REPORT

ACID GENERATING ROCK MITIGATION PLAN

Trunk Highway 1/169 Improvement Project (Eagles Nest Lake Area)

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EXECUTIVE SUMMARY

This Mitigation Plan describes the procedures that will be used during construction of the Highway 169 realignment project to mitigate the potential for acid drainage from excavated rock that contains sulfide minerals. An extensive borehole drilling and sampling program along the new alignment was performed in 2015. The results of chemical analyses performed on these samples are discussed in detail, in order to identify areas of potentially acid generating (PAG) excavated rock that will require mitigation. During construction, PAG rock will be blended with limestone and agricultural lime and placed in designated fill areas. The required amount of limestone and agricultural lime has been determined from the analytical results. The upper surfaces of the fill will be covered by the asphalt roadway and by geomembrane to prevent surface water infiltration into the PAG rock. Faces of rock cuts will be scaled, with PAG rock placed in the fill areas. If PAG rock remains exposed in the face, the surface water drainage ditch along the base of the cut will be lined with limestone gravel. After construction, surface water in the project area will be monitored to verify that the mitigation measures are functioning as intended. If any adverse conditions are identified, appropriate maintenance activities will be performed, depending on the specific nature of the problem.

Table of Contents

EXECUTIVE SUMMARY ES-1
1.0 INTRODUCTION 1
1.1 Project Background 1
1.2 Organization of Mitigation Plan 1
1.3 Implementation of Mitigation Plan 1
2.0 ROCK CUTS AND ROCK CUT SECTIONS 3
3.0 PROJECT GEOLOGY 4
3.1 Mapping Program 4
3.1.1 Natural Resources Research Institute Investigation 4
3.1.2 Regional Geology 4
3.1.3 Geology Along Alignment 5
3.2 Drilling Program 6
3.2.1 MnDOT Drilling Program 6
3.2.2 Results 6
4.0 ASSESSMENT OF ACID BASE ACCOUNTING DATA 8
4.1 Available Information 8
4.2 Assessment Criteria 8
4.3 Acid Base Accounting Assessment Methodology 8
5.0 MITIGATION ACTIVITIES 10
5.1 Excavated Rock 10
5.1.1 Cut and Fill Areas 10
5.1.2 Sequence of Activities 11
5.1.3 Limestone and Agricultural Lime 14
5.1.4 Geomembrane 15
5.2 Rock Cut Faces 15
6.0 ACID GENERATION POTENTIAL TESTING DURING CONSTRUCTION 16
6.1 Purpose 16
6.2 Rock Chip Sample Selection 16
6.3 X-Ray Fluorescence Testing 17
6.3.1 Introduction 17
6.3.2 Equipment 17
6.3.3 XRF Daily Calibration Checks and Preparation 17
6.3.4 XRF Analysis 18
6.3.5 Decontamination 19
6.3.6 Reporting 19
6.4 Acid Base Accounting 19
6.4.1 Assessment Procedure 19

6.4.2 Assessment Tool 20
6.5 Overburden Assessment 20
7.0 POST-CONSTRUCTION MONITORING 21
8.0 CLOSING 22
9.0 REFERENCES 23

List of Tables

Table 1 Boreholes and Acid Base Accounting Data used to Characterize Rock Cut Sections
Table 2 NP Adjustment Based on Fizz Rating

List of Figures

Figure 1 Rock Cut Mitigation (Sheet 1)
Figure 2 Rock Cut Mitigation (Sheet 2)
Figure 3 Rock Cut Mitigation (Sheet 3)
Figure 4 Rock Cut Mitigation (Sheet 4)
Figure 5 Rock Cut Mitigation (Sheet 5)
Figure 6 Rock Cut Mitigation (Sheet 6)
Figure 7 Summary of the Weighting Method used to Aggregate Sulfur and NP Data by Section (in text)
Figure 8 Typical Fill Section (in text)
Figure 9 Schematic of Sampling Frequency for Drill Cuttings (in text)

List of Appendices

Appendix A Borehole Data
Appendix B Assessment Tool

1.0 INTRODUCTION

1.1 Project Background

The Highway 169 realignment project will be constructed by the Minnesota Department of Transportation (MnDOT) to improve the safety of this section of highway. The project consists of constructing roadway along approximately 10,000 feet of new alignment at the west end of the project and improving about 18,000 feet of existing alignment at the east end.

Construction of the proposed alignment will require excavation of overburden (e.g., surficial soils and weathered alluvial rocks) and blasting and excavation of bedrock. Some types of bedrock contain levels of sulfide minerals that may have the potential to generate acid rock drainage (ARD). The Mitigation Plan includes a set of procedures that are designed to minimize the ARD potential of materials exposed or excavated during highway construction.

1.2 Organization of Mitigation Plan

This Mitigation Plan has been prepared by Golder Associates Inc. (Golder) to describe the actions that will be implemented to mitigate the potential ARD for this project. The level of detail in this plan is intended to provide sufficient information and guidance to develop detailed design documents that are suitable for construction. Technical requirements for mitigation are established in this plan; administrative procedures and documentation processes will be developed by the MnDOT in accordance with their internal procedures.

Section 2.0 of this Plan describes the areas where rock will be excavated, providing the basis for subsequent determination of the need for mitigation along the alignment. Section 3.0 describes the geology along the alignment, including the field drilling program and results. Section 4.0 describes the acid base accounting used to determine the need for mitigation and, where applicable, quantities of limestone. Section 5.0 describes the proposed mitigation procedures in detail, while Section 6.0 discusses the monitoring procedures during construction that will be used to confirm the acid generating potential of excavated rock. Section 7.0 describes post-construction monitoring.

1.3 Implementation of Mitigation Plan

The implementation of this Mitigation Plan will be as follows:

- MnDOT is in the process of developing roadway construction plans for the SP 6904-46 TH 1/169 Eagles Nest Project.
- The recommendations in this Mitigation Plan will be used as the framework in the development of plans, design drawings, technical specifications, and inspection procedures (the Construction Documents) developed for this project.

- The construction plan and specifications developed will be used by the construction contractor in the bidding process and ultimately in the field.
- This construction project will be staffed by MnDOT personnel as well as required consultant staff to supplement the MnDOT work force as needed.
- The MnDOT field staff, consultant staff, and a Qualified Professional hired by MnDOT will oversee the Mitigation Plan implementation during construction.
- The Qualified Professional will be a representative of MnDOT and be specifically responsible for implementation of this Mitigation Plan.

2.0 ROCK CUTS AND ROCK CUT SECTIONS

The areas that will require bedrock removal are shown in Figures 1 through 6 as 22 discrete rock cuts. The rock cuts are identified by the letters A through V; rock cut A lies at the western end of the alignment (i.e., closest to the town of Tower), and rock cut V lies at the eastern-most end of the alignment (i.e., closest to the town of Ely). The cut depth of the alignment does not pass beneath the bottom of the overburden in cuts J, P, and U and, therefore, these cuts will not intersect bedrock and are excluded from this assessment.

For the purpose of the mitigation strategy, each rock cut that will encounter bedrock has also been divided into between one and eight smaller sections (subareas) of variable length, ranging up to approximately 400 feet. These 84 sections are also shown in Figures 1 through 6 and are labelled as A1, A2, B1, B2, B3, etc. The bedrock in each of these sections is described in this report with respect to its ARD potential. Section intervals, bedrock volumes, and the boreholes associated with each section are shown in Table 1.

3.0 PROJECT GEOLOGY

Geology within the project area was described in two reports prepared by Mark Severson and John Heine of the Natural Resources Research Institute (NRRI) – University of Minnesota Duluth following an extensive geological investigation (Severson and Heine 2010, 2012). The geological descriptions from these reports are reproduced in this section.

3.1 Mapping Program

3.1.1 Natural Resources Research Institute Investigation

MnDOT initiated an extensive geological investigation to better understand the potential for ARD in the Highway 1/169 Eagles Nest Lake Improvement Project study area. This investigation included an extensive geologic and outcrop mapping project that paid special attention to presence and abundance 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 and included observation at over 530 outcrops and approximately 45 shallow test pits and trenches. Over 350 outcrop samples were collected during mapping from both sulfide-bearing and sulfide-poor exposures. One-hundred and fifty-seven (157) outcrop samples were tested for their total sulfur content by ACME Labs of Vancouver, British Columbia. One-hundred and thirty-eight (138) of the 157 samples contained less than 0.15% sulfur. The dacite porphyry exhibited extremely low sulfur contents and is the least likely to contain significant amounts of pyrite. The majority of exposures along the selected route consist of iron formation which, according to the data, presents the greatest likelihood of containing localized zones with greater than 0.15% sulfur. Complete results of the geological investigation are presented in Severson and Heine (2010, 2012).

3.1.2 Regional Geology

The bedrock geology in the area is part of the Neoarchean (~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. These rocks have been folded in the Tower-Soudan Anticline and are now rotated to near-vertical with steep dips to the north in the area of interest. A second phase of deformation associated with regional metamorphism lead to the development of regional east-west-trending shear zones. Other common fault orientations in the area are in a northeast direction and are interpreted as syn-volcanic in origin. These faults were probably reactivated during the third phase of deformation. Interpreted faults are shown on Figures 1 through 6.

3.1.3 Geology Along Alignment

Each of the geologic units encountered by Severson and Heine (2010) during mapping are briefly described below (starting with the oldest rocks/bottom of the stratigraphic pile and progressing upwards):

- **Soudan Iron Formation:** The Soudan Iron formation member overlies, and locally interfingers with, mafic volcanic rocks of the Lower Ely Greenstone member. The iron-formation is composed of thinly-laminated, magnetic chert (black to gray) with variable amounts of red jasper beds. Lesser amounts of the mafic flows, tuffs, and sediments are present throughout the iron-formation. This package of rocks formed during a period of quiescence in volcanism at the end of the deposition of the Lower Ely Greenstone. In the area of interest, the iron-formation is 1,800 to 2,000 feet thick. Bedding in the iron-formation is typically well-laminated and thin-bedded, with massive-bedded black chert more common near the top of the unit. Bedding is planar (2 millimeters [mm] to 2 centimeters [cm] thick) but in many areas is extremely folded. This folding is thought to be caused by soft sediment deformation (slumping) prior to lithification. The iron-formation is highly magnetic, making usage of a normal compass for structural measurements impossible and requiring the employment of a sun compass for the measurements. Near the top of the iron-formation, magnetite content decreases and the unit is composed of light-gray to black chert. Thin tuffaceous beds, probably correlative with the overlying Gafvert Lake volcaniclastic unit, are also common near the top of the iron-formation.
- **Altered Unit:** Mafic sediments or reworked volcaniclastic/tuffaceous units are locally interbedded with the iron-formation, and these rocks are commonly 3 to 15 feet thick. These units have been historically referred to as the “altered unit“ (ALT Unit) because of the dramatic colors the rock exhibits due to a superimposed moderate to strong alteration. The alteration consists of epidotization (both green and pink epidote), sericitization, chloritization, and silicification with local garnet-rich zones. The Altered Unit consists of fine-grained sediments or tuff and bedding is highly variable in these outcrops, ranging from thin- to massive-bedded. In some areas the alteration is so intense it is difficult to determine the precursor rock type. Small lenses of highly-folded iron-formation are also common to the ALT Unit. Overall, outcrops of the ALT Unit usually contain higher than normal pyrite concentrations (0.5% to more than 2% by visual estimation) in the area of study. The ALT Unit near Sixmile Lake, to the south of the study area, generally exhibits higher pyrite contents (plus widely-scattered, small copper-stained zones).
- **Metadiabase:** The metadiabase, spatially correlative with the Lower Ely Greenstone member, occurs as intrusive sills in the Soudan Iron formation. These sills generally extend for several hundred feet along bedding trends and are thought to have served as feeder channels to the overlying mafic volcanic units exposed elsewhere in the Soudan Iron formation (or even as feeders to the overlying Upper Ely Greenstone member). The metadiabase is characteristically plagioclase phyric with a felty texture, and varies from dark green to nearly black in color. Contacts, where exposed, commonly have a chilled margin that has locally undergone some shearing as indicated by the presence of thin chlorite schist zones.
- **Dacite Porphyry:** The dacite porphyry occurs as sills, and to a lesser extent as dikes, in the Soudan Iron formation. These rocks are thought to be the feeders for the overlying Gafvert Lake volcaniclastic unit. The dacite is white to light green gray in color and contains conspicuous phenocrysts of feldspar (2 to 10%) and quartz “eyes” (3 to 6%), with lesser amounts of hornblende (1 to 2%). Xenoliths of iron-formation are common in these intrusive sills. For the most part, the dacite sills intrude all rock types; however, local dikes of metadiabase are seen to intrude the dacite.

- **Gafvert Lake Volcaniclastic Unit:** The Gafvert Lake volcaniclastic unit is an informal subunit of the Lake Vermilion Formation and is best exposed in an area peripheral to Gafvert Lake. These rocks represent a period of explosive volcanism. In the area of this investigation, the rocks consist of a series of felsic tuffs and block-and-ash flows. The fine-grained felsic tuffs are quartz- and feldsparphyric and white to brown in color. The block-and-ash flows are characterized by rounded blocks of fine-grained tuff, iron formation, dacite porphyry, basalt, and sulfide-rich clasts within a matrix that is similar to the felsic tuffs. Pumice is found in both types of volcanic rocks. Individual tuff and block-and-ash flows have not been mapped in detail so the thickness of these flows is not known.
- **Gray Basalt:** The Gray Basalt is a thin unit within the Gafvert Lake volcaniclastic unit exposed along the North Route of this investigation. It is a fine-grained, light-grayish green mafic flow unit. Partial pillow rinds are present in one outcrop, and a few amygdules or vesicles were identified locally. These outcrops are on the north side of the current highway and the contacts between the underlying Soudan Iron formation and the overlying Gafvert Lake volcaniclastic unit are not exposed. Most of the exposures of this rock type are heavily frost-heaved, making it difficult to make structural measurements.

3.2 Drilling Program

3.2.1 MnDOT Drilling Program

MnDOT completed a geological drilling and sampling program along the proposed alignment between July and December, 2015. The drilling program included 179 boreholes drilled at 45 degree dip angles perpendicular to the alignment in order to intersect a cross section of the geological materials present in the rock cuts (see figures in Appendix A). The boreholes were located at regular intervals, or on specifically-targeted features, along the alignment.

A total of 766 drill core samples were collected during the drilling program and submitted to ALS Minerals of Reno, Nevada for laboratory analysis. All samples were analyzed for the acid base accounting (ABA) parameters paste pH, sulfur content, neutralization potential (NP), and fizz rating. Samples containing more than 1 weight percent (wt.%) sulfur were also analyzed for their metals content. The fizz rating involves the addition of acid to a sample of crushed rock and the observation of effervescent fizz, an indication that the material contains carbonate minerals. Fizz ratings are assigned on a scale of one to three and may be regarded as an indication of the abundance or availability of NP (i.e., less NP may be expected in material types that have a low fizz rating).

When compared to the final layout of the alignment, a total of 120 boreholes and 553 rock samples were located within the rock cut excavations and 5 feet beneath the alignment that may be disturbed during blasting (i.e., overbreak). These samples were included in the assessment presented in Section 4.0.

3.2.2 Results

The locations of the boreholes along the alignment are shown in Figures 1 through 6 with the weighted average sulfur content for drill core in each borehole. The weighted average sulfur and NP results for each section are also shown in Table 1.

The lithology, sulfur content, and neutralization potential ratio of the samples collected from each borehole along the alignment are shown in Figures A-1 through A-19 in Appendix A.

4.0 ASSESSMENT OF ACID BASE ACCOUNTING DATA

4.1 Available Information

Golder's assessment of ARD potential was based on sampling and analysis of rock cores collected from boreholes located at regular intervals, or on specifically-targeted features, along the alignment, described in Section 3.2.

4.2 Assessment Criteria

Golder conducted an assessment of the ABA data from the rock cuts in accordance with two site-specific guidance documents provided by the Minnesota Department of Natural Resources (MnDNR):

- MnDNR recommendations for the MnDOT highway 169 Eagles Nest project Acid Bearing Rock Mitigation Plan, dated April 8, 2016.
- Supporting comments on the recommendations provided in a follow-up email from MnDNR on April 26 in response to comments submitted by Golder.

4.3 Acid Base Accounting Assessment Methodology

The purpose of the ABA assessment was to inform a mitigation strategy for rock cuts that have the potential to produce ARD. An assessment of the ARD potential was conducted for each of the smaller rock cut sections and included the following sequence of activities:

1. The boreholes within each section were identified and grouped according to their location; either western, central, or eastern. The methodology for grouping boreholes was recommended by the MnDNR and is illustrated in Figure 7 below. Most of the sections are delineated by boreholes at either one or both ends of the section (i.e., section B2 in Figure 1). Some sections contain additional targeted boreholes (i.e., section H3 in Figure 2), which were included in the analysis to provide a greater number of samples for the assessment. The inclusion of these boreholes provides an additional degree of confidence in this approach because the targeted holes were located in areas likely to have a higher sulfur content.
2. A weighted average sulfur content was calculated for each group of boreholes. The calculation included assay data for all sample intervals located within the proposed cut depth of the alignment, weighted by the length of each sample interval.
3. The maximum weighted average sulfur content in each section was selected to represent all of the material within the section, as illustrated in Figure 7 below.
4. The weighted average NP value associated with each maximum sulfur content was also assigned to represent all of the material in the section. In accordance with guidance supplied by the MnDNR, laboratory-reported NP values were modified with the following adjustment, which was intended to account for the potentially lower acid neutralizing capacity of material with a low carbonate content:
   A. The weighted median or mean (whichever is greater) NP value was calculated for all samples with a fizz value of 1 in each rock type at each road cut. The results of this evaluation are shown in Table 2. In all rock types at all road cuts, the weighted mean NP was greater than the weighted median NP.

B. All individual NP values were adjusted by subtracting the respective weighted mean NP value.

5. A Neutralization Potential Ratio (NPR) was calculated for each rock cut section using the assigned sulfur and NP values, as shown in Table 1. The NPR values compare the relative abundance of acid neutralizing and acid generating materials in each section and are calculated according to NPR=NP/AP. The NP and AP are expressed in units of t $CaCO_3$/kt.

6. The ARD potential of each rock cut section was assessed against an NPR target value of three. In 10 rock cuts, the NPR values of each individual section were greater than three and therefore no mitigation is required because the materials are not potentially acid generating. Rock cuts D, E, H, M, Q, S, T, and V contain sections with NPR values less than three; the rock cuts and cut material from these sections will require mitigation.

7. Addition of limestone is proposed to mitigate ARD by increasing the NPR of the material in the rock cut section to a value of at least three. The mass of limestone required for mitigation was calculated assuming that NP is provided by both the rock material and the limestone additions. A specific gravity of 3.0 was assumed for the cut material. The mass of limestone required to mitigate ARD in rock cuts D, E, H, M, Q, S, T, and V is shown in Table 1 and on Figures 1 through 6.

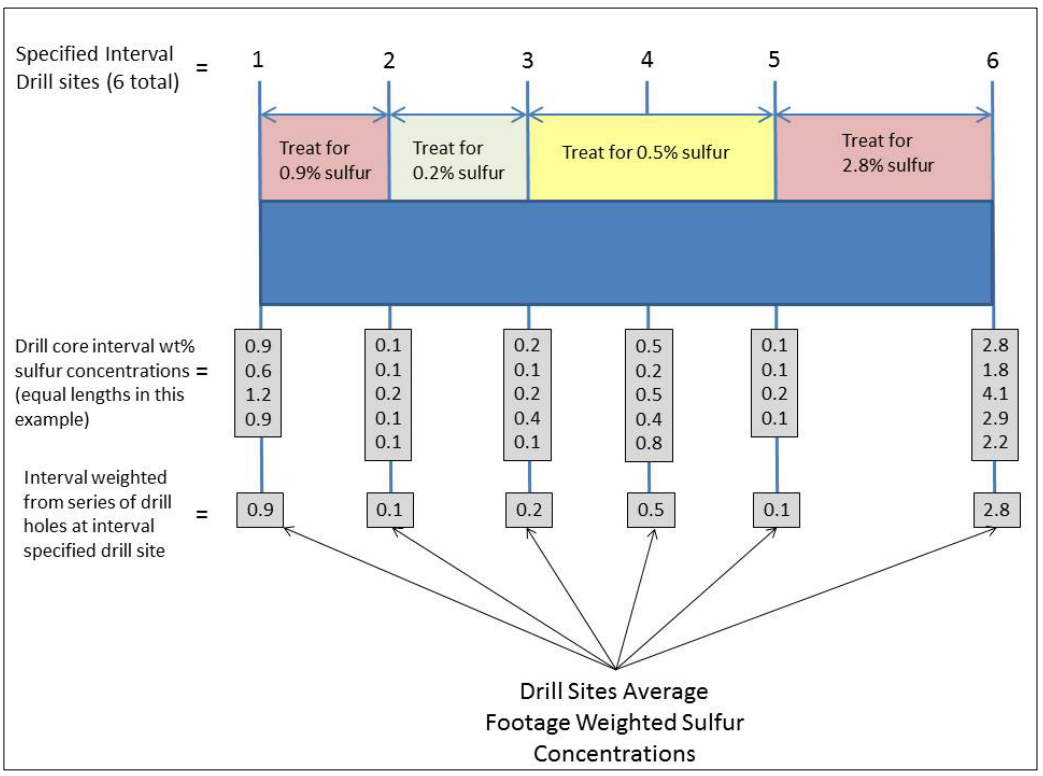


Figure 7: Summary of the Weighting Method used to Aggregate Sulfur and NP Data by Section (Schematic provided by MnDNR)

5.0 MITIGATION ACTIVITIES

Mitigation will be required to address two conditions:

- Excavated rock that is PAG
- The rock cuts where PAG rock is exposed

Based on the very extensive sampling and analysis program described earlier, the future excavated rock has been characterized in sufficient detail on a mass basis (which is applicable given the mixing that will occur during excavation, hauling, and placement) that specific mitigation requirements can be established prior to construction. For this reason, a field-based confirmatory sulfur testing program, as described in detail in Section 6.0 below, will be adequate during excavation. Mitigation of rock cut faces, however, will depend on details of the local geology, such as small scale structures and veining that can only be identified in the field as excavation progresses. For this condition, therefore, general guidelines can be established, but locations and types of mitigation will be determined in the field by a qualified engineer or geologist (the Qualified Professional) under the direction of the MnDOT.

Till and overburden soils will also be removed along the alignment and used for fill and cover soils at other locations. Because it is anticipated that the majority of overburden is already weathered, these materials are not considered potentially acid generating, provided that cobbles, boulders, and other large rock fragments are not crushed during the excavation, transport, or placement processes. This will prevent exposing fresh rock faces which, in boulders or rock fragments that contain sulfides, could generate acid. Consequently, no crushing of the large material will be performed for this project. As described in Section 6.5, the Qualified Professional will observe the overburden during construction and analyze materials for sulfur with a hand-held XRF, if considered warranted based on visual inspection (i.e. if sulfide minerals, staining, or other features potentially related to ARD are observed).

5.1 Excavated Rock

5.1.1 Cut and Fill Areas

Rock cut areas are shown on Figures 1 through 6. The smaller subareas within each rock cut are also presented. As discussed above, sulfur and NP data for each section were evaluated to determine whether the material would require mitigation for potential acid generation. Those sections requiring mitigation are shown as pink-shaded areas on the figures, while those that do not require mitigation are shown with light blue shading.

In general, material excavated from rock cuts will be used for fill in other area(s) of the alignment. Two primary areas for fill have been identified and are designated as F-3 and F-5, respectively, on Figures 1, 2, and 3. To the extent practical, all PAG rock will be placed in these fill areas. This will result in a minimized footprint which will facilitate management of the PAG material and allow more efficient monitoring of the fill

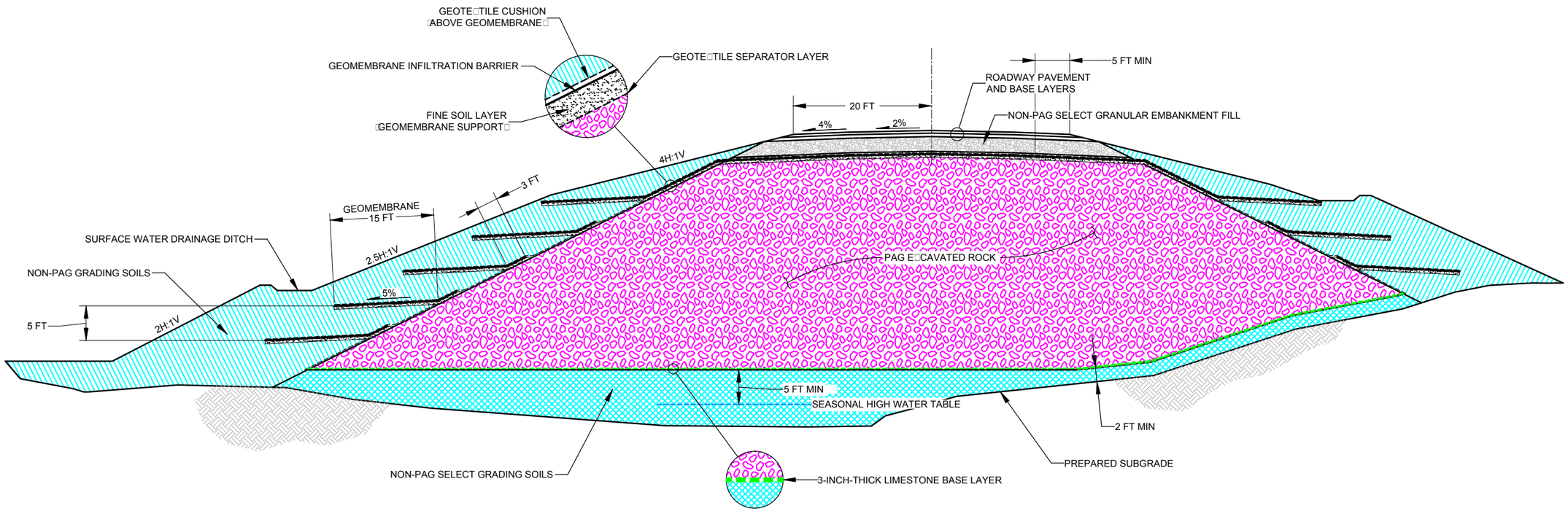
area. In addition, however, a number of smaller, secondary fill areas are shown on Figures 1 through 6. These would be used only if the available capacity of the primary areas is not sufficient to accommodate all of the PAG rock. It is not appropriate at this point in the project to specify which fill area(s) will receive material from particular cut areas; this level of detail is the responsibility of the Construction Contractor and will be determined to optimize his operations (subject to approval by the MnDOT).

5.1.2 Sequence of Activities

In general, mitigation of PAG rock will include a standard sequence of activities. A typical section of PAG rock fill illustrating this approach is shown on Figure 8. The sequence of activities is as follows:

1. Erosion and sediment control best management practices (BMPs) will be established around the fill area in accordance with the approved Stormwater Pollution Prevention Plan (SWPPP) for this project.
2. The fill area will be cleared and grubbed.
3. The subgrade in the fill area will be graded and compacted as necessary to provide a suitable working surface.
4. A minimum 2-foot-thick layer of non-PAG select grading soils will be placed above the subgrade. Where the fill area is located in a surface water drainage, a sufficient thickness of clean fill will be placed so that the elevation of the base of the PAG rock will be at least 5 feet above the seasonal high water level at that location in the drainage.
5. A 3-inch-thick layer of limestone will be spread in a uniformly-thick layer across the prepared fill area. Although the PAG rock will be blended with limestone and agricultural lime prior to placement in the fill area, this layer will provide an additional measure of protection as a contingency against the limitations of the blending process. The 3-inch dimension is the smallest layer that is considered practical for construction, but nevertheless provides a substantial additional amount of neutralizing material.
6. The quantity of limestone and agricultural lime required for blending with the excavated PAG rock from a particular blast will be calculated, based on the requirements presented in Table 1 and the confirmation testing described in Section 6.0, including corrections for the actual carbonate content of the limestone, as discussed below. An individual haul truck will be loaded with excavated PAG rock. The required quantity of limestone and agricultural lime will then be added. This quantity will be determined on a volumetric basis, using the volumes of the haul truck and the loader bucket.
7. At the designated fill area, the rock \ limestone \ lime mixture will be dumped and bulldozed to the required lift thickness. This thickness will depend on the size distribution of the excavated rock, but to ensure effective compaction, should be limited to 1 foot or 1.5 times the largest fragments, whichever is larger. Blending of the PAG rock and limestone \ lime will occur during the dumping and spreading operations. If additional mixing is determined to be necessary by the on-site Qualified Professional, based upon the size of the constituents and visual appearance of the bladed material, it can be accomplished by further blading, ripping, or similar measures as necessary.
8. The fill will be compacted to limit settlement, but the type of equipment and procedures are geotechnical and construction considerations that are beyond the scope of this mitigation plan and will be determined by MnDOT design personnel.

9. Where a fault crosses the fill area, clean excavated material will be placed in the fill 50 feet to either side of the interpreted fault line, to form a 100-foot-wide buffer zone. This is shown for fill areas F-3 and F-5 on Figures 1 through 3.



CLIENT
MINNESOTA DEPARTMENT OF TRANSPORTATION

PROJECT
HIGHWAY 169 REALIGNMENT
ARD MITIGATION PLAN

CONSULTANT

Golder Associates

YYYY-MM-DD	2016-06-30
DESIGNED	FSS
PREPARED	FSS
REVIEWED	TK
APPROVED	RV

TITLE
TYPICAL FILL SECTION

PROJECT NO.	PHASE	REV.	FIGURE
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10. At nominal 5-foot vertical intervals, geomembrane layers will be placed in the clean fill immediately adjacent to the PAG rock, as shown on Figure 8. These layers will form a series of internal "roofs" which will prevent infiltration of surface water into the PAG rock. The geomembranes will slope away from the PAG rock and will be placed on a fine soil layer and covered with a geotextile cushion layer to prevent puncture. At the top of the fill, the geomembrane will extend across the entire width of the fill.
11. Where the new roadway will be constructed above the fill, the upper 2 feet or more of fill (i.e., below the roadway subbase) will be non-PAG select granular embankment material.

For each round of excavation, the following information should be documented as a minimum:

- Source location of excavated rock
- Whether the rock is PAG or non-PAG (designated after the field assessment described in Section 6.0 has been completed)
- For PAG rock, the number of truckloads placed in the fill
- For PAG rock, the quantity and percentages of limestone and agricultural lime added to each truckload
- The general location and elevation in the PAG fill where the material is placed

5.1.3 Limestone and Agricultural Lime

The limestone will be a well-graded crushed rock material with a maximum particle size of 1 inch. Agricultural lime will be a finer limestone material, with 100% passing the U.S. no. 60 sieve. The relative proportions of the two materials will depend on the size characteristics of the excavated PAG rock. If the rock is composed of relatively large fragments with few fines, then a mixture of 75% limestone and 25% lime would be added. If, on the other hand, the rock has a small particle size and high fines content, then a mixture of 25% limestone and 75% agricultural lime would be used. A 50-50 mixture will be assumed for the initial stages of excavation. In accordance with Table 10.1 of the Pennsylvania Department of Transportation (PennDOT) Acid Bearing Rock Policy (PennDOT 2015), this mixture may be adjusted by the Qualified Professional based on the observed rock fragmentation, as different rock types are encountered, or if excavation methods are modified.

The quantity of limestone and agricultural lime used for ARD mitigation will be adjusted during construction based on the calcium carbonate equivalent (CCE) and moisture content value of the products procured by MnDOT. The CCE and moisture content values will be provided by the limestone and agricultural lime suppliers and used to modify the limestone quantity according to the following formula:

Limestone quantity applied (tons) = Calculated limestone quantity / CCE x (100% - moisture content [%])

To facilitate construction, the limestone and agricultural lime will be stockpiled at one or more convenient locations on site.

5.1.4 Geomembrane

We recommend that a 60-mil linear low density polyethylene (LLDPE) material be used for the geomembrane. This material has very high resistance to chemicals and weathering. It also has very favorable mechanical properties, particularly high elongation prior to failure, which means that it can accommodate settlement, irregular surface geometries, and other mechanical strains without rupturing.

5.2 Rock Cut Faces

The following guidelines will be applied as appropriate to mitigating PAG rock where identified during construction:

1. Erosion and sediment control BMPs will be established around the excavation area in accordance with the approved SWPPP for this project.
2. Blasting methods will be selected to produce smooth, even faces (and minimize rock fracturing to the extent practical), to reduce the surface area available for oxidation.
3. Rock faces will be scaled to remove loose rock.
4. In rock cuts where highly fractured surfaces and visible sulfide minerals are identified by the Qualified Professional, the surface water drainage ditch along the base of the cut will be lined with limestone gravel. A hand held XRF may be used to verify sulfur concentrations during construction, if required.

PAG rock removed from cut faces will be blended with limestone \ lime and placed in the fill area(s) as described previously.

6.0 ACID GENERATION POTENTIAL TESTING DURING CONSTRUCTION

6.1 Purpose

An operational monitoring program will be implemented during construction to confirm the ARD potential of the rock from blast holes in each section is consistent with the ARD potential identified from drill cores tested prior to construction (Section 4.0).

This section describes the approach that MnDOT will use in the field to characterize ARD potential. The monitoring program will include four components:

- Rock chip samples (i.e., drill cuttings) will be selected from blast holes.
- A portable X-Ray Fluorescence (XRF) spectrometry instrument will be used to measure the sulfur content of the drill cuttings.
- The measured sulfur data will be compared to the expected values to determine whether the results are consistent.
- If the sulfur content measured during construction exceeds the expected level, the pre-determined limestone blend will be supplemented with additional limestone to mitigate the additional ARD potential.

6.2 Rock Chip Sample Selection

Drill cuttings will be selected for XRF measurement according to the following scheme:

- Each subarea (e.g., B1, B2, B3, as shown on Figures 1 through 6) will be evaluated independently:
  - If the subarea volume is less than 500 cubic yards, then no sampling for XRF analysis will be performed and the material will be treated according to the classification assigned in Table 1.
  - If the subarea has a volume greater than 500 cy, then samples will be collected at 100-foot intervals along the centerline within the subarea. One sample will be collected from every drill hole located along the perpendicular pattern at the 100-foot interval. A schematic of the sampling frequency is shown in Figure 9.
- Rock chip samples will be collected from each blast hole in such a manner that the chips are randomly selected from the drill cuttings without bias and the samples represent a range of material from that blast hole.
- The Qualified Professional will observe cuttings recovered from all blast holes to qualitatively determine the nature and extent of the material types within the 100-foot interval bounded by sampling intervals. The perpendicular pattern will be selected for sampling by the Qualified Professional such that the samples collected are representative for the section.
- Samples will be analyzed for sulfur content using the portable XRF according to the procedure outlined in Section 6.3.
- If a sample cannot be analyzed immediately, it will be placed in a clean Ziploc-type bag and labeled appropriately.

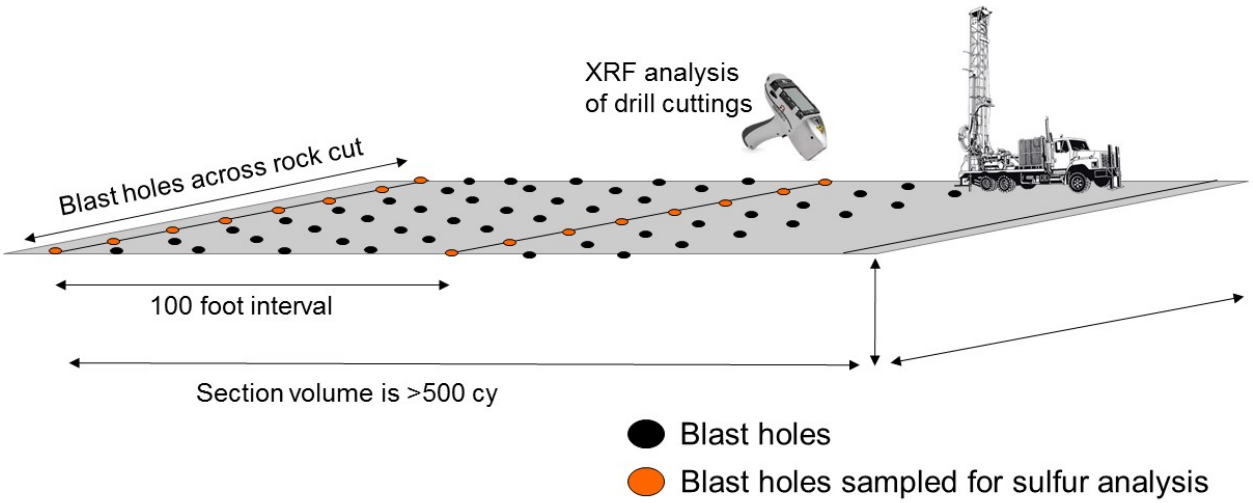

Figure 9: Schematic of Sampling Frequency for Drill Cuttings

6.3 X-Ray Fluorescence Testing

6.3.1 Introduction

The protocol presented in this section has been designed to perform on-site analysis of drill cuttings using a portable XRF instrument. The protocol was developed from the procedures in EPA Method 6200 (EPA 1998), with minor modifications made for ARD assessment rather than metals analysis. This protocol will be used in conjunction with the XRF operation manual provided with the instrument. Any changes or modifications to these procedures will be documented by the Qualified Professional and approved by the MnDOT Resident Engineer.

6.3.2 Equipment

Two portable XRF instruments will be retained on site for the duration of the field sampling work. These instruments will be capable of measuring the sulfur content of solid materials to a detection limit of 0.1 wt.% sulfur.

6.3.3 XRF Daily Calibration Checks and Preparation

Portable XRF equipment utilizes a miniaturized x-ray tube technology or radioactive isotopes. They are calibrated in the factory and do not require field calibration. However, most instruments typically self-administer a testing protocol each day to confirm proper operation of the unit. Field testing includes scanning a stainless steel target to check that the detector is reading full-scan and checking the response level by scanning a metal standard and a blank standard. If an instrument fails either of the tests, it needs to be replaced with a second, factory-calibrated instrument.

The full scan and response level will be checked at the start of each day using standard reference materials that contain known concentrations of sulfur in the 0.01 to 10 wt.% S range expected at the site. This check will be performed each day prior to sample analysis.

6.3.4 XRF Analysis

This section describes the preparation and XRF analysis method for rock chip samples collected in the field.

6.3.4.1 Supplies

The following supplies are required to implement this method:

- General sample supplies:
  - Ziploc-type bags
  - Permanent markers
  - Paper towels
  - Distilled water
  - Scrub brushes
- XRF instrument and supplies (obtained from XRF manufacturer)
- Standard reference materials containing sulfur at known concentrations in the 0.01 to 10 wt.% range

6.3.4.2 Sample Preparation and Analysis

Samples will be prepared for analysis according to the following procedure:

- **Sample inspection and classification:** The sample will be inspected to identify the rock type and any visible signs of sulfur. Any foreign materials (e.g., drilling fluids) will be removed by rinsing with clean water. If it is not possible to remove foreign materials, an alternate sample will be collected from the same borehole.
- **Drying the sample:** If the sample is wet, the sample will be air-dried at ambient temperature prior to analysis. The sample will be allowed to dry in a protected environment to prevent contamination by dust deposition. The sample will be inspected for any remaining foreign materials (e.g., drilling fluids); any such debris will be removed. Drying time will depend on the initial moisture content of the sample. Any foreign materials will be removed.

To perform XRF analysis on the sample, the sample will be placed on a solid surface and the XRF detector will be placed in contact with the sample. The XRF analysis will be conducted for a specified count time (at least 60 seconds is recommended). The same count time will be used to perform analysis of standard reference materials and samples for the same matrix. The measured sulfur concentrations will be recorded by the XRF electronic datalogger and in the XRF operator's field notebook.

6.3.5 Decontamination

If any non-disposable sample handling equipment is used to obtain a sample (e.g., stainless steel bowls, reusable trowels or spoons, etc.), it will be decontaminated prior to reuse. Decontamination procedures include (a) wiping with a clean paper towel or dry brushing loose rock and soil from each piece of equipment, (b) rinsing and/or scrubbing equipment with distilled water using a clean scrub brush, and (c) wiping dry with clean paper towels or air drying. The work area will be kept clean and clear of unnecessary equipment at all times.

6.3.6 Reporting

The results of the sulfur analysis for each rock sample recovered from drill cuttings will be recorded in a field notebook with the following details:

- Sample ID
- Borehole ID
- Approximate depth of each grab sample collected (i.e., feet below ground surface)
- Rock type (e.g., Soudan Iron Formation)
- Visual estimate of sulfur (i.e., presence/absence)

6.4 Acid Base Accounting

The results of the XRF sulfur analysis will be used to determine whether the ARD potential of the rock in the subarea is consistent with the characterization work completed prior to construction, or whether the rock in the subarea has a greater ARD potential and requires additional mitigation measures.

6.4.1 Assessment Procedure

The following procedure will be used to characterize the ARD potential of each rock cut subarea based on the XRF measurements:

- The sulfur content from each drill hole will be used to determine an average sulfur content of the particular subarea. The average sulfur content will be calculated from the XRF results according to:

  average sulfur = sum of sulfur content in each sample/ number of samples.

  Because the sample selection method is based on similar sample intervals, the results do not need to be weighted.
- The average sulfur content calculated in the field will be compared to the pre-construction sulfur content that is presented in Table 1.
- **If the field-based sulfur content is less than the pre-construction sulfur content**, no further action will be taken and the rock cut material will be managed according to the procedures described in Section 2.0.
- **If the field-based sulfur content is greater than the pre-construction sulfur content**, the difference in sulfur content will be calculated and used to determine whether additional mitigation is required. This evaluation will include the following steps:

- The NPR for the section will be calculated using the NP value in Table 1.
  - *AP = 31.25 x field-based sulfur content (in wt.%)*
  - *NPR = NP / AP*
- If the NPR resulting from the field measurements for the section is higher than three (NPR>3) no additional mitigation measures will be required and the material can be treated as non-PAG rock.
- If the NPR is less than three (NPR<3) additional limestone will be required to mitigate the increased ARD potential. In that case:
  - The volume of rock that requires mitigation will be estimated (cubic yards).
  - The amount of limestone required to mitigate the sulfur will be calculated according to the following equations:
  - *NP required (t $CaCO_3$/kt)= (3 x AP) – NP (from Table 1)*
  - *Limestone (tons) = NP required / 1000 x (volume of spoil x 0.765 x 3 x 0.907)*
  - *Limestone to be applied (tons) = Limestone demand / CCE* x (100% - moisture content [%])

Note: The values included in the limestone requirement calculation represent conversion factors of: 1,000 kg/tonne, 0.765 m^3/cy, and 0.907 tonnes/ton, and a target NP of 3. The CCE and moisture content values will be provided by the limestone and agricultural lime supplier.

6.4.2 Assessment Tool

A spreadsheet-based assessment tool will be used to process the results of the sulfur field-testing program described above and calculate the quantity of limestone required for each cut section. The Qualified Professional will enter the sulfur concentrations measured in the field into the spreadsheet and, based on the cut volume and existing ABA data for the specific section, the spreadsheet will determine whether the mitigation approach requires modification. If modifications are required, the spreadsheet will inform the Qualified Professional of how much additional limestone is required. Copies of the data entry and assessment pages of the spreadsheet are included in Appendix B.

6.5 Overburden Assessment

In addition to inspecting and sampling bedrock materials recovered from the blast holes, the Qualified Professional will also inspect overburden materials (i.e., glacial till and soils) for the presence of sulfide minerals, iron staining, salt formation, or other indicators of low-pH seepage. If potentially acid generating overburden materials are identified, they will be segregated for placement in a PAG fill area. The Qualified Professional will analyze overburden materials for sulfur with a hand-held XRF, if considered warranted based on the visual inspection.

7.0 POST-CONSTRUCTION MONITORING

Surface water in the project area will be monitored for five years following construction to verify that the mitigation measures are functioning as intended. The five-year period was selected to cover the post-construction period early in the weathering process for the excavated rock when water quality impacts would be most likely to manifest themselves. The existing surface water monitoring program performed by the MnDOT will be continued, with biannual sampling events in May/June and October/November. In addition, MnDOT will add water sampling locations in naturally-occurring water bodies downstream of PAG rock fill areas. If there is no water source, then no sampling will be performed at these locations and MnDOT will perform visual inspections.

The PAG rock fill area will be visually inspected biannually in conjunction with the surface water monitoring program for signs of:

- Erosion, particularly gully formation
- Excessive settlement, slumping, or other signs of instability
- Iron staining, salt formation, biomass accumulation (i.e., algae), or other indicators of low-pH seepage
- Distressed vegetation
- Other anomalous conditions

Photographs will be taken at fixed locations so that any changes from year to year can be documented.

If any adverse conditions are identified, appropriate maintenance activities will be performed, depending on the specific nature of the problem.

8.0 CLOSING

This Mitigation Plan has been prepared for use on this project only and should not be used for other purposes. The interpretations presented here are based upon the available data presented in this Plan. However, it should be recognized that such data are limited to the locations and points in time at which they were collected, and that conditions encountered in the field during construction could vary from those presented here.

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TABLES

Table 1: Boreholes and Acid Base Accounting Data used to Characterize Rock Cut Sections

Rock Cut	STA to STA	Boreholes in Rock Cut	Estimate Rock Volume Total (4/18/16) (cy)	Rock Cut Section	STA to STA	Approximate Volume Between Holes (cy)	Comments on Alignment	Boreholes in Section	Boreholes in Section (with samples)	Maximum Weighted Average S (wt.%)	AP (t $CaCO_3$/kt)	NP associated with max S (t $CaCO_3$/kt)	NPR	Target NPR	NP Required (t $CaCO_3$/kt)	NP Required (tons Limestone)	NP Required (tons Limestone)
A	14+92-18+84 RIGHT	1	353	A1	14+92-16+00	58	BEGINNING ROCK TO BH1	1	BH1	0.01	0.3	6.2	19.7	3	-5.2	0.0	0.0
				A2	16+00-18+84	295	BH1 TO END ROCK	1	BH1	0.01	0.3	6.2	19.7	3	-5.2	0.0	
B	23+00-33+64.50 LT & RT	6	2,078	B1	23+00-30+11	823	BEGINNING ROCK TO BH2 - BH4	3	BH2, BH3, BH4	0.01	0.4	44.3	113.4	3	-43.1	0.0	0.0
				B2	30+11-32+00	1,003	BH2 -BH4 TO BH5 - BH6	5	BH2, BH3, BH4, BH5, BH6	0.10	3.1	23.5	7.5	3	-14.1	0.0	
				B3	32+00-33+64.50	252	BH5 - BH6 TO END ROCK	2	BH5, BH6	0.10	3.1	23.5	7.5	3	-14.1	0.0	
C	37+74-45+00	4	247	C1	37+74-41+49	247	BEGINNING TO BH7-BH9	3	BH7, BH8, BH9	0.12	3.8	65.8	17.5	3	-54.6	0.0	0.0
				C2	41+49-43+50	0	BH7-BH9 TO BH10-BH13	3	BH7, BH8, BH9	0.12	3.8	65.8	17.5	3	-54.6	0.0	
				C3	43+50-45+00	0	BH10-BH13 TO END ROCK	0	-	-	-	-	-	-	-	-	
D	45+50-46+25	1	287	D1	45+50-46+81.60	87	BEGINNING TO BH167	1	BH167	0.09	3.0	0.0	0.0	3	8.9	1.6	5.3
				D2	46+80.60-47+50	200	BH167 TO END	1	BH167	0.09	3.0	0.0	0.0	3	8.9	3.7	
E	47+50-54+00	16	2,300	E1	47+50-48+50	845	BH167 TO BH14-BH19	6	BH14, BH15, BH16, BH17, BH18, BH19	0.14	4.5	2.4	0.5	3	11.2	19.7	131.5
				E2	48+50-49+50.45	677	BH14-BH19 TO BHET-1 -BHET-3	8	BH14, BH15, BH16, BH17, BH18, BH19, BHET2. BHET3	0.38	12.0	7.4	0.6	3	28.5	40.1	
				E3	49+50.45-50+60	465	BHET-1-BHET-3 TO BH20-BH25 AND BHET-4	8	BHET2, BHET3, BH20, BH21, BH22, BH23, BH24, BH25	0.51	16.0	3.6	0.2	3	44.3	42.9	
				E4	50+60-54+00	313	BH20-BH25 AND BHET-4 TO END ROCK	6	BH20, BH21, BH22, BH23, BH24, BH25	0.51	16.0	3.6	0.2	3	44.3	28.9	
F	59+00-60+75	0	0	F1	59+00-60+75	0	SMALL CUT - NO BORINGS	0	-	-	-	-	-	-	-	-	-
G	64+50-70+00	5	0	G1	64+50-67+25	0	BEGINNING ROCK TO BH26-BH28	0	-	-	-	-	-	-	-	-	0.0
				G2	67+25-67+75	0	BH26-BH28 TO BH29-BH30	1	BH31	0.01	0.3	67.0	214.4	3	-66.1	0.0	
				G3	67+75-70+00	0	BH29-BH30 TO END ROCK	1	BH31	0.01	0.3	67.0	214.4	3	-66.1	0.0	
H	70+80-92+00	32	26,291	H1	70+80-73+00	614	BEGINNING ROCK TO BH32-BH35	5	BH32A, BH32B, BH33, BH34, BH35	0.09	2.8	5.9	2.1	3	2.6	3.3	1,713.4
				H2	73+00-76+50	5,541	BH32-BH35 TO BH36-BH39	9	BH32A, BH32B, BH33, BH34, BH35, BH36, BH37, BH38, BH39	0.13	4.0	34.9	8.6	3	-22.8	0.0	
				H3	76+50-80+00	4,222	BH36-BH39 TO BH40-BH43	9	BH36, BH37, BH38, BH39, BHHT1, BH40, BH41, BH42, BH43	0.13	4.0	34.9	8.6	3	-22.8	0.0	
				H4	80+00-81+85	2,119	BH40-BH43 TO BH45-BH49	9	BH40, BH41, BH42, BH43, BH45, BH46, BH47, BH48, BH49	0.07	2.0	5.3	2.6	3	0.8	3.5	
				H5	81+85-83+00	2,446	BH45-BH49 TO BH50-BH53	9	BH45, BH46, BH47, BH48, BH49, BH50, BH51, BH52, BH53	0.33	10.3	4.0	0.4	3	27.1	137.7	
				H6	83+00-87+00	941	BH50-BH53 TO BH54-BH56	7	BH50, BH51, BH52, BH53, BH54, BH55, BH56	0.33	10.3	4.0	0.4	3	27.1	53.0	
				H7	87+00-90+00	5,962	BH54-BH56 TO BH57-BH61	9	BH54, BH55, BH56, BHHT2, BH57, BH58, BH59, BH60, BH61	0.75	23.6	0.8	0.03	3	70.0	868.4	
				H8	90+00-92+00	4,446	BH57-BH61 TO END ROCK	5	BH57, BH58, BH59, BH60, BH61	0.75	23.6	0.8	0.0	3	70.0	647.6	
I	101+00-103+00	1	82	I1	101+00-103+00	82	BH168	1	BH168	0.01	0.4	1.4	3.3	3	-0.1	0.0	0.0
J	103+00-105+00	1	0	J1	103+00-104+10	0	BEGINNING ROCK TO BH169	0	-	-	-	-	-	-	-	-	-
				J2	104+10-105+00	0	BH 169 TO END ROCK	0	-	-	-	-	-	-	-	-	
K	107+00-110+00	5	1,075	K1	107+00-109+00	689	BEGINNING ROCK TO BH62-BH66	5	BH62, BH63, BH64, BH65, BH66	0.06	2.0	16.5	8.2	3	-10.5	0.0	0.0
				K2	109+00-110+00	386	BH62-BH66 TO END ROCK	5	BH62, BH63, BH64, BH65, BH66	0.06	2.0	16.5	8.2	3	-10.5	0.0	
L	110+00-124+50	19	75,544	L1	110+00-112+00	2,639	BEGINNING ROCK TO BH67-BH69	3	BH67, BH68, BH69	0.10	3.3	30.9	9.4	3	-21.1	0.0	0.0
				L2	112+00-114+00	16,009	BH67-BH69 TO BH71-BH73	6	BH67, BH68, BH69, BH71, BH72, BH73	0.10	3.3	30.9	9.4	3	-21.1	0.0	
				L3	114+00-115+00	10,207	BH71-BH73 TO BH74-BH76	6	BH71, BH72, BH73, BH74, BH75, BH76	0.14	4.4	43.2	9.7	3	-29.9	0.0	
				L4	115+00-118+00	26,930	BH74-BH76 TO BH77-BH80	7	BH74, BH75, BH76, BH77, BH78, BH79, BH80	0.14	4.4	43.2	9.7	3	-29.9	0.0	
				L5	118+00-121+00	17,672	BH77-BH80 TO BH81-BH85	10	BH77, BH78, BH79, BH80, BHLT1, BH81, BH82, BH83, BH84, BH85	0.14	4.4	37.8	8.5	3	-24.5	0.0	
				L6	121+00-124+50	2,087	BH81-BH85 TO END ROCK	5	BH81, BH82, BH83, BH84, BH85	0.08	2.4	22.4	9.2	3	-15.1	0.0	
M	305+00-310+00	6	5,103	M1	305+00-307+00	923	BEGINNING TO BH86-BH88	3	BH86, BH87, BH88	0.09	2.8	9.1	3.2	3	-0.6	0.0	1.7
				M2	307+00-308+00	2,058	BH86-BH88 TO BH90-BH90A	4	BH86, BH87, BH88, BH90, BH90A	0.19	5.8	24.3	4.2	3	-6.8	0.0	
				M3	308+00-308+86	1,783	BH90-BH90A TO BHMT1	2	BH90, BH90A, BHMT1	0.19	5.8	24.3	4.2	3	-6.8	0.0	
				M4	308+86-310+00	339	BHMT1 TO END ROCK	1	BHMT1	0.12	3.8	8.8	2.3	3	2.5	1.7	
N	317+00-323+50	6	2,233	N1	317+00-318+00	0	BEGINNING TO BH91-BH91A	0	-	-	-	-	-	-	-	-	0.0
				N2	318+00-320+00	1,178	BH91-BH91A TO BH97-BH97A	2	BH97, BH97A	0.02	0.7	64.2	92.8	3	-62.2	0.0	
				N3	320+00-321+00	1,055	BH97-BH97A TO BH94-BH95	2	BH97, BH97A	0.02	0.7	64.2	92.8	3	-62.2	0.0	
				N4	321+00-322+00	0	BH94-BH95 TO BH100	0	-	-	-	-	-	-	-	-	
				N5	322+00-323+50	0	BH100 TO END ROCK	0	-	-	-	-	-	-	-	-	
O	328+00-331+00	10	2,808	O1	328+00-329+00	1,170	BEGINNING TO BH101-BH106	5	BH101, BH102, BH103, BH104, BH105	0.06	2.0	17.2	8.6	3	-11.2	0.0	0.0
				O2	329+00-330+00	1,622	BH101-BH106 TO BH107-BH108 & BH110-BH114	6	BH101, BH102, BH103, BH104, BH105, BH107	0.06	2.0	17.2	8.6	3	-11.2	0.0	
				O3	330+00-331+00	16	BH107-BH108 & BH110-BH114 - END ROCK	1	BH107	0.05	1.7	12.0	7.2	3	-7.0	0.0	
P	338+40-342+77	0	0	P1	338+40-340+00	0	BEGINNING TO BH115-BH117	0	-	-	-	-	-	-	-	-	-
				P2	340+00-342+00	0	BH115-BH117 TO BH118-BH121	0	-	-	-	-	-	-	-	-	
				P3	342+00-342+77	0	BH118-BH121 TO END ROCK	0	-	-	-	-	-	-	-	-	
Q	357+50-370+25	8	14,799	Q1	357+00-359+00	16	BEGINNING ROCK TO BH122-BH123	2	BH122, BH123	0.02	0.7	4.7	7.0	3	-2.7	0.0	67.6
				Q2	359+00-36100	1,617	BH122-BH123 TO BHQT1	3	BH122, BH123, BHQT1	0.02	0.7	4.7	7.0	3	-2.7	0.0	
				Q3	361+00-362+00	1,157	BHQT1 TO BH124	2	BHQT1, BH124	0.02	0.5	3.1	5.7	3	-1.5	0.0	
				Q4	362+00-365+00	4,786	BH124 TO BH125	2	BH124, BH125	0.09	2.7	5.4	2.0	3	2.7	27.0	
				Q5	365+72-368+00	7,151	BH125 TO BH128-BH129	4	BH125, BH125A, BH128, BH129	0.09	2.7	5.4	2.0	3	2.7	40.4	
				Q6	368+00-370+50	72	BH128-BH129 TO END ROCK	2	BH128, BH129	0.05	1.6	3.6	2.3	3	1.1	0.2	
R	373+75-388+75	8	4,414	R1	374+00-375+50	538	BEGINNING ROCK TO BH130-BH131	2	BH130, BH131	0.01	0.3	2.2	7.1	3	-1.3	0.0	0.0
				R2	375+50-379+00	2,888	BH130-BH131 TO BH132-BH134	2	BH130, BH131	0.01	0.3	2.2	7.1	3	-1.3	0.0	
				R3	379+00-382+50	0	BH132-BH134 TO BH137-BH138	0	-								
				R4	382+50-385+00	689	BH137-BH138 TO BH139-BH140	2	BH139, BH140	0.02	0.6	28.9	49.3	3	-27.2	0.0	
				R5	385+00-386+00	299	BH139-BH140 TO BH141-BH143	2	BH139, BH140	0.02	0.6	28.9	49.3	3	-27.2	0.0	
				R6	386+00-388+00	0	BH141-BH143 TO END ROCK	0	-	-	-	-	-	-	-	-	
S	390+25-402+00	10	10,897	S1	390+28.96-391+00	0	BEGINNING ROCK TO BH144-BH145	0	-	-	-	-	-	-	-	-	1,120.8
				S2	391+00+394+00	1,102	BH144-BH145 TO BH146-BH147	2	BH146, BH147	0.07	2.1	0.0	0.0	3	6.2	14.3	
				S3	394+00-395+56	3,379	BH146-BH147 TO BH148-BH149	4	BH146, BH147, BH148A, BH149	0.44	13.9	2.4	0.2	3	39.3	276.0	
				S4	395+056-396+00	979	BH148-BH149 TO BH148B	2	BH148A, BH149	0.44	13.9	2.4	0.2	3	39.3	80.0	
				S5	396+00-397+00	2,479	BH148B TO BH150-BH151, BH 150B, & BH 150C	3	BH150, BH150B, BH151	0.90	28.1	18.0	0.6	3	66.3	342.2	
				S6	397+00-400+00	2,958	BH150-BH151, BH 150B, & BH 150C TO BH152	4	BH150, BH150B, BH151, BH150C	0.90	28.1	18.0	0.6	3	66.3	408.3	
				S7	400+00-402+00	0	BH152 TO END ROCK	0	-	-	-	-	-	-	-	-	
T	412+75-414+50	1	169	T1	412+75-413+00	23	BEGINNING ROCK TO BH170	1	BH170	2.41	75.2	17.0	0.2	3	208.7	10.0	73.4
				T2	413+00-414+50	146	BH170 TO END ROCK	1	BH170	2.41	75.2	17.0	0.2	3	208.7	63.4	
U	417+38-422+00	0	0	U1	417+398+-419+00	0	BEGINNING ROCK TO BH153-BH154	0	-	-	-	-	-	-	-	-	-
				U2	419+00-420+00	0	BH153-BH154 TO BH155-BH156	0	-	-	-	-	-	-	-	-	
				U3	420+00-422+00	0	BH155-BH156 TO END ROCK	0	-	-	-	-	-	-	-	-	
V	429+00-440+10	4	1,353	V1	428+00-431+00	0	BEGIINING ROCK TO BH157	0	-	-	-	-	-	-	-	-	92.0
				V2	431+00-434+60	0	BH157 TO BH158-BH159	0	-	-	-	-	-	-	-	-	
				V3	434+60-438+00	0	BH158-BH159 TO BH161	0	-	-	-	-	-	-	-	-	
				V4	438+00-441.52+30	0	BH161 TO BH162	0	-	-	-	-	-	-	-	-	
				V5	441+52.30-443+00	370	BH162 TO BH164-BH164A	2	BH164, BH164A	0.41	12.7	1.8	0.1	3	36.3	27.9	
				V6	443+00-445+00	466	BH164-BH164A TO BH165	2	BH164, BH164A	0.41	12.7	1.8	0.1	3	36.3	35.2	
				V7	445+00-448+50	108	BH165 TO BH166	1	BH166	0.29	9.1	0.3	0.0	3	26.8	6.0	
				V8	448+50-451+00	409	BH166 TO END ROCK	1	BH166	0.29	9.1	0.3	0.0	3	26.8	22.8	

Table 2: NP Adjustment Based on Fizz Rating

Rock Cut and Rock Type	Sample Intervals	Samples with Fizz = 1			NP Adjustment (by cut)
		Count	Weighted Mean NP	Weighted Median NP	
A-Basalt	2	1	17.0	17.0	17.0
B-Basalt	7	0	-	-	0.0
B-Dacite	7	2	11.5	11.5	11.5
C-Basalt	1	0	-	-	0.0
C-Sediments	1	0	-	-	0.0
C-Soudan Iron Formation	1	0	-	-	0.0
D-Soudan Iron Formation	2	2	6.0	5.4	6.0
E-Diabase	1	1	20.0	16.0	20.0
E-Soudan Iron Formation	34	30	9.9	9.0	9.9
G-Basalt	1	0	-	-	0.0
H-Basalt	3	2	24.5	20.8	24.5
H-Dacite	32	4	17.9	16.1	17.9
H-Diabase	1	1	20.0	16.0	20.0
H-Sediments	9	7	19.8	17.1	19.8
H-Soudan Iron Formation	75	72	8.1	6.4	8.1
I-Soudan Iron Formation	5	5	11.4	11.0	11.4
K-Basalt	2	1	27.0	10.8	27.0
K-Dacite	5	1	10.0	9.0	10.0
K-Soudan Iron Formation	8	3	12.6	12.0	12.6
L-Basalt	15	4	23.5	20.8	23.5
L-Dacite	110	3	14.4	6.3	14.4
L-Sediments	4	0	-	-	0.0
L-Soudan Iron Formation	23	5	10.3	6.4	10.3
M-Dacite	24	6	14.2	12.7	14.2
N-Dacite	12	0	-	-	0.0
O-Basalt	1	0	-	-	0.0
O-Dacite	22	10	12.0	9.6	12.0
O-Soudan Iron Formation	12	7	9.2	7.2	9.2
Q-Basalt	1	1	17.0	10.2	17.0
Q-Dacite	5	5	11.9	7.2	11.9
Q-Diabase	9	8	15.1	14.5	15.1
Q-Sediments	1	1	15.0	10.5	15.0
Q-Soudan Iron Formation	28	22	12.6	10.6	12.6
R-Basalt	11	7	26.6	23.2	26.6
R-Dacite	3	0	-	-	0.0
R-Soudan Iron Formation	5	5	16.4	12.0	16.4
S-Basalt	4	0	-	-	0.0
S-Dacite	2	1	13.0	10.4	13.0
S-Soudan Iron Formation	50	41	11.8	9.0	11.8
T-Soudan Iron Formation	3	1	10.0	10.0	10.0
V-Dacite	4	3	10.1	5.6	10.1
V-Soudan Iron Formation	7	6	7.0	5.3	7.0

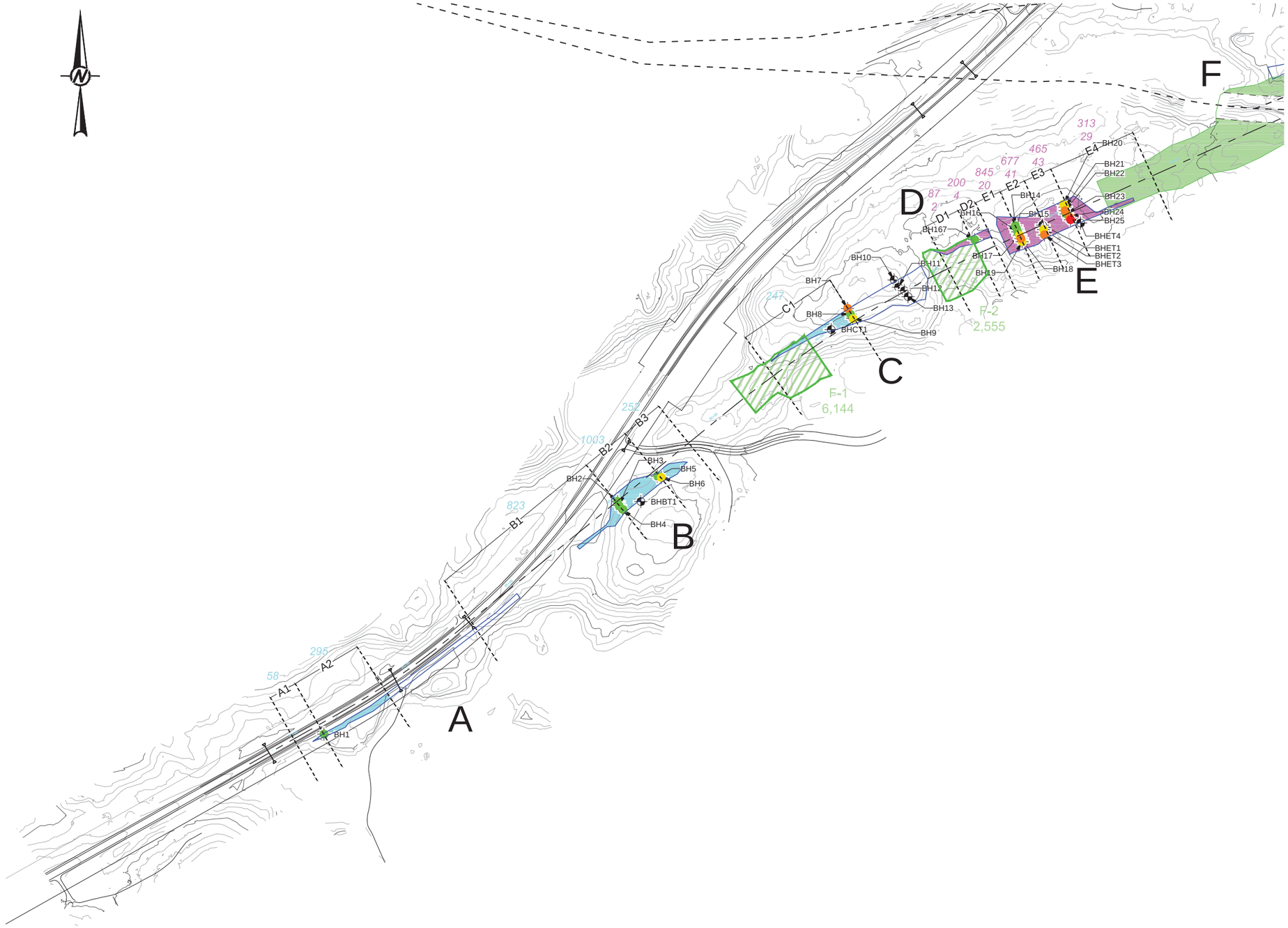
Notes:

All NP values are shown in the units of t $CaCO_3$/kt

NP adjustment is the mean or median (whichever is greatest) NP value of the samples with a fizz rating of 1 in each rock type and rock cut.

The NP adjustment value is subtracted from the NP of all samples (by rock type and rock cut).

FIGURES



NOTES:

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4. WHERE NO SHADING IS PRESENT, CUT IS ENTIRELY WITHIN OVERBURDEN.

LEGEND:

- CUT AREA BOUNDARY (NOTE 4)
- ROCK CUT - NO MITIGATION REQUIRED
- 4222 — ROCK CUT VOLUME - BANK CUBIC YARDS
- ROCK CUT - MITIGATION REQUIRED
- 941 / 53 — ROCK CUT VOLUME - BANK CUBIC YARDS / LIMESTONE REQUIRED - TONS
- PRIMARY FILL AREA
- SECONDARY FILL AREA
- F-4 — FILL AREA DESIGNATION
- 15,764 — FILL AREA VOLUME - CUBIC YARDS
- INFERRED GEOLOGIC FAULT
- BH36 — BOREHOLE (NOTES 1, 2, 3)

- Sulfur 0 to 0.1
- Sulfur 0.1 to 0.2
- Sulfur 0.2 to 1.0
- Sulfur > 1.0

0 200 400
1" = 200' FEET

CLIENT
MINNESOTA DEPARTMENT OF TRANSPORTATION

PROJECT
HIGHWAY 169 REALIGNMENT
ARD MITIGATION PLAN

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-06-30
DESIGNED	FSS
PREPARED	FSS
REVIEWED	TK
APPROVED	RV

TITLE
ROCK CUT MITIGATION (SHEET 1)

PROJECT NO.	PHASE	REV.	FIGURE
1543068	002	0	1

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0 1in IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D

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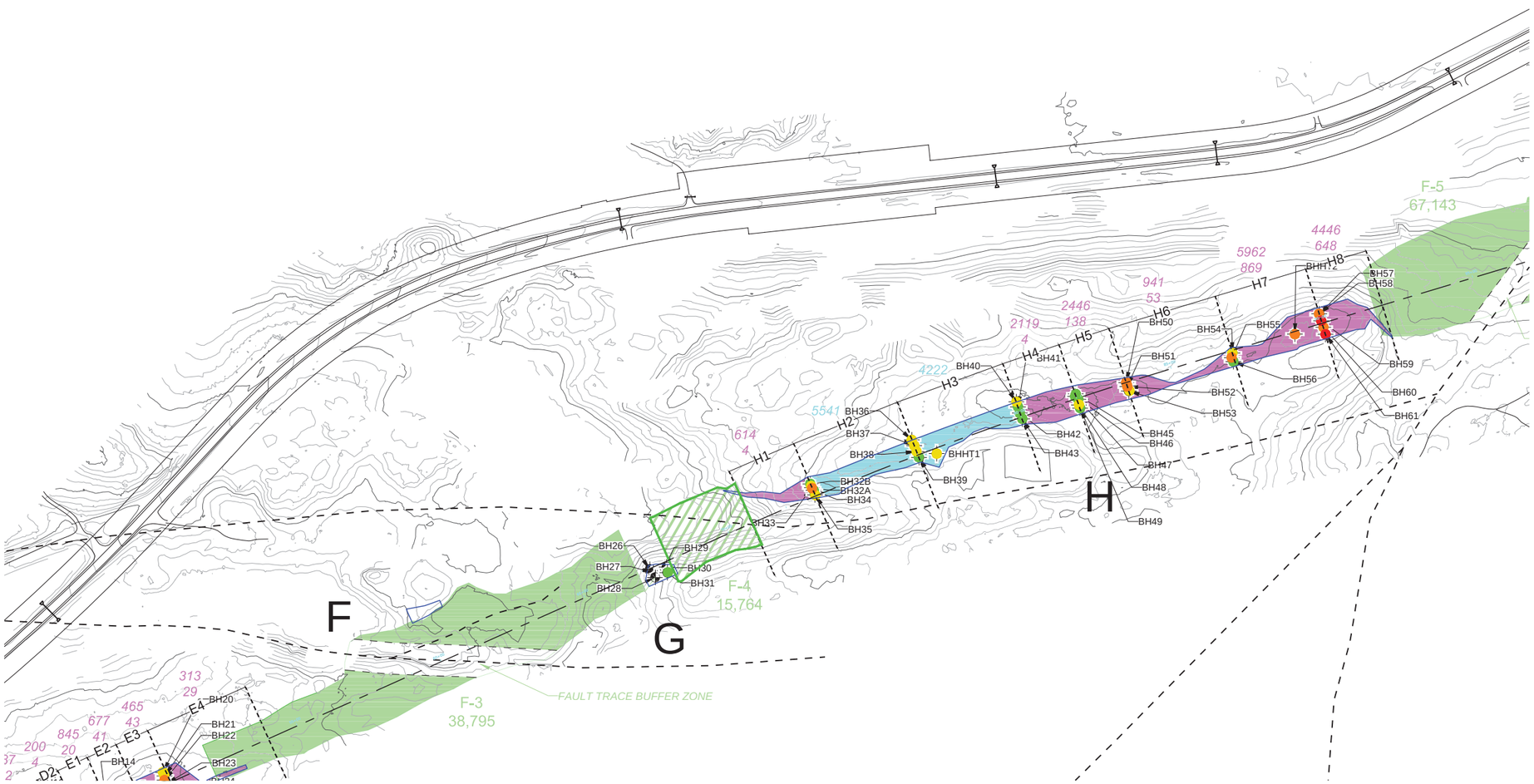

LEGEND:

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0 200 400
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CLIENT
MINNESOTA DEPARTMENT OF TRANSPORTATION

PROJECT
HIGHWAY 169 REALIGNMENT
ARD MITIGATION PLAN

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-06-30
DESIGNED	FSS
PREPARED	FSS
REVIEWED	TK
APPROVED	RV

TITLE
ROCK CUT MITIGATION (SHEET 2)

PROJECT NO.	PHASE	REV.	FIGURE
1543068	002	0	2

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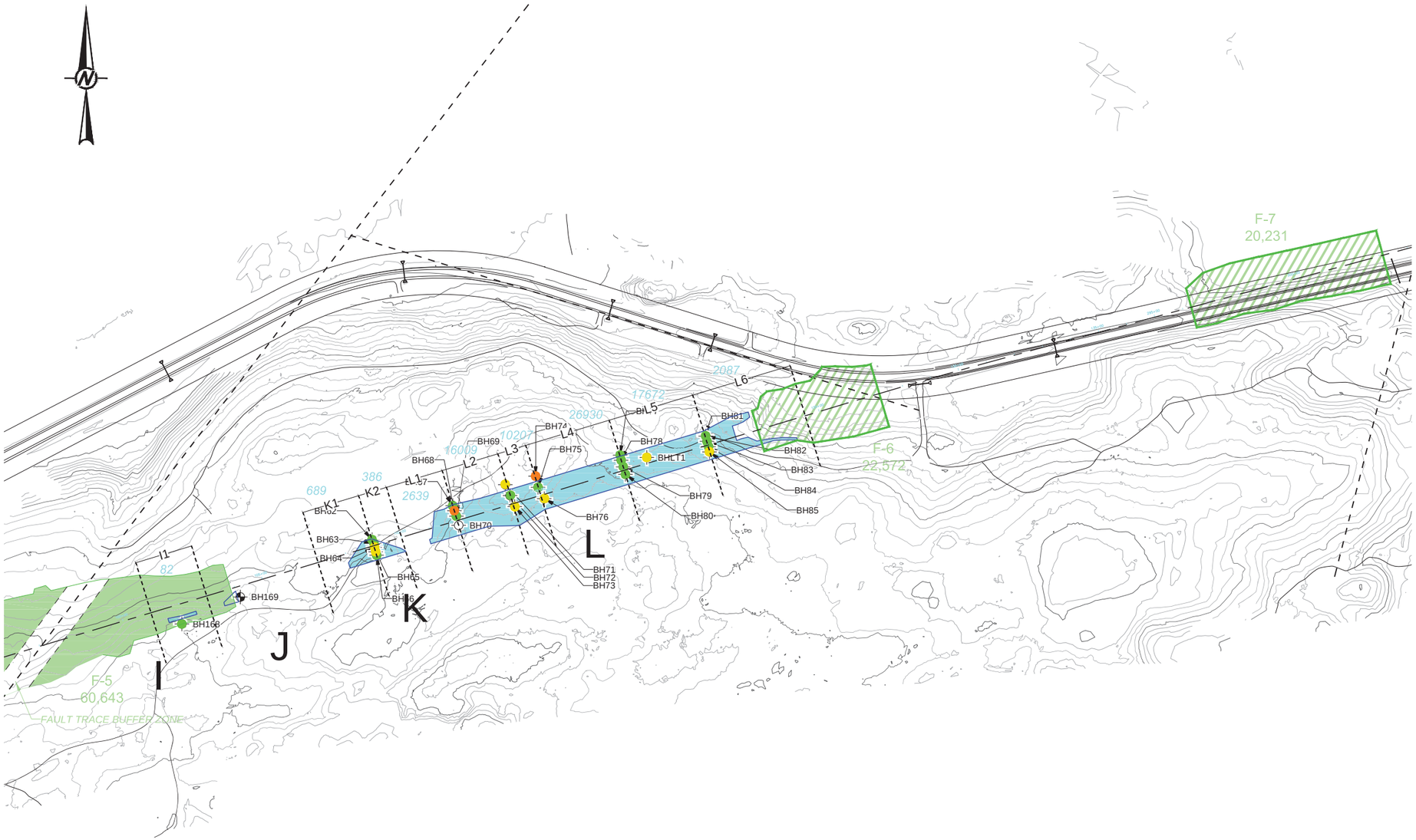

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CLIENT
MINNESOTA DEPARTMENT OF TRANSPORTATION

PROJECT
HIGHWAY 169 REALIGNMENT
ARD MITIGATION PLAN

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-06-30
DESIGNED	FSS
PREPARED	FSS
REVIEWED	TK
APPROVED	RV

TITLE
ROCK CUT MITIGATION (SHEET 3)

PROJECT NO.	PHASE	REV.	FIGURE
1543068	002	0	3

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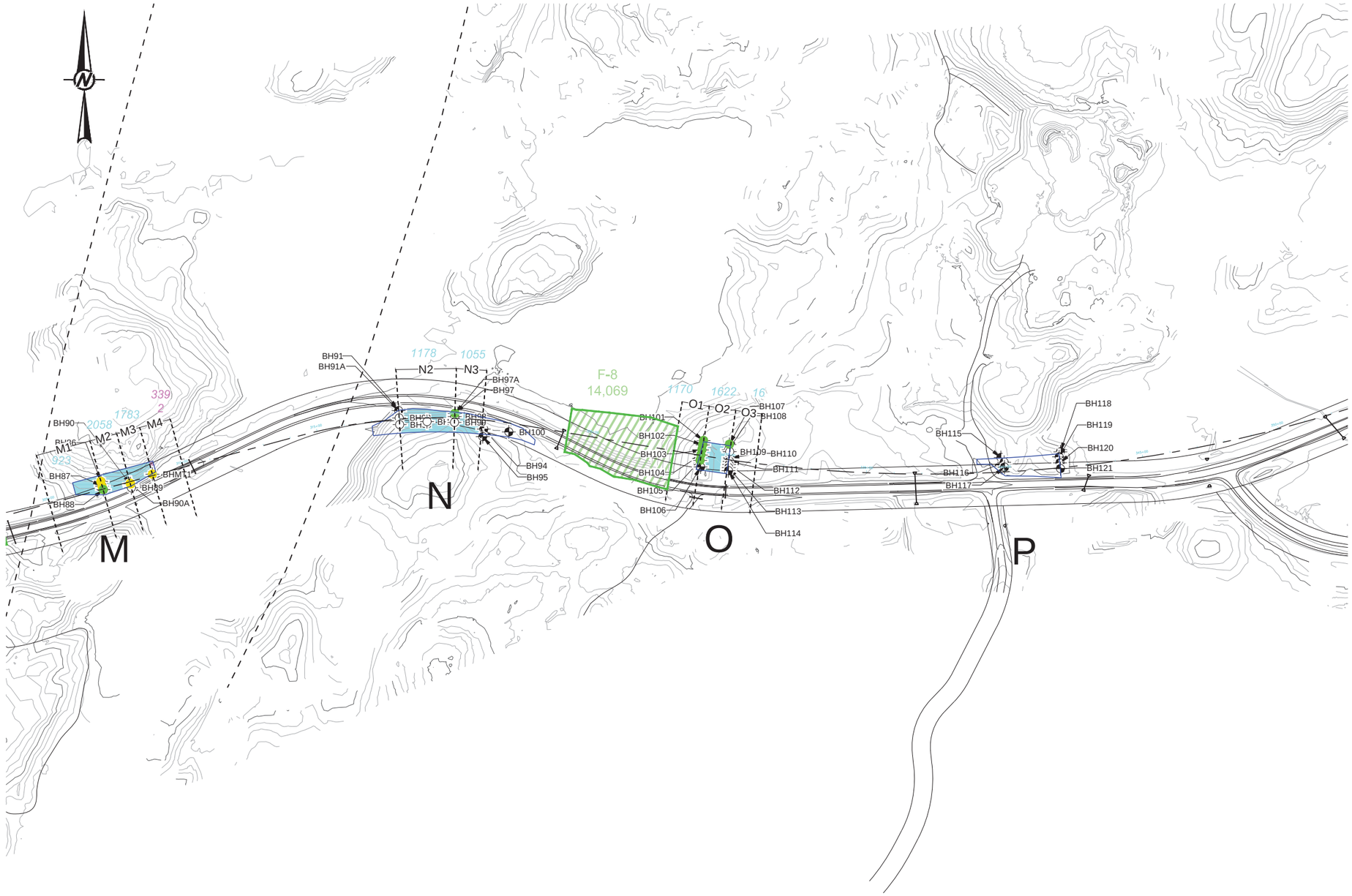
1 in
0



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CLIENT
MINNESOTA DEPARTMENT OF TRANSPORTATION

PROJECT
HIGHWAY 169 REALIGNMENT
ARD MITIGATION PLAN

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-06-30
DESIGNED	FSS
PREPARED	FSS
REVIEWED	TK
APPROVED	RV

TITLE
ROCK CUT MITIGATION (SHEET 4)

PROJECT NO.	PHASE	REV.	FIGURE
1543068	002	0	4

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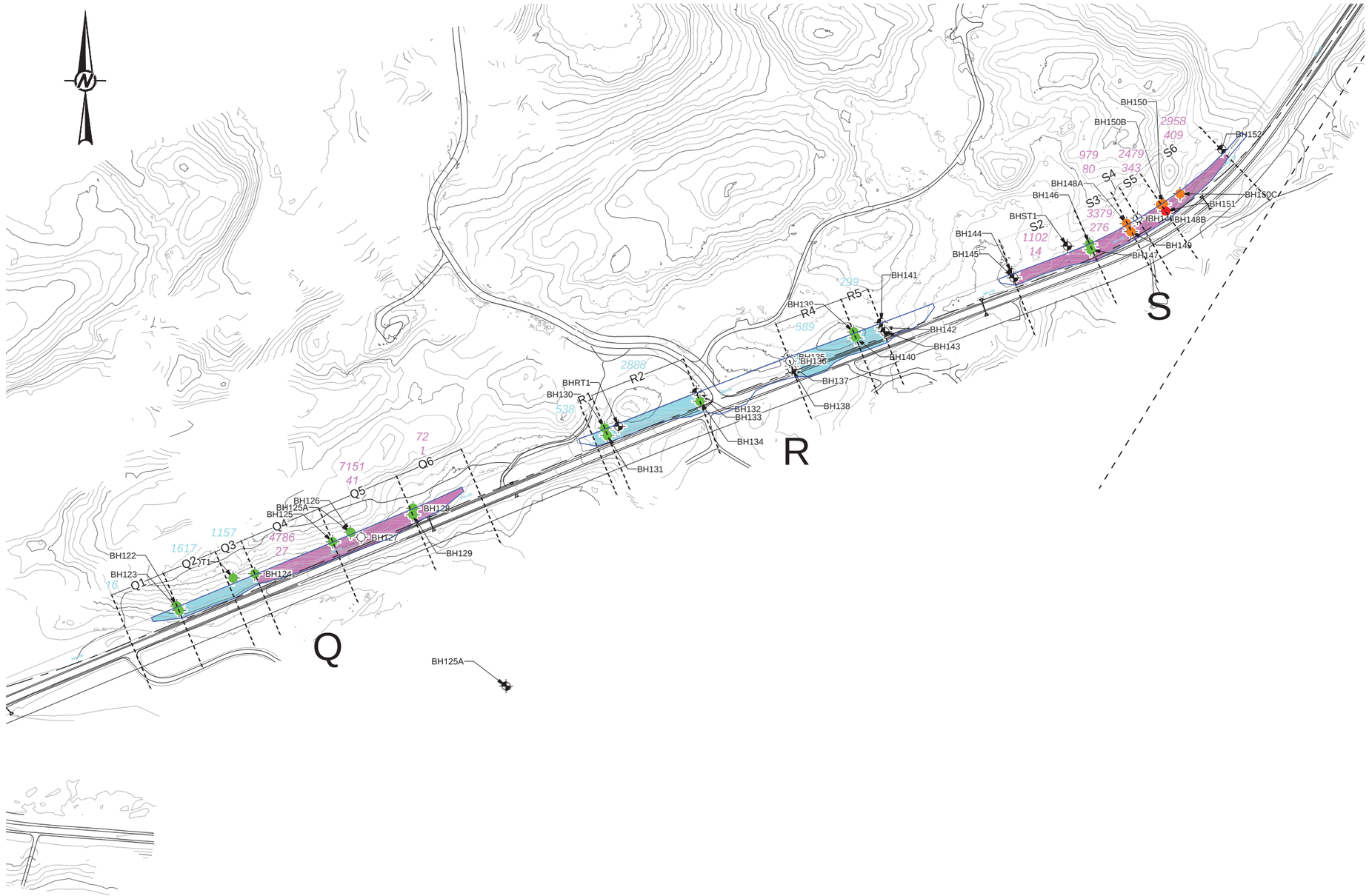

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- Sulfur > 1.0

0 200 400
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MINNESOTA DEPARTMENT OF TRANSPORTATION

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DESIGNED	FSS
PREPARED	FSS
REVIEWED	TK
APPROVED	RV

PROJECT
HIGHWAY 169 REALIGNMENT
ARD MITIGATION PLAN

TITLE
ROCK CUT MITIGATION (SHEET 5)

PROJECT NO.	PHASE	REV.	FIGURE
1543068	002	0	5

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D

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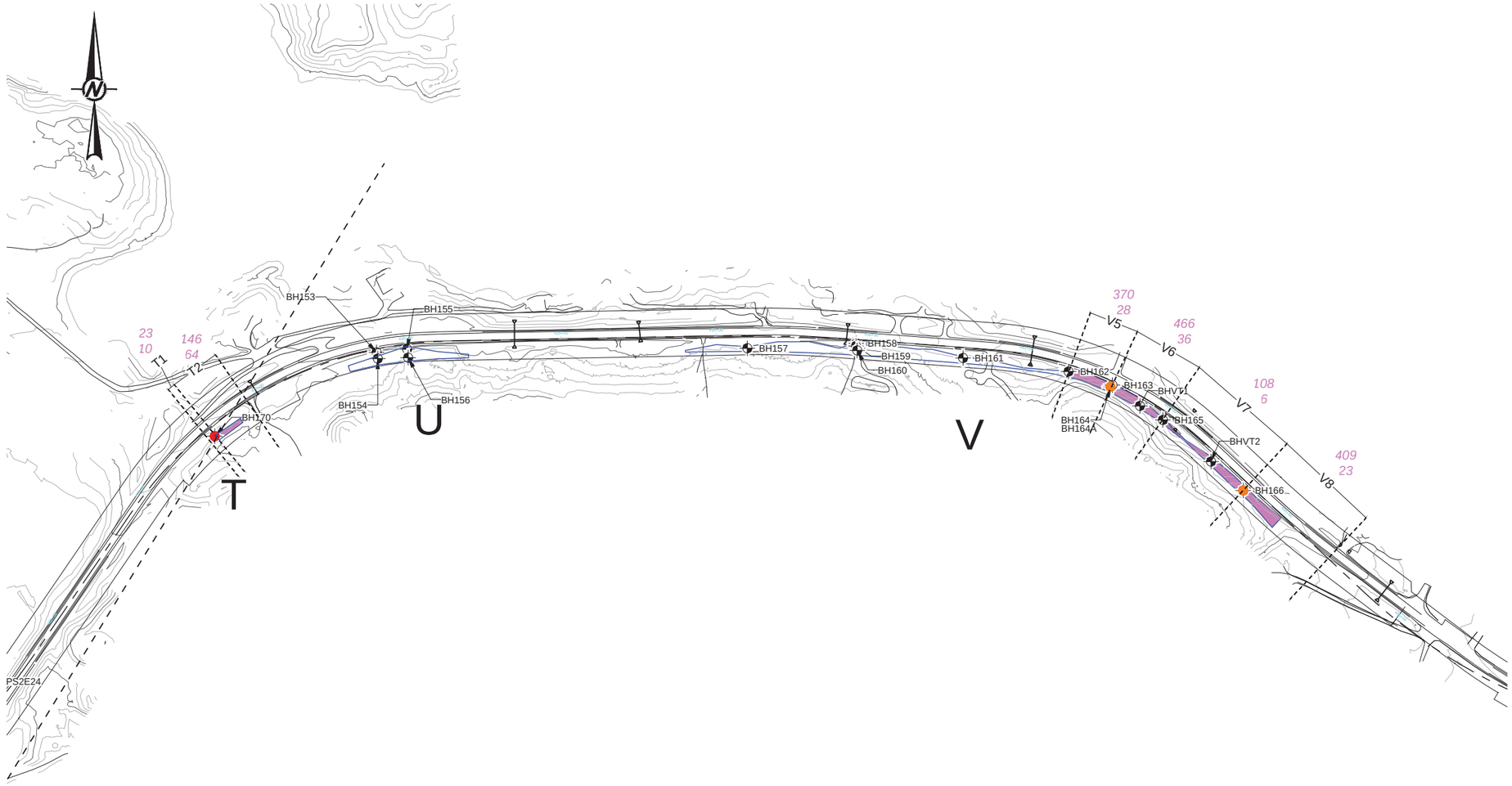

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- Sulfur 0.1 to 0.2
- Sulfur 0.2 to 1.0
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0 200 400
1" = 200' FEET

CLIENT
MINNESOTA DEPARTMENT OF TRANSPORTATION

PROJECT
HIGHWAY 169 REALIGNMENT
ARD MITIGATION PLAN

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-06-30
DESIGNED	FSS
PREPARED	FSS
REVIEWED	TK
APPROVED	RV

TITLE
ROCK CUT MITIGATION (SHEET 6)

PROJECT NO.	PHASE	REV.	FIGURE
1543068	002	0	6

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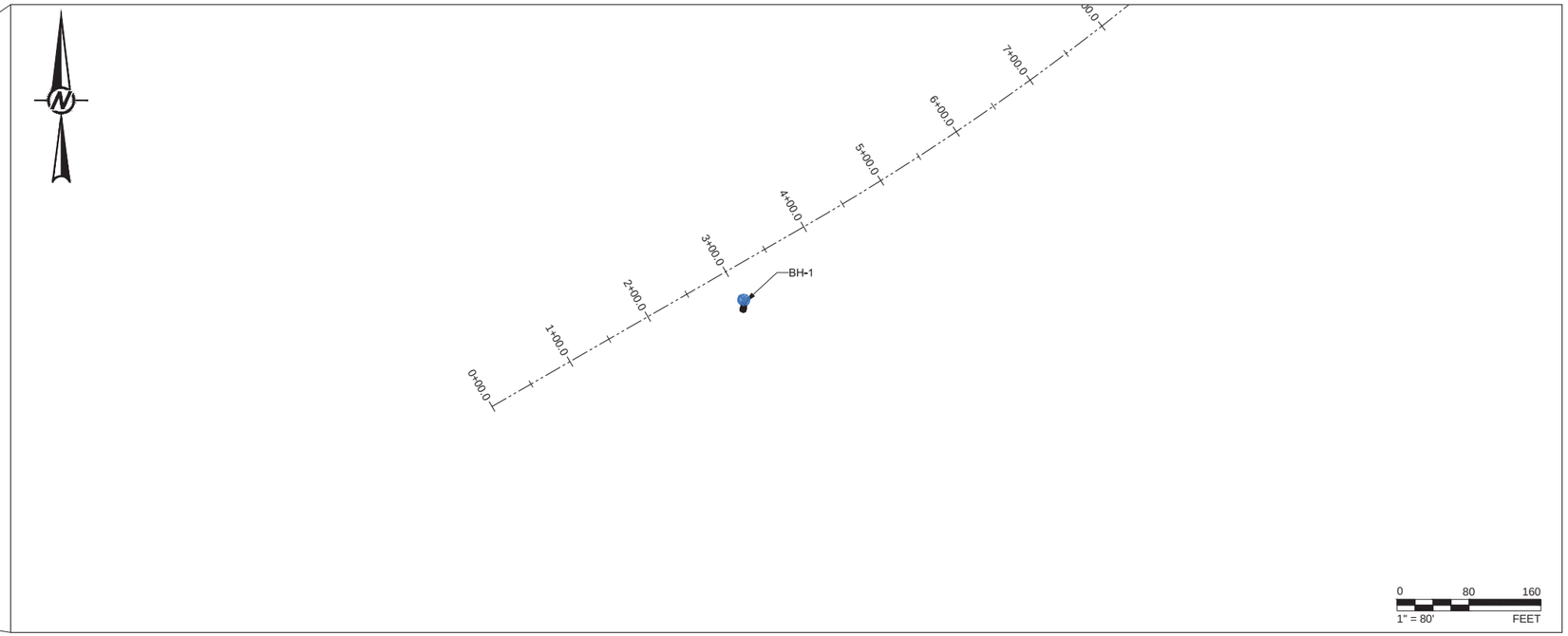
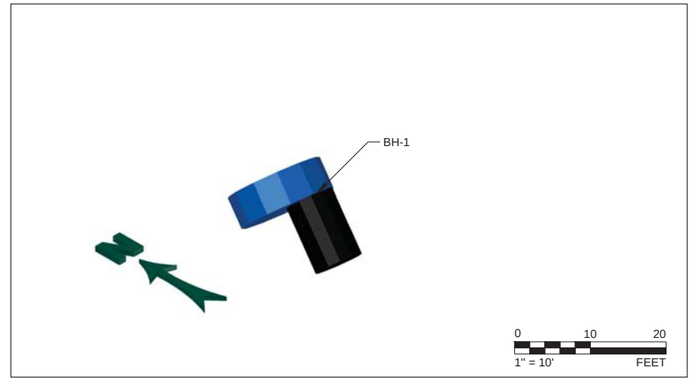
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D

APPENDIX A
BOREHOLE DATA





LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT A

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	1

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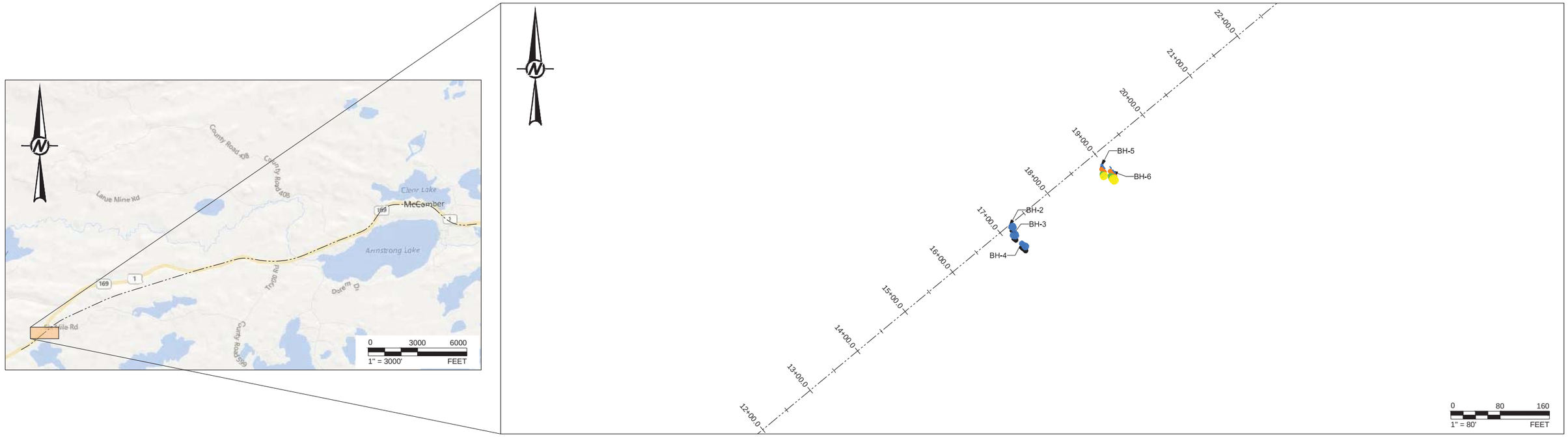

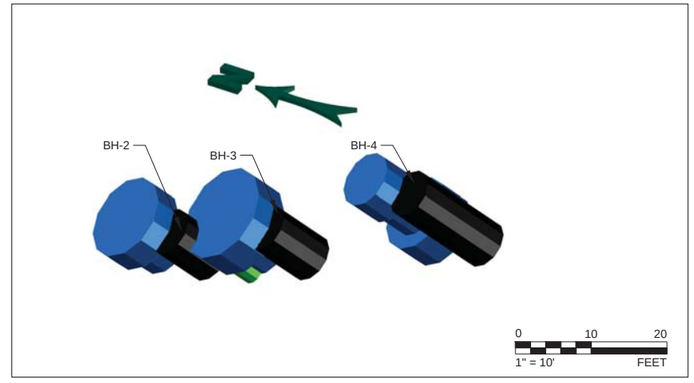

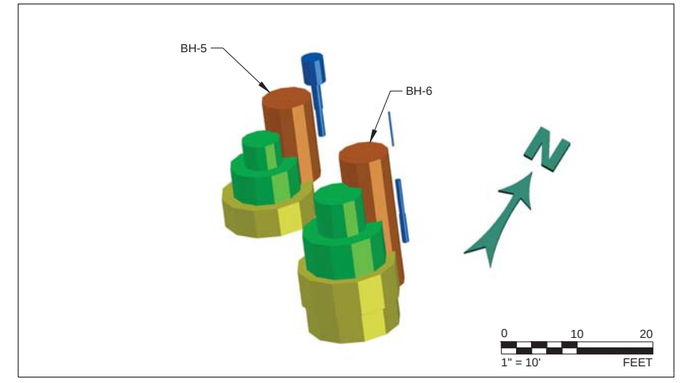

LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT B

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	2

Path: \\edmondfs\geomat$\geomat\cs\MnDOT-Duluth\EagleNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWG\ | File Name: 1543068_003_SM_003.dwg

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D
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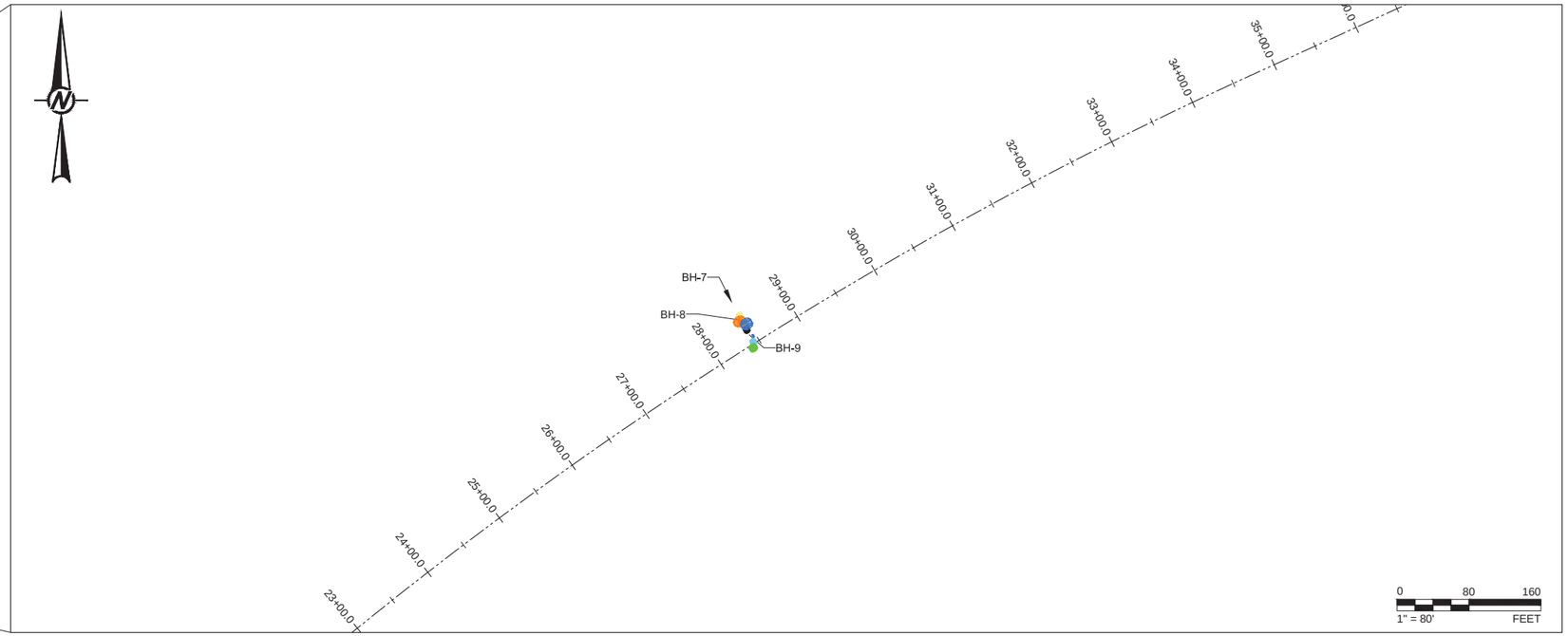
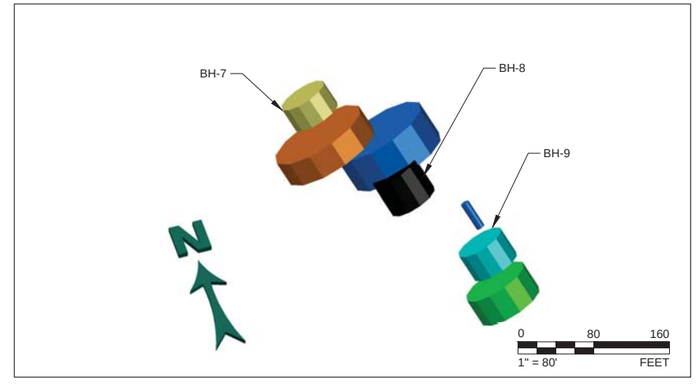




LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

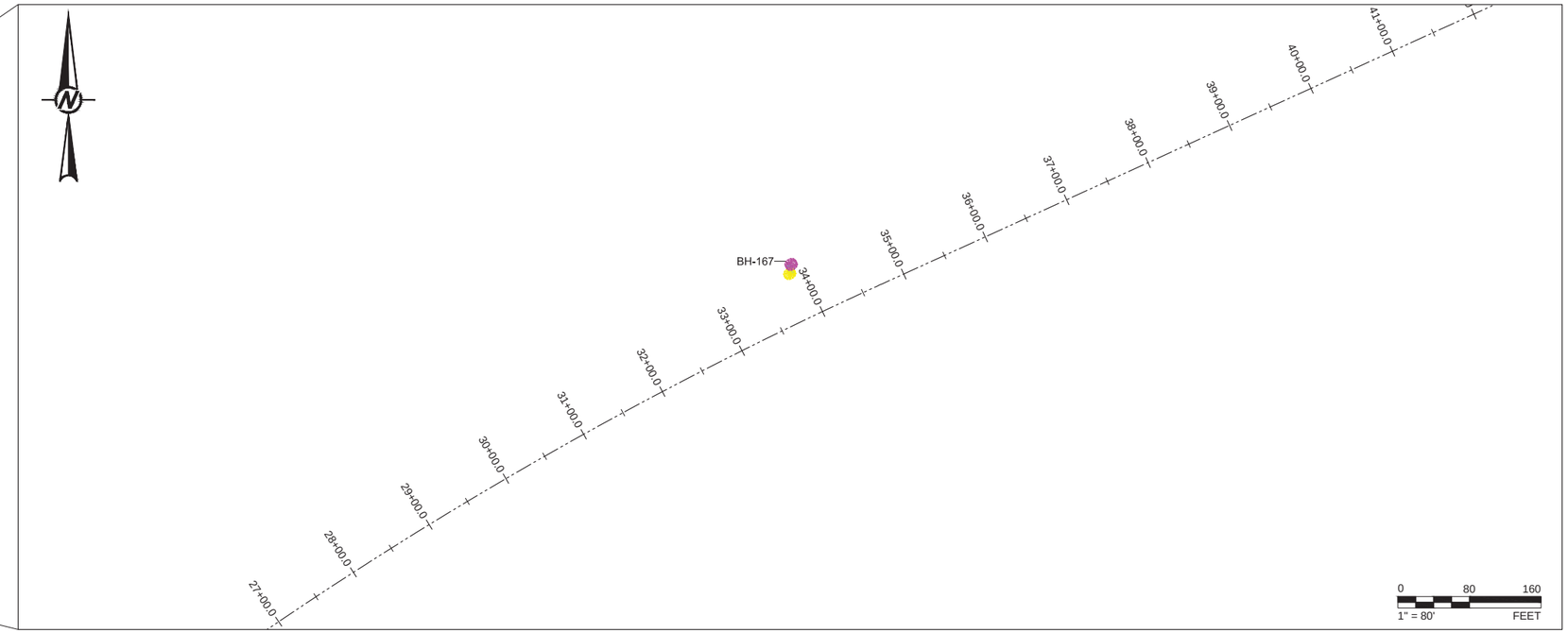
PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

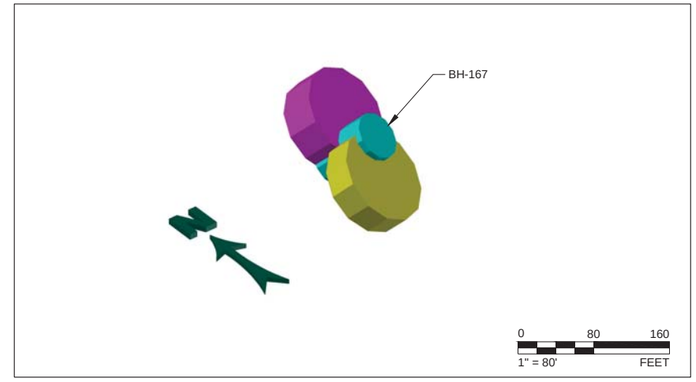
TITLE
ROAD CUT C

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	3

Path: \\eotnondfgeomat$\geomat\cs\MnDOT-Duluth\EagleNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWG\ | File Name: 1543068_003_SM_004.dwg

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D
0 1 in





LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

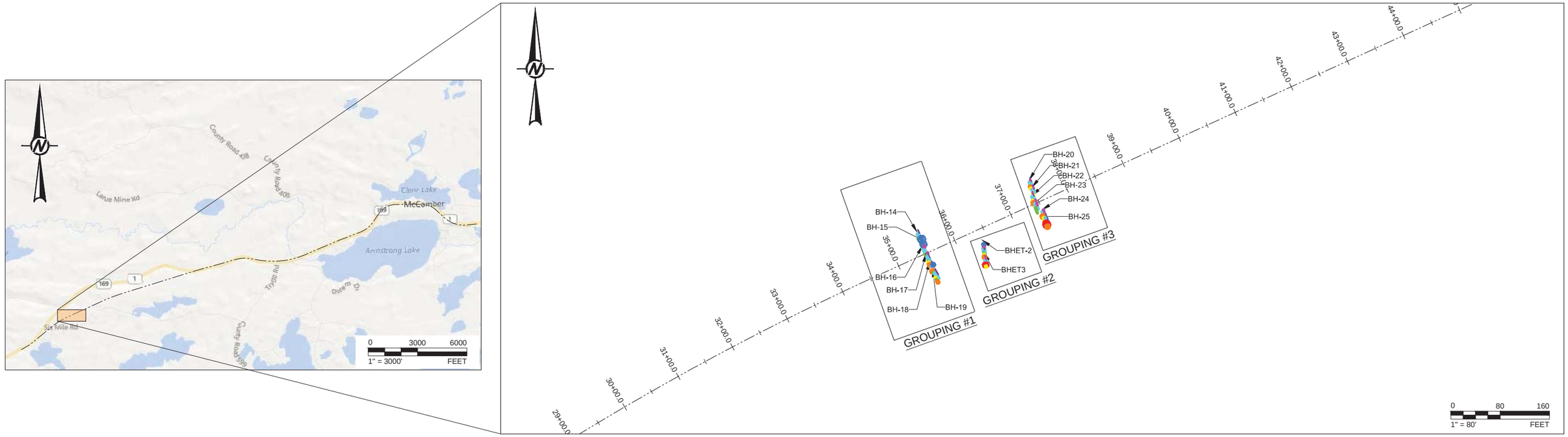
PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

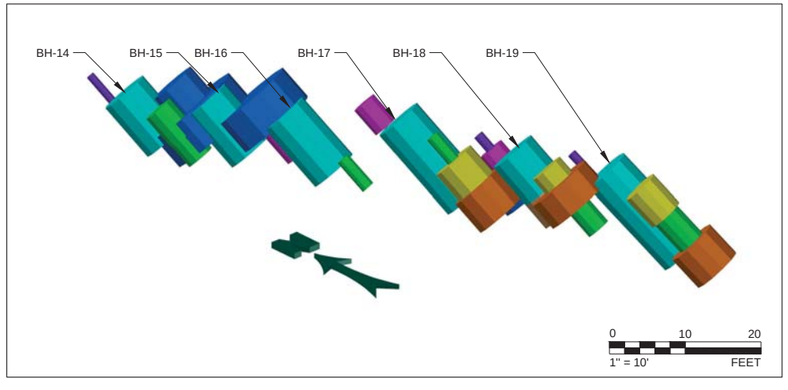
TITLE
ROAD CUT D

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	4

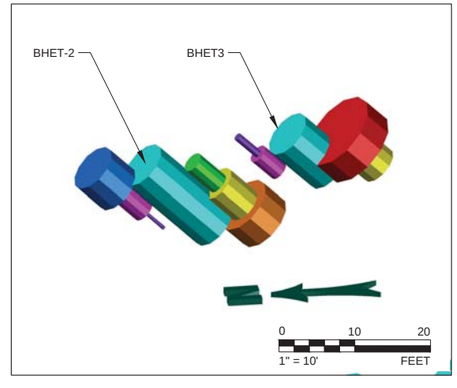
Path: \\eldmon6\geomat$\geomat\cs\MnDOT-Duluth\EaglesNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWG\ | File Name: 1543068_003_SM_005.dwg

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D
0 1 in





GROUPING #1



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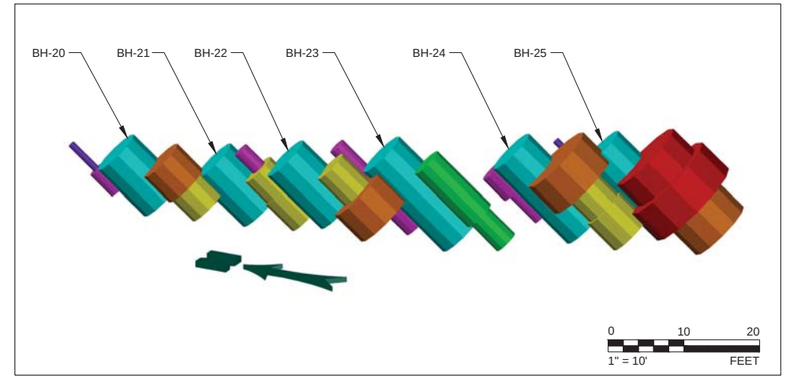


GROUPING #3

LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

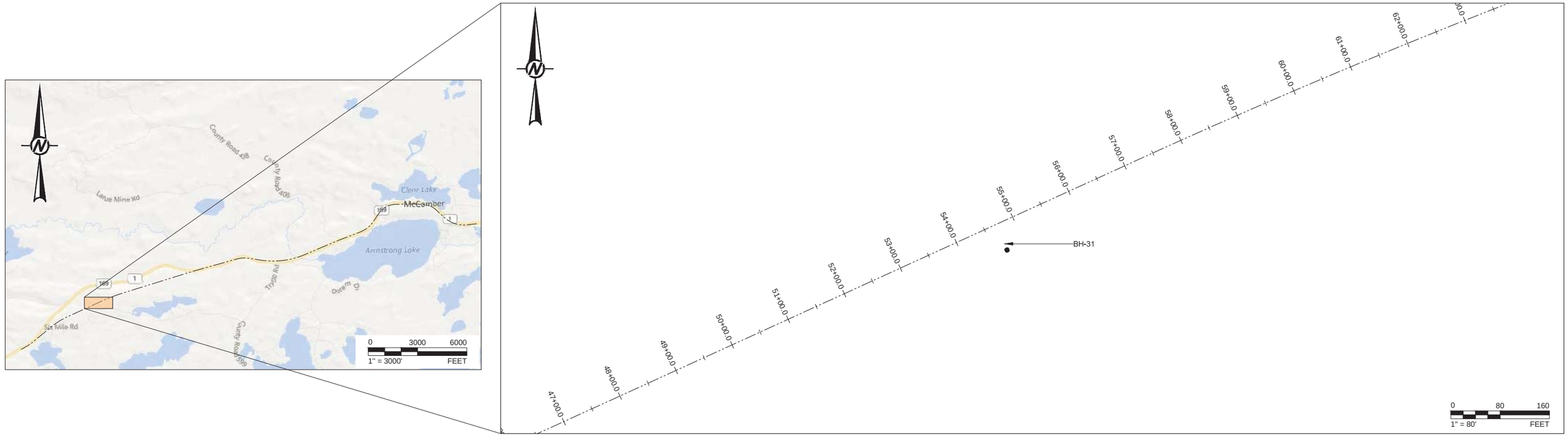
YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

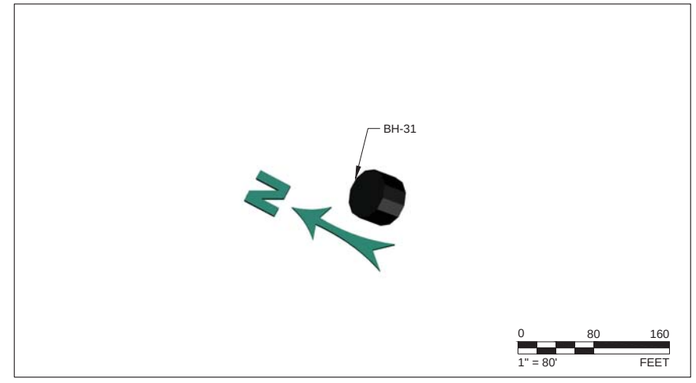
PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT E

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	5

Path: \\eldnondfs\geomatl$\geomatl\cs\MnDOT-Duluth\EaglesNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWG\ | File Name: 1543068_003_SM_006.dwg
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D
0 1 in





LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

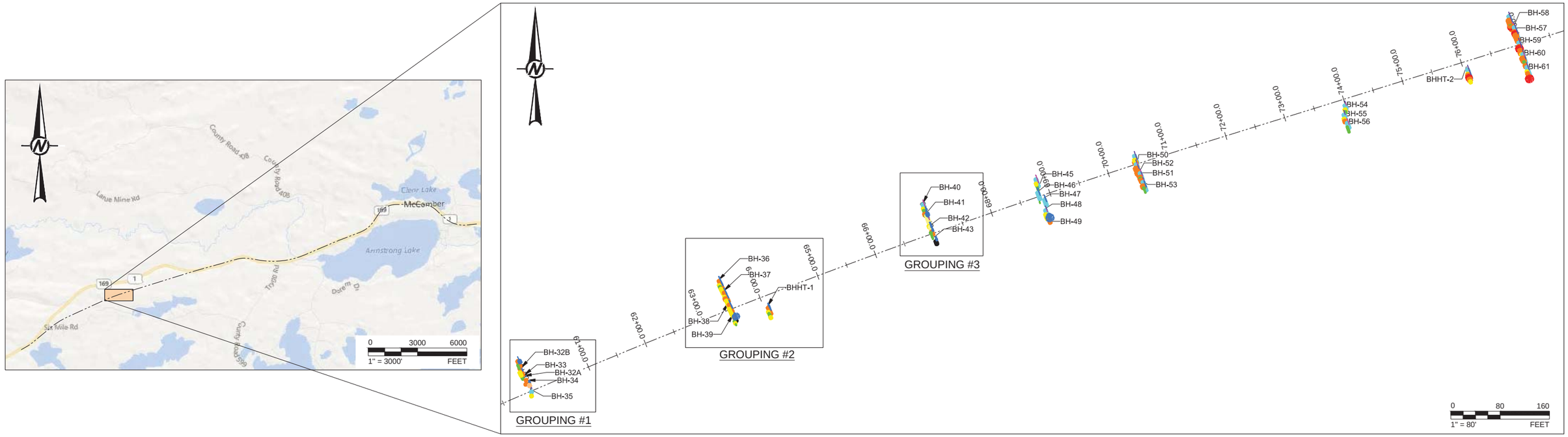
PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

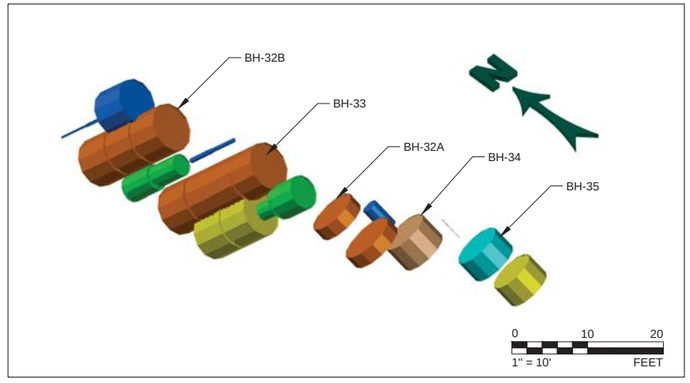
TITLE
ROAD CUT G

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	6

Path: \\vedmondfs\geomat$\geomat\cs\MnDOT-Duluth\EagleNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWG\ | File Name: 1543068_003_SM_007.dwg

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D
0 1 in





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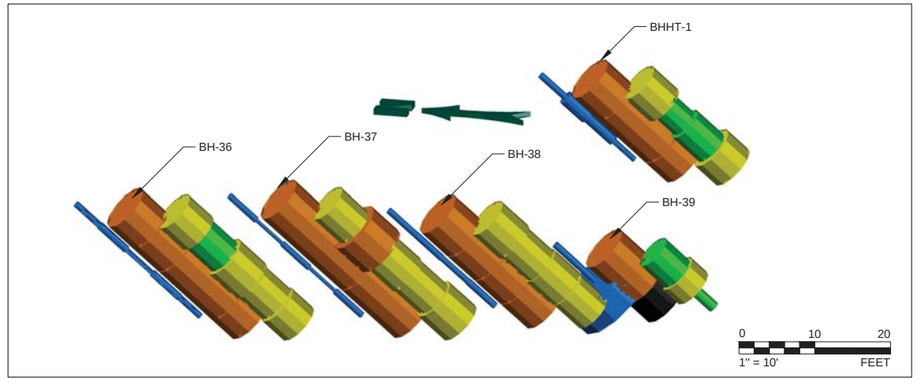

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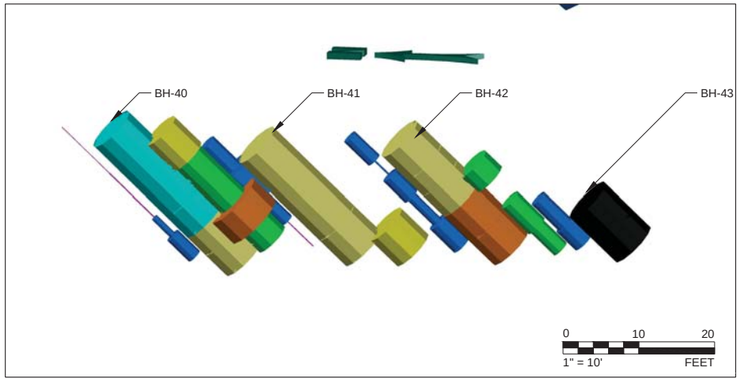


GROUPING #3

LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

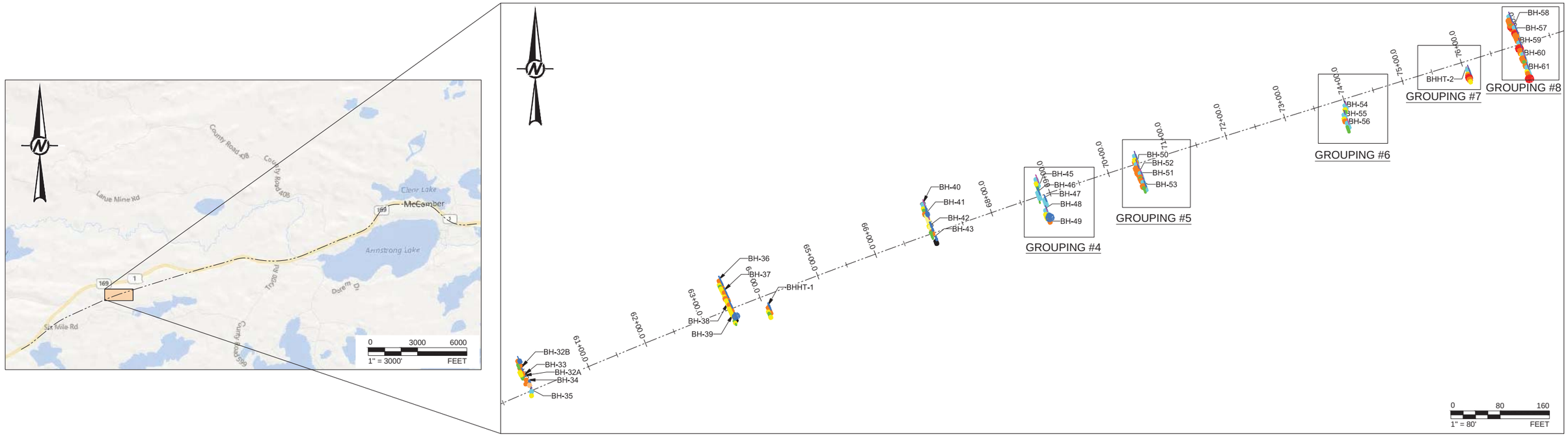
PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

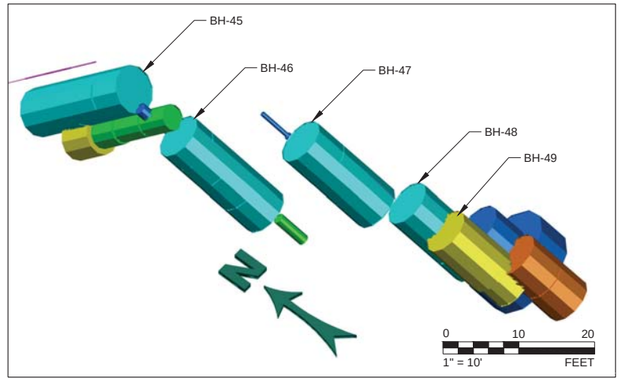
TITLE
ROAD CUT H (1 OF 2)

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	7

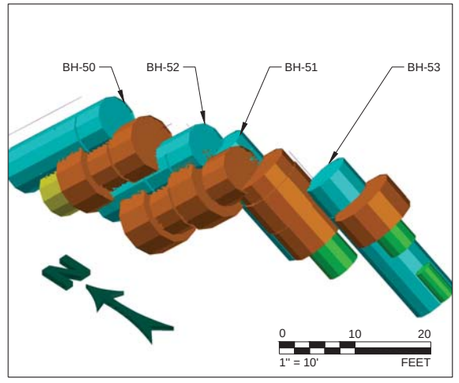
Path: \\eldnondfs\geomatl$\geomatl\cs\MnDOT-Duluth\EaglesNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWGs\ | File Name: 1543068_003_SM_001.dwg

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D
0 1 in

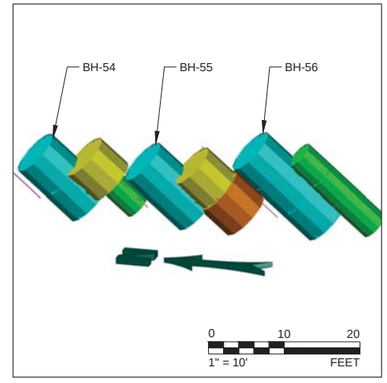




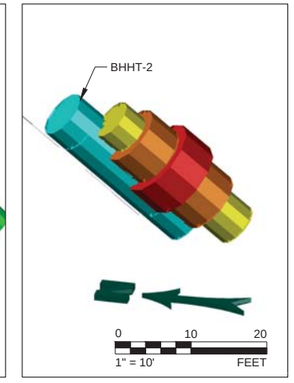
GROUPING #4



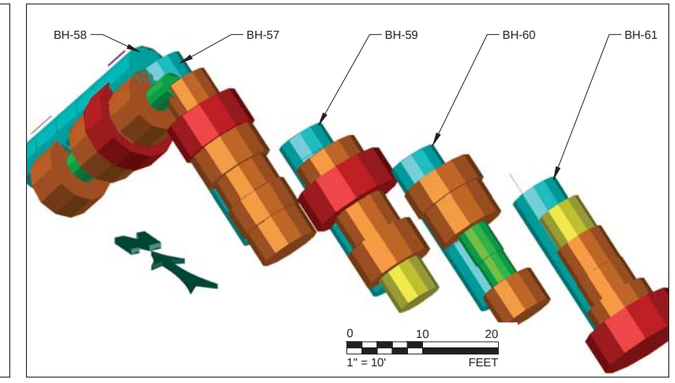
GROUPING #5



GROUPING #6



GROUPING #7



GROUPING #8

LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

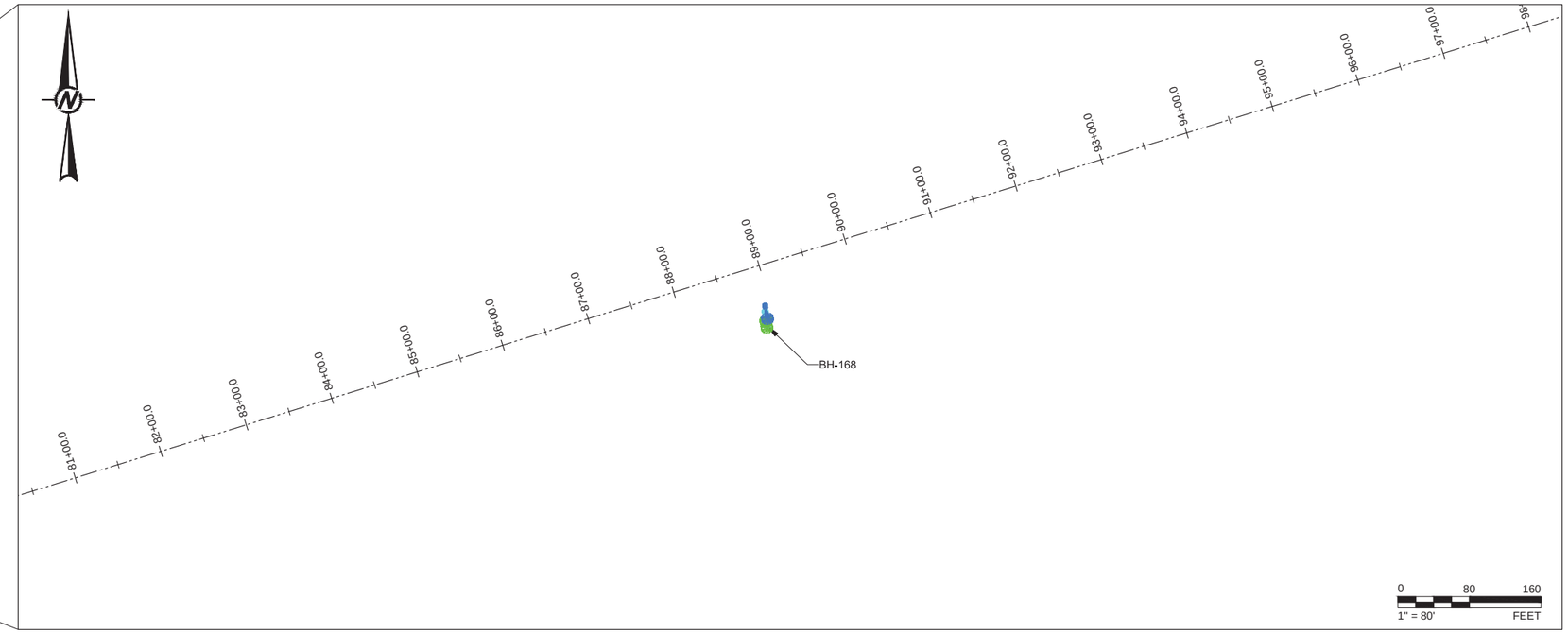
PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

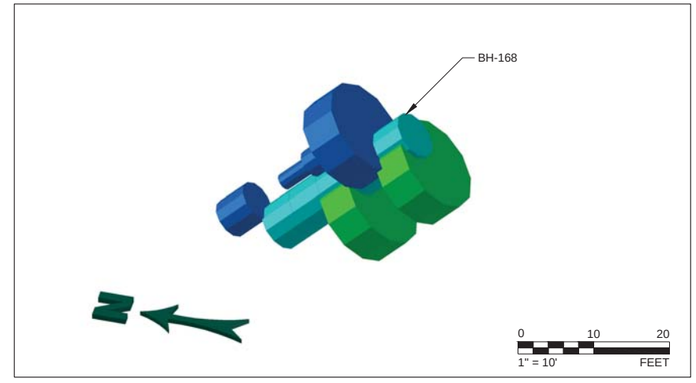
TITLE
ROAD CUT H (2 OF 2)

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	8

Path: \\eldnondfs\geomat$\geomat\c\MnDOT-Duluth\EaglesNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWGs\ | File Name: 1543068_003_SM_001.dwg

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D
0 1 in





LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

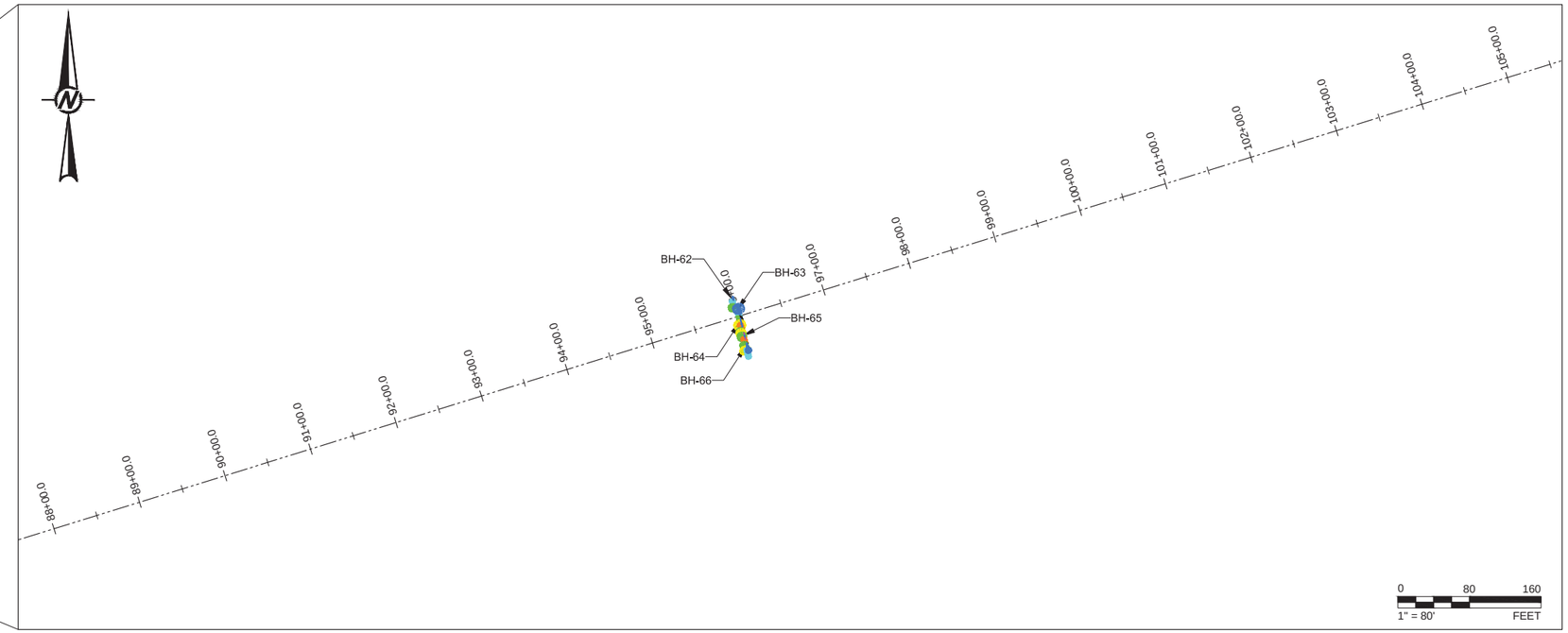
PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

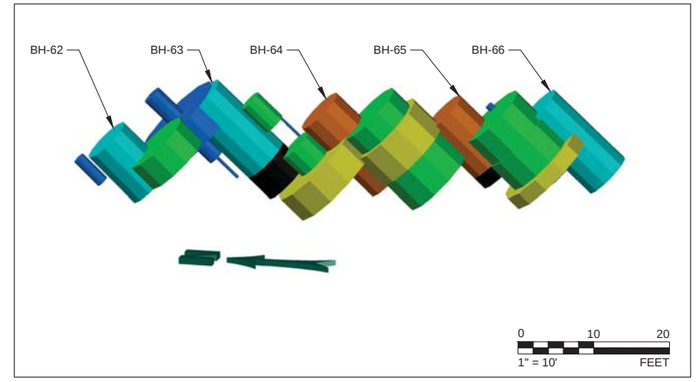
TITLE
ROAD CUT I

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	9

Path: \\eldmnnfs\geomat$\geomat\cs\MnDOT-Duluth\EagleNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWGs\ | File Name: 1543068_003_SM_008.dwg

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D
0 1 in





LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

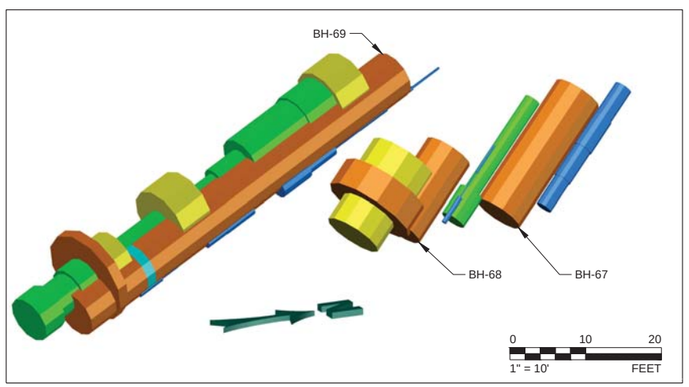
PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT K

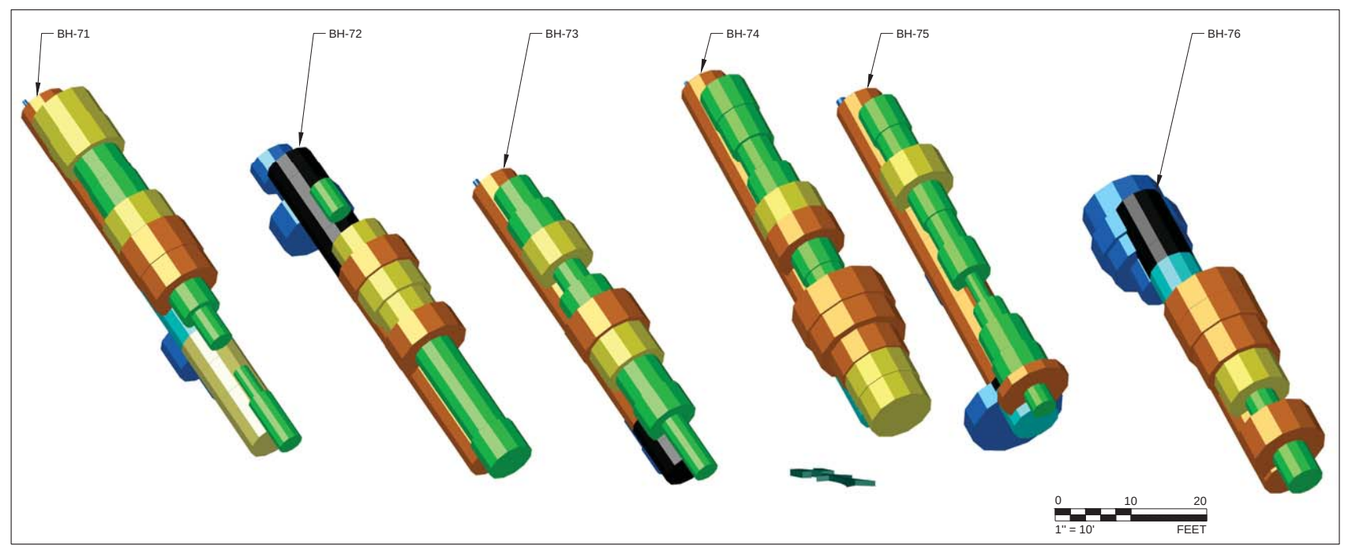
PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	10

Path: \\eqtmnnfs\geomatt$\geomatlcs\MnDOT-Duluth\EagleNest\9_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWG\ | File Name: 1543068_003_SM_009.dwg

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D
0 1 in



GROUPING #1



GROUPING #2

LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT L (1 OF 2)

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	11

Path: \\edmondfgconnat$\geomatics\MnDOT-Duluth\EaglesNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWGs\ | File Name: 1543068_003_SM_010.dwg
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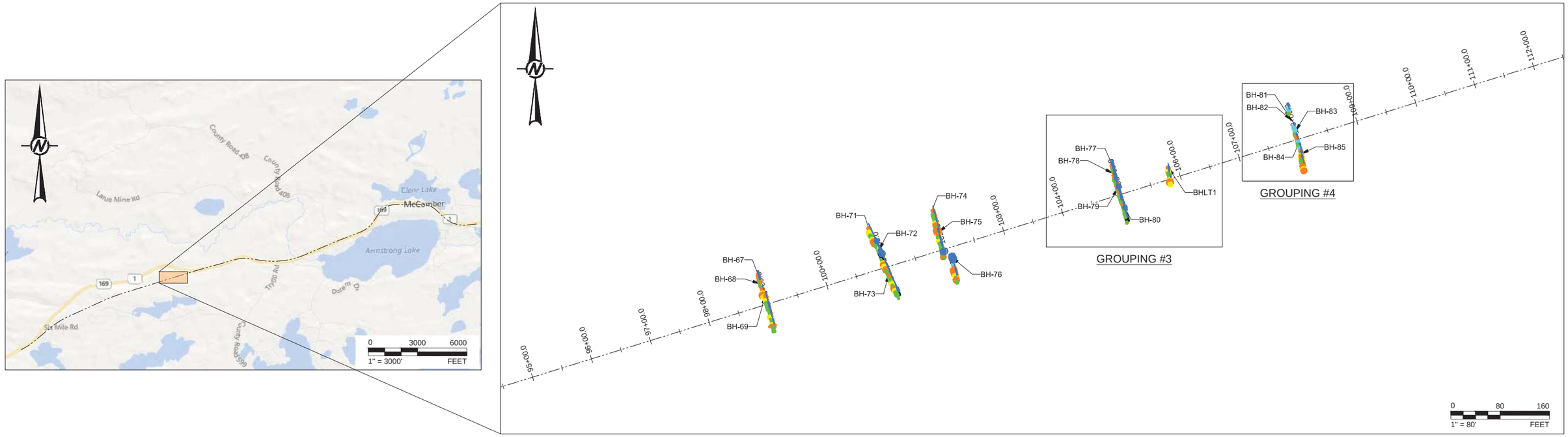

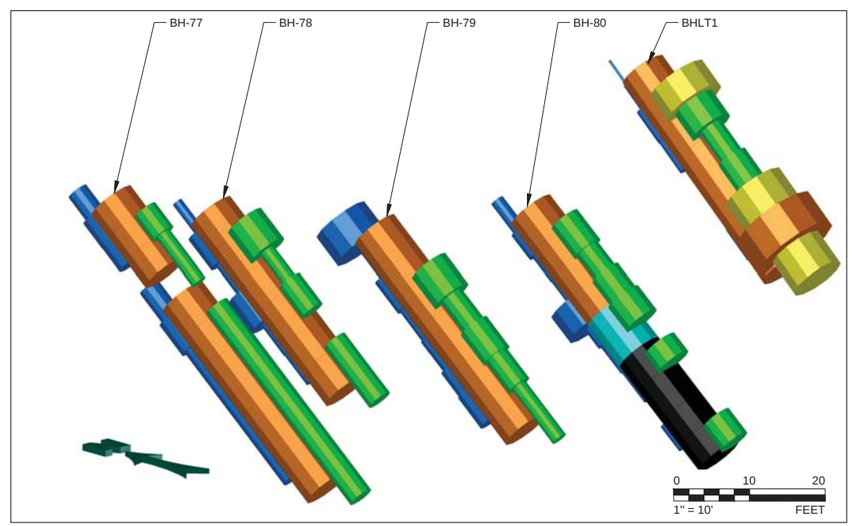

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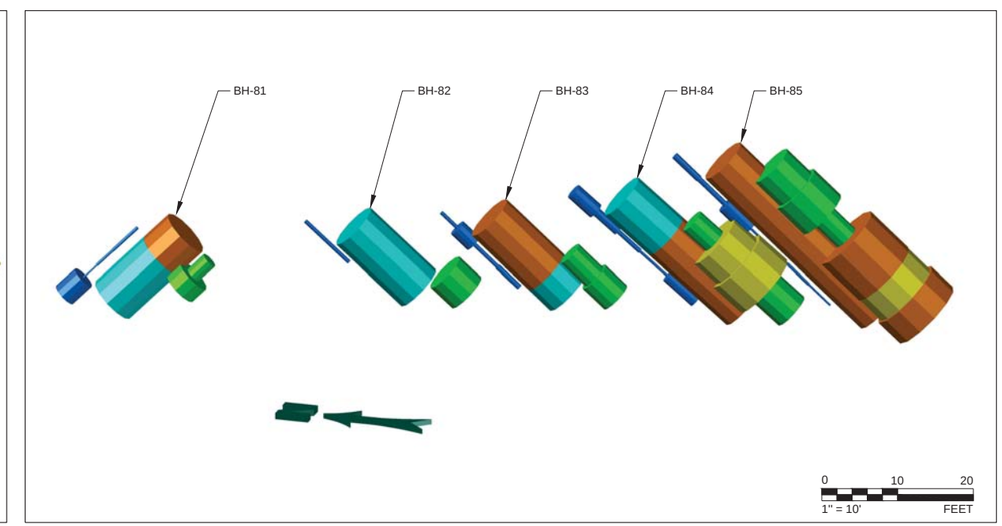

GROUPING #4

LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT L (2 OF 2)

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	12

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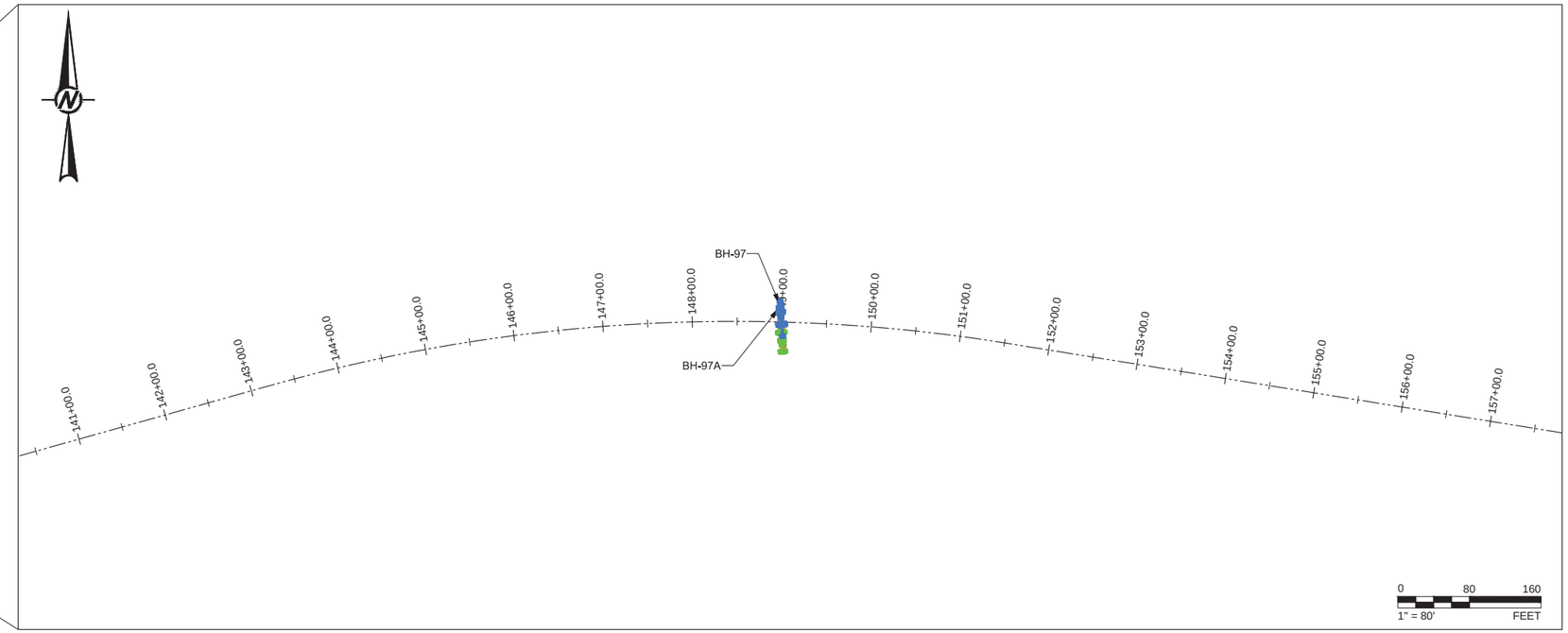

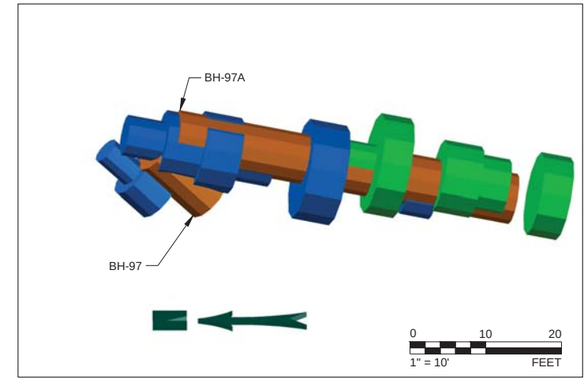

LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

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Golder Associates

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DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT N

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	13

Path: \\eldnondfs\geomat$\geomat\cs\MnDOT-Duluth\EagleNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWG\ | File Name: 1543068_003_SM_012.dwg

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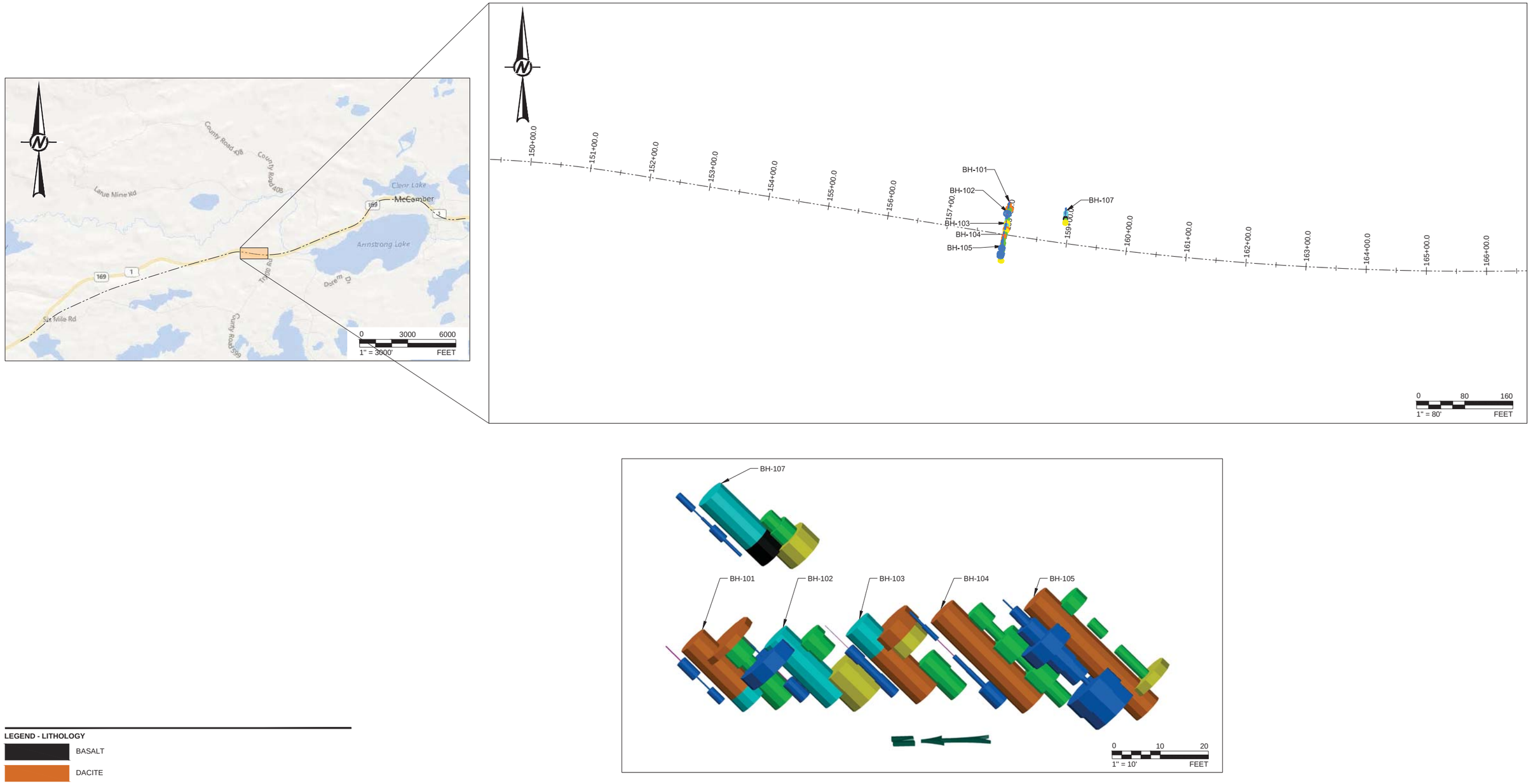

LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

CLIENT
MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT O

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	14

Path: \\vedmondfjgeomatl$\geomatl\cs\MnDOT-Duluth\EagleNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWGs\ | File Name: 1543068_003_SM_013.dwg

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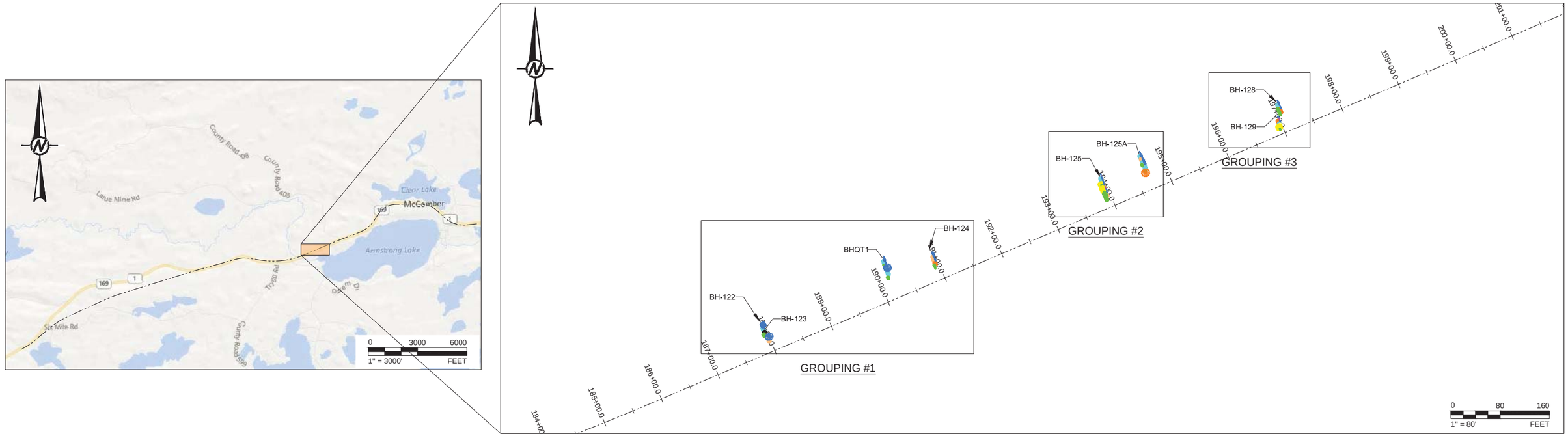

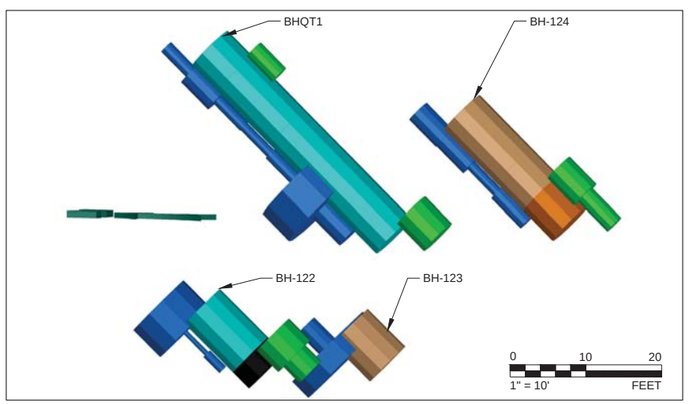

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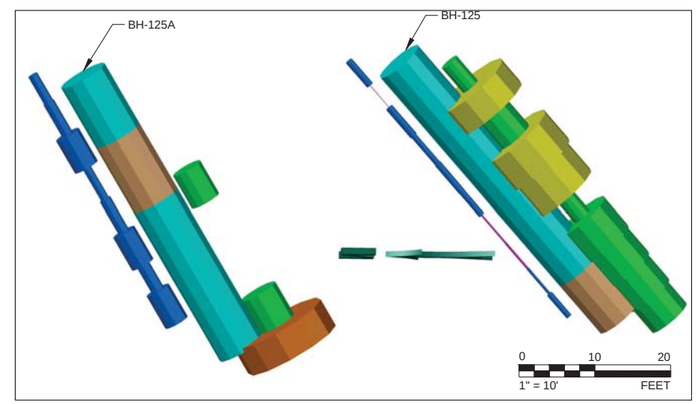

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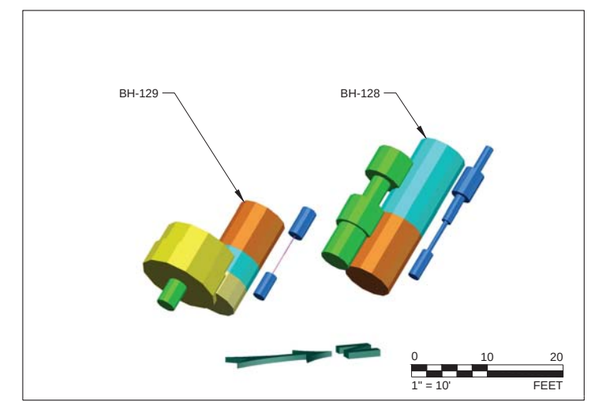

GROUPING #3

LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

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MINNESOTA DOT

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT Q

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	15

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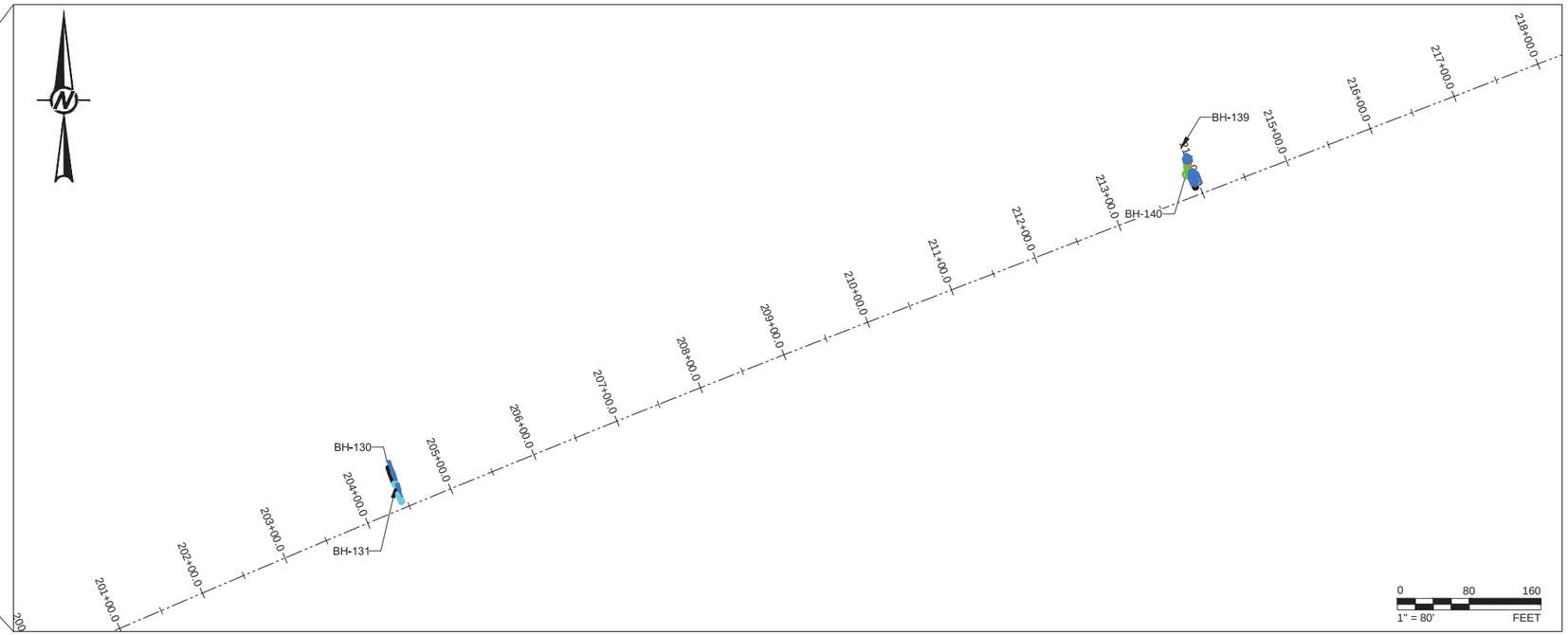

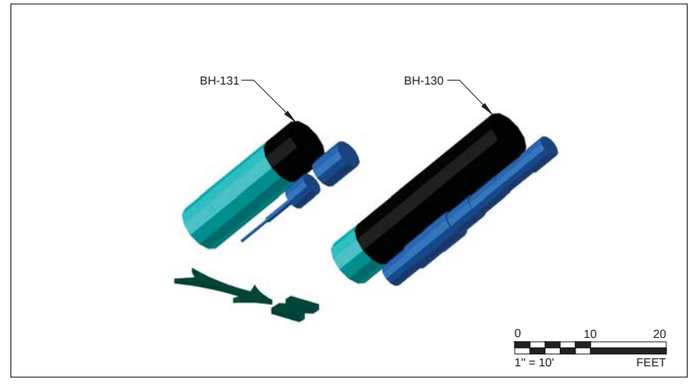

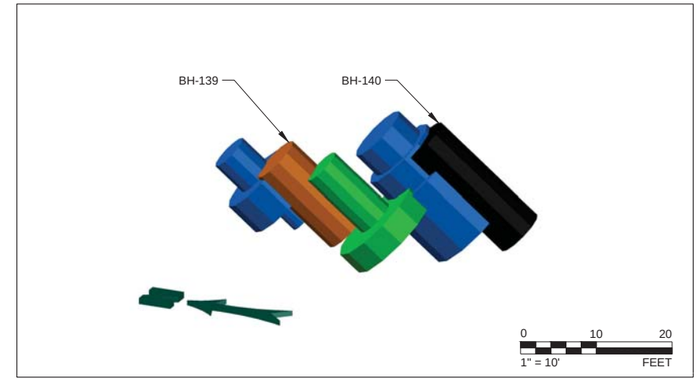

LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

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MINNESOTA DOT

CONSULTANT
Golder Associates

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DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT R

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	16

Path: \\edmondfs\geomat$\geomat\sc\MnDOT-Duluth\EagleNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWG\ | File Name: 1543068_003_SM_015.dwg

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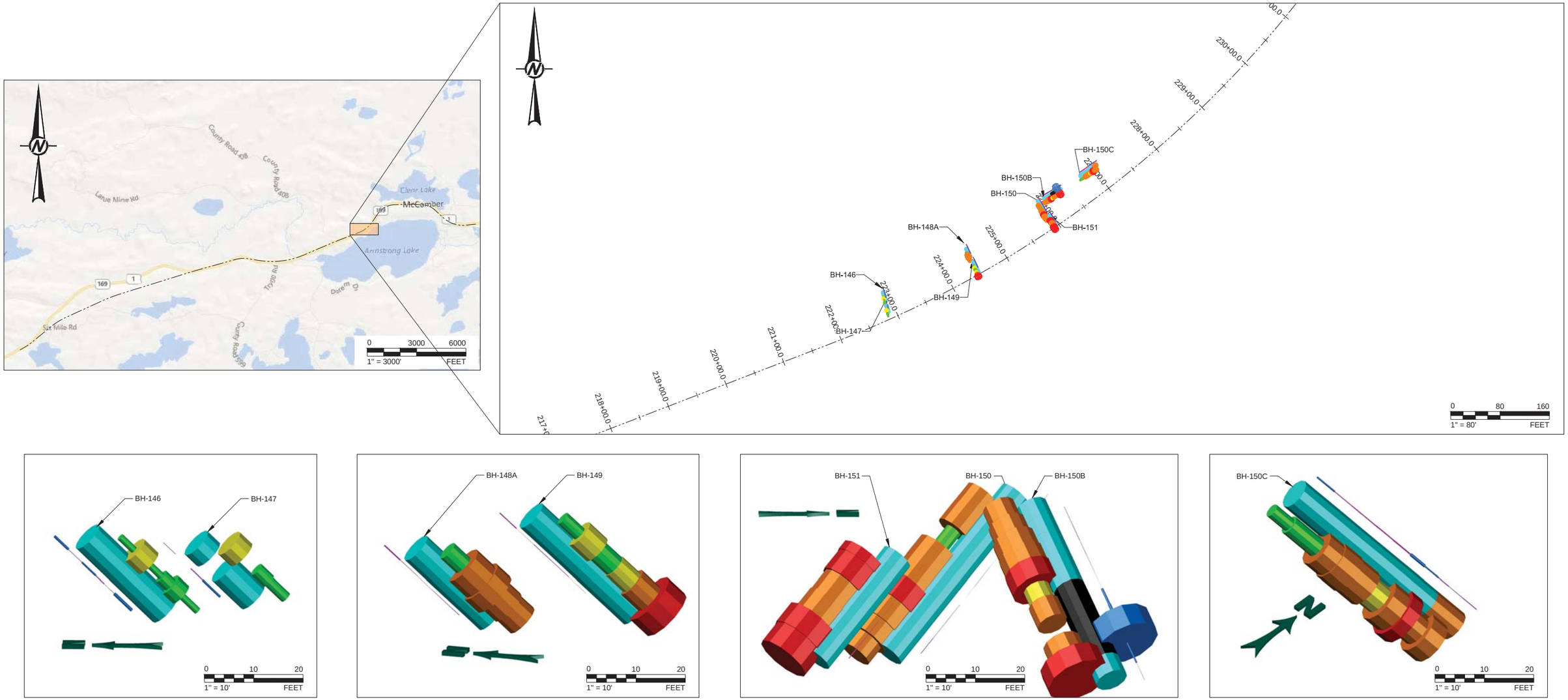
0 1 in



LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

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Golder Associates

YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT S

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	17

Path: \\edmondfgeomat$\geomatics\MnDOT-Duluth\EaglesNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWG\ | File Name: 1543068_003_SM_016.dwg

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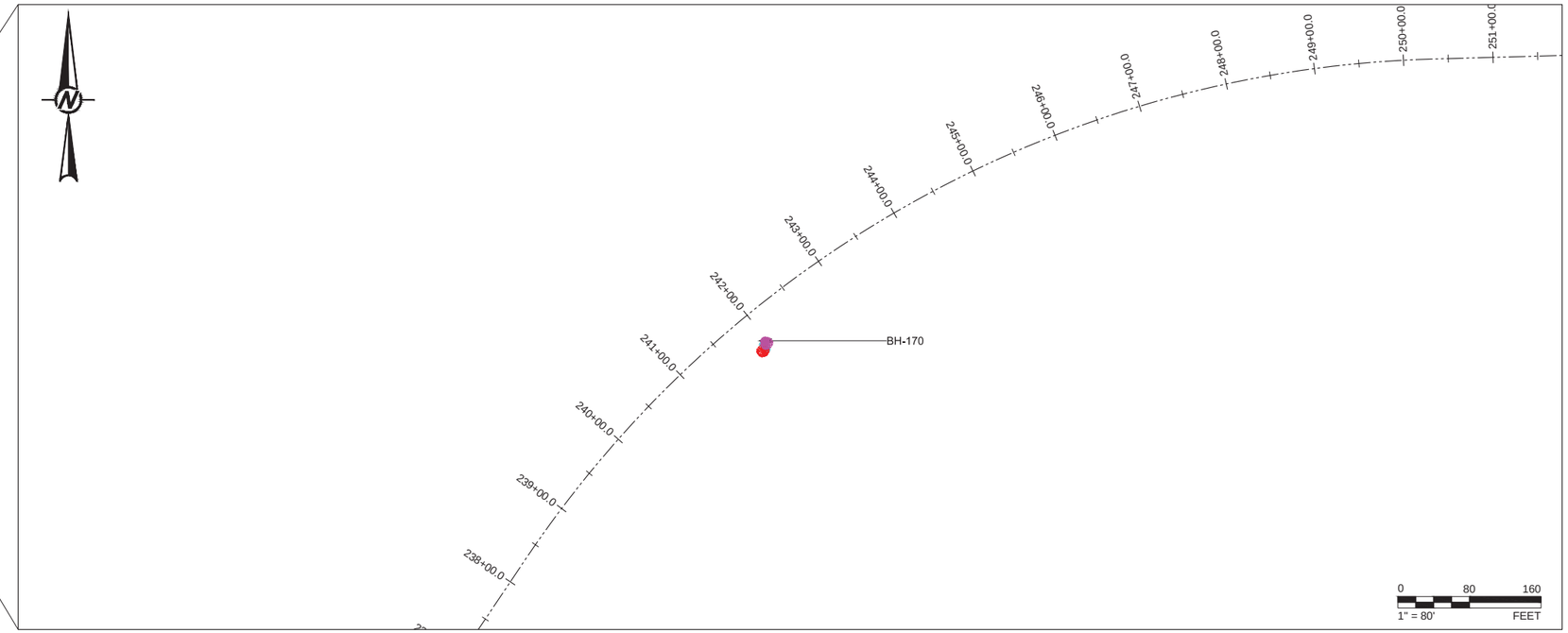
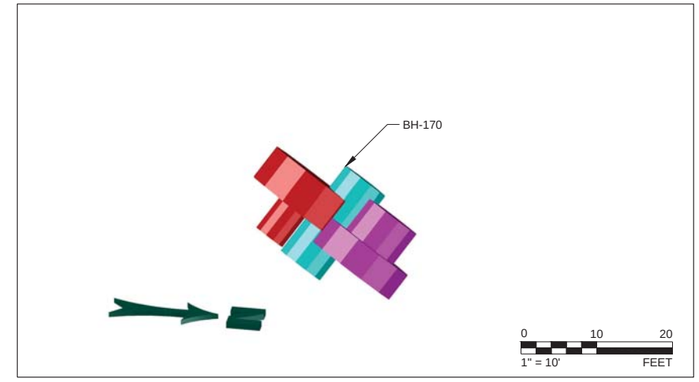
0 1 in





LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

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Golder Associates

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DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT T

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	18

Path: \\eldnondfs\geomat$\geomat\cs\MnDOT-Duluth\EagleNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWGs\ | File Name: 1543068_003_SM_017.dwg

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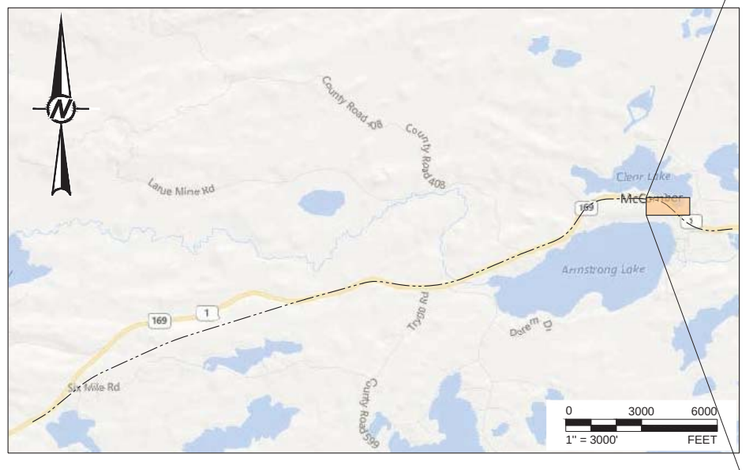
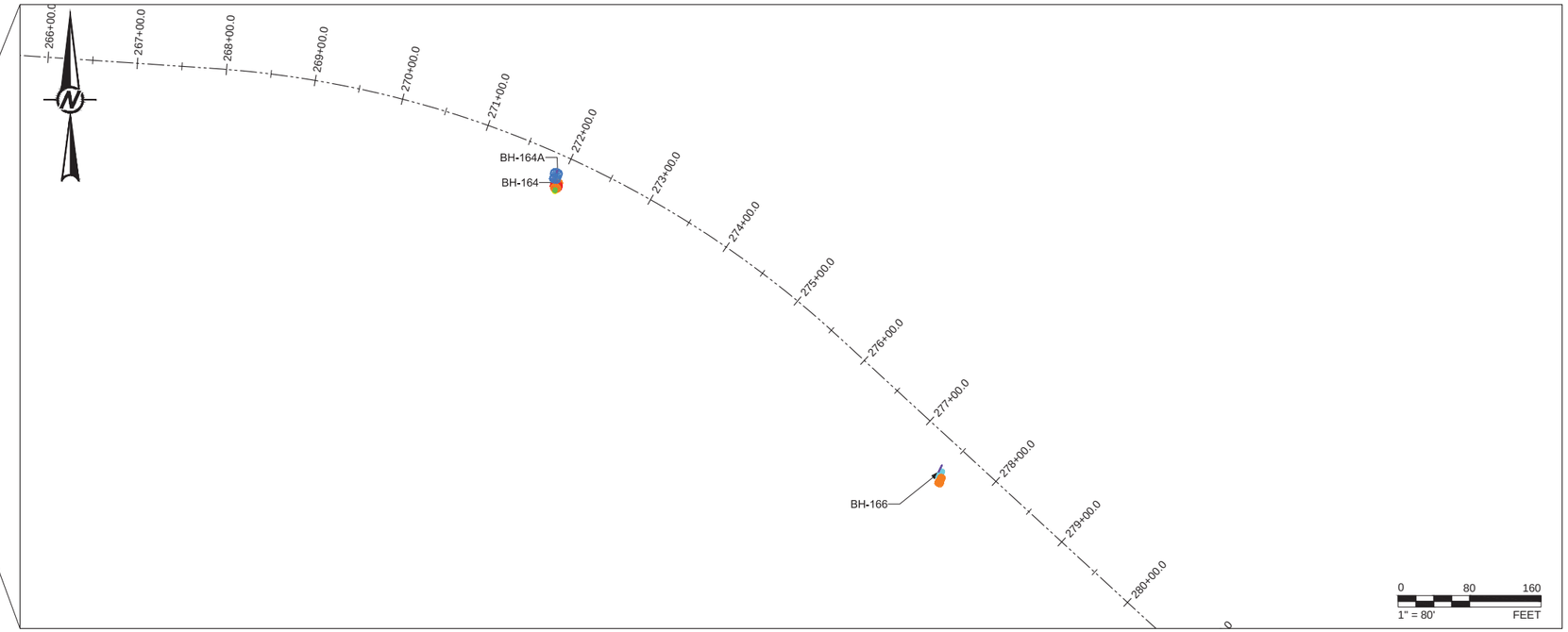
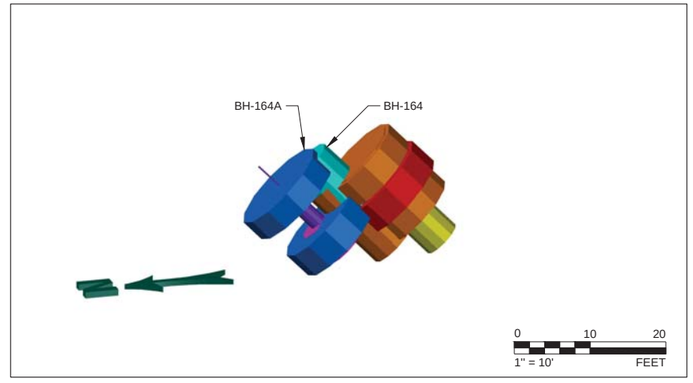
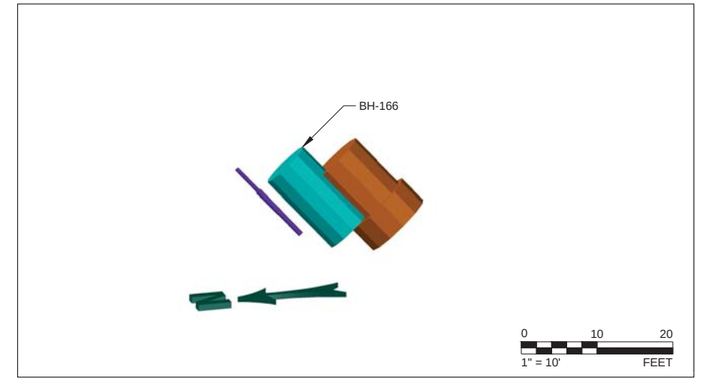
0 1 in









LEGEND - LITHOLOGY

- BASALT
- DACITE
- DIABASE
- SEDIMENTS
- SOUDAN IRON FORMATION

LEGEND - SULFUR

- 0.0% - 0.1% SULFUR CONCENTRATION
- 0.1% - 0.2% SULFUR CONCENTRATION
- 0.2% - 1.0% SULFUR CONCENTRATION
- >1.0% SULFUR CONCENTRATION

LEGEND - NPR

- 0 - 1.0
- 1.0 - 3.0
- > 3.0

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YYYY-MM-DD	2016-04-14
DESIGNED	FSS
PREPARED	THR
REVIEWED	FSS
APPROVED	RV

PROJECT
EAGLES NEST ROCK ALTERNATIVES
SULFIDE MITIGATION PLAN

TITLE
ROAD CUT V

PROJECT NO.	PHASE	REV.	FIGURE
1543068	003	A	19

Path: \\eldnondfs\geomat$\geomat\sc\MnDOT-Duluth\EagleNest\99_PROJECTS\1543068_SulfideMitigationPlan\003_Mitigation\02_PRODUCTION\DWGs\ | File Name: 1543068_003_SM_018.dwg

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D
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APPENDIX B
ASSESSMENT TOOL

MnDOT Highway 169 Realignment Project
Acid Base Accounting Field Data Assessment Tool

Prepared by: **Prepared For:** **Modified:** August, 2016

Instructions:
The purpose of this field data assessment tool is to determine the mass of limestone (if any) that should be added to rock excavated from each rock cut section in order to mitigate its acid rock drainage (ARD) potential. This spreadsheet will calculate the appropriate limestone mass by comparing the average sulfur concentrations measured during pre-construction testing with sulfur concentrations measured in the field during construction. The mass of limestone that needs to be added to the excavated rock will be calculated based on the higher of these sulfur concentrations.

In practice, this spreadsheet automatically averages and compares the sulfur concentrations and calculates the mass of limestone required. All that needs to be entered into the spreadsheet are the sulfur concentrations measured in the field (see #2) and the limestone specifications (see #6). Detailed instructions on the use of this field data assessment tool are listed below.

1. The mass of limestone necessary to mitigate ARD potential will be evaluated for each rock cut section (i.e., A1, A2, B1, B2, etc.). The Qualified Person will select rock cut sections with rock volumes greater than 500 cubic yards (cy) for testing in the field during construction according to the procedure in the Mitigation Plan. Mitigation for rock cut sections with rock volumes less than 500 cy will be implemented according to the results of a pre-construction assessment.

2. The Qualified Person will use a hand-held XRF to measure the sulfur concentrations in samples of cuttings from the blast holes. The operator will input the XRF results for each blast hole (by rock cut section) into the Field Data Entry Form (Sheet 1 of this spreadsheet).

3. For each rock cut section, the average of the sulfur concentrations across all blast holes will be automatically calculated. The average sulfur concentration for each rock cut section will appear in Column U of the ABA Classification Table (Sheet 2), and the field-calculated neutralization potential ratio (NPR) will be automatically calculated in Column W.

4. Rock cut sections with NPR > 3 contain sufficient neutralizing potential for the assigned sulfur content and do not require mitigation. These sections are shaded green in Sheet 2. No limestone addition is required for the rock excavated from these sections

5. Rock cut sections with NPR < 3 will require limestone addition to raise the NPR to 3. These sections are shaded orange in Sheet 2. The mass of limestone that needs to be added to the rock excavated from these sections will be calculated using both the pre-construction sulfur concentration (Column R) and the average sulfur concentration measured in the field during construction (Column X). The maximum of these two sulfur concentrations will be used to calculate the mass of pure limestone that needs to be added to the excavated material (Column Y).

6. The actual amount of limestone and agricultural lime required for mitigtion will be adjusted to account for the calcium carbonate equivalent (CCE) and moisture content specified by the supplier. The values should be entered below (default of 70% CCE and 5% moisture). The actual mass of limestone/agricultural lime required for each rock cut section is shown in Column Z of Sheet 2, and the total mass of limestone/agricultural lime required for each rock cut is shown in Column AA.

CCE:	70%

Moisture:	5%

SHEET 1: FIELD DATA ENTRY F

Section	B1		B2		E1		E2	
Average Sulfur %	**Blast Hole ID**	**0.09**	**Blast Hole ID**	**0.09**	**Blast Hole ID**	**0.09**	**Blast Hole ID**	**0.09**
Blast Hole ID and Sulfur %		0.19		0.19		0.19		0.19
		0.05		0.05		0.05		0.05
		0.05		0.05		0.05		0.05
		0.05		0.05		0.05		0.05
		0.06		0.06		0.06		0.06
		0.08		0.08		0.08		0.08
		0.12		0.12		0.12		0.12
		0.15		0.15		0.15		0.15

SPREADSHEET INCLUDES EXAMPLE FIELD DATA FOR DEMONSTRATION PURPOSES ONLY

SHEET 2: Field Assessment of Acid Rock Drainage Potential

Rock Cut and Section Details							Results of Pre-Construction Assessment								Results of Field Assessment Conducted During Construction					FINAL LIMESTONE REQUIREMENT		
Rock Cut	STA to STA	Estimate Rock Volume (cy)	Rock Cut Section	STA to STA	Rock Cut Section Volume (cy)	Rock Cut Section Length (ft)	Maximum Weighted Average S (wt.%)	AP (t $CaCO_3$/kt)	NP Associated With Max Sulfur (t $CaCO_3$/kt)	NPR	Target NPR	NP Required to Achieve Target NPR (t $CaCO_3$/kt)	Pre-Construction Estimate of Limestone Addition (tons)	Pre-Construction Estimate of Limestone Addition (tons)	XRF Characterization Required for Rock Cut Section	Field Average Sulfur (wt.%) *From Sheet 1*	Is Field Sulfur > Pre-Construction Sulfur?	Field Calculated NPR	Limestone Requirement Based on Field Assessment (tons)	*Limestone Requirement Selected from Pre-Construction or Field Data (tons)*	LIMESTONE ADDITION REQUIRED (tons) *[includes correction for moisture and CCE]*	LIMESTONE ADDITION BY ROCK CUT (tons)
A	14+92-18+84 RIGHT	353	A1	14+92-16+00	58	108	0.01	0.3	6.2	19.7	3	-5.2	0	0.0	No	N/A	N/A	N/A	-	0	**0**	0
			A2	16+00-18+84	295	284	0.01	0.3	6.2	19.7	3	-5.2	0		No	N/A	N/A	N/A	-	0	**0**	
B	23+00-33+64.50 LT & RT	2,078	B1	23+00-30+11	823	711	0.01	0.4	44.3	113.4	3	-43.1	0	0.0	Yes	0.09	Yes	15.13	0	0	**0**	0
			B2	30+11-32+00	1,003	189	0.10	3.1	23.5	7.5	3	-14.1	0		Yes	0.09	No	8.02	0	0	**0**	
			B3	32+00-33+64.50	252	165	0.10	3.1	23.5	7.5	3	-14.1	0		No	N/A	N/A	N/A	-	0	**0**	
C	37+74-45+00	247	C1	37+74-41+49	247	375	0.12	3.8	65.8	17.5	3	-54.6	0	0.0	No	N/A	N/A	N/A	-	0	**0**	0
			C2	41+49-43+50	0	201	0.12	3.8	65.8	17.5	3	-54.6	0		No	N/A	N/A	N/A	-	0	**0**	
			C3	43+50-45+00	0	150	-	-	-	-	-	-	0		No	N/A	N/A	N/A	-	0	**0**	
D	45+50-46+25	287	D1	45+50-46+81.60	87	132	0.09	3.0	0.0	0.0	3	8.9	2	5.3	No	N/A	N/A	N/A	-	2	**2**	8
			D2	46+80.60-47+50	200	69	0.09	3.0	0.0	0.0	3	8.9	4		No	N/A	N/A	N/A	-	4	**6**	
E	47+50-54+00	2,300	E1	47+50-48+50	845	100	0.14	4.5	2.4	0.5	3	11.2	20	131.5	Yes	0.09	No	0.80	11	20	**30**	198
			E2	48+50-49+50.45	677	100	0.38	12.0	7.4	0.6	3	28.5	40		Yes	0.09	No	2.54	2	40	**60**	
			E3	49+50.45-50+60	465	110	0.51	16.0	3.6	0.2	3	44.3	43		No	N/A	N/A	N/A	-	43	**64**	
			E4	50+60-54+00	313	340	0.51	16.0	3.6	0.2	3	44.3	29		No	N/A	N/A	N/A	-	29	**43**	
F	59+00-60+75	0	F1	59+00-60+75	0	175	-	-	-	-	-	-	0	-	No	N/A	N/A	N/A	-	0	**0**	0
G	64+50-70+00	0	G1	64+50-67+25	0	275	-	-	-	-	-	-	0	0.0	No	N/A	N/A	N/A	-	0	**0**	0
			G2	67+25-67+75	0	50	0.01	0.3	67.0	214.4	3	-66.1	0		No	N/A	N/A	N/A	-	0	**0**	
			G3	67+75-70+00	0	225	0.01	0.3	67.0	214.4	3	-66.1	0		No	N/A	N/A	N/A	-	0	**0**	
H	70+80-92+00	26,291	H1	70+80-73+00	614	220	0.09	2.8	5.9	2.1	3	2.6	3	1,713.4	Yes	0.09	Yes	2.01	4	4	**6**	2,595
			H2	73+00-76+50	5,541	350	0.13	4.0	34.9	8.6	3	-22.8	0		Yes	0.09	No	11.92	0	[illegible]	**0**	
			H3	76+50-80+00	4,222	350	0.13	4.0	34.9	8.6	3	-22.8	0		Yes	0.09	No	11.92	0	[illegible]	**0**	
			H4	80+00-81+85	2,119	185	0.07	2.0	5.3	2.6	3	0.8	4		Yes	0.09	Yes	1.82	[illegible]	15	**23**	
			H5	81+85-83+00	2,446	115	0.33	10.3	4.0	0.4	3	27.1	138		Yes	0.09	No	1.36	[illegible]	138	**207**	
			H6	83+00-87+00	941	400	0.33	10.3	4.0	0.4	3	27.1	53		Yes	0.09	No	[illegible]	9	53	**80**	
			H7	87+00-90+00	5,962	300	0.75	23.6	0.8	0.03	3	70.0	868		Yes	0.09	No	[illegible]	99	868	**1306**	
			H8	90+00-92+00	4,446	200	0.75	23.6	0.8	0.0	3	70.0	648		Yes	0.09	[illegible]	[illegible].26	74	648	**974**	
I	101+00-103+00	82	I1	101+00-103+00	82	200	0.01	0.4	1.4	3.3	3	-0.1	0	0.0	No	N/A	[illegible]	N/A	-	0	**0**	0
J	103+00-105+00	0	J1	103+00-104+10	0	110	-	-	-	-	-	-	0	-	No	[illegible]	N/A	N/A	-	0	**0**	0
			J2	104+10-105+00	0	90	-	-	-	-	-	-	0		No	[illegible]	N/A	N/A	-	0	**0**	
K	107+00-110+00	1,075	K1	107+00-109+00	689	200	0.06	2.0	16.5	8.2	3	-10.5	0	0.0	[illegible]	0.09	Yes	5.62	0	0	**0**	0
			K2	109+00-110+00	386	100	0.06	2.0	16.5	8.2	3	-10.5	0		[illegible]	N/A	N/A	N/A	-	0	**0**	
L	110+00-124+50	75,544	L1	110+00-112+00	2,639	200	0.10	3.3	30.9	9.4	3	-21.1	0	0.0	Yes	0.09	No	10.56	0	0	**0**	0
			L2	112+00-114+00	16,009	200	0.10	3.3	30.9	9.4	3	-21.1	0		Yes	0.09	No	10.56	0	0	**0**	
			L3	114+00-115+00	10,207	100	0.14	4.4	43.2	9.7	3	-29.9	0		Yes	0.09	No	14.75	0	0	**0**	
			L4	115+00-118+00	26,930	300	0.14	4.4	43.2	9.7	3	-29.9	0		Yes	0.09	No	14.75	0	0	**0**	
			L5	118+00-121+00	17,672	300	0.14	4.4	37.8	8.5	3	-24.5	0		Yes	0.09	No	12.89	0	0	**0**	
			L6	121+00-124+50	2,087	350	0.08	2.4	22.4	9.2	3	-15.1	0		Yes	0.09	Yes	7.66	0	0	**0**	
M	305+00-310+00	5,103	M1	305+00-307+00	923	200	0.09	2.8	9.1	3.2	3	-0.6	0	1.7	Yes	0.09	Yes	3.12	0	0	**0**	3
			M2	307+00-308+00	2,058	100	0.19	5.8	24.3	4.2	3	-6.8	0		Yes	0.09	No	8.30	0	0	**0**	
			M3	308+00-308+86	1,783	86	0.19	5.8	24.3	4.2	3	-6.8	0		Yes	0.09	No	8.30	0	0	**0**	
			M4	308+86-310+00	339	114	0.12	3.8	8.8	2.3	3	2.5	2		No	N/A	N/A	N/A	-	2	**3**	
N	317+00-323+50	2,233	N1	317+00-318+00	0	100	-	-	-	-	-	-	0	0.0	No	N/A	N/A	N/A	-	0	**0**	0
			N2	318+00-320+00	1,178	200	0.02	0.7	64.2	92.8	3	-62.2	0		Yes	0.09	Yes	21.92	0	0	**0**	
			N3	320+00-321+00	1,055	100	0.02	0.7	64.2	92.8	3	-62.2	0		Yes	0.09	Yes	21.92	0	0	**0**	
			N4	321+00-322+00	0	100	-	-	-	-	-	-	0		No	N/A	N/A	N/A	-	0	**0**	
			N5	322+00-323+50	0	150	-	-	-	-	-	-	0		No	N/A	N/A	N/A	-	0	**0**	
O	328+00-331+00	2,808	O1	328+00-329+00	1,170	100	0.06	2.0	17.2	8.6	3	-11.2	0	0.0	Yes	0.09	Yes	5.86	0	0	**0**	0
			O2	329+00-330+00	1,622	100	0.06	2.0	17.2	8.6	3	-11.2	0		Yes	0.09	Yes	5.86	0	0	**0**	
			O3	330+00-331+00	16	100	0.05	1.7	12.0	7.2	3	-7.0	0		No	N/A	N/A	N/A	-	0	**0**	
P	338+40-342+77	0	P1	338+40-340+00	0	160	-	-	-	-	-	-	0	-	No	N/A	N/A	N/A	-	0	**0**	0
			P2	340+00-342+00	0	200	-	-	-	-	-	-	0		No	N/A	N/A	N/A	-	0	**0**	
			P3	342+00-342+77	0	77	-	-	-	-	-	-	0		No	N/A	N/A	N/A	-	0	**0**	
Q	357+50-370+25	14,799	Q1	357+00-359+00	16	200	0.02	0.7	4.7	7.0	3	-2.7	0	67.6	No	N/A	N/A	N/A	-	0	**0**	169
			Q2	359+00-36100	1,617	200	0.02	0.7	4.7	7.0	3	-2.7	0		Yes	0.09	Yes	1.61	14	14	**21**	
			Q3	361+00-362+00	1,157	100	0.02	0.5	3.1	5.7	3	-1.5	0		Yes	0.09	Yes	1.07	14	14	**20**	
			Q4	362+00-365+00	4,786	300	0.09	2.7	5.4	2.0	3	2.7	27		Yes	0.09	Yes	1.84	34	34	**51**	
			Q5	365+72-368+00	7,151	228	0.09	2.7	5.4	2.0	3	2.7	40		Yes	0.09	Yes	1.84	51	51	**76**	
			Q6	368+00-370+50	72	250	0.05	1.6	3.6	2.3	3	1.1	0.17		No	N/A	N/A	N/A	-	0	**0**	
R	373+75-388+75	4,414	R1	374+00-375+50	538	150	0.01	0.3	2.2	7.1	3	-1.3	0	0.0	Yes	0.09	Yes	0.75	7	7	**11**	71
			R2	375+50-379+00	2,888	350	0.01	0.3	2.2	7.1	3	-1.3	0		Yes	0.09	Yes	0.75	40	40	**59**	
			R3	379+00-382+50	0	350							0		No	N/A	N/A	N/A	-	0	**0**	
			R4	382+50-385+00	689	250	0.02	0.6	28.9	49.3	3	-27.2	0		Yes	0.09	Yes	9.87	0	0	**0**	
			R5	385+00-386+00	299	100	0.02	0.6	28.9	49.3	3	-27.2	0		No	N/A	N/A	N/A	-	0	**0**	
			R6	386+00-388+00	0	200	-	-	-	-	-	-	0		No	N/A	N/A	N/A	-	0	**0**	

SPREADSHEET INCLUDES EXAMPLE FIELD DATA FOR DEMONSTRATION PURPOSES ONLY

Rock Cut and Section Details							Results of Pre-Construction Assessment								Results of Field Assessment Conducted During Construction					FINAL LIMESTONE REQUIREMENT		
Rock Cut	**STA to STA**	**Estimate Rock Volume (cy)**	**Rock Cut Section**	**STA to STA**	**Rock Cut Section Volume (cy)**	**Rock Cut Section Length (ft)**	**Maximum Weighted Average S (wt.%)**	**AP (t $CaCO_3$/kt)**	**NP Associated With Max Sulfur (t $CaCO_3$/kt)**	**NPR**	**Target NPR**	**NP Required to Achieve Target NPR (t $CaCO_3$/kt)**	**Pre-Construction Estimate of Limestone Addition (tons)**	**Pre-Construction Estimate of Limestone Addition (tons)**	**XRF Characterization Required for Rock Cut Section**	**Field Average Sulfur (wt.%) *From Sheet 1***	**Is Field Sulfur > Pre-Construction Sulfur?**	**Field Calculated NPR**	**Limestone Requirement Based on Field Assessment (tons)**	***Limestone Requirement Selected from Pre-Construction or Field Data (tons)***	**LIMESTONE ADDITION REQUIRED (tons)** *[includes correction for moisture and CCE]*	**LIMESTONE ADDITION BY ROCK CUT (tons)**
S	390+25-402+00	10,897	S1	390+28.96-391+00	0	71	-	-	-	-	-	-	0	1,120.8	No	N/A	N/A	N/A	-	0	**0**	1,694
			S2	391+00+394+00	1,102	300	0.07	2.1	0.0	0.0	3	6.2	14		Yes	0.09	Yes	0.00	20	20	**30**	
			S3	394+00-395+56	3,379	156	0.44	13.9	2.4	0.2	3	39.3	276		Yes	0.09	No	0.83	45	276	**415**	
			S4	395+056-396+00	979	44	0.44	13.9	2.4	0.2	3	39.3	80		Yes	0.09	No	0.83	13	80	**120**	
			S5	396+00-397+00	2,479	100	0.90	28.1	18.0	0.6	3	66.3	342		Yes	0.09	No	6.14	342	342	**515**	
			S6	397+00-400+00	2,958	300	0.90	28.1	18.0	0.6	3	66.3	408		Yes	0.09	No	6.14	408	408	**614**	
			S7	400+00-402+00	0	200	-	-	-	-	-	-	0		No	N/A	N/A	N/A	-	0	**0**	
T	412+75-414+50	169	T1	412+75-413+00	23	25	2.41	75.2	17.0	0.2	3	208.7	10	73.4	No	N/A	N/A	N/A	-	10	**15**	110
			T2	413+00-414+50	146	150	2.41	75.2	17.0	0.2	3	208.7	63		No	N/A	N/A	N/A	-	63	**95**	
U	417+38-422+00	0	U1	417+398+-419+00	0	160	-	-	-	-	-	-	0	-	No	N/A	N/A	N/A	-	0	**0**	0
			U2	419+00-420+00	0	100	-	-	-	-	-	-	0		No	N/A	N/A	N/A	-	0	**0**	
			U3	420+00-422+00	0	200	-	-	-	-	-	-	0		No	N/A	N/A	N/A	-	0	**0**	
V	429+00-440+10	1,353	V1	428+00-431+00	0	300	-	-	-	-	-	-	0	92.0	No	N/A	N/A	N/A	-	0	**0**	138
			V2	431+00-434+60	0	360	-	-	-	-	-	-	0		No	N/A	N/A	N/A	-	0	**0**	
			V3	434+60-438+00	0	340	-	-	-	-	-	-	0		No	N/A	N/A	N/A	-	0	**0**	
			V4	438+00-441.52+30	0	352	-	-	-	-	-	-	0		No	N/A	N/A	N/A	-	0	**0**	
			V5	441+52.30-443+00	370	148	0.41	12.7	1.8	0.1	3	36.3	28		No	N/A	N/A	N/A	-	28	**42**	
			V6	443+00-445+00	466	200	0.41	12.7	1.8	0.1	3	36.3	35		No	N/A	N/A	N/A	-	35	**53**	
			V7	445+00-448+50	108	350	0.29	9.1	0.3	0.0	3	26.8	6		No	N/A	N/A	N/A	-	6	**9**	
			V8	448+50-451+00	409	250	0.29	9.1	0.3	0.0	3	26.8	23		No	N/A	N/A	N/A	-	23	**34**	

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