ARRC MP 357.1 SLIDE AREA GEOTECH INVESTIGATION

DRAFT TECHNICAL MEMORANDUM – UPDATED FIGURES TO IFB PLANS

Subject: Geotechnical Exploration Findings and Design Decisions
From: Michael Baker International
To: Jesse Moose and Sam Phillips, ARRC
Date: March 13, 2025 – Figures Revised October 1, 2025

1. Introduction

Michal Baker International (Michael Baker) coordinated three data collection efforts with Alaska Railroad Corporation (ARRC) to gather geotechnical information to support the detailed design of Upper Drainage Feature (UDF, or upper interceptor ditch); (I) A series of test pits along the proposed alignment, (II) A series of boreholes in the active slide area between stations 18+00 and 22+00 of the UDF alignment, and (III) A geophysics GPR study across the borehole area to fill in data gaps. The intent was to identify the depth of the impermeable weathered schist bedrock (bedrock) to help inform the design as the 30% concept design plans are developed in the detailed design phase. Recent geotechnical findings and design decisions are documented in this project memo.

2. Test Pits October 8-9, 2024

The initial geotechnical field effort occurred in early October 2024 and consisted of seven test pits dug along the full alignment of the 30% design upper drainage feature. The work was performed with a small excavator, contracted by ARRC, that was able to reach a maximum depth of 18-ft. Through this effort it was apparent that the initial target depth for the ditch invert in the slide area was too shallow to reach the bedrock. The estimated depth of a 10 to 15-ft deep bedrock layer at the top of the active slide area came from the projections of the 2016 boreholes around the track area recorded in the draft Golder 2017 report. A slip surface depth of ~33-ft at the tracks was approximated by a sounding of their BH-3 in 2021 and was projected through the slide area to where shallow bedrock was observed adjacent to the slide area.

Test pits outside of the slide area further down the hill in the proposed ditch alignment found bedrock between 3 to 7-ft deep and the upper layers of rock were very weathered. The small excavator easily reached depths of 10 to 14-ft without encountering resistance from the weathered bedrock. The composition of the soil in test pits outside the slide area was a fine silty loess-like deposit overlying weathered schist bedrock. Within the slide area however, the observed soils were a highly variable mix of large cobbles, gravels, sands, and finer materials. Consistent with what could be observed in the exposed face of the bluffs directly above the slide area.

Figure 2.1 shows the locations of test pits and boreholes along the ditch alignment. Photos 2.1 through 2.6 show the excavated test pits. Samples were taken from the test pits and an analysis by Terra Firma Testing was performed to gather information on the particle size and hydraulic conductivity of the soils. Results are available in Attachment A and confirm the variation in materials observed across the project area.

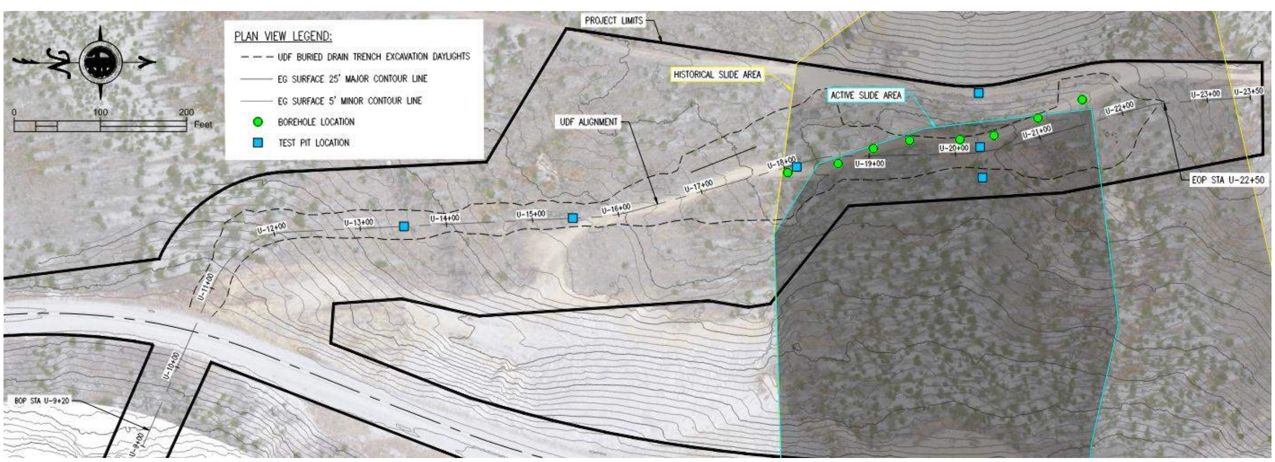


FIGURE 2.1: MP357.1 IFB DESIGN UDF PLAN VIEW WITH GEOTECH EXPLORATION LOCATIONS

*Photo 2.1: Digging TP1, STA 20+00 above CL looking uphill.
Bedrock not located in ~15-ft deep pit*

*Photo 2.2: TP1D, STA 20+00 ~50 East of CL looking uphill.
Bedrock not located in ~18-ft deep pit*

*Photo 2.3: TP1U, STA 20+00 ~65' West of CL looking downhill.
Bedrock not located in 5-ft pit*

*Photo 2.4: TP2, STA 18+00 above CL looking uphill.
Bedrock located 5 to 6-ft below EG*

*Photo 2.5: TP3, STA 15+50 on CL looking uphill,
Bedrock located 5 to 7-ft below EG*

*Photo 2.6: TP4, STA 13+50 above CL looking uphill.
Bedrock located 2.5 to 3.5-ft below EG*

3. Boreholes January 7-9, 2025

To build on the data and observations collected during the test pit excavation and determine the bedrock depth through the slide area, a three day borehole drilling program was executed. In early January 2025, Discovery Drilling was contracted with the goal of completing eight boreholes along the upper ditch alignment. These boreholes were done with the intent to confirm the bedrock depth within the active slide area from station 18+00 to 21+50 and note any presence of groundwater.

The boreholes were drilled by a CME-850X with an 8-in diameter auger using a carbide tooth bit. Subsurface conditions at depths of 15-ft and subsequent 5-ft intervals were observed directly via a split spoon sample. The split spoon was advanced 24-inches into the material at the bottom of the borehole via hammer blows. The internal sections were then retrieved, and the soil & rock trapped in the hollow section of the sampler were observed at the surface. The results of the split spoon observations are shown in Figure 3.1 and in photo 3.4 and 3.5. For the sake of time and to collect data across a broader extent of the slide area some split spoon sample depths were skipped if advancing the drill section over the previous 5-ft had little to no resistance.

From this drilling program the bedrock layer was identified between 21 to 33-ft deep beneath the existing ground surface within the slide area. The drilling progress and observations of tailings/cuttings produced during the first 15-ft of drilling were consistent with the previous test pit observations. Photos 3.1 and 3.2 show drilling setup and progress.

Photo 3.1: CME-850X Setup and operators drilling the 18+50 borehole

Photo 3.2: Boring the 18+50 borehole, surfacing tailings changed to small gravels at ~15 to 20-ft depth

Photo 3.3: Borehole 19+00 bedrock sample recovered from 30 to 32-ft deep after rapid drilling to 30-ft depth. Transition from weathered bedrock to more intact rock fabric confirmed in subsequent 32 to 34-ft split spoon sample.

Photo 3.4: Borehole 20+00 ~25-ft East of ditch CL bedrock showing both samples recovered from 20 to 22-ft and 22 to 24-ft.

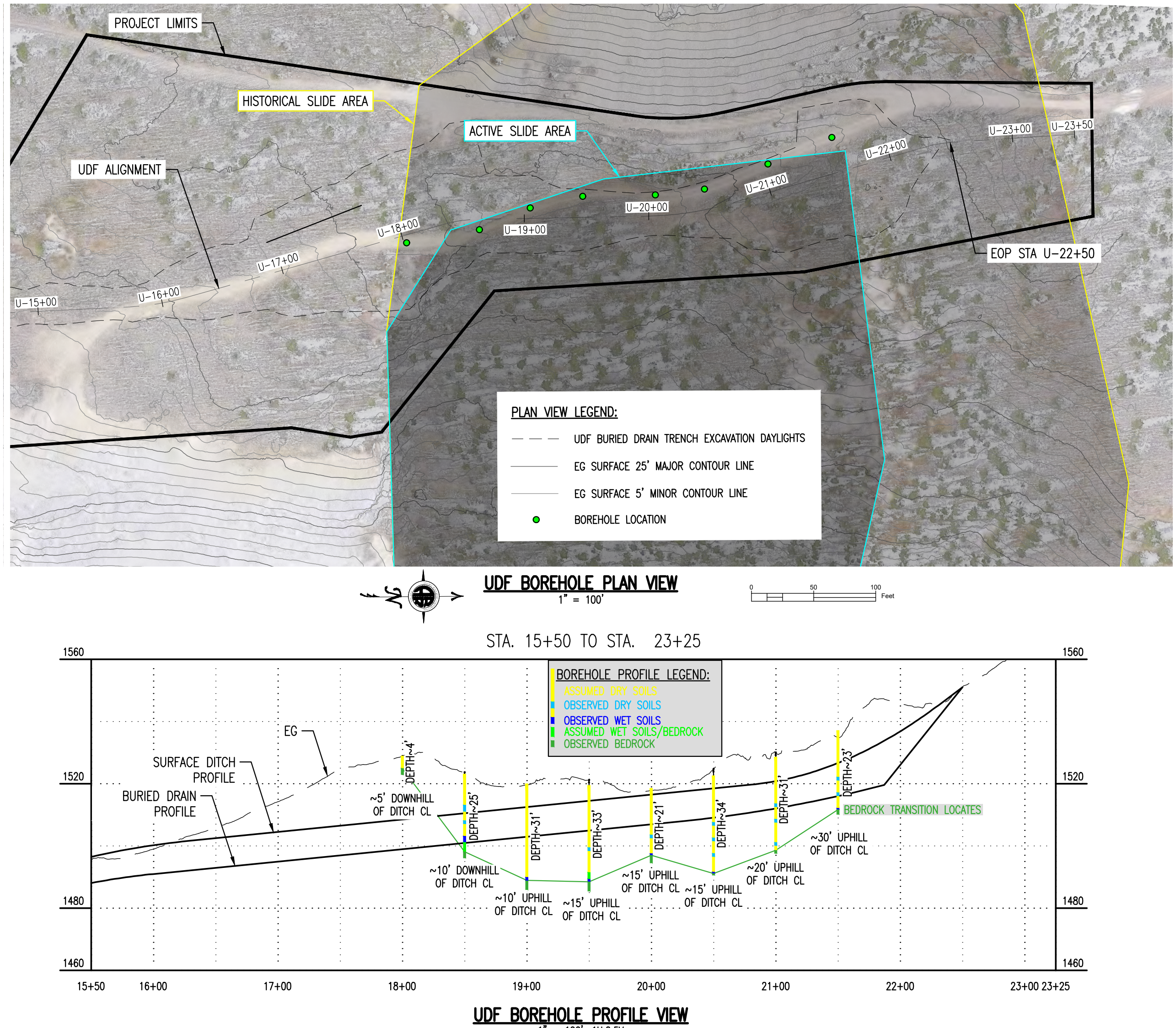


FIGURE 3.1 FENCE POST DIAGRAM OF BOREHOLE DATA WITH UPDATED IFB DESIGN ALIGNMENT & PROFILES

4. Geophysics Survey February 16-17, 2025

A third data collection effort with Logic Geophysics and Analytics LLC used the geotechnical information gathered during the previous studies to inform a geophysical study using ground penetrating radar (GPR). The borehole data was used to help calibrate/interpret the GPR results. The GPR survey collected a continuous bedrock profile along the lower access road. An additional transect was collected on the upper access road to determine if the bedrock was at a shallower depth.

The GPR survey along the lower access road resulted in a strong signal aligning with the bedrock formation identified in the boreholes with exception of gaps around BH1900 and BH1950 (Figure 4.1). A similar signature was used to interpret the bedrock profile along the upper access road (Figure 4.2). The interpreted depth of bedrock was approximately 20 feet below ground surface through the active slide area along the upper access road. The full geophysical report is available in Attachment B.

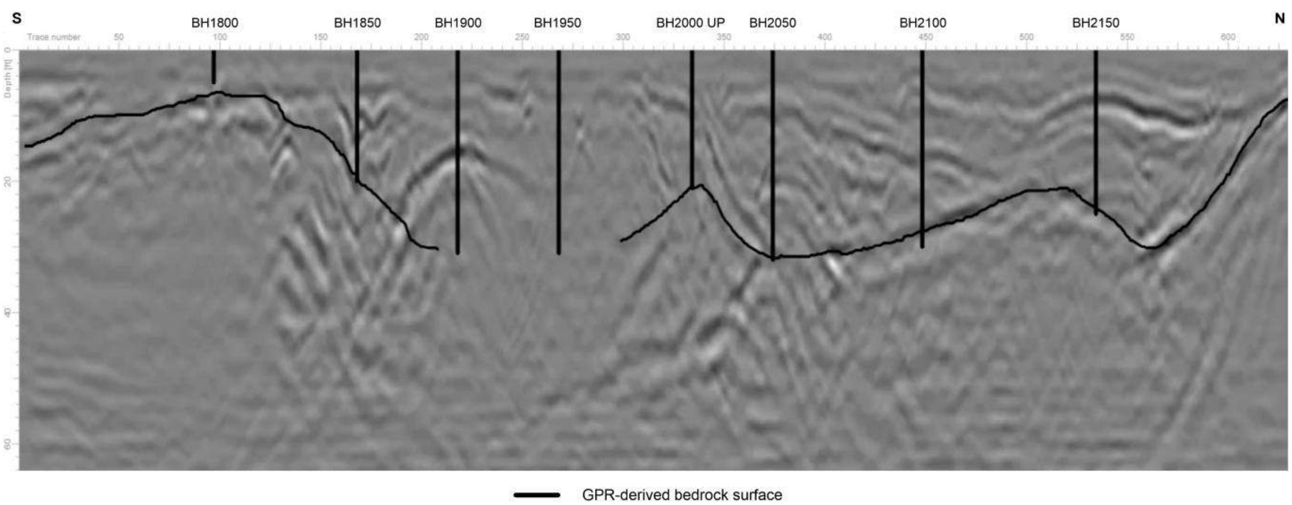


FIGURE 4.1 LOWER ACCESS ROAD GPR PROFILE

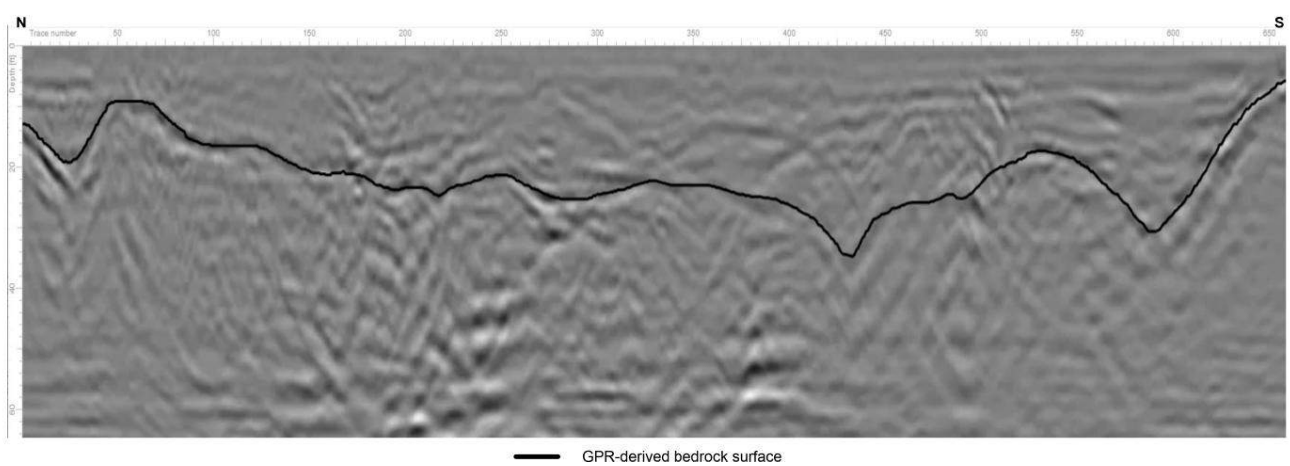


FIGURE 4.2 UPPER ACCESS ROAD GPR PROFILE

5. Conclusion

The function of Upper Drainage Feature is to cut off the uphill sources of groundwater entering the slide area at a location that appeared the most cost effective to do so. To reach the bedrock located by the drilling efforts and be free draining the buried drainpipe profile across the active slide area would have to increase to at least 30-ft deep instead of the expected 10 to 15-ft. This would create major challenges in construction for safe excavation and remaining within the permitted project limits. Targeting an intermediate depth will create less constructability challenges but allow some groundwater to flow underneath the feature through the observed porous soils. The GPR results estimate the bedrock depth is approximately 20-ft deep below the upper access road and relocating the drainage feature uphill to target this depth with an interceptor ditch would not be practical due to the unstable material above and excavation daylights outside the project limits.

6. Design Decisions Going Forward – March 6, 2025

Micheal Baker and ARRC staff met on March 6, 2025 to discuss the best path forward concerning the Upper Drainage Feature given the geotechnical findings. The boreholes and geophysical data suggest there is not a prominent spring-fed groundwater flux entering the slide area and that any groundwater contributing to the slide area is infiltrating from the surface via snow melt during the spring runoff or heavy precipitation events. With this in mind, the current alignment and targeting a ditch invert of approximately 15-20ft depth in the active slide area intercepts approximately 70% of the area and will be effective in draining a large percentage of ground water that infiltrates from the surface above the slide area. In the future, if it is determined through piezometer instrumentation that excessive groundwater is seeping below the ditch invert, a strategically placed sheetpile curtain could be installed to the bedrock depth along the upper access road to block deeper flow.

Further design criteria were discussed, and it was decided that trench slopes during the excavation of the ditch to be no steeper than 1.5H:1V. The planned excavation depth for the lower profile of the Upper Drainage Feature must leave at least 5-ft buffer between the project limits and trench excavation daylight. Outside of the slide area where the total excavation depth has regions greater than 20ft deep, the trench plan will include 10’ horizontal benches to increase excavation stability and excavation equipment access.

It was also decided during this meeting to forgo a proposed lower drainage ditch at this time. Available funds would be better allocated to improvements on the Upper Drainage Feature. In addition, forgoing the lower ditch eliminates extensive clearing and grubbing that could allow greater infiltration and increase the risk of slide area movement.

ATTACHMENT A – TEST PIT SOIL SAMPLE LAB RESULTS

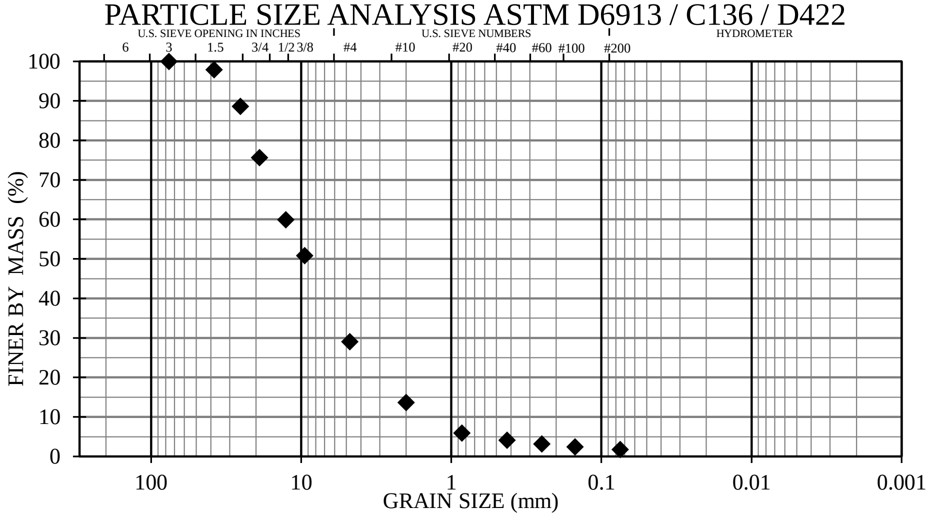
NORTHERN GEOTECHNICAL ENGINEERING, INC. / TERRA FIRMA TESTING

Laboratory Testing · Geotechnical Engineering · Instrumentation · Construction Monitoring Services · Thermal Analysis

PROJECT CLIENT:	**Michael Baker International**
PROJECT NAME:	**Healy Canyon Slide Areas**
PROJECT NO.:	**7231-24**
SAMPLE DESC.:	**TP-1 Bucket #1**
NGE-TFT ID #:	**24-S-1**
CLASSIFICATION:	**Well-graded gravel w/ sand**
DATE RECEIVED:	**10/1/2024**
TESTED BY:	**Gunner Bergstedt**
REVIEWED BY:	**Sean Totzke**

% GRAVEL	**71.0**	USCS	**GW**
% SAND	**27.3**	USACOE FC	**N/A**
% SILT/CLAY	**1.7**	% PASS. 0.02 mm	**N/A**
% MOIST. CONTENT	**3.4**	% PASS. 0.002 mm	**N/A**
UNIFORMITY COEFFICIENT (C_u)	**8.7**		
COEFFICIENT OF GRADATION (C_c)	**1.3**		
ASTM D1557 (uncorrected)	**N/A**		
ASTM D4718 (corrected)	**N/A**		
OPTIMUM MOIST. CONTENT. (corrected)	**N/A**		

PARTICLE SIZE ANALYSIS ASTM D6913 / C136 / D422



COBBLES	GRAVEL		SAND			SILT or CLAY
	Coarse	Fine	Coarse	Medium	Fine	

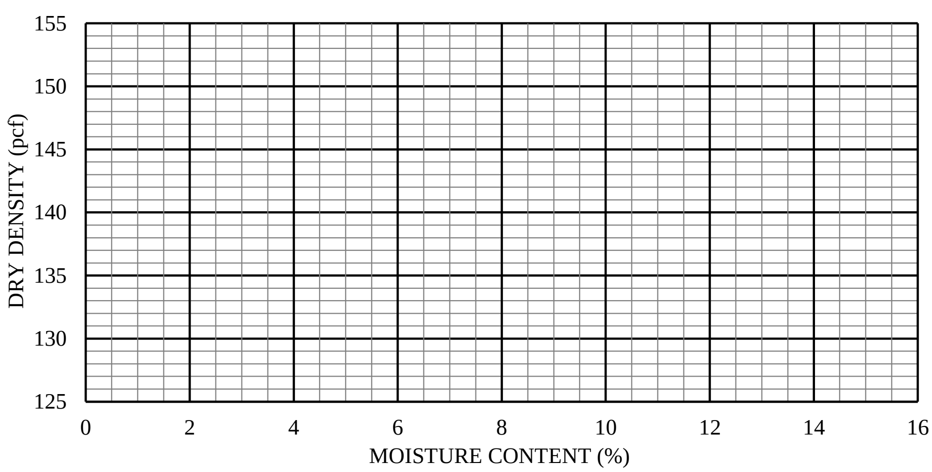
SIEVE ANALYSIS RESULT

SIEVE SIZE (mm)	SIEVE SIZE (U.S.)	TOTAL % PASSING	SPECIFICATION (% PASSING)
76.20	3"	**100**	
38.10	1.5"	**98**	
25.40	1.0"	**89**	
19.00	3/4"	**76**	
12.70	1/2"	**60**	
9.50	3/8"	**51**	
4.75	#4	**29**	
2.00	#10	**14**	
0.85	#20	**6**	
0.43	#40	**4**	
0.25	#60	**3**	
0.15	#100	**2**	
0.075	#200	**1.7**	

HYDROMETER RESULT

ELAPSED TIME (MIN)	DIAMETER (mm)	TOTAL % PASSING
0		
1		
2		
5		
8		
15		
30		
60		
250		
1440		

MOISTURE-DENSITY RELATIONSHIP ASTM D1557



FRACTURE COUNT (ASTM D5821) Double Face	**N/A**
DEGRADATION (ATM T-313)	**N/A**
LA ABRASION (ASTM C131/C535)	**N/A**
SP. GRAV. COARSE AGG. (ASTM C127)	**N/A**

The testing services reported herein have been performed to recognized industry standards, unless otherwise noted. No other warranty is made. Should engineering interpretation or opinion be required, NGE-TFT will provide upon written request.

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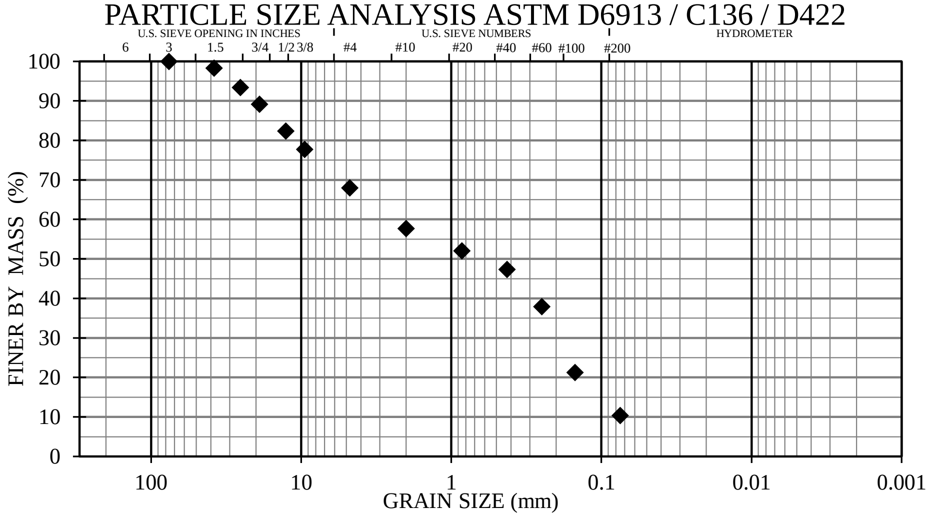
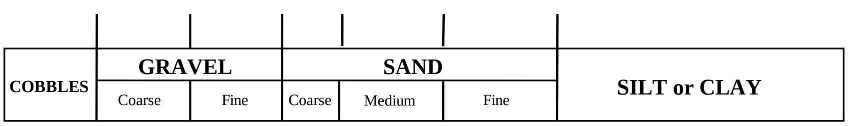
PROJECT CLIENT:	**Michael Baker International**
PROJECT NAME:	**Healy Canyon Slide Areas**
PROJECT NO.:	**7232-24**
SAMPLE DESC.:	**TP-3 Bucket #4**
NGE-TFT ID #:	**24-S-2**
CLASSIFICATION:	**Poorly-graded sand w/ silt and gravel**
DATE RECEIVED:	**10/1/2024**
TESTED BY:	**Gunner Bergstedt**
REVIEWED BY:	**Sean Totzke**

% GRAVEL	**32.0**	USCS	**SP-SM**
% SAND	**57.6**	USACOE FC	**N/A**
% SILT/CLAY	**10.4**	% PASS. 0.02 mm	**N/A**
% MOIST. CONTENT	**7.3**	% PASS. 0.002 mm	**N/A**

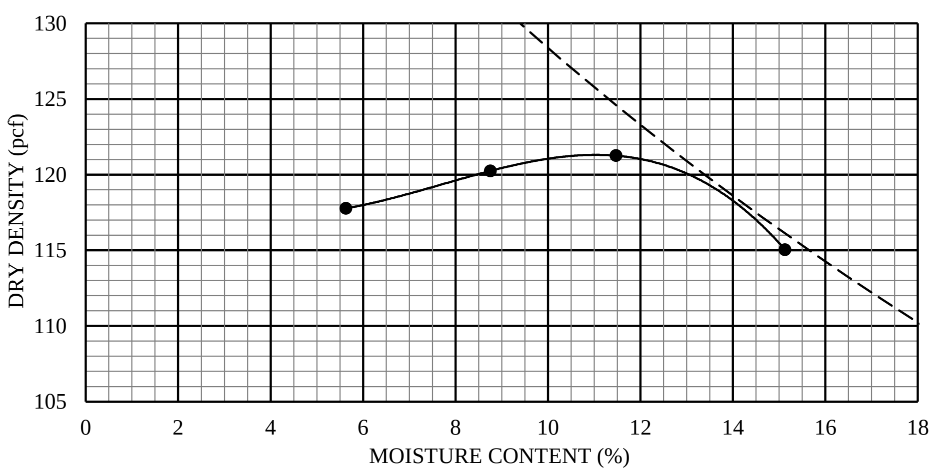
UNIFORMITY COEFFICIENT (C_u)	**UNKNOWN**
COEFFICIENT OF GRADATION (C_c)	**UNKNOWN**
ASTM D1557 - Method B (uncorrected)	**121.5** pcf
ASTM D4718 (corrected)	**132.4** pcf
OPTIMUM MOIST. CONTENT. (corrected)	**7.9** %

PARTICLE SIZE ANALYSIS ASTM D6913 / C136 / D422





MOISTURE-DENSITY RELATIONSHIP ASTM D1557 B



SIEVE ANALYSIS RESULT

SIEVE SIZE (mm)	SIEVE SIZE (U.S.)	TOTAL % PASSING	SPECIFICATION (% PASSING)
76.20	3"	**100**	
38.10	1.5"	**98**	
25.40	1.0"	**93**	
19.00	3/4"	**89**	
12.70	1/2"	**82**	
9.50	3/8"	**78**	
4.75	#4	**68**	
2.00	#10	**58**	
0.85	#20	**52**	
0.43	#40	**47**	
0.25	#60	**38**	
0.15	#100	**21**	
0.075	#200	**10.4**	

HYDROMETER RESULT

ELAPSED TIME (MIN)	DIAMETER (mm)	TOTAL % PASSING
0		
1		
2		
5		
8		
15		
30		
60		
250		
1440		

FRACTURE COUNT (ASTM D5821) Double Face	**N/A**
DEGRADATION (ATM T-313)	**N/A**
LA ABRASION (ASTM C131/C535)	**N/A**
SP. GRAV. COARSE AGG. (ASTM C127)	**N/A**

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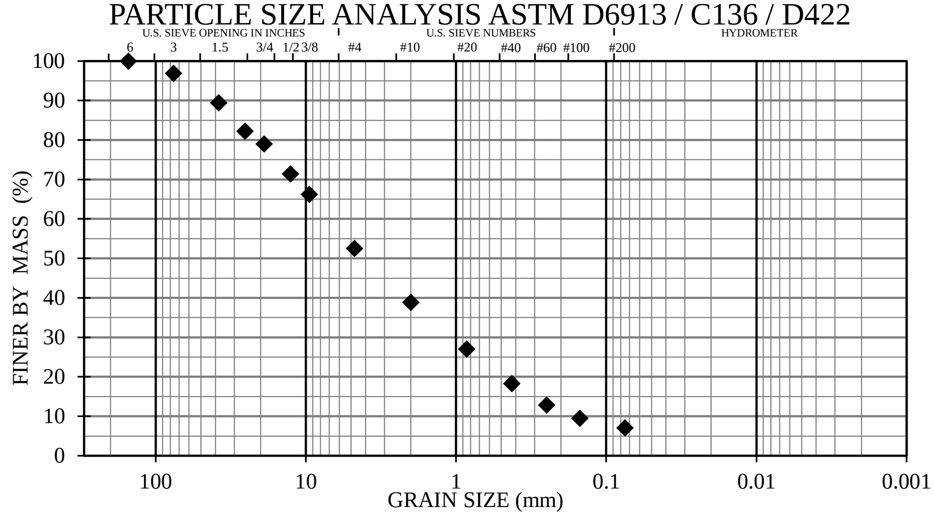
PROJECT CLIENT:	**Michael Baker International**
PROJECT NAME:	**Healy Canyon Slide Areas**
PROJECT NO.:	**7232-24**
SAMPLE DESC.:	**TP-1D Bucket #7**
NGE-TFT ID #:	**24-S-3**
CLASSIFICATION:	**Well-graded gravel w/ silt and sand**
DATE RECEIVED:	**10/1/2024**
TESTED BY:	**Chris Gerboth**
REVIEWED BY:	**Sean Totzke**

% GRAVEL	**47.4**	USCS	**GW-GM**
% SAND	**45.5**	USACOE FC	**N/A**
% SILT/CLAY	**7.1**	% PASS. 0.02 mm	**N/A**
% MOIST. CONTENT	**5.2**	% PASS. 0.002 mm	**N/A**
UNIFORMITY COEFFICIENT (C_u)		**44.4**	
COEFFICIENT OF GRADATION (C_c)		**1.1**	
ASTM D1557 (uncorrected)		**N/A**	
ASTM D4718 (corrected)		**N/A**	
OPTIMUM MOIST. CONTENT. (corrected)		**N/A**	

PARTICLE SIZE ANALYSIS ASTM D6913 / C136 / D422

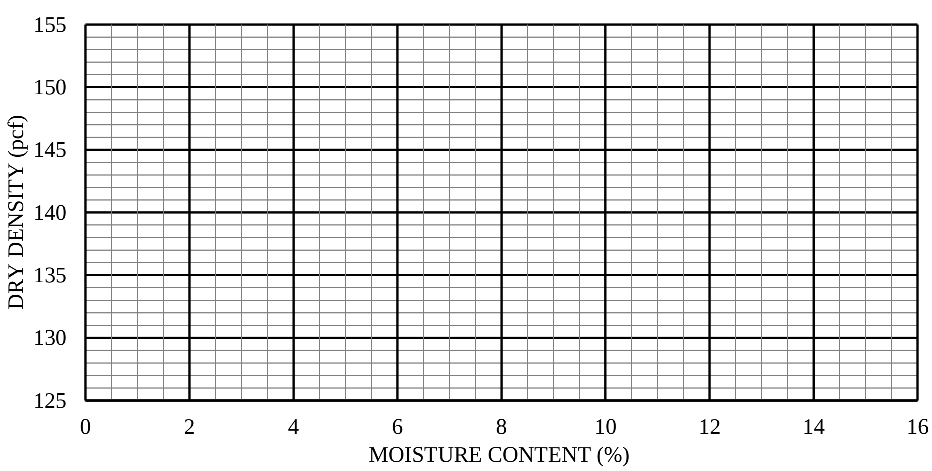


COBBLES	GRAVEL		SAND			SILT or CLAY
	Coarse	Fine	Coarse	Medium	Fine	

SIEVE ANALYSIS RESULT

SIEVE SIZE (mm)	SIEVE SIZE (U.S.)	TOTAL % PASSING	SPECIFICATION (% PASSING)
152.4	6"	**100**	
76.20	3"	**97**	
38.10	1.5"	**89**	
25.40	1.0"	**82**	
19.00	3/4"	**79**	
12.70	1/2"	**71**	
9.50	3/8"	**66**	
4.75	#4	**53**	
2.00	#10	**39**	
0.85	#20	**27**	
0.43	#40	**18**	
0.25	#60	**13**	
0.15	#100	**9**	
0.075	#200	**7.1**	

MOISTURE-DENSITY RELATIONSHIP ASTM D1557



HYDROMETER RESULT

ELAPSED TIME (MIN)	DIAMETER (mm)	TOTAL % PASSING
0		
1		
2		
5		
8		
15		
30		
60		
250		
1440		

HYDRAULIC COND. D2434 - METHOD A

CONDUCTIVITY	1.1×10^{-4} m s^{-1}
TEST TEMP.	68 °F
CORR. COND.	**1.1×10^{-4} m s^{-1}**
DRY DENSITY	123.2 pcf
SPECIMEN HEIGHT	12 Inches
SPECIMEN DIA.	9 Inches
HYDRAULIC GRAD	5

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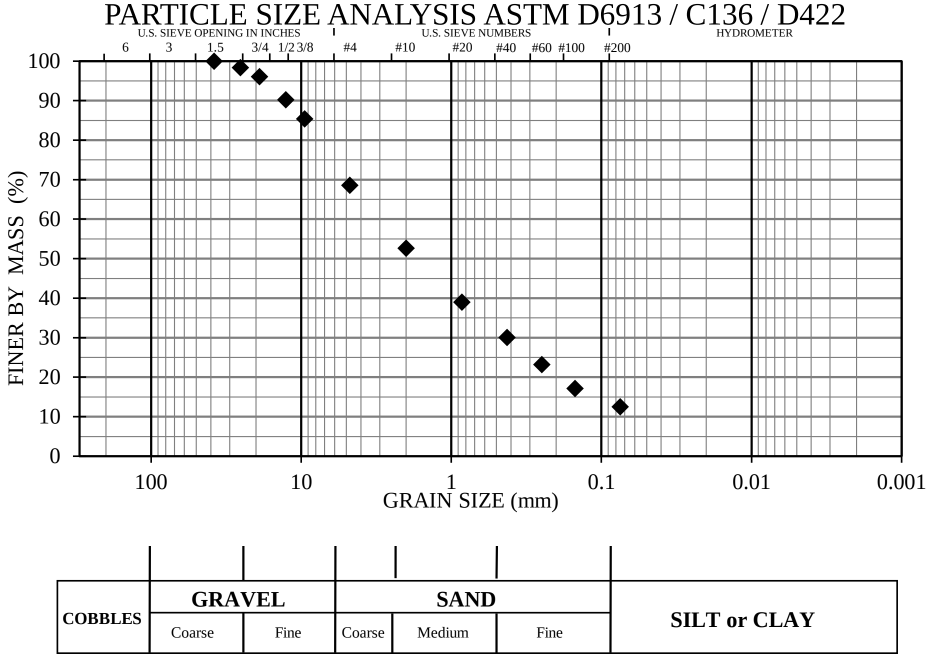
PROJECT CLIENT:	**Michael Baker International**
PROJECT NAME:	**Healy Canyon Slide Areas**
PROJECT NO.:	**7232-24**
SAMPLE DESC.:	**TP-1.5 - Bucket #6**
NGE-TFT ID #:	**24-S-4**
CLASSIFICATION:	**Silty sand w/ gravel**
DATE RECEIVED:	**10/1/2024**
TESTED BY:	**Chris Gerboth**
REVIEWED BY:	**Sean Totzke**

% GRAVEL	**31.5**	USCS	**SM**
% SAND	**56.0**	USACOE FC	**N/A**
% SILT/CLAY	**12.5**	% PASS. 0.02 mm	**N/A**
% MOIST. CONTENT	**7.8**	% PASS. 0.002 mm	**N/A**
UNIFORMITY COEFFICIENT (C_u)			**UNKNOWN**
COEFFICIENT OF GRADATION (C_c)			**UNKNOWN**
ASTM D1557 (uncorrected)			**N/A**
ASTM D4718 (corrected)			**N/A**
OPTIMUM MOIST. CONTENT. (corrected)			**N/A**

PARTICLE SIZE ANALYSIS ASTM D6913 / C136 / D422



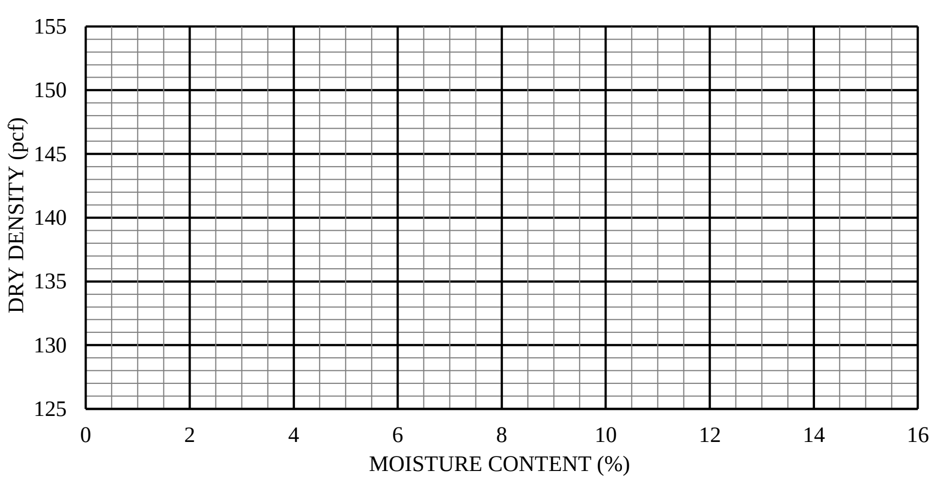
SIEVE ANALYSIS RESULT

SIEVE SIZE (mm)	SIEVE SIZE (U.S.)	TOTAL % PASSING	SPECIFICATION (% PASSING)
76.20	3"		
38.10	1.5"	**100**	
25.40	1.0"	**98**	
19.00	3/4"	**96**	
12.70	1/2"	**90**	
9.50	3/8"	**85**	
4.75	#4	**69**	
2.00	#10	**53**	
0.85	#20	**39**	
0.43	#40	**30**	
0.25	#60	**23**	
0.15	#100	**17**	
0.075	#200	**12.5**	

HYDROMETER RESULT

ELAPSED TIME (MIN)	DIAMETER (mm)	TOTAL % PASSING
0		
1		
2		
5		
8		
15		
30		
60		
250		
1440		

MOISTURE-DENSITY RELATIONSHIP ASTM D1557



HYDRAULIC COND. D2434 - METHOD A

CONDUCTIVITY	5.1×10^{-7} m s^{-1}
TEST TEMP.	68 °F
CORR. COND.	**5.1×10^{-7} m s^{-1}**
DRY DENSITY	118.2 pcf
SPECIMEN HEIGHT	8.75 Inches
SPECIMEN DIA.	6 Inches
HYDRAULIC GRAD	8

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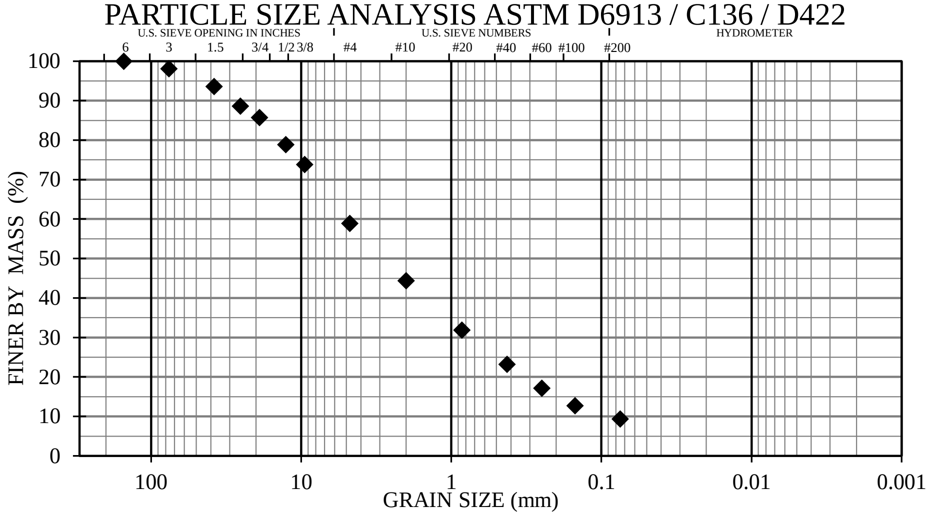
PROJECT CLIENT:	**Michael Baker International**
PROJECT NAME:	**Healy Canyon Slide Areas**
PROJECT NO.:	**7232-24**
SAMPLE DESC.:	**TP-1D Bucket #7 & TP-1.5 Bucket #6**
NGE-TFT ID #:	**24-S-5 Combined B6/B7**
CLASSIFICATION:	**Well-graded sand w/ silt and gravel**
DATE RECEIVED:	**10/1/2024**
TESTED BY:	**Chris Gerboth**
REVIEWED BY:	**Sean Totzke**

% GRAVEL	**41.1**	USCS	**SW-SM**
% SAND	**49.6**	USACOE FC	**N/A**
% SILT/CLAY	**9.3**	% PASS. 0.02 mm	**N/A**
% MOIST. CONTENT	**6.2**	% PASS. 0.002 mm	**N/A**
UNIFORMITY COEFFICIENT (C_u)		**57.0**	
COEFFICIENT OF GRADATION (C_c)		**1.3**	
ASTM D1557 Method C (uncorrected)		**133.5** pcf	
ASTM D4718 (corrected)		**137.5** pcf	
OPTIMUM MOIST. CONTENT. (corrected)		**6.9** %	

PARTICLE SIZE ANALYSIS ASTM D6913 / C136 / D422



COBBLES	GRAVEL		SAND			SILT or CLAY
	Coarse	Fine	Coarse	Medium	Fine	

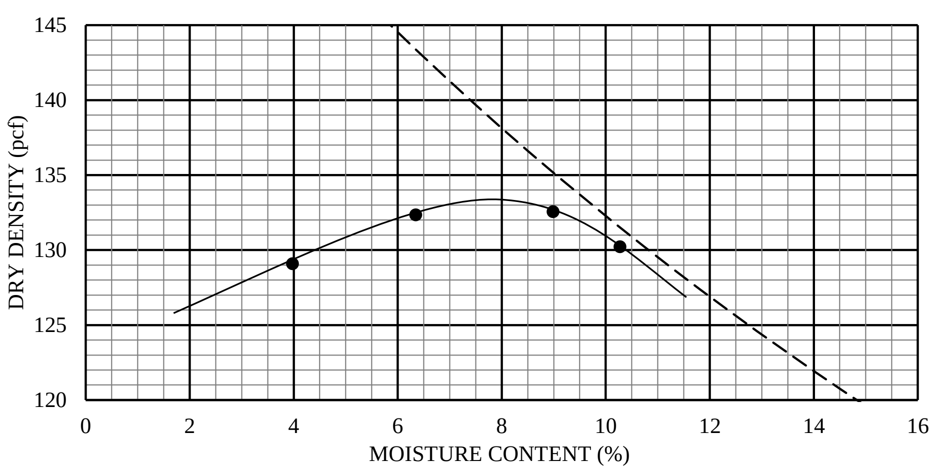
SIEVE ANALYSIS RESULT

SIEVE SIZE (mm)	SIEVE SIZE (U.S.)	TOTAL % PASSING	SPECIFICATION (% PASSING)
152.4	6"	**100**	
76.20	3"	**98**	
38.10	1.5"	**94**	
25.40	1.0"	**89**	
19.00	3/4"	**86**	
12.70	1/2"	**79**	
9.50	3/8"	**74**	
4.75	#4	**59**	
2.00	#10	**44**	
0.85	#20	**32**	
0.43	#40	**23**	
0.25	#60	**17**	
0.15	#100	**13**	
0.075	#200	**9.3**	

HYDROMETER RESULT

ELAPSED TIME (MIN)	DIAMETER (mm)	TOTAL % PASSING
0		
1		
2		
5		
8		
15		
30		
60		
250		
1440		

MOISTURE-DENSITY RELATIONSHIP ASTM D1557



FRACTURE COUNT (ASTM D5821) Double Face	**N/A**
DEGRADATION (ATM T-313)	**N/A**
LA ABRASION (ASTM C131/C535)	**N/A**
SP. GRAV. COARSE AGG. (ASTM C127)	**N/A**

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ATTACHMENT B – GEOPHYSICAL REPORT

Ground-Penetrating-Radar Surveys to Map Bedrock at MP 357.1

PREPARED FOR: Michael Baker International, Inc.
AUTHOR: Logic Geophysics & Analytics LLC
DATE: 19 February 2025, revised 02 March 2025

Logic Geophysics & Analytics LLC
Report

Date:	19 February 2025
To:	Morris Monroe and Garrett Yager | Michael Baker International, Inc.
From:	Esther Babcock, Logic Geophysics & Analytics LLC
Appendices:	A: Figures

Executive Summary

Logic Geophysics & Analytics LLC (Logic Geophysics) is submitting this report to Michael Baker International, Inc., (MBI) concerning geophysical surveys performed in February 2025 for the Alaska Railroad Corporation (ARRC) at MP 357.1. The project objectives were to estimate the depth to bedrock using ground-penetrating radar (GPR). This report includes explanations of the geophysical method, survey design, data processing, and results.

Logic Geophysics' field crew consisting of 2 personnel and an ARRC geologist collected the GPR data on February 17, 2025. The radar surveys used Sensors & Software "pulseEkkoPro" GPR system with 50-MHz antennas along 2 routes on site (Figure 1). MBI provided borehole data along the lower (eastern) alignment for ground-truth of the geophysical data.

Along the lower road, the GPR data agrees well with the boreholes except at the center of the cross-section. The bedrock depths at the upper road are overall shallower than those reported at the lower road. No borehole data exist along the upper alignment for ground-truth, however. The radar data do not show any indication of subsurface water movement or flow pathways.

The main body of this report provides additional results and discussion. Logic Geophysics appreciates the opportunity to provide these services to MBI and looks forward to working with your team again in future.

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Tasks and Deliverables

The objectives for the geophysical surveys were to collect GPR data at the site to estimate the depth to bedrock. Deliverables include figures in Appendix A showing depth to bedrock, electronically-transmitted locations of radar lines, and a report (this document) with explanation of field methods, results, figures, and discussion. Raw and processed data are available upon request.

Field Site and Conditions

The project site was located just outside Healy, Alaska, at ~68.833º N, ~148.973º W. The surface topography was steeply dipping from west to east. Two roughed-in roads provided access for the geophysical surveys (Photo 1), and the previously completed borehole drilling had also been conducted along the lower roadway (Figure 1). The road surface was partly snow-covered, with brush and rocks along the sides. Weather during the work was mostly cloudy with temperatures in the low single digits (Fahrenheit).

Photo 1: Looking south across the site, with the lower/ eastern trail on the left and the upper/western trail on the right.

Safety

Prior to deployment to the site, Logic Geophysics completed an Activity Hazard Analysis (AHA). Logic Geophysics' personnel reviewed the AHA again before project start. Before beginning work, Logic Geophysics' personnel completed a thorough safety and operations meeting as well as a site orientation. The largest site consideration was slips, trips, and falls due to the steep terrain and uneven working surface.

An emergency first-aid kit accompanied on-site workers. The team lead carried a satellite phone, and an InReach texting device for safety and communications. Cellular phones were intermittently working on site.

Radar

A GPR transmitter emits electromagnetic energy (the "signal") into the subsurface at a specified central frequency. If conductivity is low, this signal travels as a wave. Where subsurface lithology changes, often so do electrical properties. Those changes in electrical properties can cause part of the propagating signal to reflect to the surface. A co-located GPR receiver on the surface measures the reflected signal, which the system digitizes and records for later processing and subsequent interpretation.

GPR is often implemented for mapping depth to bedrock because the interface between soil and rock is often associated with a change in electrical properties. Even a small change in density, minerology, porosity, and water content usually creates a measurable change in electrical properties that reflects the radar energy to the source. Unfortunately, one of the corresponding weaknesses of the method for this application is that the GPR energy is sensitive to many subsurface changes not of importance for targeting bedrock. Changes in these properties listed can complicate interpretation, which highlights the need for borehole data to confirm results and provide guidance during interpretation. Thankfully for this project, borehole data were available for ground-truthing the GPR response at the time of processing.

Equipment

Logic Geophysics employed Sensors & Software's pulseEKKOPro GPR imaging system using 50-MegaHertz (MHz) antennas mounted in a sled (Photos 6 and 7 below). (25-MHz antennas were also tested but deemed unworkable due to the narrow roads on site as compared to the length of the 25-MHz antennas (12 feet).) The 50-MHz system incorporates a high-power transmitter and the latest available receiver technology offered by Sensors & Software, called the "Ultra," for maximum imaging depth. The high-power transmitter is about 10 times more powerful than standard GPR transmitters, and the Ultra can "stack" up to 64,000 times.

One method to improve signal-to-noise ratio for common-offset reflection GPR data is to collect more than 1 trace at each measurement position, average them, and record the average trace. This method is commonly called “stacking.” Stacking improves data quality because signal events constructively sum during the averaging process, while noise tends to deconstructively interfere. Since the data quality improves proportional to the square root of the stacks, the enhanced stacking feature of the Ultra represents a significant increase in data quality.

The system’s transmitter and receiver were mounted on external antennas. The antennas are the long grey wooden boards in Photos2 and 3, and house selectively arranged resistors and capacitors. The yellow and black box mounted on those boards are the receiver and transmitter respectively. The GPR controller is mounted on a chest-harness for the operator during acquisition. The controller is powered by its own separate battery carried in a backpack. The controller stores the incoming data, as well as displaying the data on its screen for real-time quality control. The GNSS receiver is also mounted on the operator’s backpack. During data acquisition, the GNSS antenna streams positioning information to the controller, which then ties that information to the data. Offsets were applied to the positioning information for the GPR. Table 1 provides parameters used during data collection, which followed manufacturer guidelines.

Photo 2: The 50-MHz GPR system on site in the parallel configuration

Photo 3: The 50-MHz GPR system on site in the perpendicular configuration.

Data were collected with the antennas in 2 orientations. (Each line was covered 2 separate times where site conditions allowed). The standard orientation for this system is with the antennas perpendicular to the direction of travel, as shown in Photo 3. However, due to the suspected dip of the bedrock at the site, I expected that the antennas in the parallel configuration (Photo 2) would provide better imaging of the bedrock surface.

<u>Quality Control</u>

GPR data quality control (QC) procedures included the following items:

1) System warm-up of 10 minutes;
2) Static data assessment before acquisition to verify data collection parameters and qualitatively assess data quality;
3) A “lift test” to identify any system noise and assess data quality; and
4) Real-time monitoring of GPR and GNSS data quality via the controller display.

The GPR static test allows the operator to qualitatively assess proper data collection and to examine the system for the presence of interference and/or noise. I conducted the static tests after the 10-minute system warm-up.

Before each line's collection begins, the controller displayed the system settings to ensure no unintended changes have occurred that would negatively affect data quality. Real-time QC was provided by visual monitoring of the incoming GPR data on the controller. The controller processed the incoming data for visualization purposes; but to maintain data integrity the controller only stores the raw data. With this visualization, Logic's experienced GPR operator could readily detect problems with degraded signal content or interference from external noise sources should they exist (for example, radios or above-ground objects). At this relatively remote, flat site, external interference was minimal.

Table 1: GPR Data collection Parameters

Parameter	50-MHz Setting
Survey type	Reflection (common offset)
Line spacing	Where possible
Antenna polarization	Broadside
Antenna orientation	Both perpendicular and parallel
Acquisition setting*	Free run, continuous
Along-line (trace) spacing	~1.5 feet
Time window	300 nanoseconds (ns)
First break offset	10%
Sampling interval	1 ns
Antenna separation	5.5 feet (perpendicular) 6.15 feet (parallel)
GPS-offset	X (along line) 4 feet Z (Height) 5.1 feet
Stacking	32,768
Transmitter voltage	1,000 Volts

Positioning

During data collection, the operator carried a GNSS antenna in the backpack-mounting system for the GPR controller. This GNSS antenna streamed differentially-corrected positioning information directly into the GPR controller throughout data collection at 1 Hertz. Quality control checks before data collection showed horizontal precision of less than 1 foot while receiving on 36 satellites. Roughness in the resulting georeferenced GPR lines shown in Figure 1 is likely due to operator movement, not GNSS errors.

Data Processing

The GPR data were processed using a combination of manufacturer's software (Sensors & Software "EKKOProjects") and additional commercially available cloud-based processing software tools. Processing steps followed a standardized GPR workflow, including filtering to remove unwanted reflection events and enhancing the signal strength for visualization purposes. Processing steps included the following items:

1) Bulk static shift ("time-zero" correction): Proper data collection practice requires setting the initial break in the recorded GPR signal to a time delay of about 10% of the collected time window. This setting preserved all information in the signal. Thus, applying a bulk static shift realigned all reflection events to their true recorded times. This algorithm shifted all traces equally in time to align the median value of the first break time with zero time.
2) Dewow: Dewow is a zero-phase filter generating the difference between the trace value and the average trace value over a defined window width. GPR data require the dewow process before viewing or carrying out further processing. The time window length was set to one period.
3) Background removal: This 2-dimensional filter calculated the average of the entire line data and subtracted it from the data. This filter removed the direct arrival between the antennas, of no use in interpretation, and reduced other noise from any nearby, constant-distance, metal objects.
4) Velocity analysis: Determining the correct radar-wave velocity is essential for accurate determination of layer depth and for migration processing. I estimate the overall subsurface

radar-wave velocity to be 0.36 feet per nanosecond. However, variability in soil wetness will impact the accuracy of this velocity estimate.

5) Migration: Migration is a data processing step that reduces data artifacts, such as diffraction hyperbola, and corrects dipping reflectors to the true subsurface position, which is always shorter, steeper, and up-dip from the reflection position before migration. The F-K migration algorithm used for these data applies a synthetic aperture image reconstruction process to the GPR line.
6) Gain: Since radar signal strength decreases with time due to unavoidable attenuation processes, applying a gain function boosted the later time signals for optimal visualization and interpretation. I used spreading and exponential compensation (SEC) gain, a composite of linear time gain and exponential signal recovery, to optimize late-time reflection events. This gain attempts to compensate both for spherical spreading losses and for the exponential ohmic dissipation of radar energy. SEC gain is the gain closest to physical reality and most commonly used for GPR data.
7) Time-to-depth conversion: GPR data are recorded in time. Since the desired outcome is layer depth, the final step was to use the same velocity that was applied during migration to convert the profile time values to depth.

This data processing provided individual profiles from every collected line, where the x-axis is position along the profile and the y-axis is depth or time. After these initial processing steps, I used each processed profile to pick the layer interpreted as the top of the bedrock using a semi-automatic picker and subsequent manual edits. These data were exported in csv format for use in MBI's software of choice.

Results and Discussion

Figures in Appendix A show the collected data (Figure 1), a sample GPR profile along the lower road and upper road (Figures 2 and 3 respectively), and the results for depth to bedrock in colour-coded format (Figure 4). As suspected, the data collection in the parallel configuration were able to map the bedrock with more resolution than the perpendicular configuration on the lower road. Unfortunately, we were unable to complete th upper section in the parallel sled configuration for verification due to the width of the road and the vegetation along the sides of the roadway.

Along the lower road, the GPR data agrees well with the boreholes except at the center of the cross-section (Figure 2). Either the boreholes terminated before the bedrock surface, for example encountering a boulder; or the GPR is inaccurate at these locations. At the upper road, the bedrock depths have 2 notably deeper sections, but this interpretation is lower confidence. No borehole data exist along the upper alignment for ground-truth however.

Finally, the radar data do not indicate subsurface water movement or flow pathways. From the borehole logs, water perched on top of the bedrock may be too thin a layer to resolve with the GPR system needed for this work.

Uncertainty and Limitations

Overall, the data quality was qualitatively good for this survey. For the GPR data, the largest source of uncertainty for this project is picking the correct interface that corresponds to the bedrock surface in areas with multiple reflection events.

Logic Geophysics conducts surveys in accordance with best practices for the geophysical industry. However, geophysical methods are not infallible, and results are not guaranteed. No assumption of liability or warranty of results is implied or inherent by the performance of these services and production of these interpreted results.

Closing

Logic Geophysics conducted ground-penetrating-radar surveys at MP 357.1 near Healy, Alaska; and processed the resulting data to provide interpretations relevant to the project objectives of estimating bedrock depth below surface. Logic Geophysics completed the entire project with a focus on data quality and operations safety. We appreciate the opportunity to provide these services to MBI and ARRC and hope to work with your team again in future. Please contact me if you have any questions.

Sincerely,

Esther L. Babcock

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Service Disabled Veteran Owned – Certified Alaska DOT DBE – Woman Owned Small Business

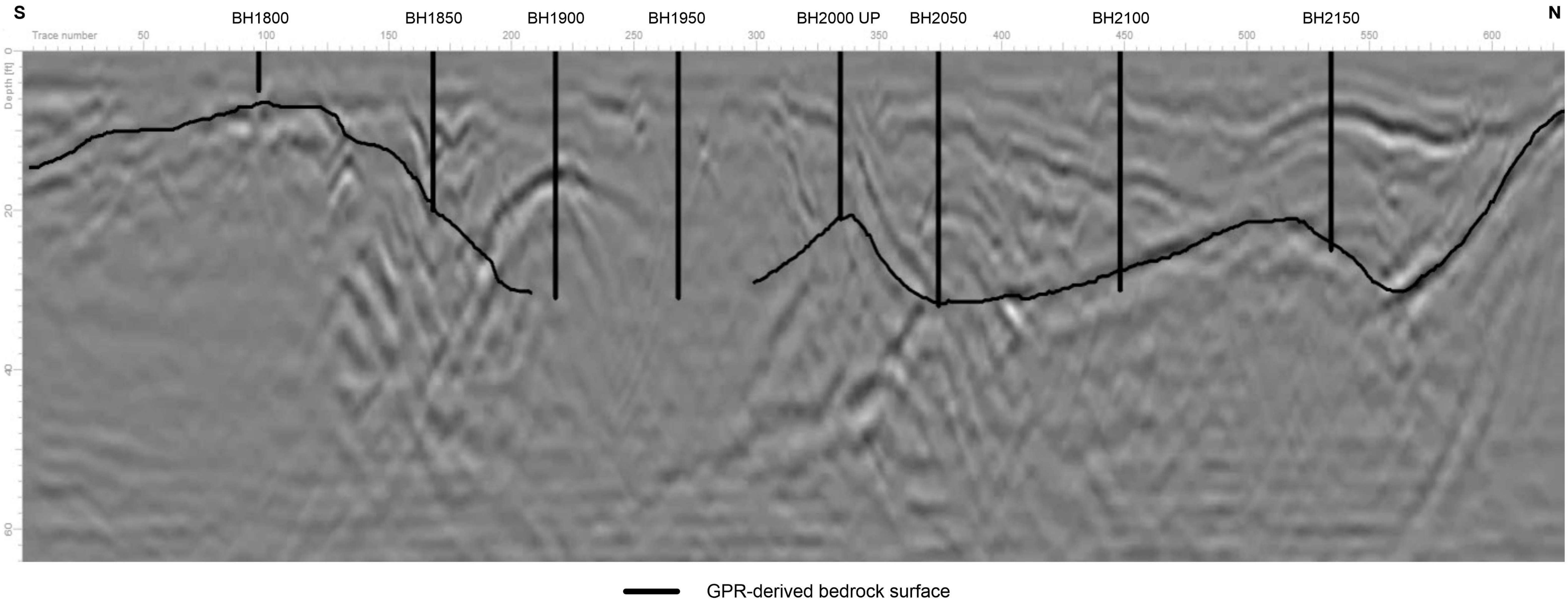
Appendix A

AK State Plane Zone 4, NAD83, Feet

Figure 1
Collected Data

LogicGeo
www.logicgeophysics.com

Project Name: Geophysical Surveys at MP357.1 Slope Stability and Drainage Improvement
Project no.: MGH25
Project Location: Healy, Alaska
File Name: ARRCHealyData.srf
Client: Michael Baker International, Inc.
Date Created: 17 February 2025
Field Dates: 16-17 Feb 2025
File Path: D:\\Projects25\MGH25\Figures



AK State Plane Zone 4, NAD83, Feet

Figure 2
Lower Road

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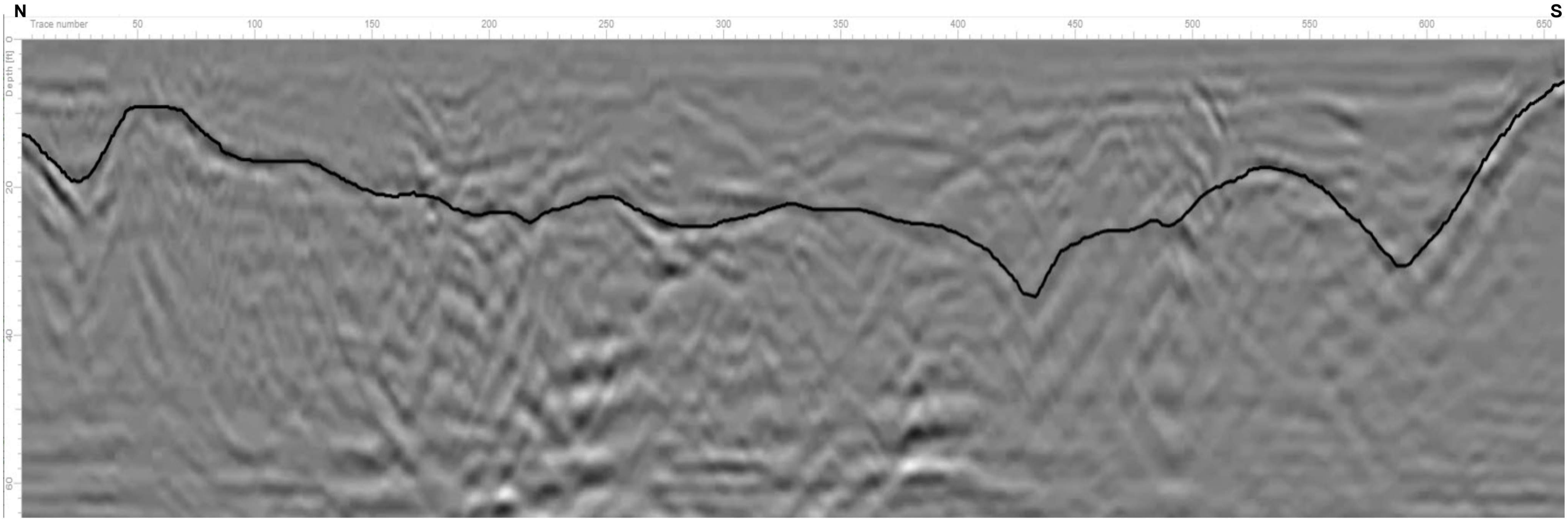
Project Name: Geophysical Surveys at MP357.1 Slope Stability and Drainage Improvement
Project no.: MGH25
Project Location: Healy, Alaska
File Name: ExampleProfile.srf
Client: Michael Baker International, Inc.
Date Created: 18 February 2025
Field Dates: 16-17 Feb 2025
File Path: D:\\Projects25\MGH25\Figures



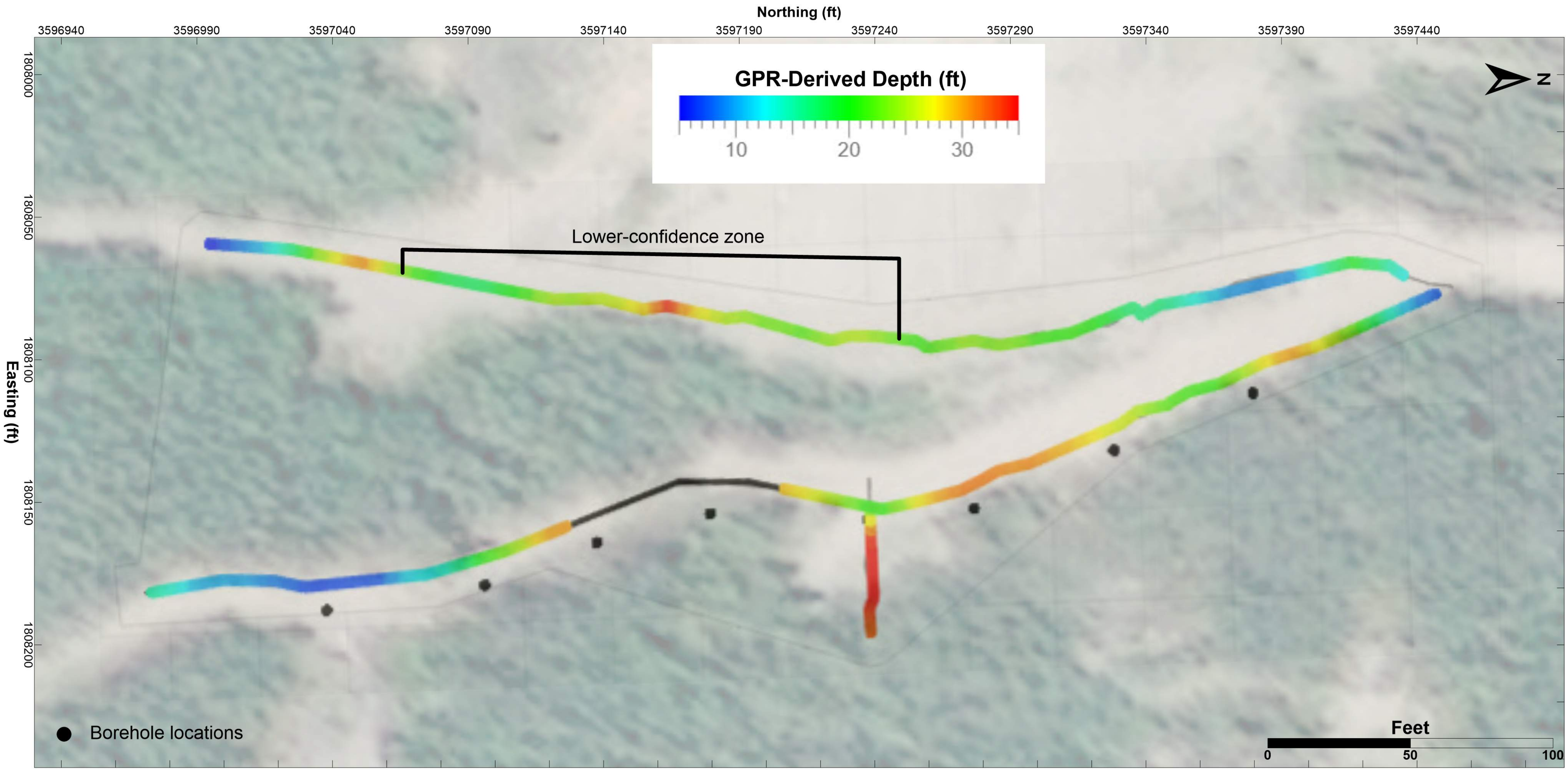
GPR-derived bedrock surface

AK State Plane Zone 4, NAD83, Feet

Figure 3
Upper Road

LogicGeo
www.logicgeophysics.com

Project Name: Geophysical Surveys at MP357.1 Slope Stability and Drainage Improvement
Project no.: MGH25
Project Location: Healy, Alaska
File Name: UpperRoad.srf
Client: Michael Baker International, Inc.
Date Created: 26 February 2025
Field Dates: 16-17 Feb 2025
File Path: D:\\Projects25\MGH25\Figures



AK State Plane Zone 4, NAD83, Feet

Figure 4
Results

LogicGeo
www.logicgeophysics.com

Project Name: Geophysical Surveys at MP357.1 Slope Stability and Drainage Improvement
Project no.: MGH25
Project Location: Healy, Alaska
File Name: Results.srf
Client: Michael Baker International, Inc.
Date Created: 18 February 2025
Field Dates: 16-17 Feb 2025
File Path: D:\\Projects25\MGH25\Figures