Appendix C

Sulfide/Acid Rock Drainage Technical Memorandum
TECHNICAL MEMORANDUM

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DATE: August 28, 2014

RE: Highway 1/169 Eagles Nest Lake Area Improvement Project – Sulfide/Acid Rock Drainage
Technical Memorandum
SEH No. 14996    File No. 4.0

Introduction

This memorandum documents the geology and sulfide minerals conditions, investigations and recommendations that have been conducted to date for the Trunk Highway 1/169 Eagles Nest Lake Area Improvement Project. The discussion, findings, and recommendations contained in this technical memorandum will be incorporated by reference in the combined federal Environmental Assessment (EA) and state Environmental Assessment Worksheet (EAW) for the project.

Project Overview and Background on Sulfide/Acid Rock Drainage Issue

The proposed Highway 1/169 Eagles Nest Lake Area Improvement Project is located in rural St. Louis County, in northeastern Minnesota. The project limits extend 5.6 miles from 1900 feet southwest of Six-Mile Lake Road to Bradach Road (see Figure 1 located in Appendix A). Proposed roadway improvements include widening shoulders and reaction zones to improve roadway safety and, in some locations, realignment of the roadway.

The project is situated within bedrock formations that have been identified to be sulfide-bearing. In June 2009, during the early planning and design phase of the highway project development process, concerns were raised by area property owners and resource agencies that the presence of sulfides in the bedrock within the project area should be considered since the proposed roadway improvements would require rock excavation; and they were concerned that sulfides in the rock could potentially weather (i.e., undergo a chemical transformation), resulting in release of acidity that could affect area water resources. Acid rock drainage (ARD) refers to the acidic water that is created when sulfide minerals are exposed to air and water and, through a natural chemical reaction, produce sulfuric acid. ARD has the potential to introduce acidity and dissolved metals into water, which can be harmful to fish and aquatic life.

The potential for acidity production from sulfide-bearing rock is dependent on a number of factors, including:

- Amount of oxygen present: Sulfide minerals oxidize more quickly where there is more oxygen available. As a result, ARD formation rates are higher where the sulfides are exposed to air than where they are buried under soil or water. (1)
- Amount of water available: Cycles of wetting and drying accelerate ARD formation by dissolving and removing oxidation products, leaving a fresh mineral surface for oxidation. In addition, greater volumes of ARD are often produced in wetter areas where there is more...
water available for reaction. Temperature: Pyrite oxidation occurs most quickly at a temperature around 30°C. (1)

- Rock permeability: Dense, impermeable rock is more resistant to weathering, since water and oxygen don’t easily penetrate the rock.
- Microorganisms present: Some microorganisms are able to accelerate ARD production. (1)
- Type of minerals present: Not all sulfide minerals are oxidized at the same rate, and neutralization by other minerals present may occur, which would slow the production of ARD. (1) Inherent buffering capacity of the rock: If the ore/rock exposed by construction or other activities, it would be less likely to produce ARD if it contains a high proportion of “acid-buffering” minerals such as lime, calcite, carbonate or bicarbonate, which are able to neutralize acidic waters.
- Surface area of sulfide minerals exposed: Increasing the surface area of sulfide minerals exposed to air and water increases sulfide oxidation and ARD formation. (1)


Understanding these factors is helpful in assessing the potential risk for ARD and in developing minimization/mitigation strategies for the proposed project, as discussed in the sections that follow.

### Research on Current/Best Practices

In July 2009, MnDOT initiated a consultation process whereby resource agencies (primarily Minnesota Department of Natural Resources [MnDNR] and Minnesota Pollution Control Agency [MPCA]) and other professionals (MnDOT staff and consultant team) began to discuss sulfides as a potential concern within the project area. Project information was distributed, including proposed highway alignments and technical reports, and periodic coordination meetings (in-person and phone conferences) have been conducted to evaluate the findings of the geologic investigations (both visual field observations and laboratory testing results), assess the potential for impacts, and advise on how to mitigate potential adverse effects. The issues raised by MnDNR and MPCA through these coordination meetings led MnDOT to research how this potential issue is addressed in other states. Information has been provided by the MnDNR regarding how Pennsylvania and Tennessee DOTs handle potential acid rock drainage (ARD) from sulfides in bedrock. MnDOT staff has also contacted several representatives at these DOTs to further discuss the topic.

### Other States Highway Practices and Experiences

State Highway Transportation Departments in Pennsylvania and Tennessee have encountered sulfide-bearing rock in areas of proposed roadway improvements and as a result, have developed identification, management, and monitoring protocols to address the issue (Virginia and North Carolina also acknowledge the presence of acid producing rock (APR) in their states but, similar to Minnesota, do not have established guidelines for mitigation since APR is rarely encountered on transportation projects). These protocols rely, in part, on guidance from the U.S. Department of Transportation (Byerly 1990¹). PennDOT received specific guidance from Penn State University while Tennessee DOT’s protocols/guidance was formulated with the assistance of Golder and Associates. This information can be acquired via the internet and/or by request. Summaries of PennDOT’s and TDOT’s guidelines were provided by staff from the MnDNR.

### Pennsylvania Department of Transportation (Penn DOT) Protocol

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The Penn DOT lists a series of 14 steps for their site assessment protocol that can be condensed and generally summarized as:

1) review existing geologic information,
2) conduct field surveys,
3) develop a drilling, sampling, and analysis plan,
4) execute the sampling plan,
5) map the information collected, and
6) summarize information collected in a report.

For the exploratory drilling mentioned above, the Penn DOT lists minimum boring requirements based on a combination of the potential for sulfide bearing rock and geological complexity and the type of excavation proposed. For roadway cuts in areas with sulfide-bearing rocks with steeply dipping or complex geologic deposits, the Penn DOT requires the greater of a) two borings per 10 acres of excavation footprint or b) two borings, plus one additional boring every 500 feet of roadway cut length. The results of the initial borings may dictate the necessity for additional borings to adequately define the nature and extent of sulfide-bearing rock.

Guided by the geochemical characterization report, the Penn DOT develops construction plans and specifications to minimize and mitigate the potential risk for ARD, including management of the sulfide-bearing rock. During construction, both site conditions and sulfide-bearing rock management construction are monitored. If sulfide-bearing rock is expected or suspected to be encountered during construction, the construction plans may specify the need for qualified personnel to be on the job to perform timely identification and assessment of the material during excavation. Following construction, site conditions are periodically monitored for up to three years.

Management plans and strategies for excavated rock focus on adding alkalinity to neutralize acid, inhibiting oxygen access and therefore sulfide mineral oxidation, and inhibiting moisture access to inhibit oxidation and also minimize reaction product transport. Methods specific to excavated rock include alkaline addition, encapsulation in high and dry conditions, and subaqueous disposal.

As part of the Penn DOT protocol, excavated rock with greater than 0.5% sulfur (by volume) cannot be placed beneath the road bed and must be handled with a greater degree of caution. Multilayer cover systems, perhaps in conjunction with alkaline material addition are presented for fill slopes and exposed excavations. The Penn DOT protocol also provides guidance on the mixture of alkaline materials. They recommend adding an amount of alkaline material at least twice that needed to provide a net neutralization potential (NNP) of 12 to 20 T CaCO3 eq/1000 T. They also indicate that alkaline particles finer than 0.25 mm are required to ensure that all of the alkalinity added is available, and provide guidance for mixing alkaline materials and construction rock in a manner that will promote intimate contact between acid-producing and acid-neutralizing solids.

Tennessee Department of Transportation (TDOT) Protocol
The TDOT developed guidelines for testing, monitoring, and prevention and mitigation for potential ARD (Golder 2007

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3) triggers and thresholds,
4) mitigation (prevention and treatment), and
5) monitoring.

The project screening and site assessment consists of an examination of existing data (geological literature and maps) and a visual site inspection to verify the accuracy of the mapping data and expected geology of the site. The goal of this phase is to determine if a project, or a project’s components, is located in Medium- or High-Risk acid producing rock (APR) potential zone(s). Medium-Risk and High-Risk classifications are established based on geology, empirical information, and professional knowledge regarding acid-producing rock in the state. Project components in Low-Risk APR zones are often exempted from additional phases such as sampling and testing.

TDOT projects with components located in Medium- or High-Risk APR zones are required to follow sampling and testing guidelines during the life of the project and monitoring at the conclusion of the project. A sampling plan is developed to identify potential acid-producing materials. The sampling plan commonly includes pre-construction and construction phase sampling. Pre-construction sampling includes sampling of water and rock (drilling/boreholes) and is intended to describe the existence, extent, and volume of potential APR-bearing geologic horizons, so that road construction and mitigation designs may be prepared.

As with the pre-construction phase, construction phase sampling includes both water and rock. Its objective is to describe in detail the presence of potential APR so it can be managed to avoid impacts. Construction phase sampling includes periodic field inspection by qualified staff, including examination of borehole cuttings and disturbed material. In addition, sampling of boreholes and non-blasted disturbed material is also part of the protocol. Water samples are used to assess existing impacts, to help establish baseline conditions, and evaluate post-construction seepage from encapsulated areas or APR-prone cut slope exposures to determine if problematic drainage is being generated.

Mitigation approaches are recommended based on analyses of samples collected. Samples are analyzed for paste pH, acid potential (AP), and neutralization potential (NP), and Net NP (NNP = NP – AP) and NP ratio (NPR = NP/AP) are calculated. These values are among the data used to determine the appropriate mitigation measures. Three different construction phase best management practices (BMPs) are considered, including blending, partial encapsulation, and full encapsulation. These three methods are appropriate for different thresholds; however, variations or modifications to or between the methods may be appropriate given site-specific conditions or site-specific materials.

The recommended action in the TDOT protocol includes determination of the amount, location, and extent of materials in each mitigation class. For new sites, rock with $0 \leq \text{NNP} \leq 12 \ T \text{CaCO}_3 \text{eq}/1000 \ T$ or $1 \leq \text{NPR} \leq 4$, pyritic S $\geq 0.1\%$, and paste pH $> 5$ can be managed by blending with limestone to attain a NNP $\geq 12 \ T \text{CaCO}_3 \text{eq}/1000 \ T$ rock. Partial encapsulation may be used if $-5 \leq \text{NNP} \leq 0 \ T \text{CaCO}_3 \text{eq}/1000 \ T$ and the water table is at least 10 feet below the encapsulation. Full encapsulation is required for rock with NNP $< -5 \ T \text{CaCO}_3 \text{eq}/1000 \ T$. It should be noted that the values above were taken both from the TDOT protocol text and illustrations and that the two sets of values appeared to differ slightly.
Minnesota Practice

As noted previously, since APR is rarely encountered on transportation projects in Minnesota, MnDOT does not have established guidelines for sulfides in construction materials like Pennsylvania and Tennessee. Therefore, for this project, an approach similar to the processes used by Pennsylvania and Tennessee was used for initial assessment of risk, and to define a process for further characterizing the rock and defining mitigation measures during project final design. In addition, Minnesota Department of Natural Resources (MnDNR) Division of Lands and Minerals and Minnesota Pollution Control Agency staff involved in mine permitting and review have expertise in sulfide-rock-related issues specific to Minnesota conditions; so these agencies were requested to review MnDOT’s findings and provide comments/suggestions as information was compiled and conclusions/recommendations were developed. The following sections describe investigations to date and the planned process for addressing the issue of ARD during project design and construction, including:

- **Investigation**: Review existing geologic information for the project area and conduct initial field review and sampling to characterize the rock within the study area.
- **Consultation**: Consult with expert advisors at MnDNR, MPCA and mining consultant (Golder Associates, Inc.). Review results of investigations and project plans, to identify potential risks and minimization/mitigation strategies.
- **Recommendations**: Based on the investigation and consultation findings, summarize the potential risks for ARD and the process for managing the risks on the Eagles Nest project.

**Investigation: Geologic Conditions**

The bedrock geology in the project area is part of the Neoarchean (approximately 2.7 billion years old) Vermilion Greenstone Belt that includes rocks of the Lower member of the Ely Greenstone; Soudan Iron-formation member of the Ely Greenstone, and the Gafvert Lake volcaniclastic sequence of the Lake Vermilion-formation. Figure 2, located in Appendix A, presents a regional geologic map of the western Vermilion District (modified from Peterson and Jirsa, 1999) showing the major geological formation names.

**Highway 1/169 Eagles Nest Lake Area Project Area Geologic Investigations**

**Phase 1: Field Investigation- Sixmile Lake Area**

In order to better understand the potential for encountering APR in the Highway 1/169 Eagles Nest Lake Improvement Project study area, MnDOT initiated an extensive investigation of geologic conditions. The first step in the investigation was to review existing geologic information. This was followed by an extensive geologic/outcrop mapping project which paid special attention to presence and amount of sulfides and their mode of occurrence within a 400 foot swath around the centerlines of the “North” and “South” Route alternatives developed during initial project scoping for the western portion of the project area (in the vicinity of Sixmile Lake). The fieldwork was completed between April and August 2010 by the Natural Resources Research Institute (NRRI) – University of Minnesota Duluth. A Technical Report was published in December 2010 entitled, “Geology and Sulfide Content of Archean Rocks Along Two Proposed Highway 169 Relocations to the North of Six-Mile Lake, St. Louis County, Northeastern Minnesota”.

Observations and GPS readings were made at over 530 outcrops, and approximately 45 shallow test pits and trenches (likely dug in the early 1900’s and associated with early mineral prospecting); the outcrop mapping technique is described in the December 2010 report. Over 200 of the outcrops that may be potentially affected by the proposed improvements were documented on inventory data sheets. The locations and shapes of the outcrops were digitized to a GIS platform. An additional step during the field investigations was to collect rock samples from outcrops located within both the North and South Route alternatives. Over 350 outcrop samples were collected during mapping from both sulfide-bearing and sulfide-poor exposures. The sampling method is described by NRRI in the December 2010 report and May 2012 Addendum.

The field investigation verified that Volcanogenic Massive Sulfides (VMS) and continuous geologic units with consistently high sulfide contents are not present in the South Route (i.e., the western portion of Alternatives 3 and 3A described in the Environmental Assessment [EA] for the project). Where present, sulfide in the South Route is found mostly in the Soudan Iron Formation Member as secondary pyrite. However, sulfide is generally confined to portions of single outcrops and commonly restricted to very small areas with sulfide contents ranging from 0.5-5% pyrite, by visual volume. These small occurrences are referred to as ‘anomalous sulfide zones’ which occur as isolated ‘islands’ in a ‘sea’ of pyrite-barren outcrops. It was also determined that the presence and percentage of sulfide contents (up to 15% by volume in some very small locales) increase near fault zones which are found mostly in fill areas on project construction profiles.

Though outcrops are not as abundant in the North Route, it was determined that sulfide/pyrite is likely more common in bedrock (and possibly sediments) in the North Route. This conclusion was based on prior exploratory drilling, geophysical data and presence and trend of the Gafvert Lake volcaniclastic unit which revealed the highest sulfide concentrations of all units encountered in both the North and South Routes. The ‘North Route” was eliminated from further consideration during early project scoping, for reasons documented in the EA. Therefore, the geologic investigations that followed focused on the alternative corridors carried forward for further assessment: Alternatives 1 and 2/2A (i.e., within or directly adjacent to the existing highway) and Alternatives 2A and 3/3A (which include the “South Route” realignment at the western portion of the project.

Phase 2: Geochemical Laboratory Testing (Sulfur Analysis)

From discussions between MnDOT, MnDNR and MPCA it was decided that the visual volume sulfide estimates made during the field investigation be verified via geochemical analysis (specifically, the Leco method) at a commercial laboratory. 157 outcrop samples were selected specifically from areas where future rock cuts may be made along the South Route. 95 of the samples were randomly selected from generic rock types whereas 62 were selected from outcrops characterized as ‘anomalous sulfide zones’. The samples were prepared by NRRI staff following methods described in the May 2012 Addendum. Samples were tested for mass-percent of total sulfur by ACME Labs of Vancouver, BC; it was assumed that in all samples the predominant sulfur-bearing species was pyrite (mass-percent of total carbon was not tested for each sample since field observations and prior research revealed very little to no carbonate presence in the area). Laboratory testing was completed in June 2011. After discussions with the DNR, 0.15% mass sulfur was established as a preliminary threshold at which acid generation could become problematic. Key findings of the lab testing include, but are not limited to, the following:

- 138 of the 157 samples contain less than 0.15% sulfur.
- Of the generic rock samples, 71 of 95 samples contained undetectable sulfur levels of less than 0.02% S and only 2 samples exceeded the 0.15% threshold. These results reinforced the
observation that most of the general rock type exposures in the investigated area have low sulfur contents.

- As expected, 38 of the 62 ‘anomalous sulfide zone’ samples exhibited sulfur contents greater than the detection limit of 0.02%. 17 of the 38 samples with detectable sulfur exceeded the 0.15% threshold. Consequently, it was revealed that the visually-estimated sulfide volumes observed during the field investigation were, in most instances, higher than the lab results.

- Of the 4 rock types observed in the South Route (Alternatives 2A and 3/3A), the dacite porphyry exhibited extremely low sulfur contents and is the least likely to contain significant amounts of pyrite. However, the majority of exposures along the South Route consist of iron formation which, according to the data, presents the greatest likelihood of containing localized zones with greater than 0.15% sulfur. There were several instances amongst the ‘anomalous sulfide zones’ samples where visually-estimated pyrite contents did not compare well with the laboratory sulfur measurements. It was determined that a ‘nugget effect’ variation is present (primarily, within the iron formation) which suggests sulfur content may vary within the unobservable portion of the sample, or third dimension. This form of variability was considered troublesome and, thus, some form of drilling was recommended to obtain more representative sulfide values.

Figures 3 through 5, in Appendix A, illustrate the visual sulfur estimates and chemical sulfur analysis percentages with respect to locations of anticipated cut areas along the South Route (figures generated by Kim Lapakko, MnDNR Reclamation Office).

Phase 3: Field Investigation- East Side of Sixmile Lake Area to Eastern Project Boundary

A second geologic field investigation was performed by NRRI personnel in November 2011 to assess the potential for exposing sulfide bearing rock during rock excavation within a portion of the proposed alignment found east of the Sixmile Lake investigation area to the eastern project boundary. Field techniques were employed which were similar to those utilized during the Sixmile Lake investigation. Existing geologic information was also reviewed prior to the field investigation and suggested that: 1.) rock units will be similar to those found during the Sixmile Lake investigation, 2.) majority of rock excavation will be in iron formation, and 3.) only 4 short sub-areas would likely be affected by rock excavation (the geologic information used during the review is discussed in NRRI’s May 2012 Addendum). Additionally, review of prior studies and drilling data revealed that the Armstrong Lake/McComber Mine area would likely contain higher sulfide concentrations than those observed in the Sixmile Lake area. Consequently, in addition to the field investigation MnDOT performed rock core drilling at 3 sites adjacent to the McComber Mine to gain preliminary insight into potentially high sulfur concentrations where proposed rock excavation was planned.

Results of the field investigation were reported in the May 2012 addendum to the December 2010 Sixmile Lake report. The investigation revealed that rare to insignificant amounts of pyrite/sulfide by visual volume are present in proposed excavation areas found east of the Sixmile Lake investigation area and west of the Armstrong Lake/McComber Mine area. Drilling may not be warranted in this stretch since the potential for exposing pyrite-rich rock is low. However, field observations coupled with past and recent borehole information suggests that rock excavation performed adjacent to the McComber Mine will likely expose high amounts of primary pyrite (>0.5% pyrite by volume found in almost all rock exposures; 10% to 15% by volume observed in an 8-foot stretch of MnDOT drill core). Though less information was available to assess the stretch
of alignment found east of the McComber Mine it was surmised that pyrite contents could also be substantial. Thus, additional borings were recommended between the McComber Mine area and the eastern project boundary to better define amount and mode of pyrite mineralization prior to rock excavations. These borings will be done during project final design, as part of the additional characterization work described in the Recommendations section below.

**Phase 4: Field Investigation- Western Stretch of “Existing TH169” Alternatives (Alternatives 1 and 2/2A)**

A third geologic field investigation was performed by NRRI personnel in October/November 2013 to assess the potential for exposing sulfide bearing rock during rock excavation within the alternatives developed earlier in 2013 that are within/directly adjacent to the existing TH 169 roadway (i.e., Alternatives 1 and 2) . The investigated stretch of existing TH169 is found between the western project boundary and, roughly, the intersection with old TH 169. Field techniques were employed which were similar to those utilized during the prior field investigations. Similar rock units were anticipated in the study area given the close proximity to the Sixmile Lake area investigation conducted in 2010.

A report is pending but preliminary results of the investigation suggest that: 1.) iron formation is the predominant rock type found in the investigation area and, 2.) visual volume estimates of pyrite/sulfide appear to be slightly higher than those observed in iron formation in the Sixmile Lake investigation area. The elevated sulfide presence is likely due to a combination of primary sulfide commonly found near the top of the iron formation member and secondary sulfide found in the vicinity of fault zones. Though outcrop samples were obtained from this stretch for geochemical testing it is likely that some form of drilling would be recommended if the preferred alternative affects rock in this area, to better characterize the sulfide presence.

**Consultation: Expert Review and Adviser**

Due to the complex nature of sulfides in bedrock and associated potential ARD and MnDOT’s moderate level of experience with this issue, an ARD expert was consulted on the Highway 1/169 Project. Dr. Rens Verburg(Ph.D., P.Geo., L.G.), a Principal Geochemist with Golder Associates Inc., was added to the review team to assist in the evaluation of project materials (field investigations, current and future sampling and laboratory tests, potential project impacts, and proposed mitigation strategies) and to help facilitate interactions between resource agencies (MnDNR, MPCA, US EPA, etc.) and MnDOT. Golder Associates and Dr. Verburg are nationally recognized for their work on sulfides and ARD. As previously referenced, Golder Associates assisted TDOT in preparing their guidelines and protocol for investigating, testing, monitoring, and mitigating acid producing rock on highway projects.

To date, Dr. Verburg has reviewed the NRRI reports, field logs, laboratory test results, proposed construction plans, and estimates of bedrock excavations. He has also advised MnDOT on potential mitigation measures (discussed in the Recommendations section below), including reasonable methods for calculating the quantity of buffering agent (limestone) potentially needed to neutralize ARD based on the sulfide percentages from the laboratory test results and the amount of excavated material.

In addition, as noted previously, Minnesota Department of Natural Resources (MnDNR) Division of Lands and Minerals and Minnesota Pollution Control Agency (MPCA) staff involved in mine permitting and review have expertise in sulfide-rock-related issues specific to Minnesota conditions. So staff experts from these agencies were requested to meet with MnDOT staff and/or
review MnDOT’s findings and to provide comments/suggestions as information was compiled and conclusions/recommendations were developed. The Recommendations for that follow resulted from the consultation with MPCA and MnDNR staff.

**Recommendations: Potential Impacts and Proposed Mitigation Plans**

**Anticipated Extent of Rock Excavation During Construction**

Based on the preliminary designs, constructing any of the proposed project alternatives will require substantial grading (cut/fill sections) in order to meet highway design safety standards. The estimated rock excavation for project alternatives ranges from approximately 70,000 to 270,000 cubic yards.

As previously stated, sulfide (pyrite) is present within bedrock in the project area, particularly the Soudan Iron Formation Member. However, visual estimates made during comprehensive field observations and corroborative geochemical laboratory testing both suggest that bedrock in the project area generally contains very low to no sulfur. The capacity to mobilize/oxidize sulfide in the excavated material (and rock slopes) along the roadway corridor is heavily dependent on surface area of rock that is exposed to weathering. Compared to the high surface areas produced by mining activities (which involve extensive crushing rock into more fine-grained material with high surface area), the rock (and rock slopes) exposed by the roadway construction process would have relatively low surface areas, since the rock fill produced by blasting will primarily be large-diameter (+3 inch to +6 inch size) material. In addition, the iron formation rock has very low permeability, which means that water and air would not easily penetrate the rock. Except for pyrite found along the relatively few fracture/joint faces (the ‘anomalous sulfide zones’ described in the Phase I Field Investigations section above), there would be minimal internal weathering at exposed rock faces and within crushed particles.

**Proposed Mitigation Plans**

In November of 2013, MnDOT project staff reviewed the field investigation results and estimated project impacts related to rock excavation and rock fill placement with MPCA and MnDNR staff. NRRI’s recommendations for additional drilling, the practices used by PA and TN DOT’s, and the recommendations of MnDOT’s consultant expert Dr. Verberg were also reviewed with agency staff. Based on consideration of all of this information, agency staff and MnDOT agreed on a process for avoiding/minimizing/mitigating the potential production of ARD in the project. The process that will be followed – which is similar to the process used in other states -- includes the following steps:

*Perform additional drilling investigations for the preferred alternative:* Following completion of the environmental review process (i.e., confirmation of the preferred alternative), MnDOT will review previous recommendations for additional drilling (described in the Investigation section above) and the project plans with Dr. Verburg and staff from MPCA and MnDNR, to develop a proposed plan (including locations, protocols, etc.) for additional drilling, to better characterize the rock characteristics in the preferred alternative corridor.

*Develop plans and practices to avoid/ minimize ARD:* Based on the results of the drilling investigation, MnDOT will work with Dr. Verburg and staff from MPCA and MnDNR, to develop a ‘best management practices’ (BMP) plan for excavating, handling, and use of APR rock, and, if determined to be appropriate, use of limestone or other neutralizing materials to minimize ARD.
Examples of practices that are currently being used in other states that may be utilized for this project include:

- Rock excavation that employs pre-split blasting methods for rock faces to ensure lowest surface area exposure. Discussions with MnDNR personnel indicate that rock faces are of less concern than crushed fill (from a surface area standpoint) and, thus, corrective/preventative measures at rock faces may not be necessary.

- Crushing rock to +3-inch or +6-inch size thereby creating low available surface areas for potential oxidation within the fill. Crushing to these sizes also produces very few particulates/fines.

- Encapsulating fill materials applied above the seasonal high water table under the impervious road bed, thereby minimizing direct air and/or water exposure. Limestone rock can also be mixed into bedrock fill material to serve as a buffering/neutralization agent for any potential acid production. Limestone calculations would be made by the third party expert and based on mass percent of sulfur from field samples. The constructive practice for limestone addition has not been determined, though several options are being considered. Any additional sample testing will refine the current limestone calculations.

- Fill materials applied below the seasonal high water table that are submerged, thereby preventing oxidation of sulfur.

*Identify if pre or post-construction monitoring is needed:* Discussions with MPAC and MnDNR staff will also include consideration of whether monitoring of excavated rock materials and/or surface water chemistry in water bodies in the project areas are needed to characterize the materials encountered during construction and/or whether post-construction water chemistry changes occur.
Appendix A

Figure 1 – Project Study Area Map
Figure 2 – Regional Geologic Conditions
  Figure 3 – East Cut Area
  Figure 4 – Middle Cut Area
  Figure 5 – West Cut Area
Figure 2 – Regional Geologic Conditions
Figure 3 – East Cut Area

Fig. 1 East Cuts. The map displays sulfur sample information near proposed roadcuts. One inset table lists the sulfur chemical assays and the other inset table has visual sulfide mineral estimates from the NRRI report. The blue highlighted records indicate samples that are within the proposed roadcuts or very near to roadcuts, and have sulfur content or indicated sulfide mineral content at levels of concern.
Fig. 2 Middle Cuts. The map displays sulfur sample information near proposed roadcuts. One inset table lists the sulfur chemical assays and the other inset table has visual sulfide mineral estimates from the NRRI report. The blue highlighted records indicate samples that are within the proposed roadcuts or very near to roadcuts, and have sulfur content or indicated sulfide mineral content at levels of concern.
Fig. 5 – West Cut Area

The map displays sulfur sample information near proposed roadcuts. One inset table lists the sulfur chemical assays and the other inset table has visual sulfide mineral estimates from the NRRI report. The blue highlighted records indicate samples that are within the proposed roadcuts or very near to roadcuts, and have sulfur content or indicated sulfide mineral content at levels of concern.
Appendix B – List of Studies

Studies and Analyses Conducted for the Project, incorporated by reference into this memorandum:


Severson, M.J. and Heine, J.J. (2010), Geology and Sulfide Content of Archean Rocks Along Two Proposed Highway 169 Relocations to the north of Sixmile Lake, St. Louis County, Northeastern Minnesota: University of Minnesota Duluth, Natural Resources Research Institute, Technical Report NRRI/TR-2010/31. 46p
Appendix C – Additional Reference Sources


Websites with General Information:
http://www.miningfacts.org/Environment/What-is-acid-rock-drainage/#sthash.wxAbRO2a.dpuf