HIA) in Nova Scotia, Canada in the early 1980s, it became apparent that acidic runoff containing high levels of heavy metals was resulting from the excavated bedrock construction material. The runways and taxiways were initially constructed in the late 1950s using sulphide-bearing pyritic slate bedrock from the Meguma group. Hicks (2003) identified that over the course of two decades, CAD 20 million was spent on various methods to address the ARD issue, including dry and wet covers, wetlands, and different types of lime treatment plants. Ultimately, a CAD 7 million water treatment facility has been operating since 2002, which has been successful in meeting water quality standards with ongoing optimization efforts due to high operating costs. This case at HIA, while smaller in scale compared to mining sites, presents valuable insights into managing environmental and financial challenges posed by ARD/ML.

Case Study - Highway 97C

Morin and Hutt (2007) discuss a case study regarding an environmental prosecution related to the construction of Highway 97C (the Coquihalla Connector) in British Columbia, Canada. The British Columbia Ministry of Transportation and Infrastructure (MOTI) faced charges under the Canadian Fisheries Act due to the release of ARD/ML runoff from two relatively small rock cuts into nearby water bodies. The study reveals that despite no visual clues or observations indicating ARD/ML before construction, the MOTI faced prosecution for not actively assessing the potential for ARD/ML based on expert recommendations that were available at the time. The arguments were deemed weak due to the lack of concrete evidence that the MOTI should have foreseen the ARD/ML issues at that specific site during the highway's construction in the late 1980s. Ultimately, the study by Morin and Hutt (2007) questions the reasoning behind holding the MOTI to higher standards based on examples like the HIA's ARD/ML issues and recommendations from published materials that may not have been widely implemented in highway construction practices at the time.

Case Study – I-99 Skytop Roadcut

A technical forum presentation by Gold et al., (2011) identified the geological and engineering challenges faced during the construction of a highway section in Pennsylvania, USA. The planning and selection process for the route spanned over several years from the late 1950s to the late 1990s. The construction involved crossing Bald Eagle Ridge at Skytop, resulting in a rollercoaster-like roadway between the valley floor and ridge crest alignments.

Excavation works disturbed unexpected geology such as folds, faults, and sulphide veins that posed challenges during construction. While there had been reported occurrences of zinc and lead in the vicinity of the excavation, the overall extent of pyrite and other sulphide mineralization encountered during the excavation was not anticipated. Gold et al., (2011) described that a "perfect storm" of challenges arose due to the excavation occurring along the axis of a syncline, resulting in landslides. Changes in road grade and slope angle were necessary to stabilize the slopes, necessitating the use of excavated pyritic rocks as fill material. The improper characterization of this sulphide-rich fill material resulted in the distribution of ARD/ML rock along a 20-mile stretch of the roadway.

Guidelines Developed for the Mining Industry

As with the case studies above, the potential risks associated with the onset of ARD/ML were not commonly known or understood within the infrastructure space. Nor was an infrastructure-specific ARD/ML characterization guidance document available at the time to inform the early stages of these projects. As the risks associated with ARD/ML from infrastructure projects were coming to light, but where industry-specific guidance was not yet available, non-mining proponents relied on ARD/ML characterization frameworks developed for use in the mining industry to assess their infrastructure projects.

Within the mining industry, there are several known and widely available legislation, guidelines, and best management practices that pertain to ARD/ML. These guidance documents establish industry standard practice and are applied as the basis for most ARD/ML characterization programs. These documents include:

- Guidelines for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia (Price and Errington, 1998).
- Policy for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia (BC MEM and BC MELP, 1998).
- Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia (Price, 1997).
- Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials - MEND Report 1.20.1 (Price, 2009).
- Guidelines and reference materials provided under the Mine Environment Neutral Drainage (MEND) initiative (MEND, 2005)
- Global Acid Rock Drainage (GARD) Guide (INAP, 2014).

Guidelines for Non-Mining Infrastructure Projects

Over the last decade, efforts have been made to develop and implement ARD/ML prediction guidance documents for assessments involved with infrastructure projects, which are based on ARD/ML characterization frameworks from the mining industry. Three of these guidance documents are described in the following subsections.

Technical Circular T-04/13 - British Columbia Ministry of Transportation and Infrastructure (MOTI, 2013)

In the wake of the release of acidic and metalliferous run-off from Highway 97C rock cuts, the British Columbia Ministry of Transportation and Infrastructure (MOTI) issued Technical Circular T-04/13 (MOTI, 2013). This document applies to MOTI related activities that require the excavation or production of materials from quarries, rock cuts and stockpiled rock or talus materials. The document outlines a systematic approach for evaluating the potential ARD/ML risks associated with these activities, with the goal of preventing environmental impacts and ensuring the responsible management of materials. Figure 1 presents a flowchart of the recommended ARD/ML evaluation process to be implemented by the qualified professional (QP).

Key components of MOTI (2013) include:

1. **Site characterization**: Conducting a comprehensive assessment of the geological, hydrogeological, and geochemical characteristics of the site to identify potential sources of sulphide minerals and other acid-generating materials.
2. **Laboratory testing**: Implementing a testing protocol to analyze representative samples of rock or talus materials for parameters such as sulphide mineral content, pH, acid-base accounting (ABA), and metal leaching potential. These tests help determine the likelihood of ARD/ML occurring when the materials are exposed to air and water.
3. **Risk assessment**: Using the results of laboratory testing and site characterization to assess the potential environmental risks associated with the materials and develop appropriate mitigation measures if necessary.
4. **Mitigation measures**: Implementing measures to manage and minimize the risks of ARD/ML, which may include covering or treating exposed materials, implementing erosion and sediment control measures, and implementing water management practices to prevent the release of acidic drainage.

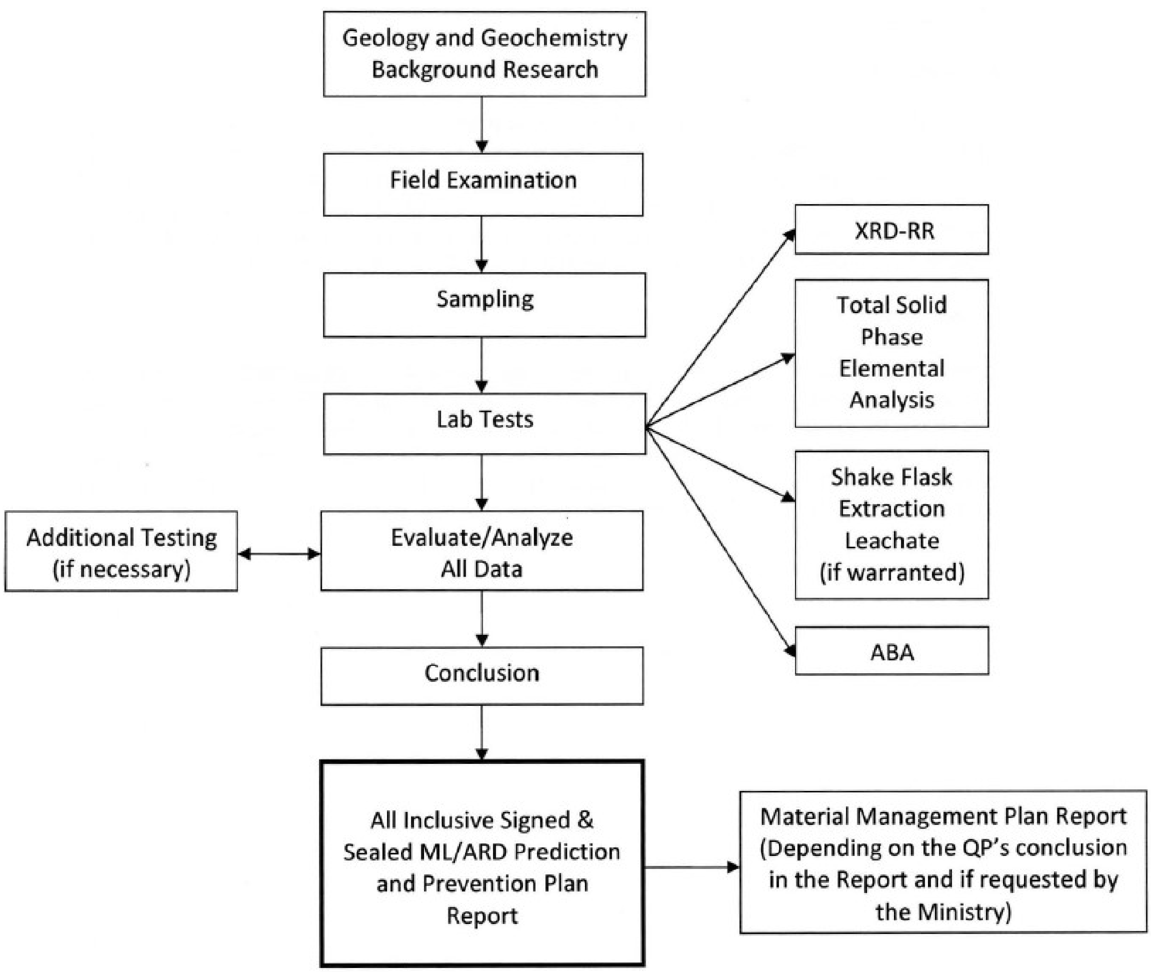

Figure 1. MOTI Recommended ARD/ML Evaluation Flowchart (MOTI, 2013)

Overall, the technical circular provides valuable guidance for evaluating and managing the environmental risks associated with quarrying, rock cutting, and the use of stockpiled rock or talus materials by the MOTI, helping to ensure the protection of water quality and natural ecosystems.

Guidance Manual for Potentially Acid-Generating Materials in Northern Minnesota - Minnesota Department of Transportation (MnDOT, 2019)

The Minnesota Department of Transportation (MnDOT) initiated a project aimed at developing a manual to identify, handle, and monitor Potentially Acid-Generating (PAG) materials during highway construction. Prior to this initiative, there were no specific guidelines, which resulted in increased costs and effort for projects such as the reconstruction of Trunk Highway 169 Eagles Nest Lake Area in northern Minnesota. The manual involved a thorough process including reviewing existing methods, developing geographic information system (GIS) tools, and creating mitigation strategies such as using membranes and limestone to counteract acidic drainage.

The Guidance Manual for Potentially Acid-Generating Materials in Northern Minnesota (MnDOT, 2019) serves as a critical resource for MnDOT to assess and manage PAG materials in Northern Minnesota highway projects effectively. It starts with a desktop study to screen project areas, progressing to field reconnaissance, characterization programs based on sample testing, and mitigation strategies if needed, like neutralizing agents or disposal off-site. The manual also includes monitoring plans post-construction to ensure the efficacy of mitigation efforts. Ultimately, the project successfully consolidated research and expertise, presenting MnDOT decision-makers with a comprehensive tool to mitigate risks associated with PAG materials in future highway projects in northern Minnesota. MnDOT (2019) is now accessible on MnDOT's website for implementation. It should also be noted that this is the third manual that has been developed within the United States of America (USA) and that both Pennsylvania and Tennessee also have similar documents available for highway construction projects.

Quarry Sampling and Testing Guidance for Identification of Acid Rock Drainage and Metal Leaching Potential - Draft Report – Government of Northwest Territories (GNWT, 2022)

The Government of Northwest Territories (GNWT) developed the Quarry Sampling and Testing Guidance for Identification of Acid Rock Drainage and Metal Leaching Potential (GNWT, 2022) draft report, which outlines guidelines for quarry operators to detect rocks prone to ARD and/or ML to prevent environmental harm due to contaminant release, which is prohibited in the Northwest Territories (NWT). The guidance aims to comply with territorial legislation and assist quarry operations in avoiding negative environmental impacts. It replaces the previous Interim Quarry Sampling Program Guide and focuses on the rapid identification of problematic rocks to prevent the excavation of harmful materials and assess already excavated stockpiles. The document covers sampling, testing, and assessment methods, including reconnaissance, field assessments, static testing, and follow-up testing recommendations for quarries.

The document is intended to increase the awareness and understanding of ARD/ML quarry owners and operators, as well as to emphasize the importance of utilizing QPs with expertise in ARD/ML characterization for rock assessment in quarries. It notes the significance of specific qualifications and experience in geological investigations for evaluating potential ARD/ML risks.

Applicability of Existing Framework to Infrastructure Projects

It is beneficial to have a set standard available to help guide ARD/ML characterization programs in the early stages of any project (mining or non-mining). However, it is crucial to understand that evaluating ARD/ML generation is not standard for every project. The evaluation methods and criteria provided in documents such as MOTI (2013), GARD (2014), and MEND (2009) should be considered as tools for these evaluations, but cannot replace developing site-specific criteria based on measurable parameters, a knowledgeable assessment of the limitations of the results; and understanding the natural environment, the project, the geological materials, and the protection requirements. We must also consider the applicability of using ARD/ML characterization frameworks developed for mining projects to infrastructure projects. The GARD Guide (INAP, 2014) provides an idealized overview of an ARD/ML prediction program for a mining project from cradle to grave. This discussion will focus on the ARD/ML program activities identified during the initial exploration and advanced exploration phases (INAP, 2014) and how they relate to the initial phase of an infrastructure project.

Applicability of Exploration Phase ARD/ML Program Activities for Infrastructure Project

In an ideal world, the initial exploration phase of a mining project includes activities like geological mapping, drilling, and baseline data collection that are used to establish a geological model for the mineral prospect. As the mining project moves into the advanced exploration phase, more detailed drilling is carried out to enhance ore body delineation and support preliminary mine design. Water sampling in the area is typically carried out during this stage to assess drainage quality issues. These activities lay the foundation for subsequent evaluations related to ARD/ML potential, including the design of a phase 1 static test program based on the geological model.

The ARD/ML program activities described above may not be entirely applicable to the initial phase of an infrastructure project. Typically, the breadth of site information that a geochemist would receive from early phase mining project is not available during the initial phases of most infrastructure projects. As such, pre-screening for ARD/ML characterization must rely predominantly on publicly available information (such as geological mapping databases, historical reports in proximity to the project, personal communications, etc.). Additionally, most infrastructure projects do not have the availability of trained geologists on- or off-site, so it may be necessary for the geochemist or QP to initiate an early site visit to collect the data necessary to inform the pre-screening stage (or site characterization phase as described in MOTI, 2013) of the ARD/ML characterization.

Case Study – Recent Involvement with a Hydroelectric Project

Knight Piésold Ltd. (KP) was recently engaged to evaluate the constructability of a hydroelectric project based on an existing feasibility study (FS). KP performed a gap analysis and optimization assessment of the existing FS and noted that no desktop pre-screening had been completed and no geochemical characterization samples had been collected for testing to date. Had this been a mining project at FS level design, it is likely that several phases of static and kinetic geochemical testing would be available or ongoing and that ARD/ML risks would be well understood. This data gap can be attributed to the project location within a jurisdiction that does not have industry standard guidelines or requirement to perform ARD/ML characterization. It should be noted that the need for geochemical characterization work was only known to the design team as a result of public consultation with stakeholders.

Adapting the Existing Framework Based on Lessons Learned

Summary of Lessons Learned

The lessons learned based on the case studies and limitations that have been discussed are:

- The geological setting must be well understood far ahead of construction.
- Inter-disciplinary communication during the planning stages of projects is required, to understand the interactions between the geotechnical, hydrological, hydrogeological, and geochemical characterization of the project footprint.
- The materials excavated must be appropriately characterized before use and/or redistribution to avoid extensive remediation costs and delays.
- Given the limited site information that is typically available in the initial phase of infrastructure projects, additional efforts may be required during the desktop/screening for ARD/ML characterization to ensure adequate information is collected and available to inform the project.

- The cost associated with an effective geochemical characterization program early in the process is orders of magnitude less than the cost of having to treat water in perpetuity.

A Phased and Risk-Based Approach to ARD/ML Characterization

Given the limitations associated with most infrastructure projects, ARD/ML characterization should not only be phased, but should also take a risk-based approach. A phased and risk-based approach allows for the execution of a timely, focused, and appropriate ARD/ML characterization program.

Lorax (2014) presented a phased and risk-based approach to ARD/ML assessment for linear projects such as roads, at the 2014 MEND Workshop. The approach involved a phased strategy starting with the conceptual design, followed by subsequent design iterations, to minimize risks efficiently.

Lorax (2014) emphasized the use of a screening tool that considers the application of ratings to stressors (like geochemistry), pathways (like hydrology), and receptors (such as toxicology) to calculate overall risk ratings for potential environmental effects (Figure 2).

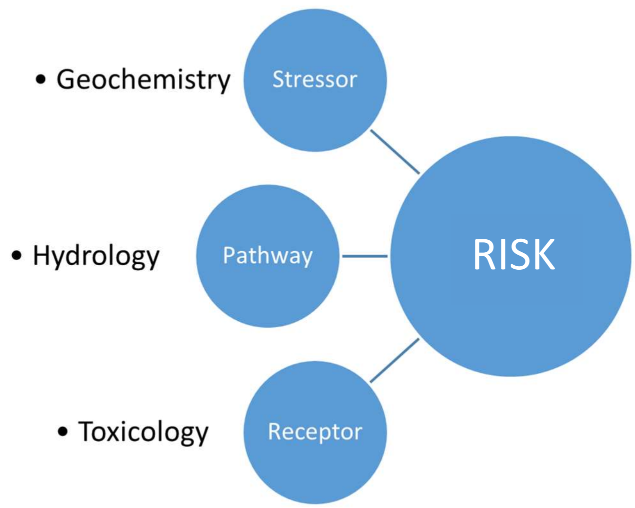

Figure 2. Risk-based approach based on Lorax (2014)

Stressor ratings consider the ARD/ML potential based on geological features, with subsequent sampling for site-specific criteria. Pathway ratings estimate contact flow and receiver low flow, while receptor ratings examine the sensitivity of aquatic organisms to water quality changes based on stream size and species present. This comprehensive risk assessment aims to provide timely design input, avoid risks, and focus efforts on high-risk areas efficiently.

The use of a methodical and phased approach that includes risk assessments based on specific environmental factors, aims to streamline ARD/ML assessments for infrastructure projects like roads, ensuring environmental protection and sustainable development (Lorax, 2014).

Case Study – Sea-to-Sky Highway Upgrade Characterization Success

An example of the successful use of a risk-based approach for ARD/ML characterization for an infrastructure project is the Sea-to-Sky Highway upgrade that was initiated in the early 2000s.

To improve the safety of motorists, the Sea-to-Sky Highway required upgrades along an approximately 40 km length between Vancouver and Whistler, BC. The timeline associated with this upgrade was crucial, since the highway had to be available for use for the 2010 Olympic Winter Games. Given that the known impacts from the release of acidic and metalliferous seepage from Highway 97C were still in the public eye and that the upgrade would require excavation that could expose pyritic-bearing basaltic rock, the aggressive timeline was widely scrutinized.

Golder (2003) presented the ARD/ML assessment for the Sea-to-Sky Parkway at the 2003 MEND Workshop. Given the large footprint of the area to be studied and the limited timeline, Golder (2003) implemented an impact assessment style approach for ARD/ML characterization. The main objective of the assessment was to characterize the overall (bulk) ARD/ML potential of the materials along the corridor. Geological, geochemical, and hydrologic analyses were carried out in unison to characterize the potential metal loadings to receptors (waterbodies) in the receiving environment. This approach resulted in the early availability of ARD/ML information that could inform preliminary designs, as well as focus additional efforts on the areas of higher risk to the overall project (Lorax, 2014).

This approach was both effective and efficient, and the project was able to move through construction on time and within budget.

I-99 Skytop Roadcut Case Study Revisited

Let's consider the I-99 Skytop case study and assume that guidance documents, such as MnDOT (2019) were available during the initial phase of the project. Given that no geological information was available prior to construction, bedrock geology mapping, drilling, test-pitting would have been recommended. These studies would have identified both the complex structural geology, the extent of the mineralization, and potentially the hydrologic relationship with the bedrock in the area.

With the availability of these data, a phased and risk-based approach for ARD/ML characterization could have been initiated, which would have assessed the cumulative environmental risks associated with the construction excavations. This may have been sufficient to focus subsequent investigation efforts on the areas of high risk for geotechnical hazards. These risks could have been communicated to the interdisciplinary project team to discuss potential re-alignment and/or ARD/ML mitigation options ahead of exposure. While it is speculation, it is possible that the use of current best practices, industry-specific guidance documents, lessons learned, and use of a risk-based assessment could have been sufficient to reduce the overall negative impacts from the I-99 Skytop on the receiving environment.

CONCLUSIONS

The increasing awareness and understanding of the importance of ARD/ML characterization, coupled with the recent accessibility of non-mining related guidance documents is a positive step forward to mitigate potential detrimental environmental effects from the development of infrastructure projects. Additionally, a systematic and risk-based approach in ARD/ML characterization has demonstrated success to accommodate the rapid timelines, limited data availability, and necessity for early guidance associated with infrastructure projects.

A challenge that remains, which is also applicable to the mining industry, is that interdisciplinary communication of geochemical characteristics must occur in the early stages of the project. An example of when this was done successfully is for the Vancouver Island Highway Project (VIHP).

Initial steps in ARD/ML control for the VIHP involved realignment of the highway right-of-way and fine adjustments to its elevation (Morin and Hutt, 2005). This was made possible because appropriate site information was available early in the project life, which allowed for early ARD/ML characterization. Early communication between the project teams allowed for informed design changes, which ultimately minimized the amount of ARD/ML rock that would be exposed or moved, thus reducing the risk and potential liability costs.

As scientists and engineers, we must protect the public and the environment from harm. Successful ARD/ML characterization prior to the construction will minimize the potential for environmental impacts and escalated project costs associated with unexpected ARD/ML and the subsequent treatment and remediation efforts.

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