APPENDIX A
ACID ROCK MANAGEMENT

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Memo

To: Peter Fleming – Transportation and Infrastructure Renewal **Date:** 23 July, 2019

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Ref: TV184002

Re: EA – Connector Road between Exit 5A and Trunk 2 at Wellington
Support to Metal Leaching and Acid Rock Drainage Management and Monitoring Program

As part of the early planning stages and the environmental assessment (EA) of the proposed Connector Road, Nova Scotia Transportation and Infrastructure Renewal (TIR) has retained WOOD Environment & Infrastructure Solutions (Wood) to provide consulting support in developing an approach to the management of metal leaching and acid rock drainage (ML/ARD) along the planned corridor that is in compliance with regulatory requirements.

This memo is a first step in providing advice for ML/ARD management and monitoring for the planned road development. The information has been generated in support of the EA registration document that TIR prepared for Nova Scotia Environment (NSE) approval pursuant to the Nova Scotia EA Regulation.

The information provided demonstrates that the processes causing ML/ARD are well understood. Various design and engineering approaches are available and have been successfully applied in numerous small- and large-scale projects. The success of ML/ARD management requires a thorough understanding of existing conditions, a site-robust design, and specific quality assurance and quality control (QA/QC) procedures during construction.

It is our understanding that upon approval of the EA registration document, and upon consultation with NSE, TIR will advance the management concept and prepare an ML/ARD Management and Monitoring Plan in close consultation with NSE for approval pursuant to the *Sulphide Bearing Material Disposal Regulations*.

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1. INTRODUCTION

1.1. Background

The Nova Scotia Department of Transportation and Infrastructure Renewal (TIR) is proposing the construction of a new 5 kilometer (km) Connector Road between Highway 102 Aerotech Interchange (Exit 5A) to Trunk 2 in Wellington, Nova Scotia. The proposed connection is required to alleviate traffic congestion in the Fall River area while improving the connectivity of the highway network between Highway 102 and Trunk 2.

The Connector corridor is underlain by the Goldenville and Halifax Groups of the Cambrian-Ordovician Meguma Supergroup. The Halifax Group rock material is sulphide bearing. Therefore, it is expected that sulphide-bearing rock material will be encountered during the cut and fill activities. Sulphide-bearing rock material is known to generate acid drainage when exposed water and oxygen and therefore will require management in accordance with the Nova Scotia *Sulphide Bearing Material Disposal Regulations*. The two Domains where sulphide bearing rock will be encountered and management and monitoring plans are required includes:

1. Rock encapsulated within potentially acid generating (PAG) rock disposal facility (PAG facility) within the road bed; and
2. Exposed rock faces in the backslope cuts.

The exposed rock faces can essentially be considered similar to rock placed within the PAG facility, yet there are significantly lesser amounts of rock surface area available for oxidation processes to occur in an exposed face compared to the rock in a PAG facility. Hence the potential for metal leaching and acid rock drainage (ML/ARD) impacts and contaminant loads due to water flow are lesser from the exposed faces.

Within the connector road expansion there are residential areas that utilize the groundwater for domestic use and there may be a hydraulic connection (surface water or groundwater) to the local drinking water supply. As a result a robust ML/ARD Management and Monitoring Plan is required to mitigate risk to an acceptable level.

1.2. Purpose and Objectives

As part of the early planning stages and the environmental assessment (EA) of the proposed Connector Road, TIR has retained WOOD Environment & Infrastructure Solutions (Wood) to provide consulting support in developing an approach to the management of acid generating rock along the planned corridor that is in compliance with regulatory requirements. This memo is a first step in providing advice for the ML/ARD management and monitoring for the planned road development and discusses:

- ML/ARD process;
- Proven approaches and technologies to managing ML/ARD;
- Risks associated with the ML/ARD management and related mitigation;
- Project examples and experiences with ML/ARD; and
- Proposed management philosophy for the Connector Road Corridor.

The information has been generated in support of the EA registration document that TIR has prepared for Nova Scotia Environment (NSE) approval pursuant to the Nova Scotia EA Regulation. Upon approval of the registration document, and upon consultation with NSE, TIR will advance the management philosophy and prepare an ML/ARD Management and Monitoring Plan and apply for NSE approval pursuant to the Sulphide Bearing Material Disposal Regulations. This application will entail detailed design and including contract drawings and specification as well as a proposed monitoring program.

2. METAL LEACHING AND ACID ROCK DRAINAGE

PAG rock is associated with sulphide oxidation and the concomitant release of constituents of potential concern (CoCs). In North America this process is known as ML/ARD. Acidic effluent from PAG rock can adversely affect both surface water and groundwater. Even if acid-generating weathering of the PAG rock does not occur, neutral drainage can also contain elevated levels of metals or other CoCs.

Metal Ecotoxicity Quotient (MEQ) is used to compare measured metal concentration (lab) to specific limits, guidelines or background for a given site (divide concentration by guideline). MEQ clearly identifies situations where solute concentration exceeds such values. Following MEQ analysis, water quality monitoring can be optimized to focus on these solutes of interest. Values greater than 1 indicate that the measured concentration will exceed the average background concentration. Conversely, MEQ values less than 1 indicate that the measured concentration in water (or lab test results) has not exceeded background concentrations. For the Project at hand, Monitoring Plan will need to include establishing background water quality and laboratory characterization to facilitate a MEQ analysis for evaluation of surficial groundwater and surface water discharged from the road corridor.

The ML/ARD acid formation process is typically represented by the oxidation of pyrite (Equation 1). For every mole of pyrite oxidized, 4 moles of acidity are released (Weber et al., 2006).

$$FeS_2 + {}^{7}/_{2}H_2O + {}^{15}/_{4}O_2 \Rightarrow Fe(OH)_3 + 2H_2SO_4 \qquad [1]$$

While there are other sulphide minerals that may contribute to ML/ARD, such as pyrrhotite, chalcopyrite, and arsenopyrite, overall the processes are known to be complex and interrelated and strongly related to geochemical characteristics of the rock, climate and oxygen and water ingress rates (Lottermoser, 2010). For example, there have been numerous studies completed on oxidation reactions of PAG rock at BHP

Billiton's Mt Whaleback Mine in Western Australia where spontaneous combustion of PAG rock occurs. In addition to chemical reactions, biological reactions are known to accelerate ML/ARD generation.

Nevertheless, a key aspect of mitigating ML/ARD risk is understanding that the method of rock placement, and the site environment (physical conditions) in which the rock is placed have been shown to be more important than the geochemical properties themself (Meiers and O'Kane, 2018).

Rock placement strategies such as source control, discussed within the following section, should be considered within the PAG facility design stage for the Connector Road Project to limit the period of time that PAG rock is exposed to favorable conditions for the generation of ML/ARD.

3. ML/ARD MITIGATION

Best available technology (BAT) for managing PAG rock includes:

1. **Source control,** e.g., prevention of oxidation to limit the formation of stored oxidation products to the extent possible within a PAG storage or disposal facility;
2. **Minimization of contaminant load or mobilization,** e.g., reducing net percolation, surface water interactions, and shallow groundwater interactions, which is the transport medium (e.g., pathway) for stored oxidation products; and
3. **Establishment of a waste rock management plan** to limit PAG rock interactions with potential pathways through placement strategies.

3.1. Source Control

Source control focusses on minimizing the generation of stored oxidation products during and following construction of the PAG facility through managing oxidation processes through controls on available oxygen.

The structure of the PAG rock facility, texture of the rock, and packing density influence oxygen flow into the facility, where subsequent oxidation reactions can occur. Diffusive movement of oxygen is primarily restricted to the outer surface or near surface of the facility. The movement of oxygen within and into the facility primarily occurs by advection due to differential pressure and vertical temperature gradients. Advective oxygen supply is typically an order of magnitude greater than diffusive oxygen (Brown et al., 2014). Oxygen ingress can also occur as dissolved oxygen in infiltration water, but these rates are very low. While there have been strategies to mitigate oxidation reactions through controls on water ingress, there is typically enough water available to satisfy pyrite oxidation requirements in most storage facilities, except for very dry materials. Nova Scotia is characteristic of relatively high monthly rates of precipitation and hence, it would be challenging to limit oxidation reactions through water restrictions.

Given that oxygen and water flux are major controls in the production and release of ML/ARD to the receiving environment, facility construction and rock placement are significant variables driving ML/ARD risk. Minimizing oxidation of sulfide minerals involves strategic placement of PAG rock such that exposure to climatic conditions is limited and advective gas transport within the facility (i.e. oxygen transport) is limited because airflow capacity (air permeability) is controlled. Air flow capacity is reduced by one, or some combination of the following methods, but not limited to:

- short end-tipping heights,
- paddock dumping,
- compacted fine textured traffic layers (interim covers), and
- fine textured toe bunds (Meiers et al., 2018).

PAG rock placement strategies focus on minimizing ML/ARD risk through minimizing oxidation of sulfide minerals during and following PAG rock placement. By placing PAG rock in a manner to minimize stored oxidation products (or more appropriately, stored acidity), long-term reliance on a cover system as the "sole" means of managing seepage from the facility is reduced.

Following the construction of the PAG facility the placement of a cover system will further reduce oxygen ingress and retardation of oxidation reactions. Limiting the advective transport of oxygen requires that the cover or waste restrict air flow by reducing pressure and/or thermal gradients, and/or the permeability of the material. It is often easiest to control the permeability of the material through engineering means, and in the case of oxygen, this can often lead to controlling the diffusion coefficient. In the latter case, this is often achieved by creating and sustaining a tension-saturated layer within the cover system. Oxygen diffusion and advection can also be restricted by decreasing the diffusion coefficient with interim cover layers by creating layers of higher degrees of saturation during placement and construction. Compacted interim cover layers placed within the facility have greater water retention properties and wet-up with the infiltration of meteoric waters.

Conversely, through the use of a geomembrane cover system controls on oxygen diffusion are not linked to the degree of saturation but the diffusion coefficient of the geosynthetic product. Controls on oxidation reactions (exothermic reactions) also limits heat generation through and thermal gradients that drive gas flow.

Source control can also include additional buffering capacity through lime additions to prevent the onset of ARD during construction of the facility. This ensures that the risk of any mobilization pathways is mitigated.

3.2. Mobilization

Water and oxygen are two reagents associated with sulphide oxidation that contribute to the formation of acidity. Water is also responsible for transport of the generated or stored acidity from PAG rock. The primary pathways are:

1. Net percolation or water ingress through the surface;
2. Runoff waters; and
3. Facility interacting with surface water or surficial groundwater.

Cover systems limit net percolation through water store-and-release and / or through runoff and lateral drainage. Cover systems also limit ML/ARD mobilization through the generation of clean runoff water and lateral drainage above a cover system barrier layer. Specific aspects that need to be considered in the design of cover systems are briefly discussed in 3.2.1.

Shallow groundwater or surface waters near the base of the facility can provide a mobilization pathway. This requires and understanding of hydrology / geohydrology at the site. Surface water interactions can be mitigated through a surface water management plan and placement of non-acid generating (NAG) fill at the base of the facility with a relatively high permeability to limit head generation or mounding within the base of the facility.

3.2.1. Cover Systems

Cover system design requires establishing objectives and performance criteria. The cover system design can then be developed to meet the objectives and address the ML/ARD risk. Cover system design also requires an understanding of factors that will contribute to their long-term performance. Initial performance will change as a result of physical, chemical, and biological processes. Cover system design numerical modeling generally provides quantitative predictions of physical processes that affect long-term performance. Inclusion of the biological and chemical processes in the design phase is generally from a qualitative perspective (MEND, 2004).

Low permeability compacted clay barrier cover system are primarily influenced by wet/dry and freeze/thaw cycles (Meiers et al., 2011). These cycles cause volume changes (i.e. shrinkage and swelling) resulting in an increase in the creation of a secondary structure of macropores or fractures that cause an increase in the saturated hydraulic conductivity. The saturated hydraulic conductivity of compacted clays exposed to wet/dry or freeze/thaw cycles can increase up to three orders of magnitude. Freeze/thaw cycling of a barrier is prevented with the application of a cover with a growth medium with adequate depth, while wet/dry cycling is mitigated with adequate water holding capacity to sustain rates of evapotranspiration above the barrier layer.

Net percolation for a cover system that includes a geomembrane can occur through diffusion, but the transmission rates are very low. In general, the hydraulic conductivity corresponding to water diffusion is on the order of 10^{-14} to 10^{-17} m/s (Giroud and Bonaparte, 1989). In a cover system, leakage through holes can only be triggered when positive pressures (i.e. ponding) develop on top of the geomembrane near the defect (Meiers and Bradley, 2017)

Even with recent advances in the testing and installation of geomembranes, they are almost never installed without holes. The primary factors leading to holes in geomembranes are: 1) inadequate welds and attachments to structures; 2) imposed stresses and mechanical damage during construction; and 3) service stresses that induce stress cracking at points of stress and weld separation (Peggs, 2010). Stress cracking is commonly associated with aging of the geomembrane. In addition, post-construction damage can be introduced due to physical and biological processes primarily attributed to anthropogenic activities, animal burrowing, insect bioturbation, and the effects of vegetation.

In terms of cover systems that include a geosynthetic barrier layer; one is commonly drawn into the debate of how many holes will occur in the barrier and what is the predicted service period for the product. There is a need to acknowledgment that 'yes' holes will occur during installation of the geosynthetic, placement of the confining layer and post construction, but more importantly, through sound engineering principles, design and construction QA/QC one can reduce the risk associated with leakage through holes to an acceptable level, providing performance well past the service period of the geosynthetic product.

3.3. PAG Rock Management Plan

Geochemical characterisation of rock involves a variety of acid-base accounting (ABA) techniques. The industry standard approach is to determine the net acid generation of the sample. This is the difference between the neutralizing potential, which typically represents carbonates, and the maximum acid potential.

A number of other tests are commonly used for ML/ARD geochemical characterisation, including paste pH, column leach tests, humidity cell trials, and a variety of field trials to help confirm classification processes. A key aspect of these tests is developing an understanding of lag time to acid onset in the short term (Weber et al., 2016). Through an understanding of the PAG facility conceptual model and mobilization pathways there can be opportunity to place lower risk ML/ARD rock within locations where there is potential for mobilization, and placement of high risk PAG rock deeper within the PAG facility or below interim covers where there will be less opportunity for oxidation reactions to occur.

Geochemical characterization of the rock can provide an understanding for the 'typical signature' of seepage water quality and identify likely CoCs. These test results are informative to support elements to be measured within a groundwater monitoring program and support a MEQ analysis.

4. CONSTRUCTION QA/QC AND PERFORMANCE MONITORING

Construction quality control / quality assurance (QA/QC) are essential for the successful design and operation of a PAG facility. This involves establishment of performance criteria such as rates of water and oxygen ingress. The design should be robust yet flexible to allow for use of typical construction QA/QC used in the industry and enabling performance criteria to be met.

Performance monitoring is critical for evaluating whether a system meets performance expectations / objectives. Key objectives of a monitoring program may include:

- Develop confidence with all stakeholders with respect to cover system and overall PAG facility performance;
- Track the evolution of the cover system in response to various site-specific physical, chemical, and biological processes; and
- Develop a database of monitoring data to support and increase confidence in future / ongoing ML/ARD management projects.

Direct cover system performance monitoring focusses on components of the water balance and oxygen ingress and can be implemented in combination with surface water and surficial groundwater analysis. Traditional performance monitoring programs, which only focus on water quality analyses of seepage alone, empirically describe a PAG facility through monitoring of its cumulative effect at the base. Monitoring performance with only water quality, can fall short in that without additional forms of monitoring, there may not be sufficient information to explain observed impacts if they do not meet expectations (Meiers, 2015). This lack of “upfront performance” monitoring limits one’s ability to predict and develop appropriate mitigation to unforeseen conditions.

Establishing background conditions for surface and groundwater quality will be an important aspect of the monitoring program to ensure that performance can be evaluated openly and objectively. The background water quality would serve to identify CoCs when compared to the results of leach tests in a MEQ.

5. ML/ARD MANAGEMENT EXPERIENCE (PROJECT EXAMPLES)

The approaches and technologies for ML/ARD management that were discussed in the Section 3 have been applied and proven successful in numerous other projects on small and large scales. Below, two example projects are presented to provide insight into the current experience with ML/ARD management and PAG facility designs including cover systems in particular.

5.1. ML/ARD Management for TIR Interchange Rehabilitation 102/103

TIR is in the process of implementing a comprehensive ML/ARD management plan for the Highway 102/103 Interchange Rehabilitation (July 2019). It includes a PAG facility and exposed rock face domains. The focus of the rock storage facility ML/ARD management is based on the control of mobilization pathways and includes the use of a geomembrane for the PAG facility and a low permeability compacted clay barrier cover system for the exposed rock face. Exposed rock faces are being reclaimed with compacted clay barrier cover systems to reduce water and oxygen ingress. The experience with this work is directly relevant for the ML/ARD management planning and design for the Highway 102 Aerotech Interchange Connector Road and will be used in the detailing of its PAG facility Management and Monitoring Plan.

5.2. ML/ARD Management at Whistle Mine (Backfilled Open Pit Cover System)

A cover system and landform design was developed for the Whistle Mine backfilled pit to minimize ML/ARD (2000 – 2018). Based on the results of geochemical modelling, limiting the influx of atmospheric oxygen to the waste rock was of greater importance than limiting the infiltration of meteoric water on the long-term water quality of the pit.

A multi-layer soil cover system comprised of a levelling course, a low permeability compacted clay barrier layer, and a growth medium layer was selected for covering the 9.7 ha backfilled pit PAG rock. The cover system design project comprised the following major tasks:

- Determination of the preferred material for the barrier layer through evaluation of field performance monitoring data obtained from test covers and review of estimated costs for full-scale construction of various alternatives;
- Physical and hydraulic laboratory characterization of the barrier layer and growth medium materials;
- Soil-plant-atmosphere numerical modelling for determination of the minimum cover layer thicknesses based on predictions of net percolation and oxygen ingress, including 2-D simulations to address the potential impact of the sloping cover on saturation levels in the barrier layer. Growth medium thickness evaluated against wet/dry and freeze/thaw cycles;
- Slope stability analyses of the preferred pit cover system;
- Landform evolution and erosion numerical modelling for the development of a sustainable pit cover runoff management system design;
- Establish Construction QA/QC program;
- Design of a performance monitoring program for the pit cover system; and
- Consideration of the potential impacts of various physical, chemical and biological processes on sustainable performance of the preferred cover design.

Construction of the pit cover system occurred in 2004 and 2005, based on developed construction quality assurance and quality control (QA/QC) program. A field performance monitoring program was design and implemented for the cover system to evaluate its performance over time. Based on field data collected up to 2018, the pit cover system is performing as expected; the influx of atmospheric oxygen and meteoric water to the PAG rock backfill has been substantially reduced since construction of the cover system, and the landform is stable. More information can be found in Ayres et al., (2012).

Other example projects with comprehensive and successful ML/ARD management and cover system designs that the author has been directly involved in include:

- Feasibility WRD Design – Compañia Minera Mantos de Oro, La Coipa Mine, Chile. Design of the Phase 7 Expansion PAG facility to minimize ML/ARD generation and mobilization.
- Detailed Design. INAC Tundra Mine, Northwest Territories. Technical support to geomembrane cover system design.
- Preliminary PAG Facility Design – New Gold, Rainy River Project, Ontario Canada. Comparative PAG facility designs including wetting-up analyses and generation of stored acidity during construction.
- PAG Facility Design – Glencore McArthur River Mine, NT, Australia. Design largescale WRD field trial to evaluate waste placement strategies on oxygen ingress and generation of stored acidity during and post construction.

6. ML/ARD MANAGEMENT FOR THE CONNECTOR ROAD

As stated earlier, due to the characteristics of the geological environment along the Connector Road corridor it is expected that sulphide-bearing rock material will be encountered during the cut and fill activities. In accordance with the Nova Scotia “Sulphide Bearing Material Disposal Regulations” this will require the development and approval of an ML/ARD Management Plan.

For EA purposes preliminary management and design concepts have been developed to support the effects assessment. At this stage it has been determined that the ML/ARD management will involve:

- Assessment of background site water quality;
- Conceptual model to determine ML/ARD risks;
- Design of a PAG storage facility and mitigation plan;
- Design of a cover system;
- Implementation of a construction QA/QC program; and
- Design and implementation of post construction performance monitoring plan.

6.1. ML/ARD Conceptual Model and Connector Road PAG Facility Design

The ML/ARD risk along the corridor can only truly be addressed by a source – pathway – receptor type model where each component of the model needs to be well understood to determine the risk. This will determine areas of greater risk for ML/ARD. Currently, Woods preliminary conceptual model for the site is:

- PAG rock will be encountered during the construction process given current knowledge of geology in the area;
- ML/ARD impacts and contaminant loads are lower for the exposed faces in the backslope cut compared to the PAG facility;
- Precipitation occurs during all months of the year and hence there will be sufficient water within the placed PAG rock to facilitate sulphide oxidation reactions and mobilization;
- Oxidations reactions will be limited by availability to oxygen;
- Surface water flows and surficial groundwater flows are expected and may provide a mobilization pathway; and
- Reduction in net percolation to ‘low’ or ‘very low’ rates will require a low permeability compacted clay layer or geomembrane cover system.

Based on the aforementioned the following high-level conceptual mitigation strategies are provided:

- The disposal of PAG rock would occur in right-of-way (ROW) fill locations under the Connector Road bed. It is anticipated that this would be focused within one larger area but possibly include additional smaller fill sites under the road bed;
- The primary mitigation strategy would focus on mobilization pathways. This would be completed through implementation of barrier type cover systems and limiting contact of PAG rock with surface water or surficial groundwater. Diversion and collection ditches will be required to manage surface water and surficial groundwater.
- ‘Opportunistic’ source control mitigation will be implemented during construction of the PAG facility. Should finer texture material, such as glacial till or crusher fines, be available during construction of the Connector Road, this material would be placed as interim cover layers to provide some reduction in oxygen ingress during construction. It is anticipated that up to a maximum of three interim cover layers could be implemented. Acknowledging that acidophiles type bacteria have been reported to accelerate oxidation reactions in Nova Scotia PAG rock the interim cover layers would retard bacterial catalyzed reactions.
- Rock encountered during the Project will be crushed to grain size in the range of 25 to 37 mm minus. While this will increase the reactive surface area for ML/ARD reactions in the short-term, the dense packing may result in some reduction in air permeability limiting long-term ML/ARD risk.

- The current conceptual PAG Rock Management Plan assumed that all material encountered during the construction will be classified as PAG. However; should the results of basic ABA geochemical characterization testing provide index tests that could identify higher and lower ML/ARD risk materials this would be incorporated into the placement strategy.
- The exposed backslope cut would focus on limiting net percolation of water and oxygen supply. The current conceptual level design includes the implementation of a low permeability compacted clay layer / growth medium cover system.

6.2. Performance Monitoring

To support the facility design and obtain baseline for future performance monitoring the ML/ARD management plan will detail the approach to monitoring, in particular it will entail:

- Groundwater monitoring plan, and
- Surface water monitoring plan.

Each plan will establish:
- background (pre-construction) sampling;
- Proposed locations;
- Sampling parameters;
- Monitoring frequency; and
- Indicator parameters.

7. IMPLEMENTATION, NEXT STEPS

It is expected that the following staged approach would be implemented for managing the ML/ARD risk along the Connector Road corridor for each of the construction Domains for:

- Preliminary design based on updated conceptual model and preferred mitigation measures;
- Estimate acid generating rock volumes;
- Geochemical characterization to understand PAG classification, lag time to acid onset, identify CoCs and potential field index tests to provide understanding of higher ML/ARD risk materials;
- ML/ARD Management Plan with;
  - preliminary storage cell design;
  - performance control; and
  - field performance monitoring plan.
- Consultation with NSE;
- Detailed design and construction specifications and QA/QC plan;
- Detailed Monitoring Plan; and

- Submission of approval application to NSE (pursuant to the "Sulphide Bearing Material Disposal Regulations")

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