THURBER ENGINEERING LTD.

COUGAR CREEK LONG TERM MITIGATION PROJECT
GEOTECHNICAL INVESTIGATION FOR PHASE 1 – OPTIONS ANALYSIS

Report
to
the Town of Canmore

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NOV 9, 2015

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Date Nov. 9, 2015
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File: 19-598-440

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1. INTRODUCTION

This report summarizes the results of a geotechnical investigation carried out by Thurber Engineering Ltd. (Thurber) for the Town of Canmore (the Town), at the Cougar Creek alluvial fan. The work was conducted as part of the "Options Analysis" phase of the Cougar Creek Long Term Mitigation (CC LTM) project.

The work was originally conducted for ISL Engineering and Land Services Ltd. (ISL), under the terms of the contract between Thurber and ISL. As requested by ISL, this final report has been updated to reflect Thurber's new contract with the Town of Canmore.

The geotechnical investigation was aimed at assessing the subsurface conditions over a relatively wide reach of Cougar Creek, to a level suitable for selection of the most appropriate location of a debris flood retention structure, from a geotechnical perspective.

The investigation was planned and conducted with consideration given to protection of the environment (e.g., access to all test locations was selected so as not to damage vegetation). An implicit assumption is that a more detailed final investigation will be conducted at the selected location of the structure, during the design phase.

This report describes the work performed, discusses the anticipated stratigraphy at the currently proposed structure locations, and presents preliminary design parameters for the structure foundation.

This report is subject to the Statement of Limitations and Conditions included at the end of the text. The reader's attention is specifically drawn to these conditions as it is considered essential that they be followed for the proper use and interpretation of this report.

1.1 Background

Following a forensic analysis conducted by BGC Engineering Inc. (BGC), and an assessment and implementation of short-term risk mitigation measures, the Town retained *alpinfra consulting+engineering gmbh* (Alpinfra), based in Austria, to conduct an initial assessment of the options available for long term mitigation.

Three debris flood retention structure options were proposed by Alpinfra and presented at a meeting with representatives of the Town, ISL and Thurber on June 24, 2014, and at a workshop including several stakeholders on June 25, 2014. Three possible locations for the structure were presented, termed Options A, B and C. The structures considered are rockfill embankments with a thin reinforced concrete core, as well as a central concrete/steel rake component for debris retention. The structures ranged in height from about 11 m to 38 m above the current creek bed, and span the width of the valley. More details are included in Alpinfra's Interim Report 03, dated August 20, 2014. The axes of the structure in the three options, as provided by Alpinfra, are shown in Figures 1 and 2 in Appendix A.

It is understood that the options will also include additional smaller structures such as check dams, and in one case (Option C), will incorporate an additional gravel retention structure located more than a kilometre downstream of the main structure. No investigations were carried out at these other locations, and the recommendations provided herein should not be considered applicable to design of these ancillary structures.

1.2 Scope of Work

The scope of work for this investigation was outlined in our proposal to ISL dated July 10, 2014. A summary of the key tasks performed is as follows. It should be noted that due to the fast-track nature of this project, most of the tasks were conducted simultaneously and not necessarily in the order shown below.

- A site reconnaissance of the project area, to ascertain logistics for the field programs.
- A desk study, including a review of published and unpublished geological and geotechnical information.
- Surficial geology mapping of the project area.
- A geotechnical test hole drilling and test pitting program, to log overburden stratigraphy and depth to bedrock, and obtain samples for laboratory testing.
- Installation of groundwater monitoring wells at select locations, and completion of hydraulic conductivity tests.
- A geophysical survey program, to map depth to bedrock and, where possible, stratigraphic boundaries within the overburden soils. Vertical shear wave velocity profiles were also established near test hole locations.

- Preparation of a preliminary memorandum, to summarize the results of this investigation (issued on August 18, 2014), as well as a draft report (issued on September 22, 2014), followed by this final report.

Authorization to proceed with the work was provided by Mr. Félix Camiré, E.I.T., of the Town of Canmore via email message, dated July 11, 2014.

2. METHODOLOGY

2.1 Field Reconnaissance and Planning

On June 27, 2014, a detailed field reconnaissance of the project area was undertaken by Mr. Lucas Barr, P.Eng. and Dr. Heinrich Heinz, P.Eng. of Thurber to assess logistics requirements for the field drilling and test pitting programs.

2.2 Desk Study

Published and unpublished geotechnical and geological reports were collected and reviewed to help interpret the soil and bedrock conditions, and help establish preliminary design parameters for the various deposits. These included historic site investigations conducted to assess the subsurface conditions of proposed residential and commercial developments, and of sand and gravel resources in the Canmore corridor area. Recent records of anchor installation at the debris net installed near the location of Option A, and the test pitting information collected by BGC, as part of their debris flood hazard assessment of Cougar Creek, were also reviewed.

The desk study included geo-referencing all collected information. Table 1 lists the reports reviewed and the relevant geotechnical information extracted from each of them. The location of all historic and recent test holes and test pits is shown in Illustration 4, presented subsequently in Section 3.2 of this report.

Table 1. List of reports summarizing site investigations conducted near the study area

Reference	Report Title	Information Relevant to this Report
Edwards (1979)	Sand and Gravel Deposits in the Canmore Corridor Area, Alberta	Regional surficial geology map; one 60 m deep bore hole near Elk Run Blvd
O'Connor (1980)	Geotechnical Evaluation – Proposed Canmore Residential Subdivision and Commercial Area	Test hole and test pit log information; groundwater levels; water content; grain size distribution

Reference	Report Title	Information Relevant to this Report
EBA (1996)	Geotechnical Evaluation – Eagle Terrace Development Phase 1, Canmore, Alberta	Test hole log information; groundwater levels; BPT data
Sabatini (1997)	Geotechnical Design Report. Eagle Terrace Phase 2, Canmore, Alberta	Test hole log information; groundwater levels
Sabatini (2000)	Geotechnical Design Report. Eagle Terrace Phase 6, Canmore	Test hole log information; groundwater levels; BPT data
Keller (2014)	Various installation reports (field sheets)	Test hole log and test anchor reports
BGC (2014)	Cougar Creek – Debris Flood Hazard Assessment (Final)	Test pitting information

Notes:

1) The full references are listed at the end of the text of this report.

2) Mr. Félix Camiré provided the unpublished geotechnical reports and images for the area, available in the Town's archives. These reports are listed in the "references" section at the end of this report (refs. 3, 10, 12 and 13).

2.3 Surficial Geology Mapping

Geological field mapping was carried out to supplement the interpretation of the subsurface conditions based on limited drilling and geophysics. It also provided background for estimating ranges of properties based on geological origin of some of the deposits.

The work was conducted over a two-day period on July 21 and 22, 2014 by University of Calgary graduate student Ms. Mary Kruk, G.I.T., with support from Prof. Gerald Osborn, P.Geol. and Thurber's Ms. Rebecca Korolnek, E.I.T. Following a review of available published maps and reports for the general Canmore area, systematic field observations were conducted over the project area, including geo-referenced mapping and photographing of the various landforms, soil deposits and bedrock outcrops, as well as limited sampling. The resulting map is presented in Figure 1 in Appendix A.

2.4 Field Drilling and Test Pitting Programs

The program consisted of drilling five test holes and seven test pits at the locations shown in Figure 2 in Appendix A, and summarized in Table 2. Test holes TH14-2 to TH14-5 were drilled in the floodplain, and TH14-1 was drilled in the upper "kame terrace". The depth of the test holes ranged from 3.7 m to 24.4 m. All test pits were dug in the floodplain. The depth of the test pits ranged from 2.7 m to 5.8 m.

The locations of the test holes and test pits were established in the field by Thurber, and subsequently surveyed by ISL. All locations were cleared of underground utilities by Alberta One-call and a private locator prior to drilling. The test holes were located based on availability of access for a truck-mounted rig, with consideration given to minimizing impact to the environment (e.g., access to all locations was selected so as not to damage vegetation).

Table 2. Summary of test hole drilling and test pitting conducted by Thurber

Test ID	UTM NAD83		Ground Elev. (m)	Hole/Pit Depth (m)	Observation Well (see Table 4)
	Easting (m)	Northing (m)			
TH14-1	617376.0	5661244.0	1416.2	3.7	No
TH14-2	617452.0	5661164.0	1393.0	24.4	No
TH14-3	617434.1	5661321.7	1399.5	12.2	Yes
TH14-4	617496.7	5661467.7	1406.1	15.2	No
TH14-5	617561.2	5661618.0	1413.2	21.3	Yes
TP14-2	617450.4	5661173.0	1393.3	5.8	-
TP14-3	617427.5	5661308.4	1398.8	4.6	-
TP14-4	617494.1	5661499.6	1407.6	4.3	-
TP14-5	617552.4	5661606.9	1412.3	4.6	-
TP14-6	617421.0	5661260.8	1397.0	4.3	-
TP14-7	617464.6	5661310.1	1399.1	3.5	-
TP14-8	617544.8	5661467.7	1406.9	2.7	-

A truck-mounted dual rotary (“Barber”) drill rig supplied by Earth Drilling Co. Ltd. was used to drill in the floodplain. The Barber rig was used for its superior ability to penetrate the dense deposits with cobbles and boulders expected at the site. However, it should be noted that the dual rotary drilling method uses a percussion method to advance double walled drill pipe into the ground. Air is injected down the hole, forcing all cuttings to rise to the surface between the pipe walls and are discharged through a cyclone. As a result, only relatively small pieces of the overburden soils and bedrock are collected.

A small track mounted Fraste ML rig equipped with coring capabilities, supplied by Mobile Augers & Research Ltd., was used to drill in the “kame terrace”. It should be noted that coring of these soils was not entirely successful, as circulation water and vibrations dislodged the gravels and cobbles from the walls of the test hole, jamming the core barrel and limiting the depth of the hole to about 3.7 m (compared to a target of 8 m to 10 m).

The test pits were excavated using a John Deere 350D LC backhoe excavator operated by Bremner Engineering and Construction Ltd. The test pits were excavated within Cougar Creek floodplain; some were situated near the test hole locations and were used to enhance the assessment of the near surface conditions.

Representative samples from the major lithological units were obtained from cutting returns. All samples were logged in the field and then returned to Thurber's Calgary laboratory for further classification and testing. Samples of groundwater were also collected from the creek (immediately east of TP14-5), for chemical testing required as background for some of the geotechnical laboratory tests. In addition, a bulk soil sample was obtained from the wall of the "kame terrace" using the bucket of the excavator.

Observation wells were installed in test holes TH14-3 and TH14-5 to allow measurement of groundwater levels and performing in-situ hydraulic conductivity (permeability) tests.

Supervision of the drilling and testing programs was undertaken by Mr. Lucas Barr, P.Eng., Ms. Sarah Bryant, E.I.T., and Mr. Chris Murray, E.I.T. of Thurber. Field drilling and test pitting on the floodplain alluvium were undertaken from July 17 to 20, 2014, and on the "kame terrace" on July 29, 2014. The in-situ hydraulic conductivity (permeability) tests were performed by Mr. David Gorling, P.Geol. and Dr. Mauricio Pinheiro, P.Eng., on August 7, 2014.

Soil lithology and conditions encountered during drilling and test pitting (e.g. seepage, ease/ difficulty of drilling), as well as results of some laboratory tests performed, are summarized in the test hole and test pit logs presented in Appendix B. A summary of symbols and terminology used on the logs, as well as the Modified Unified Soil Classification System used in Alberta, is also included in Appendix B.

2.5 Geophysical Program

Geophysical surveys were carried out in July, 2014 by DMT Geosciences Ltd. The surveys consisted of three components: seismic refraction (SR), ground penetrating radar (GPR), and multispectral analysis of surface waves (MASW).

The objectives of the SR and GPR surveys were to map depth to bedrock, and where possible, map stratigraphic boundaries above the bedrock. A secondary objective of these surveys was to identify the location of possible paleo-channels along the west and east banks of Cougar Creek. The main objective of the MASW survey was to provide vertical profiles of shear-wave velocity at various test hole locations, to estimate elastic moduli for the modern alluvium and bedrock materials.

A report was prepared by DMT Geosciences summarizing the results of their investigation and interpreted surficial geology along the surveyed lines, and is included in Appendix D.

2.6 Laboratory and In Situ Testing Programs

Upon completion of the drilling and test pitting, a laboratory program was undertaken to characterize the alluvial fan and “kame terrace” deposits, and assess their potential for use as engineering materials. Potential degradation and erodibility of the “kame terrace” deposits when exposed to water were also assessed, on a preliminary basis.

Table 3 summarizes all the laboratory testing conducted by Thurber for this project.

Table 3. Laboratory and in situ testing conducted by Thurber for the Cougar Creek project

Test	Reference Method	Sample/Test Location	Purposes
Water Content Determination	ASTM D2216-10	TP14-2	Aid identification of various soil horizons.
Grain Size Distribution	ASTM D6913-04 (sieve and hydrometer analyses)	TP14-2, 3, 4 and 5 (see Illustration 5) and bulk sample (see Illustration 6)	Characterize the alluvial fan and “kame terrace” deposits, and estimate design parameters for these materials.
Crumb Testing	ASTM D6572-13E	TP14-6 and bulk sample	Indicator of resistance to erosion of the “kame terrace” deposit when exposed to water.
Jar Slake Testing	Santi (1998)	TP14-6 and bulk sample	Indicator of potential for degradation of the “kame terrace” deposit when exposed to water.
Creek Water Analysis	Various (see Appendix C)	East of TP14-5	Routine potability, pH and background for jar slake testing.

In addition to the laboratory testing described above, falling head and raising head permeability tests were performed in situ, in general accordance with ASTM D4044-96, on the observation wells installed on test holes TH14-3 and 5.

3. GEOLOGY

3.1 Bedrock Geology

The project area is situated in the Front Ranges of the Southern Rocky Mountains. The mountains in the area were formed as once-horizontal sedimentary beds were thrust from west to east during tectonic events, stacking up in a system of thrust faults and folds, as shown schematically in Illustration 1.

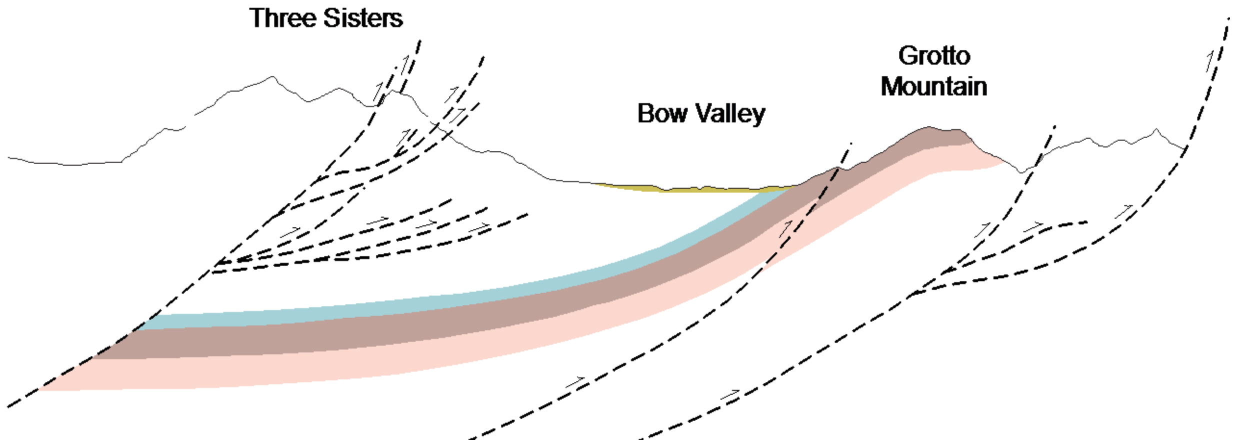

Illustration 1. Geological cross-section immediately east of project area – Looking west (adapted from GSC Structure Section No. 1, Map 1265A and 1266A, 1970). Colours illustrate different bedrock formations, and arrows denote location of thrust faults

Near Canmore, the faults are aligned in an approximate northwest to southeast direction. The bedrock on the southwest facing slopes of the Cougar Creek valley, located on the left-hand side of Grotto Mountain in Illustration 1, dips to the southwest.

Glacial and fluvial action within the Bow Valley resulted in erosion of the valley walls, cutting steep slopes across the layers on both valley walls. As a result, unsupported rock slabs dipping into the valley on the right side (looking west) slid down, with the rockslide debris carried away by further glacial and fluvial action. Within the Cougar Creek area, it is believed the rock surface was subsequently buried with glacial and post-glacial soil deposits, including those associated with fan deposition, as shown schematically in Illustration 2.

Illustration 2 helps explain why the bedrock in the test holes drilled within the project area was found to be alternately shallow and deep, with jagged edges outcropping in a few locations. The bedrock between the TransCanada Highway and Elk Run Boulevard appears to be very deep, in excess of 60 m below ground surface (based on Edwards, 1979 – log of test hole DH-76-4 – and anecdotal evidence).

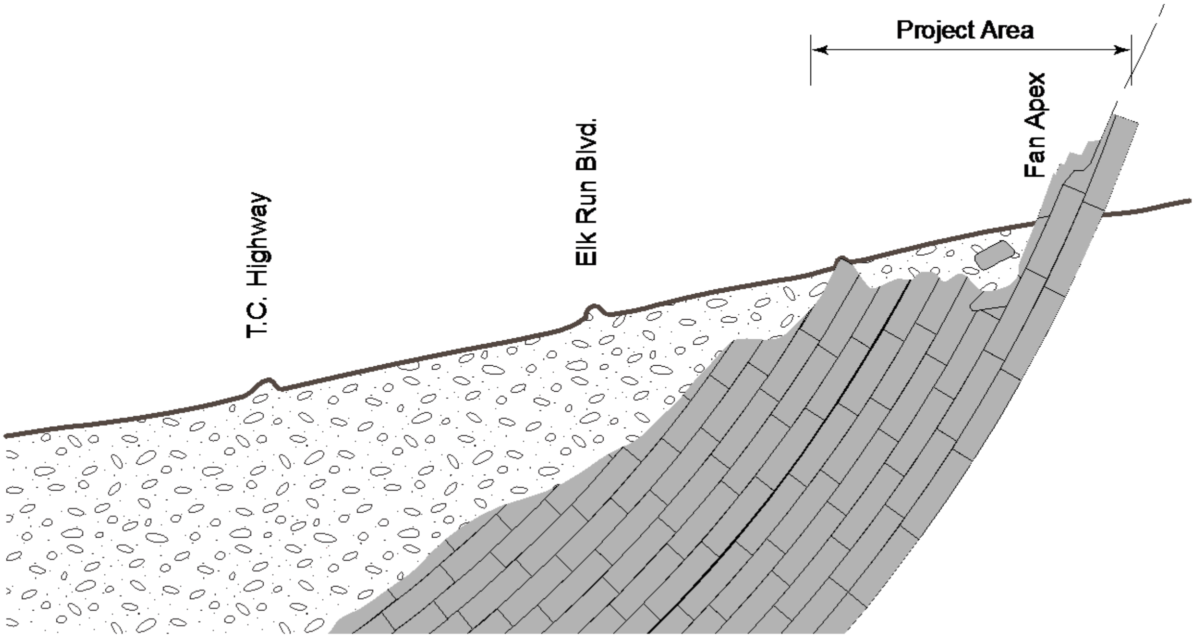

Illustration 2. Possible profile along Cougar Creek drainage near project area showing bedrock "slabs" overlain by mostly granular deposits – Looking west

Bedrock has been mapped at various locations within the project area shown in Figure 1 in Appendix A. Based on Map 1266A published by the Geological Survey of Canada (GSC) in 1970, and as part of the surficial geology mapping conducted for this project, the following bedrock formations have been identified in the area:

Mississipian Etherington Formation (Met)

Light grey limestone, cherty limestone and calcarenitic limestone, dolomite, cherty dolomite, green and red shale, siltstone, breccia.

Permian and Pennsylvanian Rocky Mountain Group (PPrm)

Light grey quartz sandstone, dolomitic sandstone, silty dolomite, chert.

Triassic Sulphur Mountain Formation (Trsm)

Dark grey and brown, thin bedded siltstone, silty mudstone, shale and dolomitic siltstone.

The approximate boundaries between these formations are shown on the surficial geology map in Figure 1, Appendix A.

3.2 Surficial Geology

Descriptions of the glacial history of the area, as well as the naming of the various glacial deposits in the Bow Valley corridor, have been traditionally based on Rutter (1972). For this project, however, the mapping and nomenclature utilized by Edwards (1979) have been adopted, as these were prepared for gravel resource development and contain soil properties of interest to design. Edwards's glacial history appears consistent with Rutter's; however, his surficial geology map (shown in Figure 3, Appendix A) is a better match of the topography encountered in the vicinity of Cougar Creek than that published by Rutter.

Both Edwards and Rutter recognized multiple Pleistocene glaciations in the Canmore area, with some differences in the interpreted origin and naming of the various deposits (e.g., Rutter's "kame terrace" deposits in the general area are termed "dirty outwash" by Edwards). Both authors indicate that the subsurface conditions of the area are complex, with multiple layers of glacial till, glaciofluvial sands and gravels, and glaciolacustrine silts and clays underlying the present ground surface.

Into the Holocene (an epoch that began 11,700 years ago at the end of the Pleistocene and continues to the present), Cougar Creek began to cut into the Pleistocene deposits on the northwest side of the Bow Valley. The creek reworked the older deposits and added debris from the creek catchment, with consequent redistribution of sediment out onto the alluvial fan to the southwest. There were also episodes of aggradation, when gravel was deposited along the creek instead of being eroded from it, eventually reaching the modern day flood plain level. Illustration 3, derived from the 2013 post-flood LiDAR provided by the Town, gives an insight into these glacial and postglacial geologic processes.

The surficial geology mapping carried out specifically for this project involved a review of the 2013 LiDAR imagery, a review of Edwards's glacial geology map (incorporated in Illustration 4), and field mapping for identification of the various units. The following is an abbreviated description of the glacial and bedrock deposits identified in Figure 1 in Appendix A.

Modern Cougar Creek Alluvium (Qma)

This unit consists of moderately well to well-sorted gravels, cobbles and boulders. Clasts are typically sub-rounded to rounded and are mainly quartzite, carbonates (probably both limestone and dolostone), and quartz-rich sandstone. Most of the gravels appear to have been affected by recent anthropogenic activity (i.e., caused or influenced by humans), particularly since the 2013 flood event.

Cougar Creek Colluvium/Alluvium – Lower and Upper Bench (Qc/a-l and Qc/a-u)

This material is found within "lower" benches straddling both sides of the creek and situated one to two metres above the modern flood plain, and an "upper" bench five to seven metres higher than the lower benches. This unit is highly variable, consisting mostly of a poorly sorted diamict but with lenses of sorted gravels. Clast content is up to 70% and clast sizes range from gravel to boulder. There is some cementation, but not sufficient to provide significant mechanical strength. In the upper bench, there are fewer exposures of the unit but available indications are that the sediment there is similar to that in the lower benches.

Glaciofluvial Dirty Outwash – "Kame Terrace" (Qgf)

This clast-supported deposit has massive unsorted beds alternating with well-sorted outwash gravel to cobble beds with distinct imbrication of clasts. Clast content is high (up to 80%) and clasts are sub-angular to rounded, and are mostly limestone, dolostone, quartzite and sandstones. Edwards (1979) stated that this unit carries between 5% and 10% fines. This unit displays varying degrees of cementation.

Till (Qt)

This massive, unsorted diamict unit is matrix-supported with approximately 40% clast content. The matrix is a silty fine sand with low to moderate cementation, judging from mechanical strength, but is highly effervescent when tested with HCl acid, indicating a calcite-dominant matrix. The clasts are of mixed lithology, but mainly quartzite. Clasts range in size from coarse sand to cobble and are angular to sub-rounded. The till overlies the glaciofluvial dirty outwash deposits.

Illustration 3. 2013 post-flood LiDAR imagery provided for the Town of Canmore. Note erosion of the glacial deposits by Cougar Creek (boxed area)

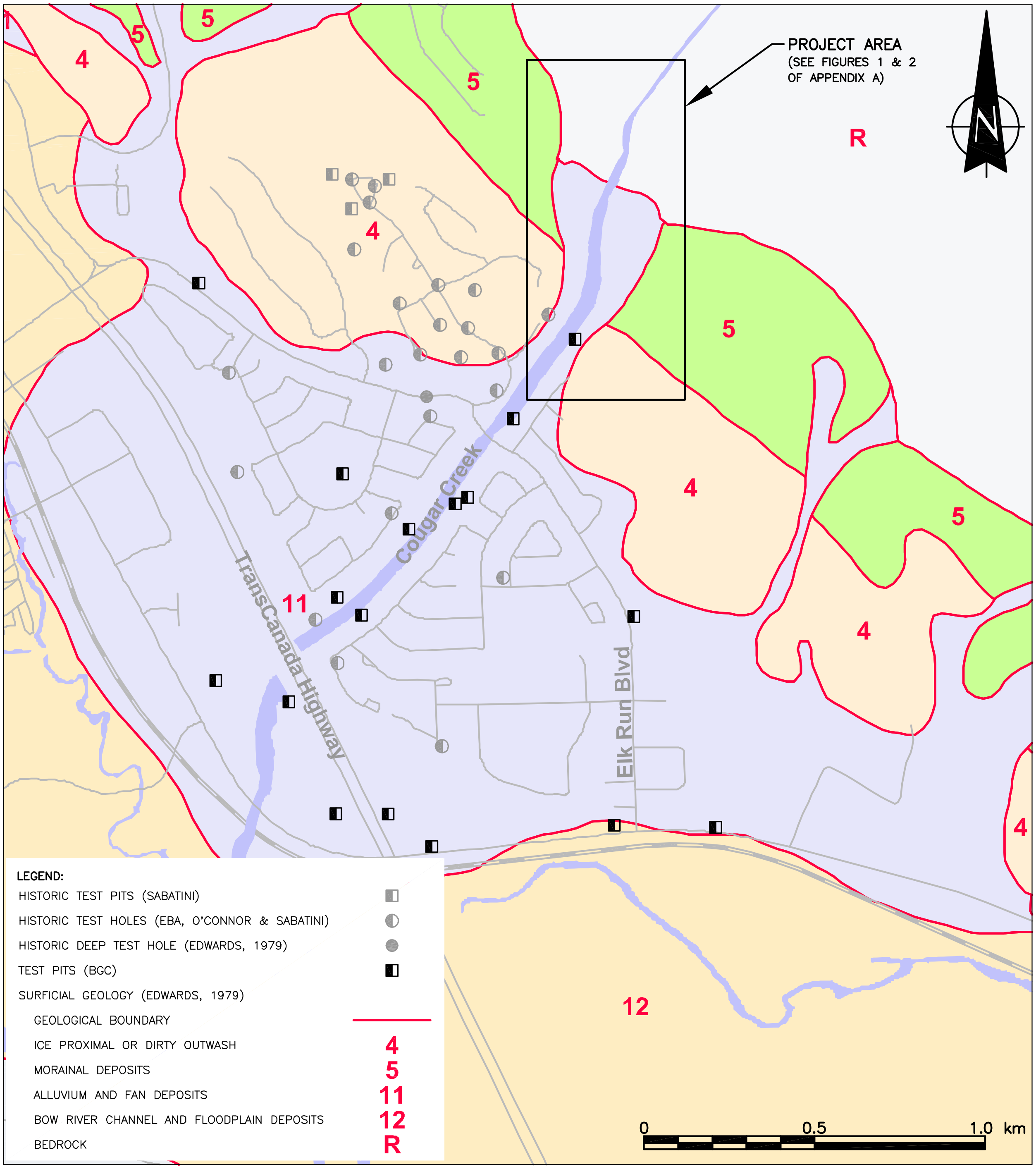

Illustration 4. Glacial geology map by Edwards (1979) and location of historic site investigations. Note very limited historic investigations were carried out within the project area

4. SUBSURFACE CONDITIONS WITHIN PROJECT AREA

4.1 Stratigraphic Sections

Preliminary stratigraphic sections are presented in Figure 3, Appendix A. These were drawn based on the geology mapping, test hole drilling, test pitting and geophysical surveys; however the information collected for Option A was augmented with the records of installation of anchors for the temporary debris flow net which exists at that location. The stratigraphic boundaries between the Cougar Creek geological units Qma (modern alluvium) and Qc (older colluvium/alluvium), and the top of bedrock were interpreted primarily on the basis of the geophysical seismic refraction and GPR surveys.

These stratigraphic sections are considered adequate for a discussion on selection of the structure option from a geotechnical perspective, and for identification of areas requiring further investigations. They are not recommended for design purposes.

4.2 Subsurface Conditions

The results of the drilling and test pitting program, in conjunction with the historic data, geological mapping and geophysical surveys, allow a preliminary characterization of the main soil deposits of interest to this project. These were augmented by the limited laboratory testing conducted for the various soil deposits.

For the level required for the present assessment, and following the geological descriptions included in Section 3 (and shown on the stratigraphic sections), the characteristics of the key units are as follows:

Modern Cougar Creek Alluvium (Qma) and Colluvium/Alluvium (Qc/a) Deposits

These soils occupy a large proportion of the proposed structure foundations, are of local origin (mostly quartzite and limestone), and predominantly well graded gravels and gravel-sand mixtures with little fines; however they include horizons with higher (> 60%) fines content, and a significant (up to 50%) component of cobbles and boulders.

Grain size testing was performed on six samples collected from the test pits excavated within the modern flood plain. Five of the samples were truncated at a maximum grain size of 100 mm. For one sample (from TP14-03 at 1.6 m depth), the maximum size was set at 300 mm.

Illustration 5 shows the grain size distribution curves for these materials, together with grain size curves reported by Edwards (1979), O'Connor (1980) and the range given by BGC (2014) for debris flood deposits in this area.

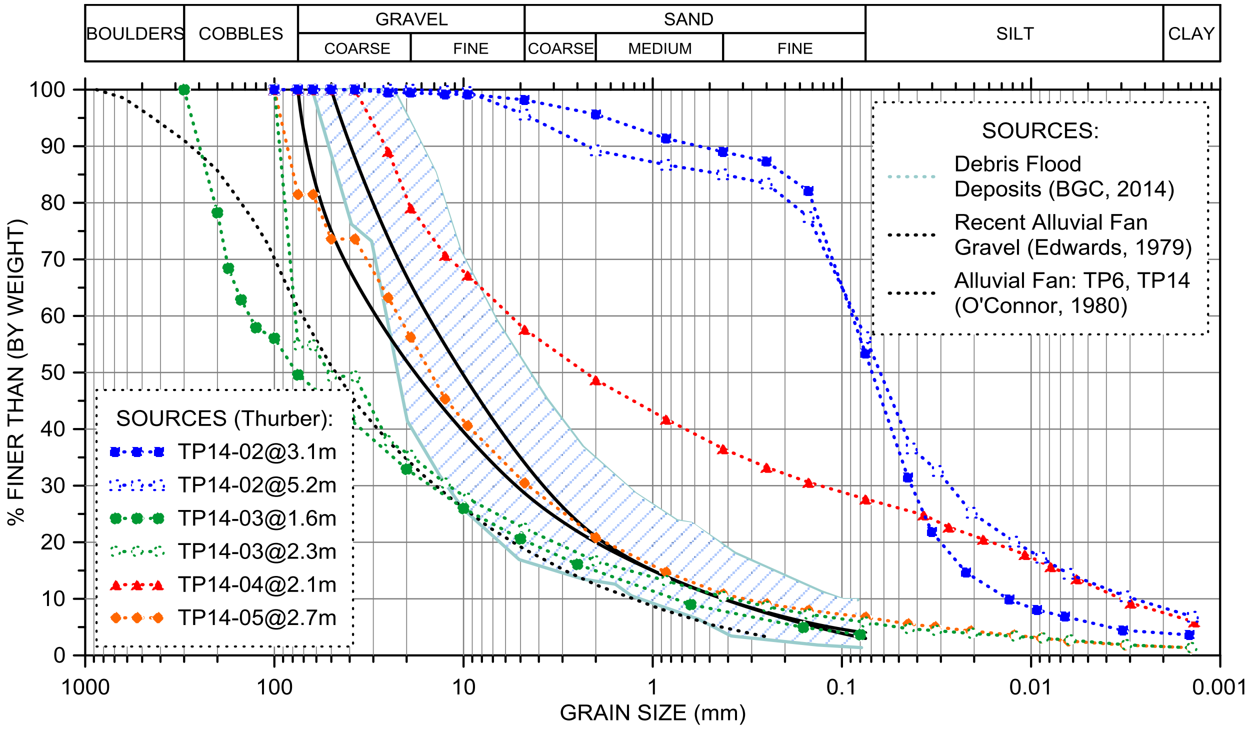

Illustration 5. Grain size curves for the Modern Cougar Creek Alluvium (Qma) and Colluvium/Alluvium (Qc/a) deposits

Becker hammer blow counts measured in other areas of the Cougar Creek fan were mostly in the 40 to 120 range within the upper 10 m. These deposits are therefore considered to be generally in a dense to very dense state. Moisture contents measured during this investigation were usually under 10%, and occasionally up to 20% in the horizons with higher fines content. These appear to be higher than those measured within the fan, outside the project area, where the sand and gravel deposits were essentially dry.

Shear wave velocity measurements in these deposits vary widely, and based on a review of the data collected by DMT (Appendix D), result in dynamic shear moduli (G_{max}) in the 100 MPa to 500 MPa range.

An important observation concerns groundwater inflows into the test pits. Major water inflow was encountered during excavation of test pits TP14-3, 5 and 8. Most of the seepage was noted below a depth of approximately two metres; however, in test pits TP14-7 and 8, the seepage was shallower and caused significant sloughing of the excavation walls. These field observations indicate very pervious soils, and are consistent with hydraulic conductivities in the order of $k = 10^{-2}$ m/s to 10^{-3} m/s, estimated from the grain size curves. The range calculated from the in situ tests, screened below 2 m depth, is lower and between $4 \cdot 10^{-5}$ m/s and 10^{-4} m/s, suggesting either a decrease in hydraulic conductivity with depth, or a high variability within these deposits. Because of the high significance of water inflows for design and construction of the structure's foundations, additional testing will need to be considered in the final investigation.

Glaciofluvial Dirty Outwash – "Kame Terrace" (Qgf)

These deposits are encountered primarily on the right (west) abutment of Options B and C, as illustrated in Figures 1 and 3, Appendix A. They display a high gravel and cobble content and varying degrees of cementation, and are able to stand at essentially vertical slopes. Though not apparent at this location, these deposits can include clean outwash sand horizons, which could be more permeable and of potential concern due to a higher permeability. Moreover, while the steep exposed slopes indicate a high shear strength, it is not known how much of this shear strength is dependent on the cementation bonds, which in similar cemented soils have been observed to degrade when subject to wetting or groundwater seepage.

A grain size analysis was conducted in a sample collected by Thurber from an exposed terrace face. The grain size distribution curve for this material is presented in Illustration 6, together with a curve reported by Edwards (1979) for a sample of Bow Valley "ice proximal outwash dirty sand gravel" (exact location unknown). Both samples display up to about 80% gravel size and under 10% fines, which is consistent with Edwards's observations. It should be noted that some breaking of the smaller clasts was induced during sample preparation.

Test holes drilled using a Becker hammer drill rig in the residential subdivisions located immediately to the east displayed variable but high blow counts, generally between 50 and 200. These are indicative of the very dense state of these soils. Moisture contents were generally under 5%.

Jar slake tests and crumb tests were conducted on the bulk soil sample obtained from the terrace wall and on a “buried” sample obtained from TP14-6 at 4.3 m. These tests were conducted with both distilled water and creek water, with a maximum immersion time of 24 hours. The results of these tests, summarized in Appendix C, indicate these materials present a surficial “fines” phase, with high potential for degradation and erodibility, and a deeper “coarse” phase, which is cemented and less prone to degradation and erosion. It should be noted that a significant portion of the cementation bonds were broken due to washing of the bulk sample, suggesting a relatively high potential for erodibility of these deposits when exposed to flowing water.

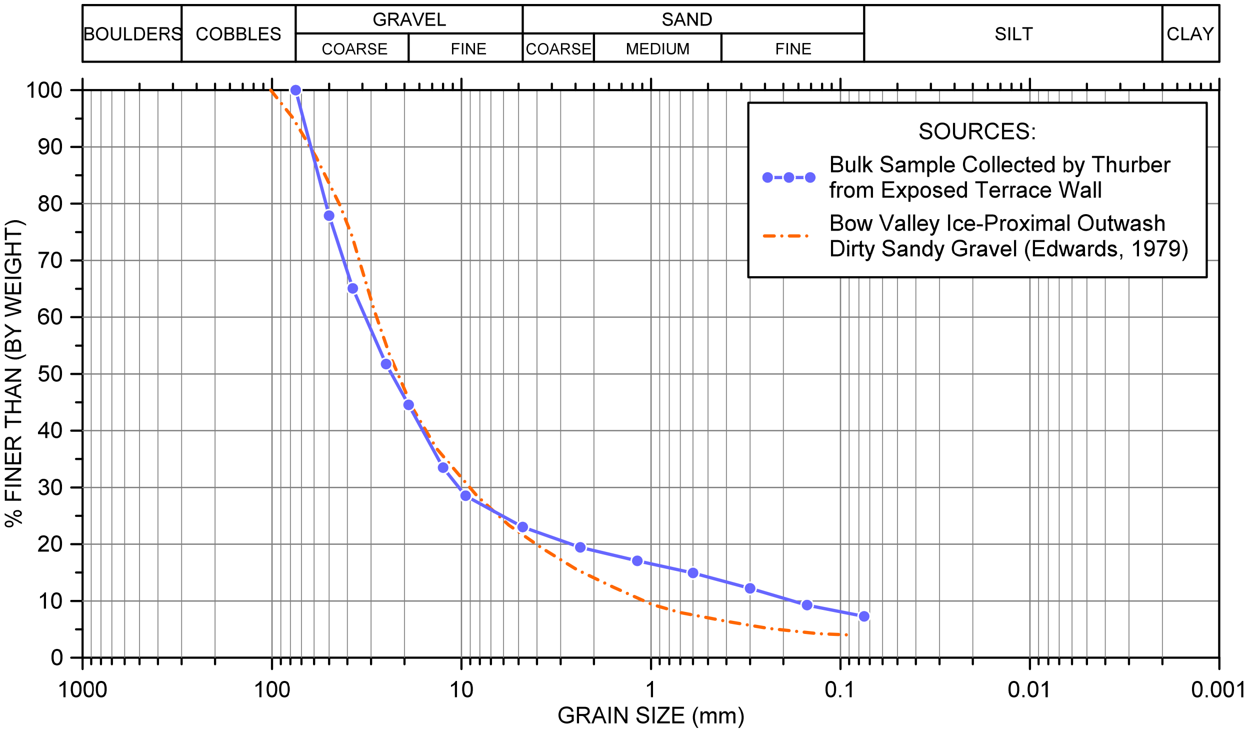

Illustration 6. Grain size curves for the Glaciofluvial Dirty Outwash (“Kame Terrace”)

Till (Qt)

These soils could be encountered in the abutments of all three structure options currently being considered, but appear to be more prominent on the left (east) abutment of Option B. Although these “mountain tills” are generally mechanically strong, no testing was conducted and more investigations may be required for final design, depending on the option chosen.

Bedrock (PPrm and Trsm)

No bedrock coring was conducted during this initial investigation. Inspection of some outcrops was conducted, and the identified outcrops are mapped in Figure 1. The bedrock outcrop at the north end of the project area, near the Option A alignment, appears to be limestone, with strike and dip 140°/30° (SW). The outcrops near Options B and C were identified as brown siltstone, with strike and dip 140°/45° (SW).

Qualitative strength testing, based on the number of blows required to break a sample using a geologist's hammer, suggests unconfined compressive strengths ranging from medium strong to strong (25 MPa to 100 MPa). These strengths are approximate and likely representative of weathered rock only (i.e., less than the strengths anticipated in deeper, less weathered horizons).

4.3 Groundwater Conditions

Depth to groundwater in the observation wells was recorded in July 2014 on completion of the test holes, and again in August 2014, before performing the slug tests. Table 4 provides a summary of this information.

Table 4. Summary of recorded groundwater elevations

Test Hole	Ground Elevation (m)	Screen Depth (m)	Average Water Elevation (m)	Recorded Season
TH14-3	1399.5	2.7–4.5	1397.7	July-August, 2014
TH14-5A	1413.2	4.0–5.8	1409.6	July-August, 2014
TH14-5B	1413.2	11.0–14.2	1408.9	July-August, 2014

The groundwater table was also inferred from the geophysical SR surveys, based on the velocity contrast between saturated and unsaturated sediments (see Appendix D). The inferred water table is shown on the stratigraphic sections in Figure 3, Appendix A.

It should be noted that groundwater levels fluctuate seasonally and in response to climatic conditions. They are expected to be lower in the fall and winter, as compared to spring and summer; however since no recorded measurements exist at this location, it would be necessary to conduct measurements over at least one or two years to assess the potential variability of the water table.

5. GEOTECHNICAL PARAMETERS FOR PRELIMINARY DESIGN

Due to the coarse nature of the soils at this site, and the short time frame in which the investigations were conducted, no testing that could yield density and strength parameters was conducted. To establish the preliminary design parameters given in Table 5, emphasis was placed on an analysis of index tests and correlations with the results of in situ tests conducted in nearby sites, categorized geologically as described in Section 4.2.

The properties suggested in Table 5 are based on visual descriptions made during the field investigations, analysis of limited laboratory testing, grain size tests, rising head permeability tests conducted in the wells installed in TH14-3 and 5, and correlations with deposits identified in the area (e.g. Edwards, 1979; O'Connor, 1980; EBA, 1996; Sabatini, 1997 and 2000).

6. CLOSURE

The following key observations and findings of this investigation should be considered in the preliminary design, and in the planning of subsequent investigations.

- Major water inflow was encountered during excavation of test pits TP14-3 and TP14-5 to TP14-8. Most of the seepage was noted below a depth of approximately two metres; however, in TP14-7 and 8, the seepage was shallower and caused significant sloughing of the excavation walls.
- The surface of the bedrock is believed to be located at variable depths, and is likely irregular ("jagged"), due to the nature of the geological formations. The bedrock stiffness could also be significantly higher than that of the surrounding coarse-grained soils. There is a moderate concern with positioning of the structure components in order to reduce the risk of differential settlements after construction.
- The coarse-grained soils in the floodplain are, in principle, adequate for use in the structure shells. Consideration will have to be given, during the next phase of the investigation, to establish the compaction properties and construction specifications for these soils.
- For Options B and C, there is moderate concern with degradation and erodibility of the "kame terrace" material in the presence of flowing water. While this does not appear to be an obstacle for any of these two option locations, consideration may have to be

given, in the final design, to some form of protection of the terraces against flowing water.

- For Options B and C, there is also a moderate concern with an increase in underground seepage, due to the impoundment of water, towards the western portion of the site and potentially under residential areas. This seepage could occur through more pervious horizons occurring within the “kame terrace” deposits, or underneath these deposits.
- Based on the anticipated consequence category and regional seismicity, the structure should be designed to withstand earthquake loading. On a preliminary basis, it is recommended that an Earthquake Design Ground Motion (EDGM) of 0.15 g be used in the designs.

REFERENCES

1) Alpinfra, 2014. Moutain Creek Hazard Mitigation – Design of Mitigation Measures. Interim Report 03: Basic Data Assessment Option Analysis - Update 01. Dated: August 20, 2014.
2) BGC Engineering Inc., 2014. Cougar Creek – Debris Flood Hazard Assessment (Final). Report TC13-010, prepared for the Town of Canmore.
3) Duncan, J.M. (2004). Notes of a lecture presented at the Kenneth L. Lee Memorial Seminar, Long Beach, CA.
4) EBA Engineering Consultants Ltd., 1996. Geotechnical Evaluation – Eagle Terrace Development Phase 1, Canmore, Alberta. Prepared for Southwell Trapp and Associates Ltd.
5) Edwards, W.A.D., 1979. Sand and Gravel Deposits in the Canmore Corridor Area, Alberta. Alberta Research Council. Earth Sciences Report 79-2.
6) Fookes, P.G., Gordon, D.L. & Higginbottom, I.E., 1975. Glacial landforms, their deposits and engineering characteristics. Proc., Symp. Engineering Behaviour of Glacial Materials, Univ. of Birmingham.
7) Gadd, B., 2009. Canadian Rockies Geology Road Tours, Corax Press, Jasper, AB.
8) Heinz, H. K., 1988. Properties of soils in glaciated upland valleys (part of Ph.D. Thesis on Large Cross Section Tunnels in Soft Ground, Dept. of Civil Eng., U. of Alberta).
9) Hvorslev, M.J., 1951. Time lag and soil permeability in ground-water observations. Bull. No. 36, Waterways Experiment Station, Corps of Engineers, US Army.

10) Kulhawy, F.H. & Mayne, P.W., 1990. Manual on Estimating Soil Properties for Foundation Design. Cornell University, Ithaca, NY. Prepared for Electric Power Research Institute.

11) Leps, T.M., 1970. Review of shearing strength of rockfill. J. Soil Mechanics and Foundations Division, ASCE, SM4, pp. 1159-1970.

12) O'Connor and Associates, 1980. Geotechnical Evaluation – Proposed Canmore Residential Subdivision and Commercial Area. Report 10-038, prepared for Engineering Canada Associates.

13) Rutter, N. W., 1972. Geomorphology and multiple glaciation in the area of Banff, Alberta. GSC Bulletin 206.

14) Sabatini Earth Technologies Inc., 1997. Geotechnical Design Report. Eagle Terrace Phase 2, Canmore, Alberta. Prepared for Southwell Trapp & Associates Ltd. and Eagle Terrace Inc.

15) Sabatini Earth Technologies Inc., 2000. Geotechnical Design Report. Eagle Terrace Phase 6, Canmore. Prepared for Southwell Trapp & Associates Ltd.

16) Santi, P. M. 1998. Improving the Jar Slake, Slake Index, and Slake Durability Tests for Shales. Environmental & Engineering Geoscience, Vol. IV, No. 3, pp. 385-396.

17) Sitar, N., 1990. Seismic Response of Steep Slopes in Weakly Cemented Sands and Gravels. Proceedings of the H.B. Seed Memorial Symposium, pp. 67-82.

18) Somerville, S.H. 2005. Control of Groundwater for Temporary Works. CIRIA.

19) Terzaghi, K., Peck, R.B. & Mesri, G., 1996. Soil Mechanics in Engineering Practice. 3rd. John Wiley & Sons, New York.

20) Thurber Engineering Ltd., 2007. Review of SPT-BPT correlations and BPT procedural requirements (internal report).

Table 5. Preliminary geotechnical properties of soils encountered in the study area

Soil Properties/ Parameters	Alluvial Fan (Qma)	Colluvium/ Alluvium (Qc/a)	Glaciofluvial "Kame Terrace" (Qgf)	Till (Qt)	Remarks
Unified Soil Classification	ML, GP-GM, GP, GW-GM, GW	*Assume properties equal to **Qma** for preliminary design purposes*	GP-GM		Based on the grain size curves presented in Section 5
Particle Shape	sub-angular to sub-rounded		sub-angular to rounded	angular to sub-rounded	Based on visual observations
Water Content (%)	< 5		< 5		Based on historic data, and water content determination tests presented in Appendix B
Relative Density	dense to very dense		dense to very dense		Based on BPT data*
Bulk Unit Weight (kN/m^3)	17.7–21.6		–		Heinz (1988)
	–		17.7–20.6		Fookes et al. (1975)
	20		**20**		Recommended
Cohesion (kPa)	0		–		Uncemented cohesionless material
	–		10		Conservative estimate for cemented gravels (close to lower values published by Sitar, 1990 and other authors)
	0		**10**		Recommended
Friction Angle (degrees)	45–47		–		Terzaghi et al. (1996) – Fig. 19.4 and Tab. 19.3 (Class C or R5 grade[†])
	–		44–48		Terzaghi et al. (1996) – Fig. 19.4 for n = 0.30–0.35
	44–46		–		Leps (1970) – Fig. 1 for normal pressure: 126–210 kPa[‡] (data augmented by Duncan, 2004)
	>45 or >41		>45 or >41		Kulhawy & Mayne (1990) – Tab. 4-3 (N_{SPT} > 50)*
	–		36.6		Fookes et al. (1975)
	–		–	37	Sabatini (1997) – Adopted for slope stability assessment
	42		**37**	**37**	Recommended
Young's Modulus (MPa)	60–400				MASW tests
	100				Recommended
Hydraulic Conductivity (m/s)	$1 \cdot 10^{-2}$–$3 \cdot 10^{-2}$		$8 \cdot 10^{-5}$		Based on grain size distribution provided by Edwards (1979)[¥]
	$1 \cdot 10^{-3}$–$6 \cdot 10^{-3}$		$4 \cdot 10^{-4}$		Based on grain size distribution curves for TH14-3[¥]
	$4 \cdot 10^{-5}$–$1 \cdot 10^{-4}$		–		Based on slug tests conducted by Thurber for this project (observation wells installed on test holes TH14-3 and TH14-5)[£]
	$\mathbf{10^{-3}}$		$\mathbf{4 \cdot 10^{-4}}$		Recommended

Notes:

* Becker penetration test (BPT) data from EBA (1996) and Sabatini (2000). N_{SPT} assumed equal to N_{BPT} (Thurber, 2007).

[†] R5 grade: very strong rock (q_c = 100–250 MPa)

[‡] Vertical effective stress within the range 126–210 kPa (for a 12–20 m high embankment with an average bulk unit weight of 21 kN/m^3).

[¥] Estimated values based on Hazen's equation: $k = C/1000 \cdot (D_{10})^2$; where: D_{10} (in mm), C is a constant, typically equal to 100 for preliminary estimation (Somerville, 2005).

[£] Slug test results interpreted using Hvorslev Time Lag method (Hvorslev, 1951).

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This Report has been prepared in accordance with generally accepted engineering or environmental consulting practices in the applicable jurisdiction. No other warranty, expressed or implied, is intended or made.

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b) Reliance on Provided Information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to Thurber. Thurber has relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, Thurber does not accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations, or fraudulent acts of the Client or other persons providing information relied on by Thurber. Thurber is entitled to rely on such representations, information and instructions and is not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.

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d) Construction Services: During construction Thurber should be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions in order to confirm and document that the site conditions do not materially differ from those interpreted conditions considered in the preparation of the report. Adequate field reviews are necessary for Thurber to provide letters of assurance, in accordance with the requirements of many regulatory authorities.

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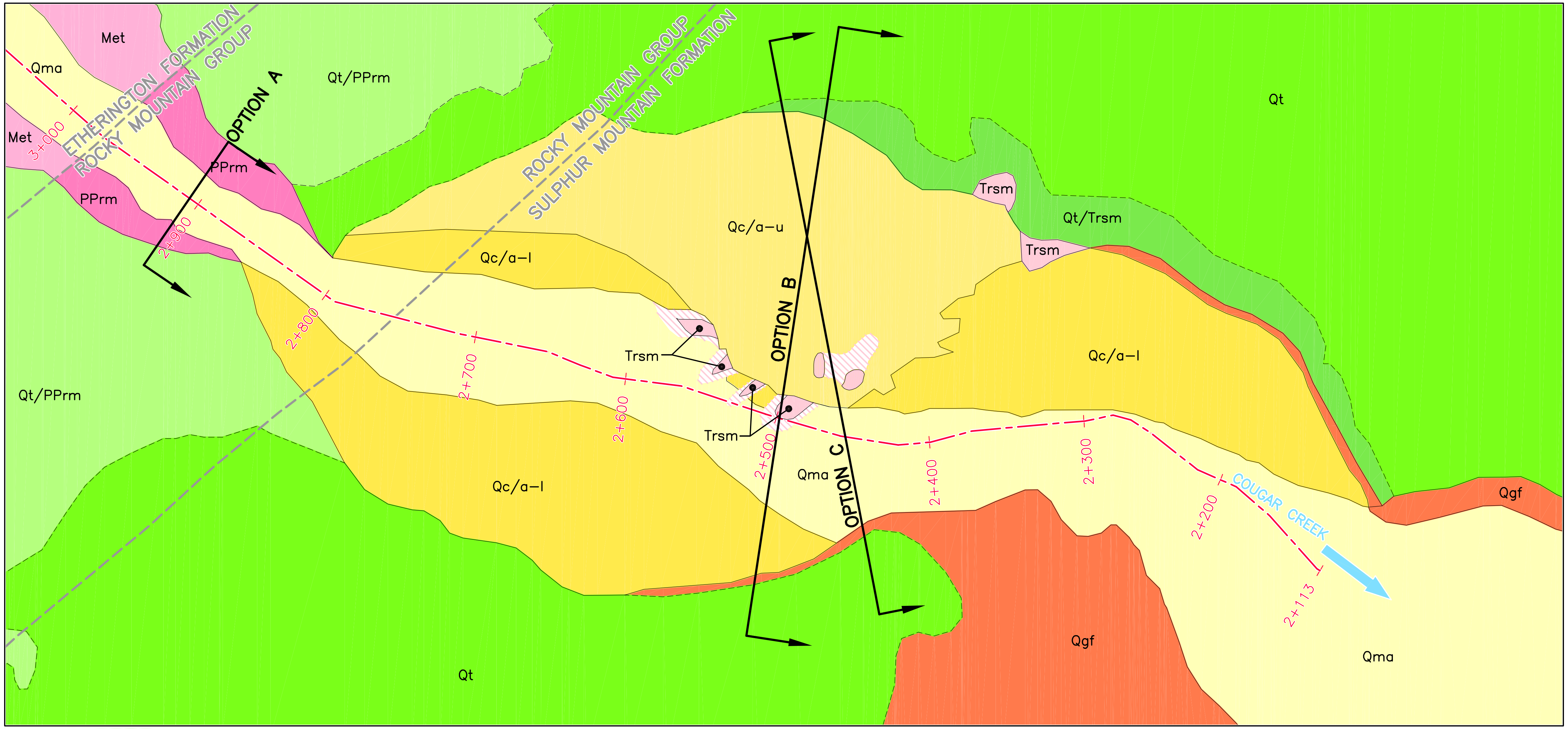
APPENDIX A

Figures



LEGEND:

CHAINAGE	— - —
MODERN COUGAR CREEK ALLUVIUM	Qma
COUGAR CREEK COLLUVIUM/ALLUVIUM (LOWER)	Qc/a–l
COUGAR CREEK COLLUVIUM/ALLUVIUM (UPPER)	Qc/a–u
TILL	Qt
GLACIOFLUVIAL DIRTY OUTWASH ('KAME TERRACE')	Qgf
ETHERINGTON FORMATION (BEDROCK)	Met
ROCKY MOUNTAIN GROUP (BEDROCK)	PPrm
SULPHUR MOUNTAIN FORMATION (BEDROCK)	Trsm
POTENTIAL SHALLOW BEDROCK	▨
TILL/COLLUVIUM VENEER OVERLAYING BEDROCK	Qt/PPrm
TILL/COLLUVIUM VENEER OVERLAYING BEDROCK	Qt/Trsm
CONTACT LINE	———
INFERRED CONTACT LINE	- - - - -

NOTES:

1 DRAWING MUST BE USED IN CONJUNCTION WITH THE ATTACHED REPORT REFERENCE 15–598–440 DATED NOVEMBER 2015.

2 OPTION A, B AND C ALIGNMENTS PROVIDED BY THE TOWN OF CANMORE (JULY 9, 2014)

3 BEDROCK FORMATION BOUNDARIES FROM GSC MAP 1266A (1970).

0 50 100 150 200 m

Town of CANMORE

COUGAR CREEK DEBRIS FLOOD MITIGATION

SURFICIAL GEOLOGY

FIGURE 1

DRAWN BY	SEC
DESIGNED BY	MPS
APPROVED BY	HKH
SCALE	1:3000
DATE	AUGUST 11, 2014
FILE No.	19–598–440–A4C

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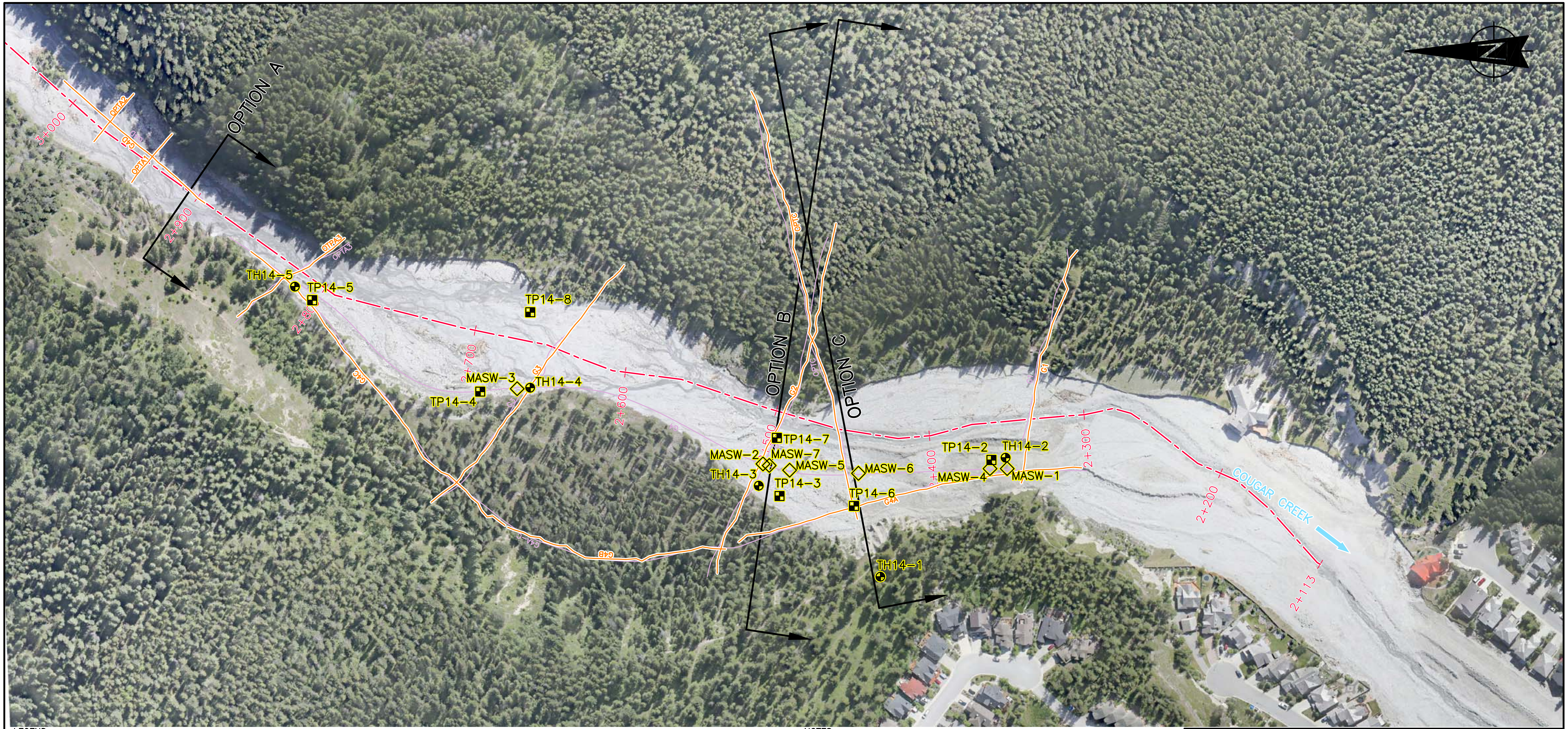


LEGEND:

TEST HOLE LOCATION	⊕
TEST PIT LOCATION	▣
MULTISPECTRAL ANALYSIS OF SURFACE WAVES LOCATION	◇
CHAINAGE	— · —
GEOPHYSICAL SURVEY LINE	——

NOTES:

1 DRAWING MUST BE USED IN CONJUNCTION WITH THE ATTACHED REPORT REFERENCE 15–598–440 DATED NOVEMBER 2015.

2 POST 2013 FLOOD ORTHOPHOTOGRAPH PROVIDED BY THE TOWN OF CANMORE.

3 OPTION A, B AND C ALIGNMENTS PROVIDED BY THE TOWN OF CANMORE (JULY 9, 2014)

0 50 100 150 200 m

Town of CANMORE

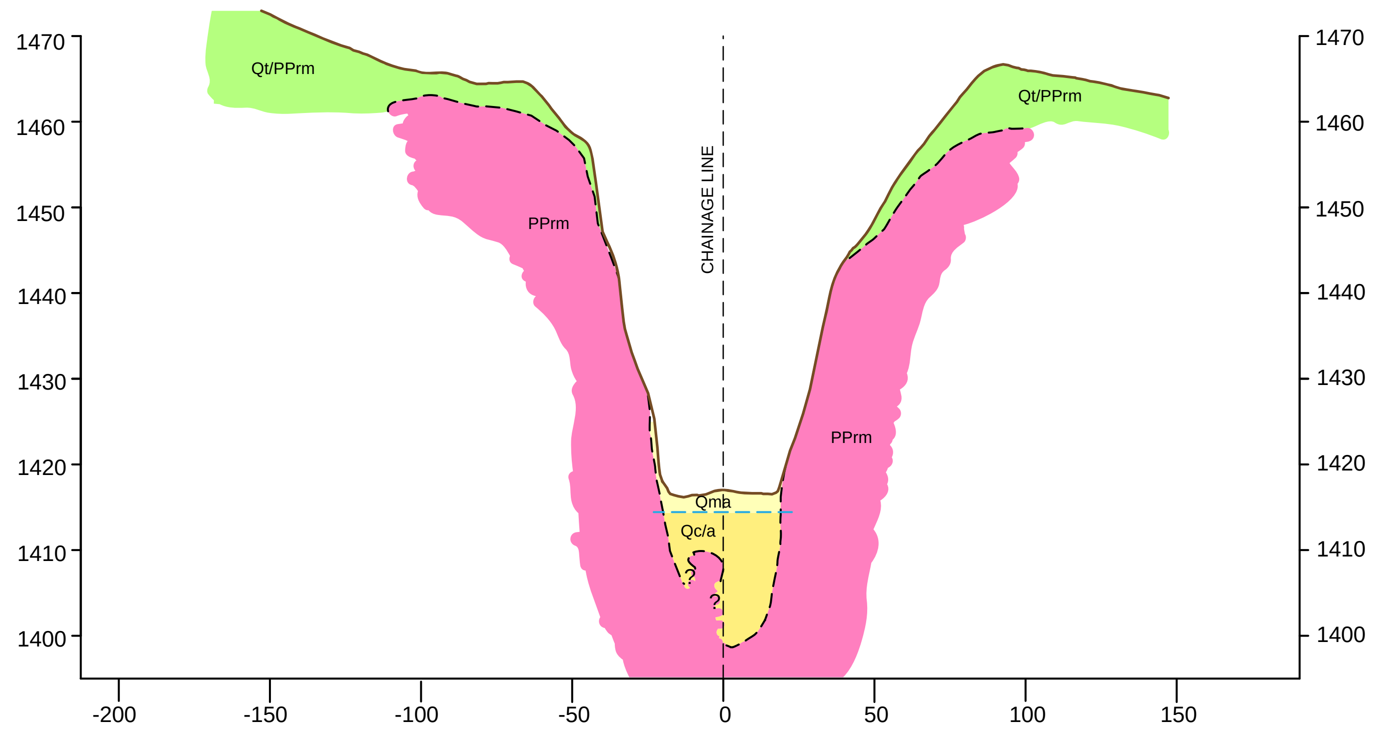
COUGAR CREEK DEBRIS FLOOD MITIGATION

TEST HOLE, TEST PIT & GEOPHYSICAL SURVEY LOCATION PLAN

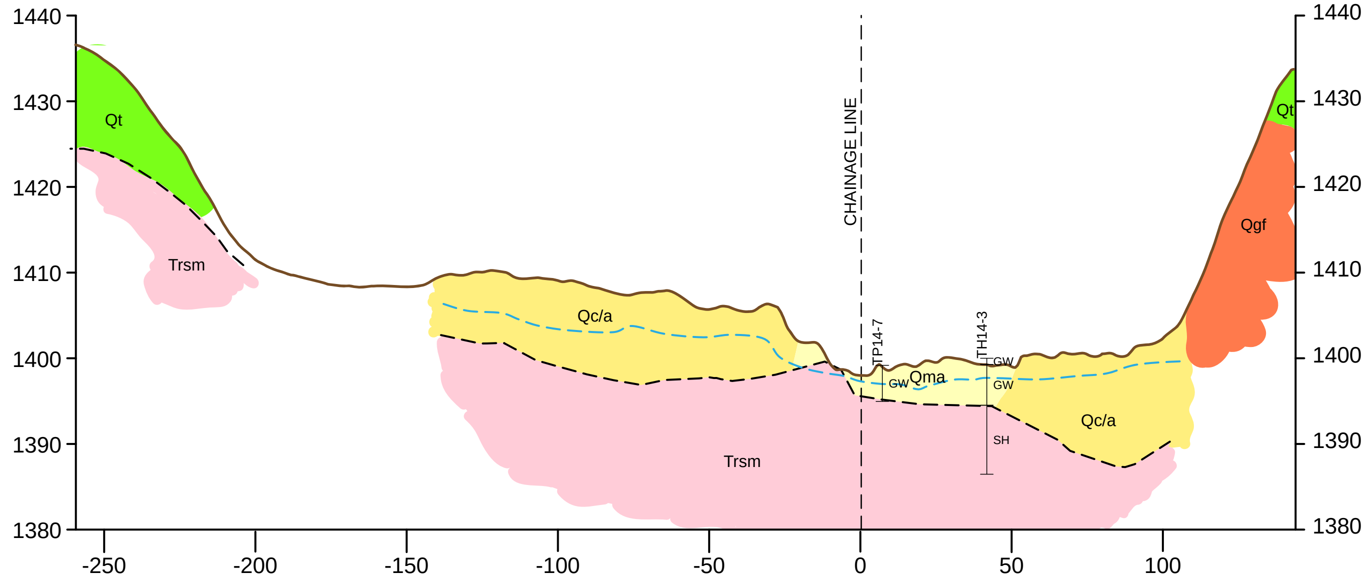
FIGURE 2

DRAWN BY	SEC
DESIGNED BY	MPS
APPROVED BY	HKH
SCALE	1:2500
DATE	JULY 10, 2014
FILE No.	19–598–440–A3E

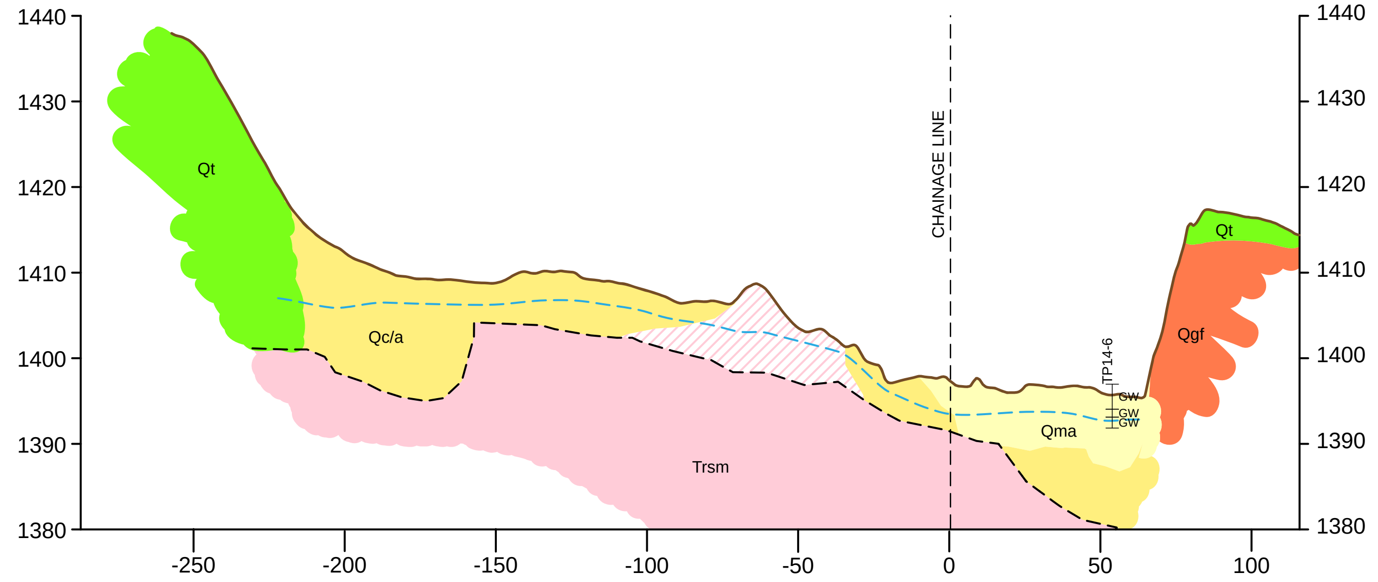
THURBER ENGINEERING LTD.



OPTION A



OPTION B



OPTION C

LEGEND:

MODERN COUGAR CREEK ALLUVIUM	Qma
COUGAR CREEK COLLUVIUM/ALLUVIUM (LOWER)	Qc/a-l
COUGAR CREEK COLLUVIUM/ALLUVIUM (UPPER)	Qc/a-u
TILL	Qt
GLACIOFLUVIAL DIRTY OUTWASH ('KAME TERRACE')	Qgf
ROCKY MOUNTAIN GROUP (BEDROCK)	PPrm
SULPHUR MOUNTAIN FORMATION (BEDROCK)	Trsm
POTENTIAL SHALLOW BEDROCK	▨
TILL/COLLUVIUM VENEER OVERLAYING BEDROCK	Qt/PPrm
INFERRED CONTACT LINE	– – – –
INFERRED WATER TABLE (JULY 2014)	– – – –

Town of CANMORE

COUGAR CREEK DEBRIS FLOOD MITIGATION

PRELIMINARY
CROSS SECTIONS AT LOCATIONS OF
OPTIONS A, B AND C

FIGURE 3

DRAWN BY	SEC
DESIGNED BY	MPS
APPROVED BY	HKH
SCALE	AS SHOWN
DATE	AUGUST 18, 2014
FILE No.	19-598-440-A8B

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APPENDIX B

Test Hole and Test Pit Logs

SYMBOLS AND TERMS USED ON TEST HOLE LOGS

1. VISUAL TEXTURAL CLASSIFICATION OF MINERAL SOILS

CLASSIFICATION	APPARENT PARTICLE SIZE
Boulders	Greater than 200 mm
Cobbles	75 mm to 200 mm
Gravel	5 mm to 75 mm
Sand	Not Visible to 5 mm
Silt	Non-Plastic particles, not visible to the naked eye
Clay	Plastic particles, not visible to the naked eye

2. TERMS DESCRIBING CONSISTENCY (COHESIVE SOILS ONLY)

DESCRIPTIVE TERM	APPROXIMATE UNDRAINED SHEAR STRENGTH	
Very Soft	Less than 10 kPa	
Soft	10 - 25 kPa	
Firm	25 - 50 kPa	
Stiff	50 - 100 kPa	
Very Stiff	100 - 200 kPa	Modified from National Building Code
Hard	200 - 300 kPa	
Very Hard	Greater than 300 kPa	

3. TERMS DESCRIBING DENSITY (COHESIONLESS SOILS ONLY)

DESCRIPTIVE TERM	STANDARD PENETRATION TEST (SPT) (Number of Blows per 300 mm)	
Very Loose	0 - 4	
Loose	4 - 10	
Compact	10 - 30	Modified from National Building Code
Dense	30 - 50	
Very Dense	Over 50	

4. LEGEND FOR TEST HOLE LOGS

SYMBOL FOR SAMPLE TYPE

■	Shelby Tube	▤	A- Casing
◿	SPT	▥	Grab
⊠	No Recovery	◨	Core

● MC - Moisture Content (% by weight) as determined by sample

▼ Water Level

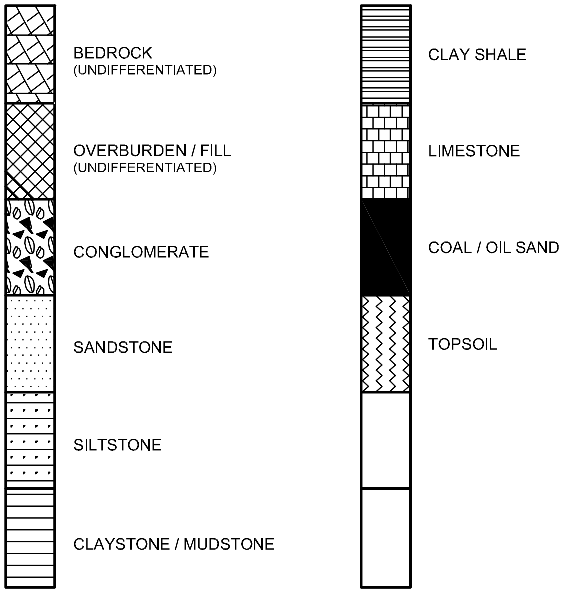
CPen - Shear Strength determined by pocket penetrometer

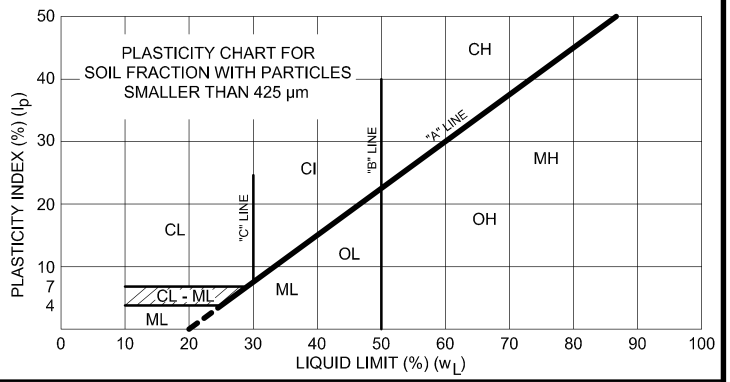
Cvane - Shear Strength determined by pocket vane

Cu - Undrained Shear Strength determined by unconfined compression test

MAJOR DIVISION			SYMBOL	THURBER LOG SYMBOL	TYPICAL DESCRIPTION	LABORATORY CLASSIFICATION CRITERIA		
COARSE-GRAINED SOILS (MORE THAN HALF BY WEIGHT LARGER THAN 75 µm)	GRAVELS MORE THAN HALF COARSE GRAINS LARGER THAN 4.75 mm	CLEAN GRAVELS (LITTLE OR NO FINES)	GW		WELL GRADED GRAVELS, GRAVEL - SAND MIXTURES, LITTLE OR NO FINES	Determine percentages of gravel and sand from grain size curve. Depending on percentages of fines (fraction smaller than 75 µm) coarse grained soils are classified as follows: Less than 5% GW, GP, SW, SP More than 12% GM, GC, SM, SC 5% to 12% Borderline cases requiring use of dual symbols	$C_u = \frac{D_{60}}{D_{10}} > 4$; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} = 1$ to 3	
			GP		POORLY GRADED GRAVELS, GRAVEL-SAND MISTURES, LITTLE OR NO FINES		NOT MEETING ALL GRADATION REQUIREMENTS FOR GW	
		GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)	GM		SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES		ATTERBERG LIMITS BELOW "A" LINE I_p LESS THAN 4	Above "A" line with I_p between 4 and 7 are borderline cases requiring use of dual symbols
			GC		CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES		ATTERBERG LIMITS ABOVE "A" LINE I_p MORE THAN 7	
	SANDS MORE THAN HALF COARSE GRAINS SMALLER THAN 4.75 mm	CLEAN SANDS (LITTLE OR NO FINES)	SW		WELL GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES		$C_u = \frac{D_{60}}{D_{10}} > 6$; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} = 1$ to 3	
			SP		POORLY GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES		NOT MEETING ALL GRADATION REQUIREMENTS FOR SW	
		SAND WITH FINES (APPRECIABLE AMOUNT OF FINES)	SM		SILTY SANDS, SAND-SILT MIXTURES		ATTERBERG LIMITS BELOW "A" LINE I_p LESS THAN 4	Above "A" line with I_p between 4 and 7 are borderline cases requiring use of dual symbols
			SC		CLAYEY SANDS, SAND-CLAY MIXTURES		ATTERBERG LIMITS ABOVE "A" LINE I_p MORE THAN 7	
FINE-GRAINED SOILS (MORE THAN HALF BY WEIGHT SMALLER THAN 75 µm)	SILTS BELOW "A" LINE NEGLIGIBLE ORGANIC CONTENT	$w_L < 50\%$	ML		INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY	CLASSIFICATION IS BASED UPON PLASTICITY CHART (see below)		
		$w_L > 50\%$	MH		INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS, FINE SANDY OR SILTY SOILS			
	CLAYS ABOVE "A" LINE NEGLIGIBLE ORGANIC CONTENT	$w_L < 30\%$	CL		INORGANIC CLAYS OF LOW PLASTICITY, GRAVELLY, SANDY, OR SILTY CLAYS, LEAN CLAYS			
		$30\% < w_L < 50\%$	CI		INORGANIC CLAYS OF MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS			
		$w_L > 50\%$	CH		INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS			
	ORGANIC SILTS & CLAYS BELOW "A" LINE	$w_L < 50\%$	OL		ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW AND MEDIUM PLASTICITY			
		$w_L > 50\%$	OH		ORGANIC CLAYS OF HIGH PLASTICITY, ORGANIC SILTS			
HIGHLY ORGANIC SOILS			PT		PEAT AND OTHER HIGHLY ORGANIC SOILS	STRONG COLOUR OR ODOUR, AND OFTEN FIBROUS TEXTURE		

SPECIAL SYMBOLS





MODIFIED UNIFIED SOIL CLASSIFICATION SYSTEM

(MODIFIED BY PFRA, 1985)

THURBER ENGINEERING LTD.

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST HOLE NO: **TH14-1**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661244 m, Easting: 617376 m	ELEVATION: 1416.17 m

SAMPLE TYPE: ☒ No Recovery

BACKFILL TYPE:

DEPTH (m)	SAMPLE TYPE	SAMPLE ID SPT (N)	Shear Strength (kPa) ▲ Cpen 50 100 150 200 ■ SPT (N) Blows/300 mm ■ 10 20 30 40 PL W.C. (%) LL 10 20 30 40	REMARKS	MUSCS / ISRM	SOIL SYMBOL	DESCRIPTION	DEPTH (m)
0				Flushed top 0.75 m of material setting casing			Probable terrace material	0
	☒	NR-1					- core barrel jammed by dislodged cobble - probable boulder - some undisturbed gravel in core barrel	
1	☒			Flush is relatively free of cuttings Minor loss of flush water				1
	☒	NR-2			SW-GW			
2	☒							2
	☒			Increasing loss of flush water				
	☒			Decrease in loss of flush water			- some undisturbed gravel in core barrel	
3	☒	NR-3						3
	☒	NR-4					- no sample recovery	
							END OF HOLE at 3.7 m - backfilled with cutting mud and bentonite to surface - core barrel jamming at 3.7 m (refusal) - cave in at 1.8 m after removal of core barrel	
4								4
5								5
6								6
7								7
8								8
9								9
10								10

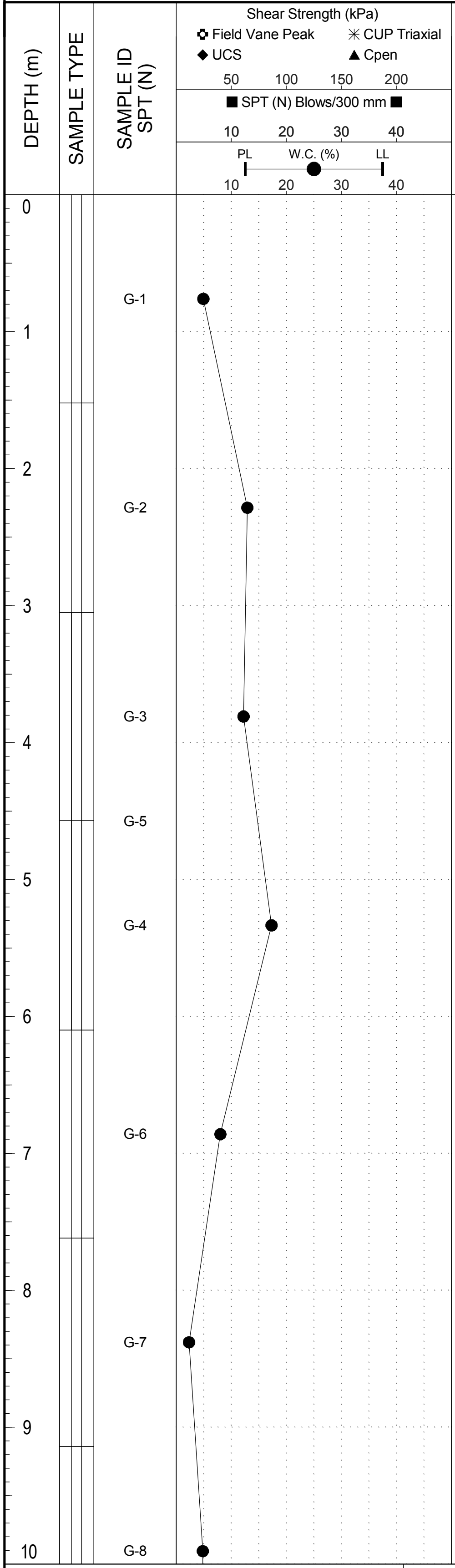
THURBER ENGINEERING LTD.

DRILLING CO.: Mobile Augers & Research Ltd.		
RIG TYPE: Fraste ML	COMPILED BY: CAM	COMPLETION DEPTH: 3.7 m
DRILL METHOD: Core Rig	REVIEWED BY: HKH	COMPLETION DATE: 29/07/2014
INSPECTOR: CAM/LAB		Page 1 of 1

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST HOLE NO: **TH14-2**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661164 m, Easting: 617452 m	ELEVATION: 1392.95 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE:



REMARKS	MUSCS / ISRM	DESCRIPTION
	GW	COBBLES, gravelly, well graded, dense, grey, dry, limestone
	SP	SAND, trace silt, fine to medium grained, brown, moist - cobbles and boulders at 0.9 m - damp at 3.0 m - some gravel at 6.7 m
	GW	GRAVEL, sandy, some silt, dense to very dense, grey, damp

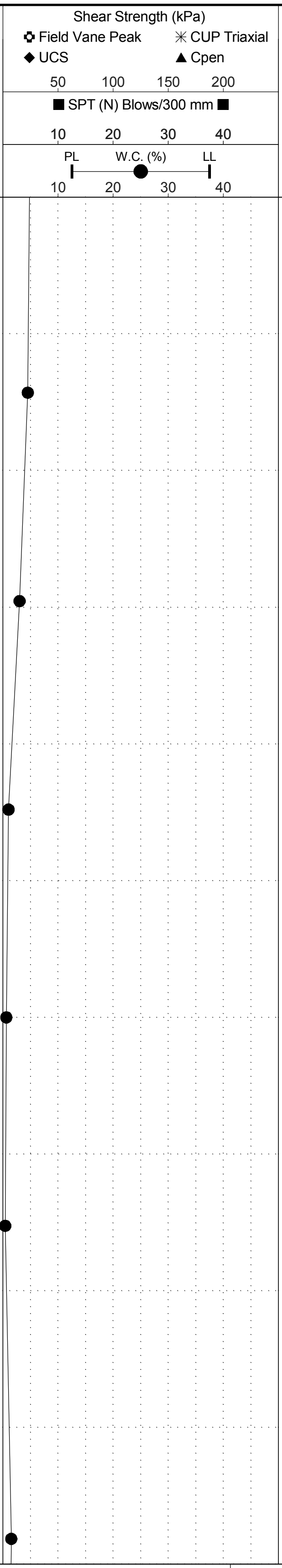
THURBER ENGINEERING LTD.

DRILLING CO.: Earth Drilling Co. Ltd.		
RIG TYPE: Foremost DR-24	COMPILED BY: CAM	COMPLETION DEPTH: 24.4 m
DRILL METHOD: Dual Rotary	REVIEWED BY: HKH	COMPLETION DATE: 17/07/2014
INSPECTOR: LAB		

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST HOLE NO: **TH14-2**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661164 m, Easting: 617452 m	ELEVATION: 1392.95 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE:



DEPTH (m)	SAMPLE TYPE	SAMPLE ID SPT (N)	REMARKS	MUSCS / ISRM	DESCRIPTION	DEPTH (m)
10	▥				- boulders at 9.8 m	10
11	▥				BEDROCK, strong, grey, dry, alternating limestone, shale, sandstone	11
		G-9				
12	▥				- change to dark grey shale at 12.2 m	12
13		G-10				13
14	▥					14
		G-11				
15	▥					15
16		G-12				16
17	▥					17
		G-13		BR		
18	▥					18
19						19
20		G-14				20

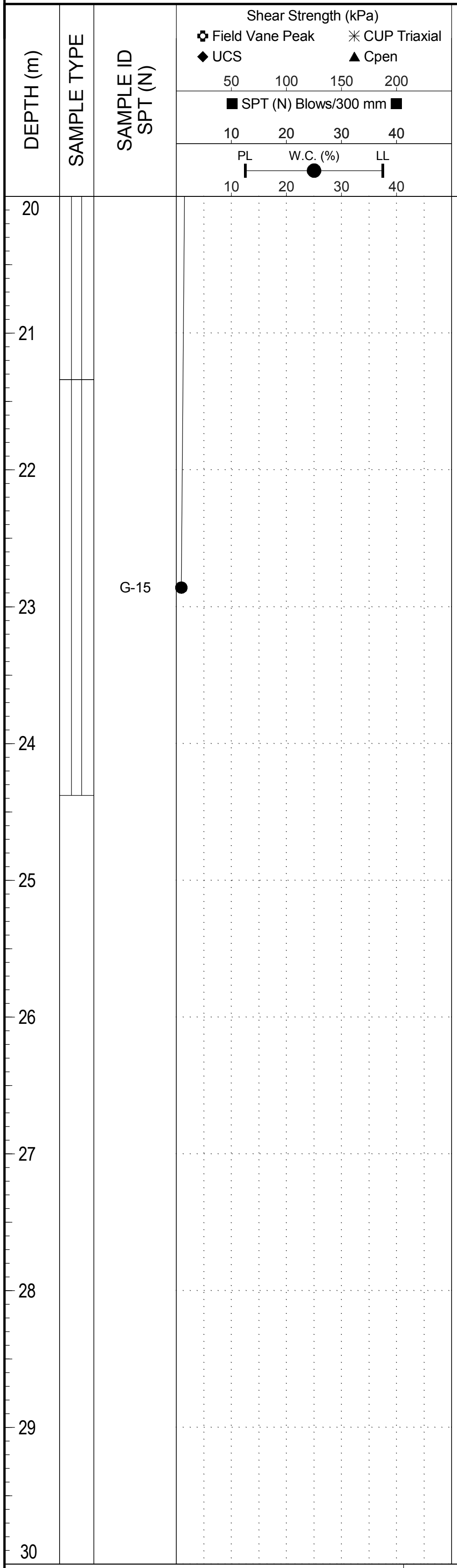
THURBER ENGINEERING LTD.

DRILLING CO.: Earth Drilling Co. Ltd.		
RIG TYPE: Foremost DR-24	COMPILED BY: CAM	COMPLETION DEPTH: 24.4 m
DRILL METHOD: Dual Rotary	REVIEWED BY: HKH	COMPLETION DATE: 17/07/2014
INSPECTOR: LAB		

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST HOLE NO: **TH14-2**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661164 m, Easting: 617452 m	ELEVATION: 1392.95 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE:



REMARKS	MUSCS / ISRM	SOIL SYMBOL	DESCRIPTION	DEPTH (m)
		▨		20–24.4
			END OF HOLE at 24.4 m - backfilled with cuttings to 0.9 m, bentonite chip seal to 0.3 m, cuttings to surface	

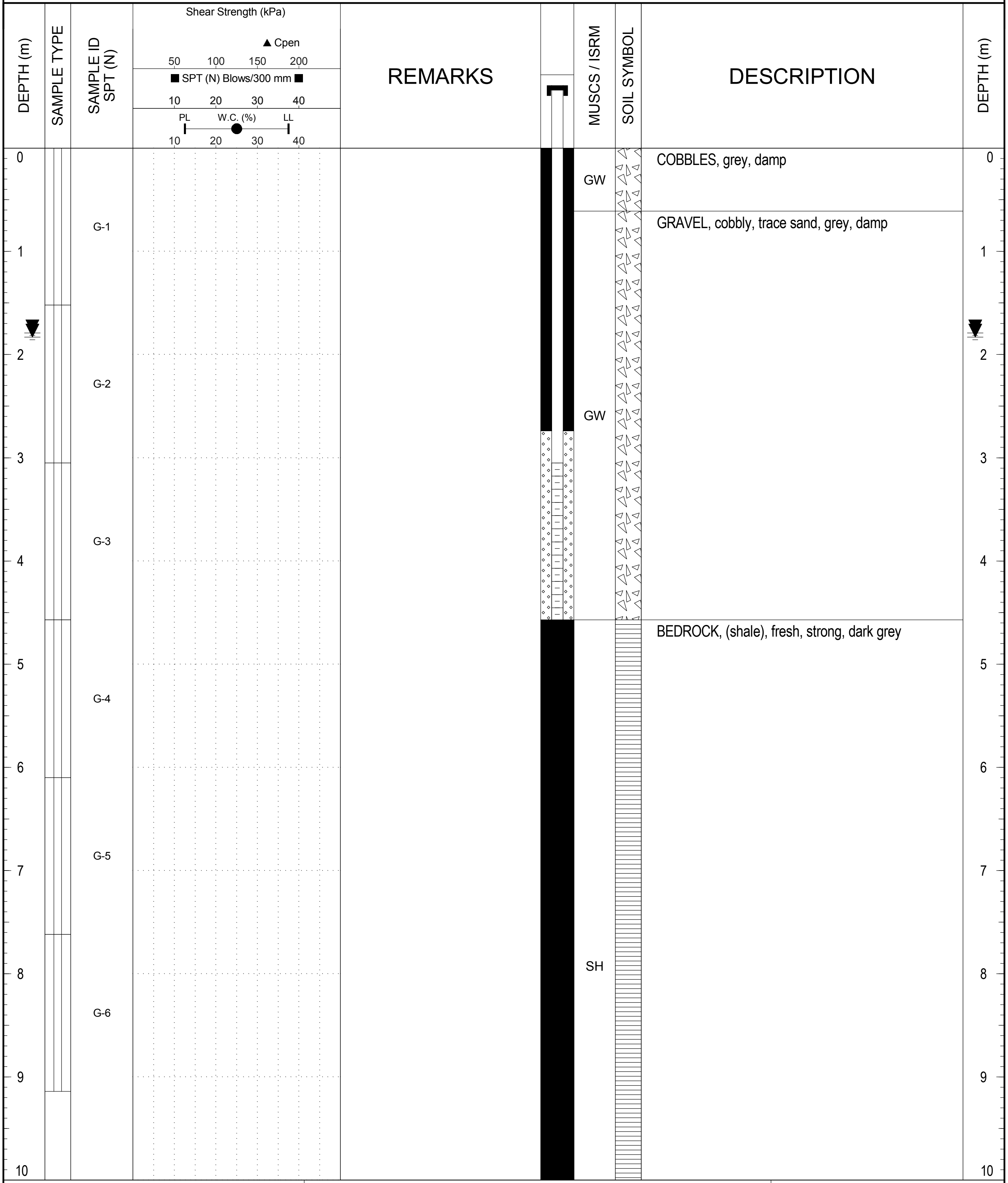
THURBER ENGINEERING LTD.

DRILLING CO.: Earth Drilling Co. Ltd.		
RIG TYPE: Foremost DR-24	COMPILED BY: CAM	COMPLETION DEPTH: 24.4 m
DRILL METHOD: Dual Rotary	REVIEWED BY: HKH	COMPLETION DATE: 17/07/2014
INSPECTOR: LAB		Page 3 of 3

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST HOLE NO: **TH14-3**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661322 m, Easting: 617434.10 m	ELEVATION: 1399.49 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE: ■ BENTONITE ⛶ SAND



COBBLES, grey, damp

GRAVEL, cobbly, trace sand, grey, damp

BEDROCK, (shale), fresh, strong, dark grey

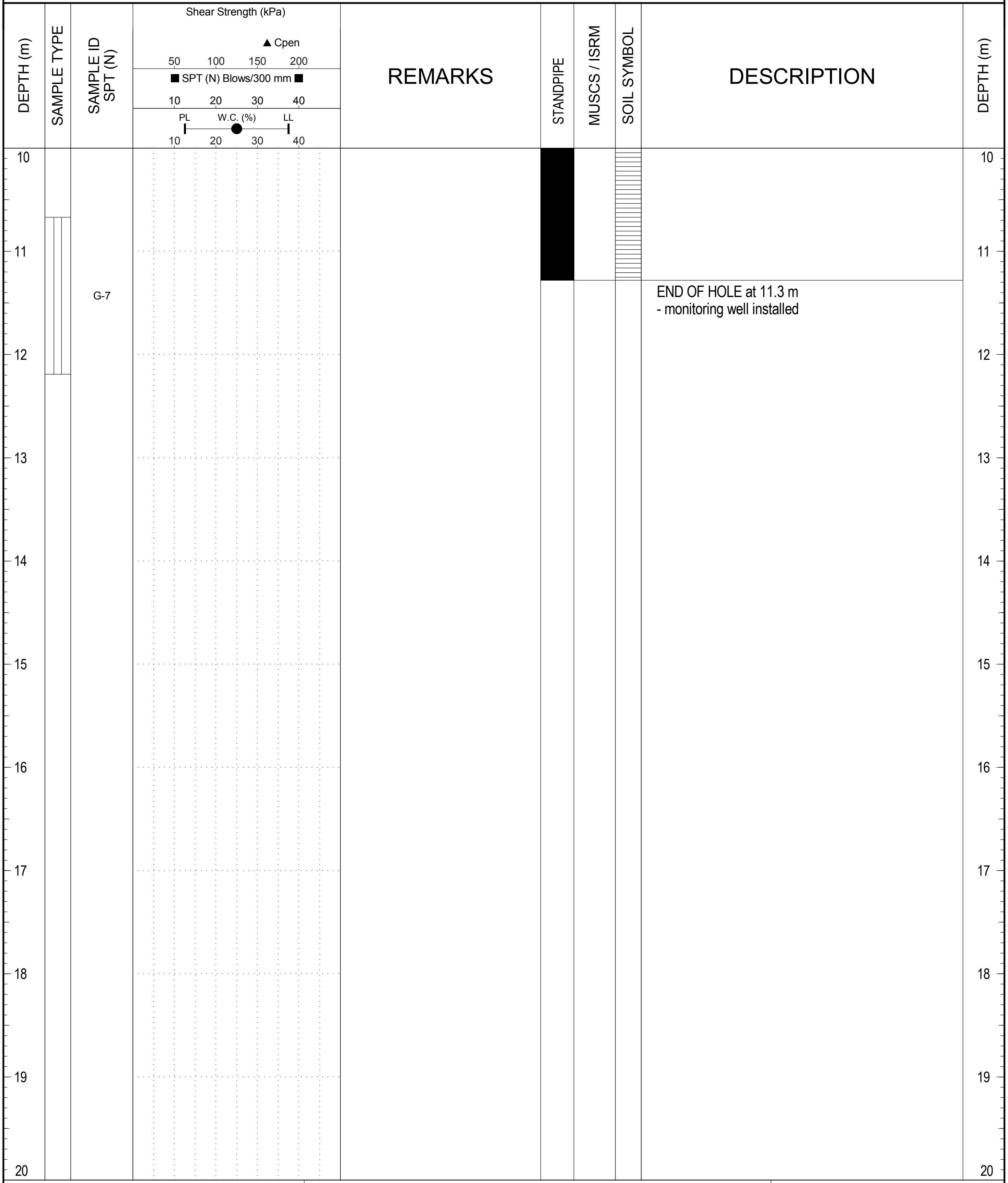
DRILLING CO.: Earth Drilling Co. Ltd.		
RIG TYPE: Foremost DR-24	COMPILED BY: CAM	COMPLETION DEPTH: 11.3 m
DRILL METHOD: Dual Rotary	REVIEWED BY: HKH	COMPLETION DATE: 17/07/2014
INSPECTOR: LAB		Page 1 of 2

THURBER ENGINEERING LTD.

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST HOLE NO: **TH14-3**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661322 m, Easting: 617434.10 m	ELEVATION: 1399.49 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE: ■ BENTONITE ⁙ SAND



END OF HOLE at 11.3 m
- monitoring well installed

DRILLING CO.: Earth Drilling Co. Ltd.		
RIG TYPE: Foremost DR-24	COMPILED BY: CAM	COMPLETION DEPTH: 11.3 m
DRILL METHOD: Dual Rotary	REVIEWED BY: HKH	COMPLETION DATE: 17/07/2014
INSPECTOR: LAB		Page 2 of 2

THURBER ENGINEERING LTD.

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST HOLE NO: **TH14-4**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661468 m, Easting: 617496.70 m	ELEVATION: 1406.11 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE:

DEPTH (m)	SAMPLE TYPE	SAMPLE ID SPT (N)	Shear Strength (kPa) ▲ Cpen 50 100 150 200 ■ SPT (N) Blows/300 mm ■ 10 20 30 40 PL W.C. (%) LL 10 20 30 40	REMARKS	MUSCS / ISRM	SOIL SYMBOL	DESCRIPTION	DEPTH (m)
0	▥	G-1			GW		COBBLES AND GRAVEL, grey, damp - boulders (>1000 mm) noted at surface - some sand at 1.5 m	0
2	▥	G-2		Quicker drilling	GW		GRAVEL, grey, damp, potential cobbles and boulders - sandy at 3.1 m - light grey from 3.7 m to 4.6 m (potential boulder) - water noted coming up casing - dry at 6.1 m	2
	▥	G-3						
	▥	G-4						
	▥	G-5						
7	▥	G-6			SP		SAND, silty, dense to very dense, reddish brown, damp - lighter brown at 8.5 m	7
9	▥						BEDROCK, (shale), strong, dark grey	9
10		G-7						10

THURBER ENGINEERING LTD.

DRILLING CO.: Earth Drilling Co. Ltd.		
RIG TYPE: Foremost DR-24	COMPILED BY: CAM	COMPLETION DEPTH: 15.2 m
DRILL METHOD: Dual Rotary	REVIEWED BY: HKH	COMPLETION DATE: 18/07/2014
INSPECTOR: LAB		Page 1 of 2

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST HOLE NO: **TH14-4**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661468 m, Easting: 617496.70 m	ELEVATION: 1406.11 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE:

DEPTH (m)	SAMPLE TYPE	SAMPLE ID SPT (N)	Shear Strength (kPa) ▲ Cpen 50 100 150 200 ■ SPT (N) Blows/300 mm ■ 10 20 30 40 PL W.C. (%) LL 10 20 30 40	REMARKS	MUSCS / ISRM	SOIL SYMBOL	DESCRIPTION	DEPTH (m)
10	▥							10
11								11
12	▥				SH			12
13								13
14		G-8						14
15							END OF HOLE at 15.2 m - seepage at 4.6 m - backfilled with cuttings to 0.9 m, bentonite chip seal to 0.3 m, cuttings to surface	15
16								16
17								17
18								18
19								19
20								20

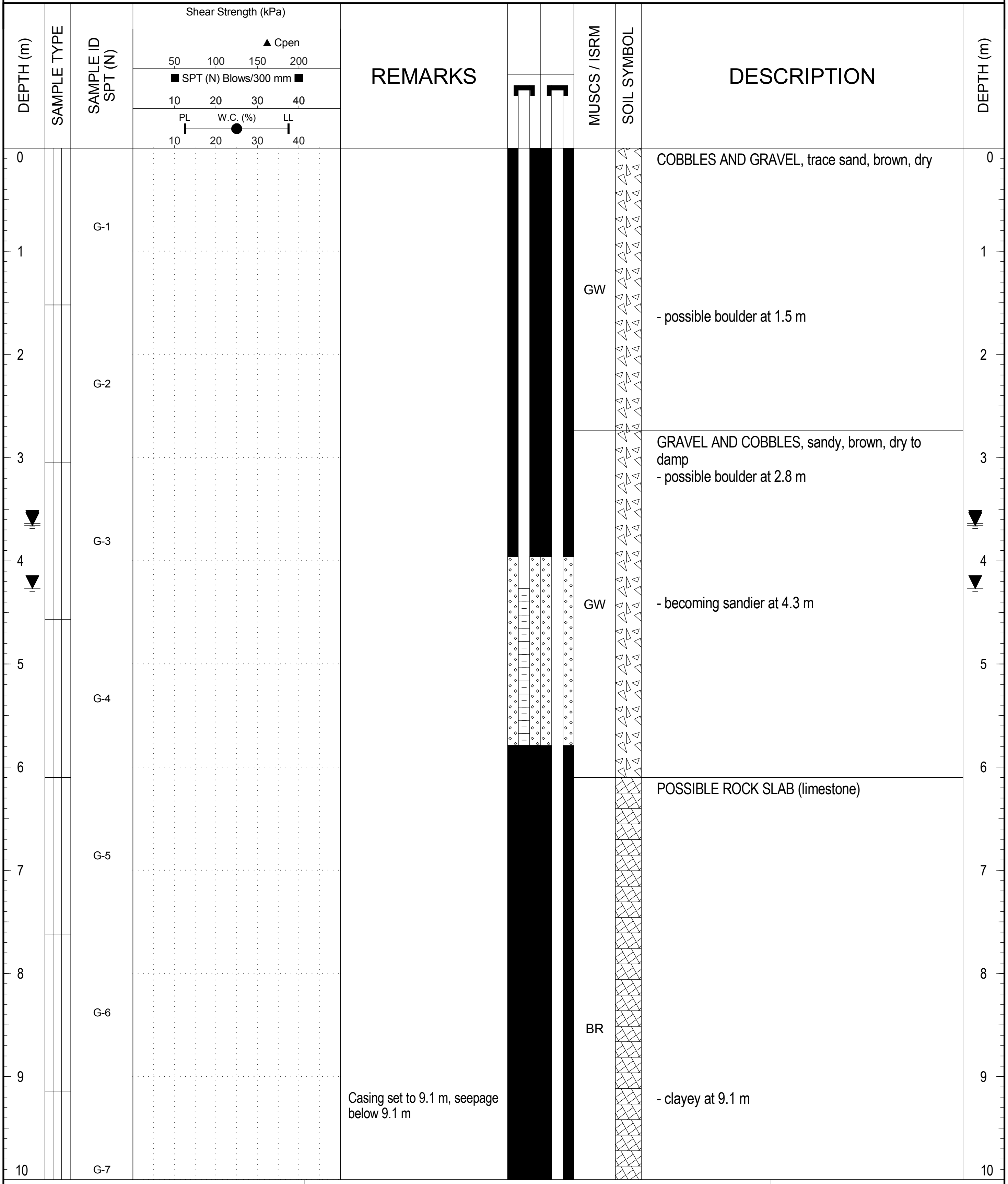
THURBER ENGINEERING LTD.

DRILLING CO.: Earth Drilling Co. Ltd.		
RIG TYPE: Foremost DR-24	COMPILED BY: CAM	COMPLETION DEPTH: 15.2 m
DRILL METHOD: Dual Rotary	REVIEWED BY: HKH	COMPLETION DATE: 18/07/2014
INSPECTOR: LAB		Page 2 of 2

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST HOLE NO: **TH14-5**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661618 m, Easting: 617561.20 m	ELEVATION: 1413.21 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE: ■ BENTONITE ⁙ SAND



REMARKS

Casing set to 9.1 m, seepage below 9.1 m

DESCRIPTION

COBBLES AND GRAVEL, trace sand, brown, dry

- possible boulder at 1.5 m

GRAVEL AND COBBLES, sandy, brown, dry to damp
- possible boulder at 2.8 m

- becoming sandier at 4.3 m

POSSIBLE ROCK SLAB (limestone)

- clayey at 9.1 m

DRILLING CO.: Earth Drilling Co. Ltd.		
RIG TYPE: Foremost DR-24	COMPILED BY: CAM	COMPLETION DEPTH: 21.3 m
DRILL METHOD: Dual Rotary	REVIEWED BY: HKH	COMPLETION DATE: 20/07/2014
INSPECTOR: LAB		Page 1 of 3

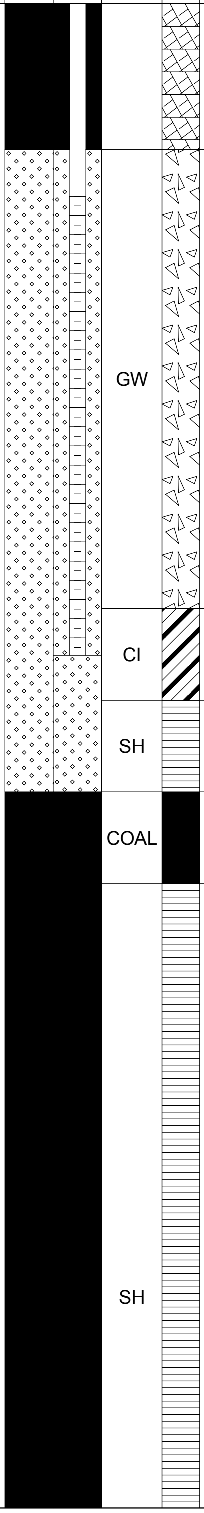
THURBER ENGINEERING LTD.

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST HOLE NO: **TH14-5**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661618 m, Easting: 617561.20 m	ELEVATION: 1413.21 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE: ■ BENTONITE ⁘ SAND

DEPTH (m)	SAMPLE TYPE	SAMPLE ID SPT (N)	Shear Strength (kPa) ▲ Cpen 50 100 150 200 ■ SPT (N) Blows/300 mm ■ 10 20 30 40 PL W.C. (%) LL 10 20 30 40	REMARKS	STANDPIPE	STANDPIPE	MUSCS / ISRM	SOIL SYMBOL	DESCRIPTION	DEPTH (m)
10				Seepage stopped with casing to 9.8 m						10
11		G-8		Seepage at 11.0 m					GRAVEL, occasional clay bed	11
12							GW			12
13		G-9							- less clay at 12.8 m, size of gravel increasing	13
14		G-10					CI		CLAY (TILL), trace gravel, trace sand, medium plastic, brown, moist	14
							SH		BEDROCK, (shale)	
15		G-11					COAL		COAL, black	15
16									BEDROCK, (shale), dark grey, dry, occasional sandstone layer	16
17										17
18							SH			18
19		G-12								19
20										20



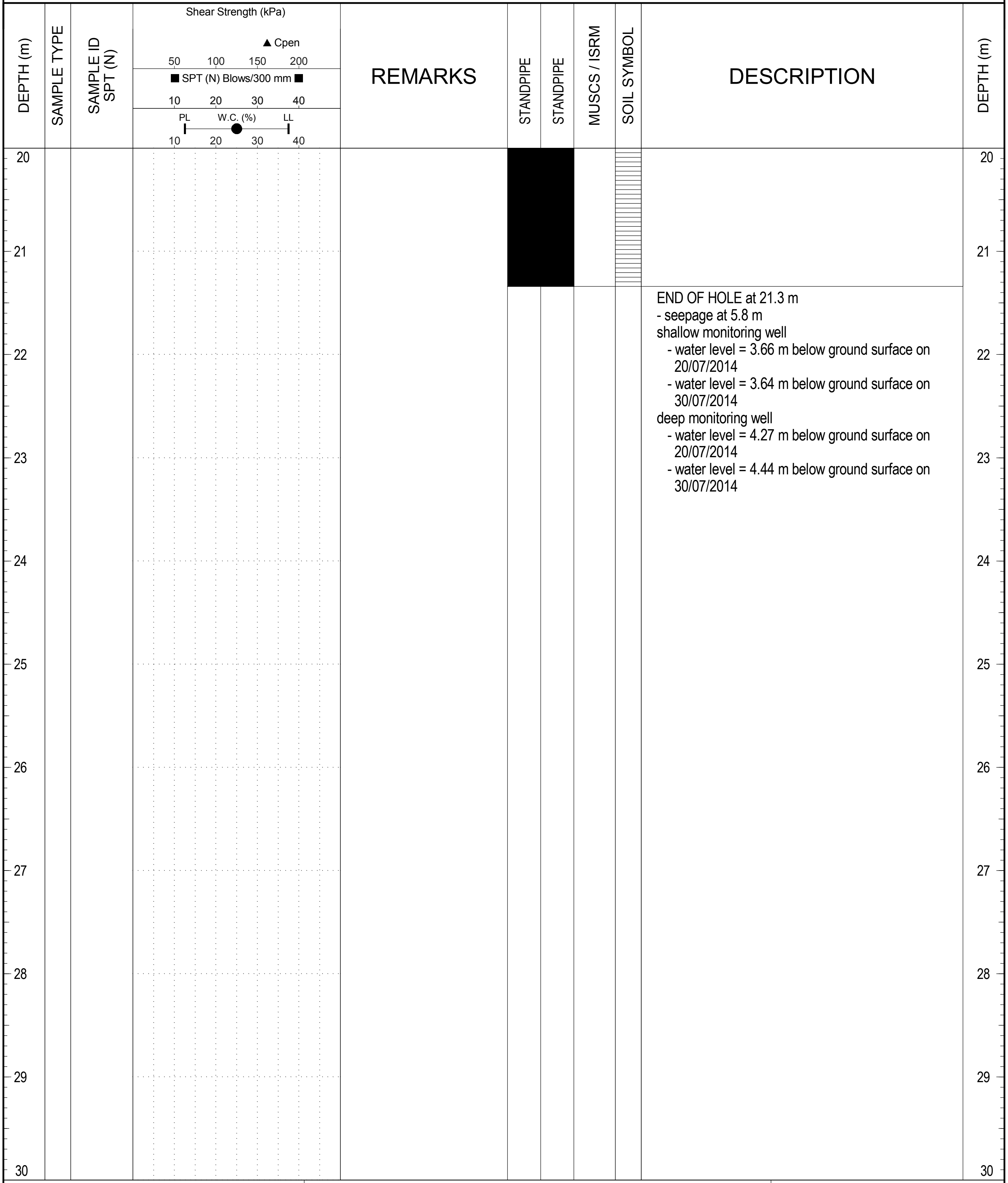
THURBER ENGINEERING LTD.

DRILLING CO.: Earth Drilling Co. Ltd.		
RIG TYPE: Foremost DR-24	COMPILED BY: CAM	COMPLETION DEPTH: 21.3 m
DRILL METHOD: Dual Rotary	REVIEWED BY: HKH	COMPLETION DATE: 20/07/2014
INSPECTOR: LAB		Page 2 of 3

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST HOLE NO: **TH14-5**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661618 m, Easting: 617561.20 m	ELEVATION: 1413.21 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE: ■ BENTONITE ⁙ SAND



END OF HOLE at 21.3 m
- seepage at 5.8 m

shallow monitoring well
- water level = 3.66 m below ground surface on 20/07/2014
- water level = 3.64 m below ground surface on 30/07/2014

deep monitoring well
- water level = 4.27 m below ground surface on 20/07/2014
- water level = 4.44 m below ground surface on 30/07/2014

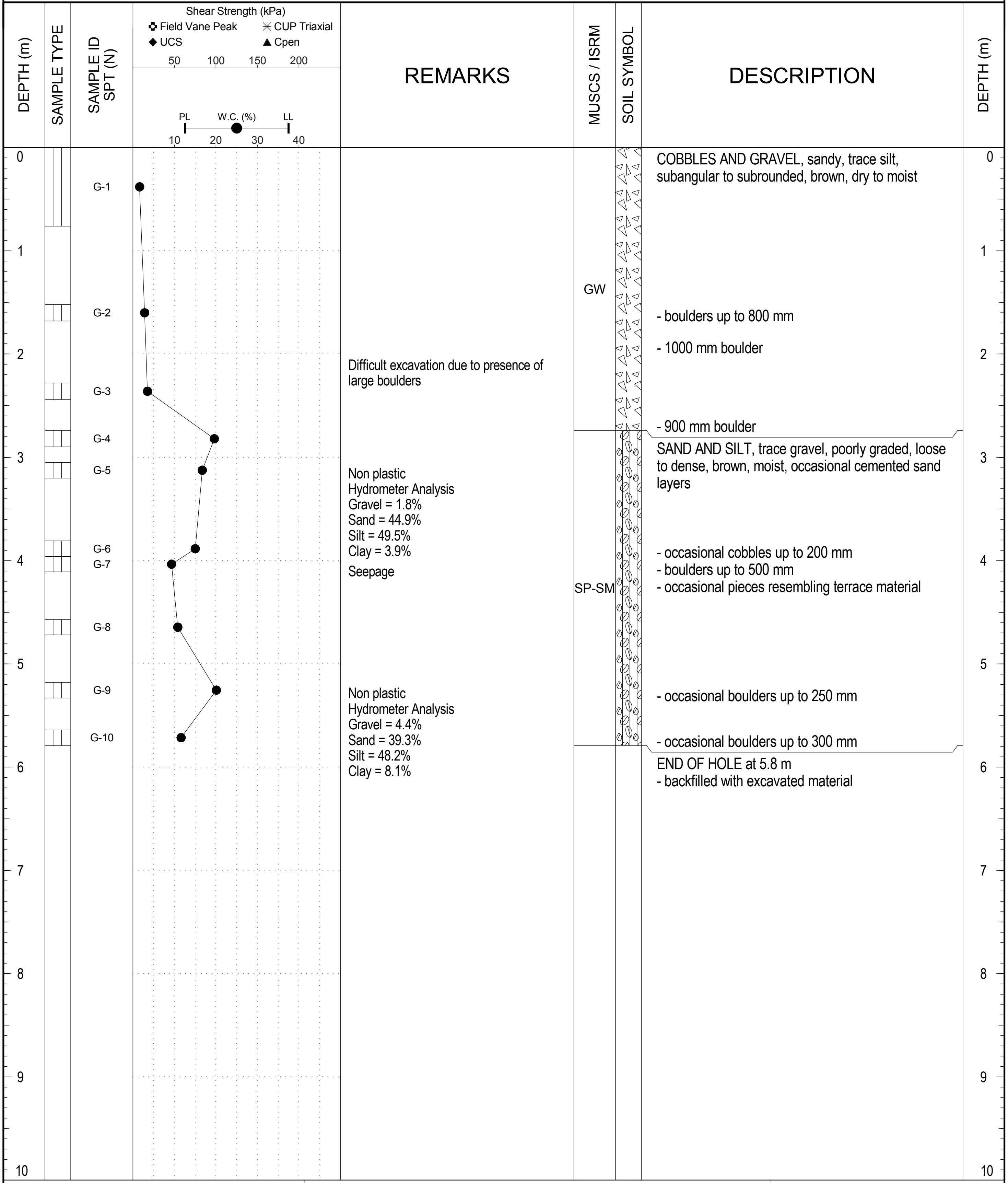
THURBER ENGINEERING LTD.

DRILLING CO.: Earth Drilling Co. Ltd.		
RIG TYPE: Foremost DR-24	COMPILED BY: CAM	COMPLETION DEPTH: 21.3 m
DRILL METHOD: Dual Rotary	REVIEWED BY: HKH	COMPLETION DATE: 20/07/2014
INSPECTOR: LAB		

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST PIT NO: **TP14-2**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661173 m, Easting: 617450.40 m	ELEVATION: 1393.34 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE:



REMARKS

Difficult excavation due to presence of large boulders

Non plastic
Hydrometer Analysis
Gravel = 1.8%
Sand = 44.9%
Silt = 49.5%
Clay = 3.9%

Seepage

Non plastic
Hydrometer Analysis
Gravel = 4.4%
Sand = 39.3%
Silt = 48.2%
Clay = 8.1%

DESCRIPTION

COBBLES AND GRAVEL, sandy, trace silt, subangular to subrounded, brown, dry to moist

- boulders up to 800 mm
- 1000 mm boulder
- 900 mm boulder

SAND AND SILT, trace gravel, poorly graded, loose to dense, brown, moist, occasional cemented sand layers

- occasional cobbles up to 200 mm
- boulders up to 500 mm
- occasional pieces resembling terrace material
- occasional boulders up to 250 mm
- occasional boulders up to 300 mm

END OF HOLE at 5.8 m
- backfilled with excavated material

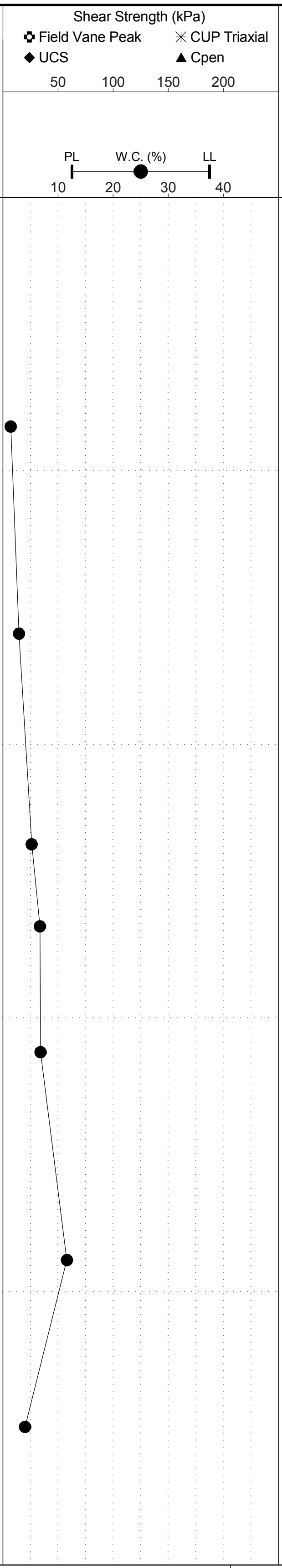
THURBER ENGINEERING LTD.

EXCAVATION CO.: Bremner Engineering and Construction Ltd.		
EXCAVATOR TYPE: John Deere 350 DLC	COMPILED BY: CAM	COMPLETION DEPTH: 5.8 m
EXCAVATION METHOD: Excavation	REVIEWED BY: HKH	COMPLETION DATE: 18/07/2014
INSPECTOR: SKB		Page 1 of 1

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST PIT NO: **TP14-3**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661308 m, Easting: 617427.50 m	ELEVATION: 1398.77 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE:



DEPTH (m)	SAMPLE TYPE	SAMPLE ID SPT (N)	REMARKS	MUSCS / ISRM	DESCRIPTION
0				GW	COBBLES AND GRAVEL, sandy, trace silt, subangular to subrounded, brown, dry to wet, frequent boulders
	▥	G-1			
1					
	▥	G-2			- boulders up to 500 mm
	▥	G-3	Heavy seepage		
2					
	▥	G-4	Hydrometer Analysis Gravel = 77.6% Sand = 16.6% Silt = 4.3% Clay = 1.5%		- boulders up to 1300 mm
				GW-GM	trace clay, some sand, trace silt, frequent cobbles and boulders up to 1000 mm
	▥	G-5			
3					
	▥	G-6			- fines content increases
	▥	G-7	Decreased inflow		- boulders up to 900 mm
4					
	▥	G-8			- boulders up to 750 mm
					END OF HOLE at 4.6 m - sloughing of near surface material - backfilled with excavated material - refusal on probable bedrock
5					

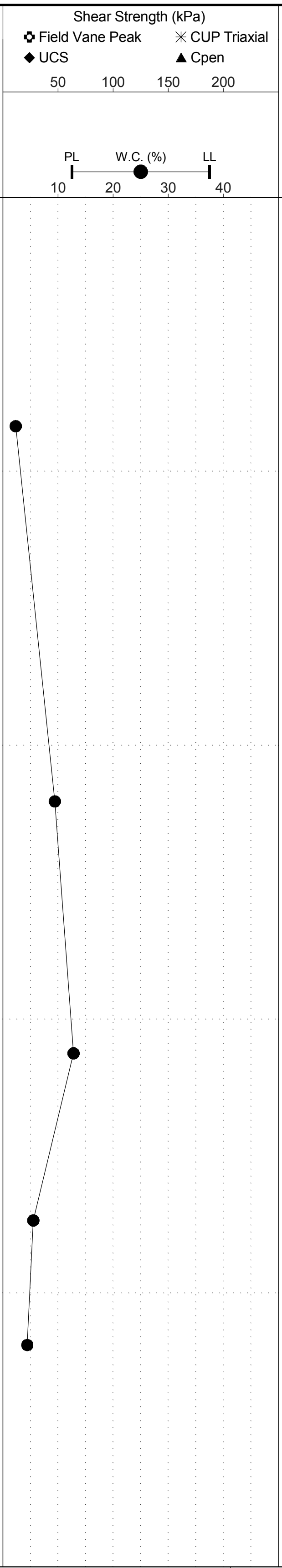
THURBER ENGINEERING LTD.

EXCAVATION CO.: Bremner Engineering and Construction Ltd.		
EXCAVATOR TYPE: John Deere 350 DLC	COMPILED BY: CAM	COMPLETION DEPTH: 4.6 m
EXCAVATION METHOD: Excavation	REVIEWED BY: HKH	COMPLETION DATE: 18/07/2014
INSPECTOR: SKB		

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST PIT NO: **TP14-4**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661500 m, Easting: 617494.10 m	ELEVATION: 1407.56 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE:



DEPTH (m)	SAMPLE TYPE	SAMPLE ID SPT (N)	REMARKS	MUSCS / ISRM	DESCRIPTION	DEPTH (m)
0					COBBLES AND GRAVEL, some sand, medium to coarse grained, subangular to subrounded, brown, dry to wet, frequent boulders - 1200 mm boulder	0
	▥	G-1				
1				GW		1
			Seepage			
2						2
	▥	G-2	Hydrometer Analysis Gravel = 42.4% Sand = 30.0% Silt = 20.4% Clay = 7.2% Seepage, high recharge/flow rate	GW	sandy, trace clay (medium plastic), frequent boulders	
				GW	trace silt, trace sand, medium to coarse grained	
3						3
	▥	G-3				
					- fines content decreasing	
				GW	trace silt, trace sand, coarse grained - boulders up to 600 mm	
	▥	G-4				
4						4
	▥	G-5				
					END OF HOLE at 4.3 m - backfilled with excavated material - refusal on probable large boulders	
5						5

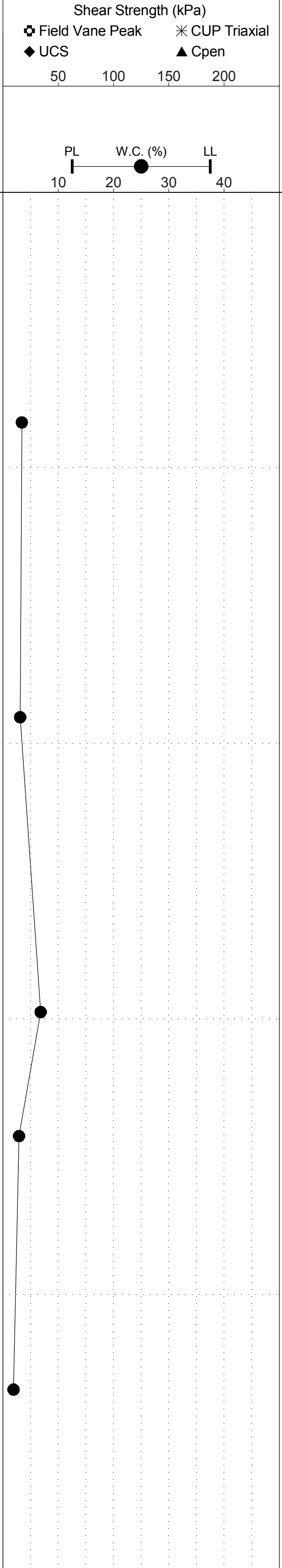
THURBER ENGINEERING LTD.

EXCAVATION CO.: Bremner Engineering and Construction Ltd.		
EXCAVATOR TYPE: John Deere 350 DLC	COMPILED BY: CAM	COMPLETION DEPTH: 4.3 m
EXCAVATION METHOD: Excavation	REVIEWED BY: HKH	COMPLETION DATE: 19/07/2014
INSPECTOR: SKB		Page 1 of 1

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST PIT NO: **TP14-5**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661607 m, Easting: 617552.40 m	ELEVATION: 1412.33 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE:



DEPTH (m)	SAMPLE TYPE	SAMPLE ID SPT (N)	REMARKS	MUSCS / ISRM	DESCRIPTION	DEPTH (m)
0				GW	GRAVEL, sandy, coarse grained, loose, subangular to subrounded, brown, damp, frequent cobbles and boulders up to 400 mm	0
	▥	G-1				
1				GW	COBBLES AND GRAVEL, some sand, coarse grained, subangular to subrounded, brown, damp to wet, frequent boulders	1
	▥	G-2			- boulders up to 1300 mm	
2						2
	▥	G-3	Hydrometer Analysis Gravel = 69.5% Sand = 23.7% Silt = 5.2% Clay = 1.5% Heavy seepage below 2.7 m	GW	sandy, trace clay, trace silt, coarse grained - boulders up to 500 mm	
				GW	trace sand, trace silt	
3	▥	G-4				3
	▥	G-5			- boulders up to 250 mm	
					- boulders up to 800 mm	
4						4
	▥	G-6			- boulders up to 600 mm	
					END OF HOLE at 4.6 m - backfilled with excavated material - refusal on possible bedrock	
5						5

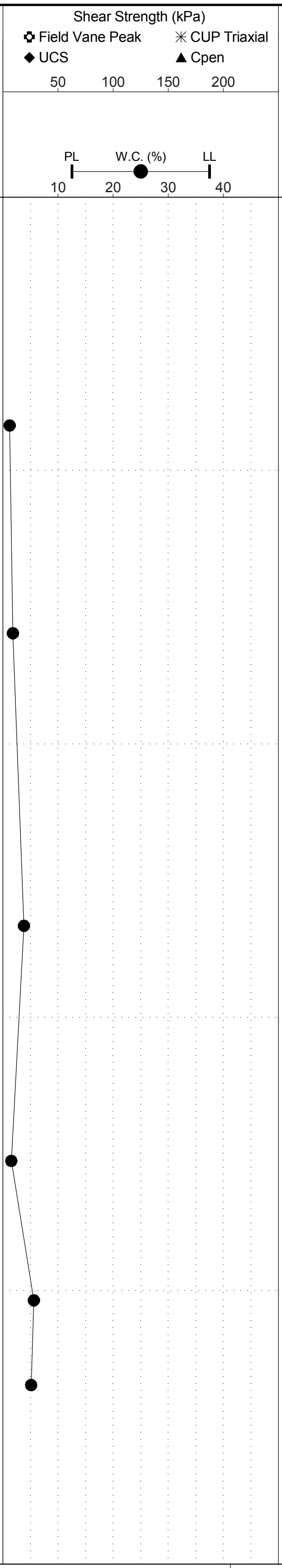
THURBER ENGINEERING LTD.

EXCAVATION CO.: Bremner Engineering and Construction Ltd.		
EXCAVATOR TYPE: John Deere 350 DLC	COMPILED BY: CAM	COMPLETION DEPTH: 4.6 m
EXCAVATION METHOD: Excavation	REVIEWED BY: HKH	COMPLETION DATE: 19/07/2014
INSPECTOR: SKB		

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST PIT NO: **TP14-6**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661261 m, Easting: 617421 m	ELEVATION: 1396.97 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE:



DEPTH (m)	SAMPLE TYPE	SAMPLE ID SPT (N)	REMARKS	MUSCS / ISRM	DESCRIPTION	DEPTH (m)
0				GW	COBBLES AND GRAVEL, trace sand, subangular to subrounded, brown, damp, frequent boulders up to 900 mm	0
	▥	G-1				
1						1
					- 1000 mm boulder	
					- 1000 mm boulder	
	▥	G-2				
2						2
					- boulders up to 900 mm	
				GW	GRAVEL, trace sand, trace silt, brown, moist, frequent cobbles and boulders up to 900 mm	
	▥	G-3				
3						3
				GW	COBBLES AND GRAVEL, trace sand, subangular to subrounded, brown, moist to wet, trace clay pockets (low plastic)`	
	▥	G-4				
			Heavy seepage			
4	▥	G-5			- fines content increasing - boulders up to 400 mm	4
	▥	G-6			- pieces of cemented sand and gravel, no defined layer visible	
					END OF HOLE at 4.3 m - backfilled with excavated material	
5						5

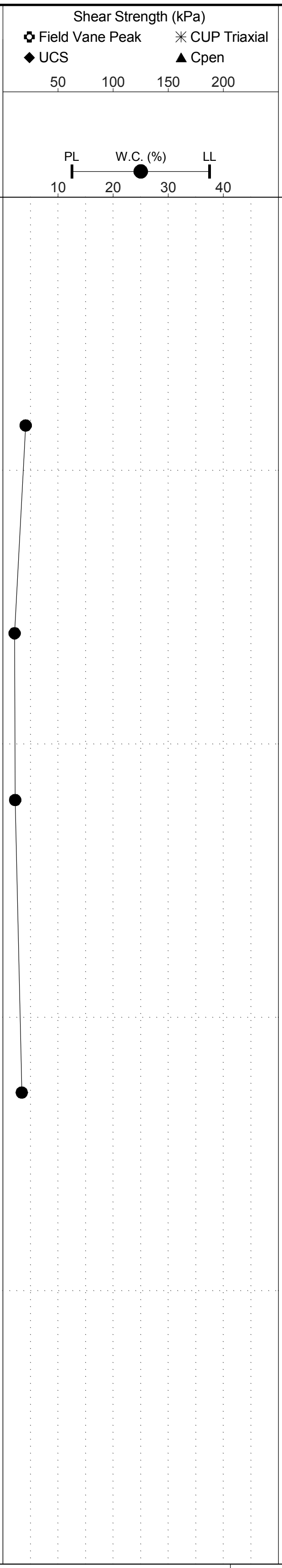
THURBER ENGINEERING LTD.

EXCAVATION CO.: Bremner Engineering and Construction Ltd.		
EXCAVATOR TYPE: John Deere 350 DLC	COMPILED BY: CAM	COMPLETION DEPTH: 4.3 m
EXCAVATION METHOD: Excavation	REVIEWED BY: HKH	COMPLETION DATE: 18/07/2014
INSPECTOR: SKB		Page 1 of 1

CLIENT: Town of Canmore	PROJECT: Cougar Creek Debris Flood Mitigation	TEST PIT NO: **TP14-7**
PROJECT NO: 19-598-440	UTM 11 NAD 83, Northing: 5661310 m, Easting: 617464.60 m	ELEVATION: 1399.11 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE:



DEPTH (m)	SAMPLE TYPE	SAMPLE ID SPT (N)	REMARKS	MUSCS / ISRM	SOIL SYMBOL	DESCRIPTION	DEPTH (m)
0						COBBLES AND GRAVEL, trace sand, trace silt, subangular to subrounded, brown to grey, moist to wet, frequent cobbles and boulders up to 900 mm	0
	▥	G-1					
1			Heavy seepage			- boulders up to 1000 mm	1
	▥	G-2					
				GW			
2							2
	▥	G-3				- boulders up to 700 mm	
						- boulders up to 800 mm	
3							3
	▥	G-4				- frequent cobbles and boulders up to 500 mm	
						END OF HOLE at 3.5 m - significant sloughing of surface material - backfilled with excavated material - refusal on probable bedrock	
4							4
5							5

THURBER ENGINEERING LTD.

EXCAVATION CO.: Bremner Engineering and Construction Ltd.		
EXCAVATOR TYPE: John Deere 350 DLC	COMPILED BY: CAM	COMPLETION DEPTH: 3.5 m
EXCAVATION METHOD: Excavation	REVIEWED BY: HKH	COMPLETION DATE: 18/07/2014
INSPECTOR: SKB		Page 1 of 1

CLIENT: Town of Canmore

PROJECT: Cougar Creek Debris Flood Mitigation

TEST PIT NO: **TP14-8**

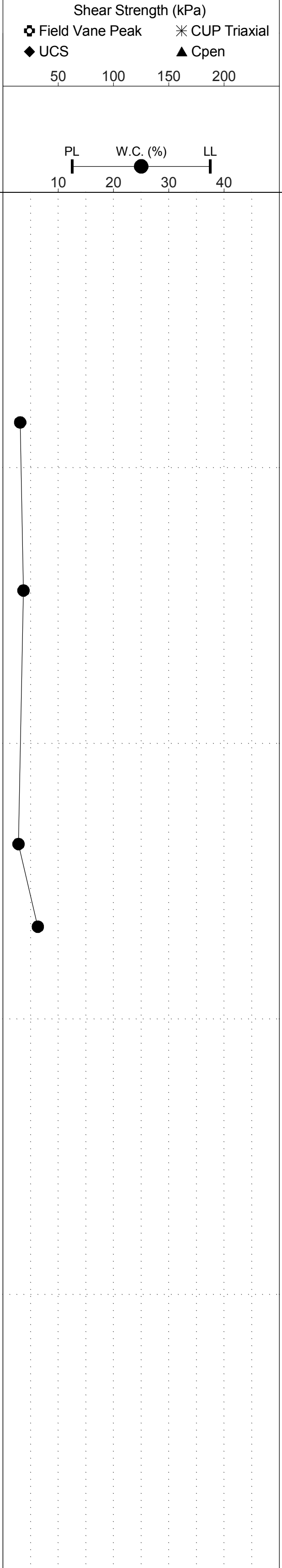
PROJECT NO: 19-598-440

UTM 11 NAD 83, Northing: 5661468 m, Easting: 617544.80 m

ELEVATION: 1406.88 m

SAMPLE TYPE: ▥ Grab Sample

BACKFILL TYPE:



DEPTH (m)	SAMPLE TYPE	SAMPLE ID SPT (N)	REMARKS	MUSCS / ISRM	DESCRIPTION	DEPTH (m)
0				GW	COBBLES AND BOULDERS, some gravel, trace sand, trace silt, coarse grained, subangular to subrounded, grey, dry	0
				GW	COBBLES AND GRAVEL, some sand, subangular to subrounded, brown to grey, moist to wet, frequent boulders up to 500 mm	
	▥	G-1				
1			Heavy seepage			1
	▥	G-2			- boulders up to 700 mm	
					- boulders up to 800 mm	
2						2
	▥	G-3			- boulders up to 800 mm - 900 mm boulder	
	▥	G-4				
			Sloughing		- boulders up to 600 mm	
					END OF HOLE at 2.7 m - unable to progress past 2.7 m due to sloughing - backfilled with excavated material	
3						3
4						4
5						5

THURBER ENGINEERING LTD.

EXCAVATION CO.: Bremner Engineering and Construction Ltd.

EXCAVATOR TYPE: John Deere 350 DLC

COMPILED BY: CAM

COMPLETION DEPTH: 2.7 m

EXCAVATION METHOD: Excavation

REVIEWED BY: HKH

COMPLETION DATE: 19/07/2014

INSPECTOR: SKB

APPENDIX C

Laboratory Tests on Dirty Outwash (“Kame Terrace”): Summary Table, Lab Sheets and Photos

Water Creek Analysis

LABORATORY TESTS ON DIRTY OUTWASH
("KAME TERRACE")

Table C1 - Summary of Lab Tests on Dirty Outwash (Kame Terrace) Material

Test Type	Sample No.	Location	Water Type	Classification	Photos (4)	Notes
CRUMB TESTS (ASTM D6572-13)	1	Valley Wall	Distilled	1 (1)	1, 2	Some crumbling/diffusion of fines. Air bubles exiting specimen during first hour.
	2	Valley Wall	Distilled	1 (1)	3, 4	Some crumbling/diffusion of fines. Air bubles exiting specimen during first hour.
	3	TP14-06@14 ft	Distilled	1 (1)	5, 6	Some crumbling during first hour.
	4	TP14-06@14 ft	Distilled	1 (1)	7, 8	Some crumbling during first hour.
JAR SLAKE TESTS (SANTI, 1998)	# 2	Valley Wall	Distilled	1 (2)	9	Surficial weathered zone degrades within 10 minutes of immersion. "Core" was single piece of gravel.
	# 34	Valley Wall	Creek	1 (2)	10	Surficial weathered zone degrades within 10 minutes of immersion. Cemented particles held together after 24 hrs.
	#35	TP14-06@14 ft	Distilled	1 (3)	11, 13	Immediate release of surficial sand particles after immersion. Cemented particles held together after 24 hrs but 30% breakable w fingers.
	#36	TP14-06@14 ft	Creek	1 (3)	12, 14	Immediate release of surficial sand particles after immersion. Cemented particles held together after 24 hrs only 10% breakable w fingers.

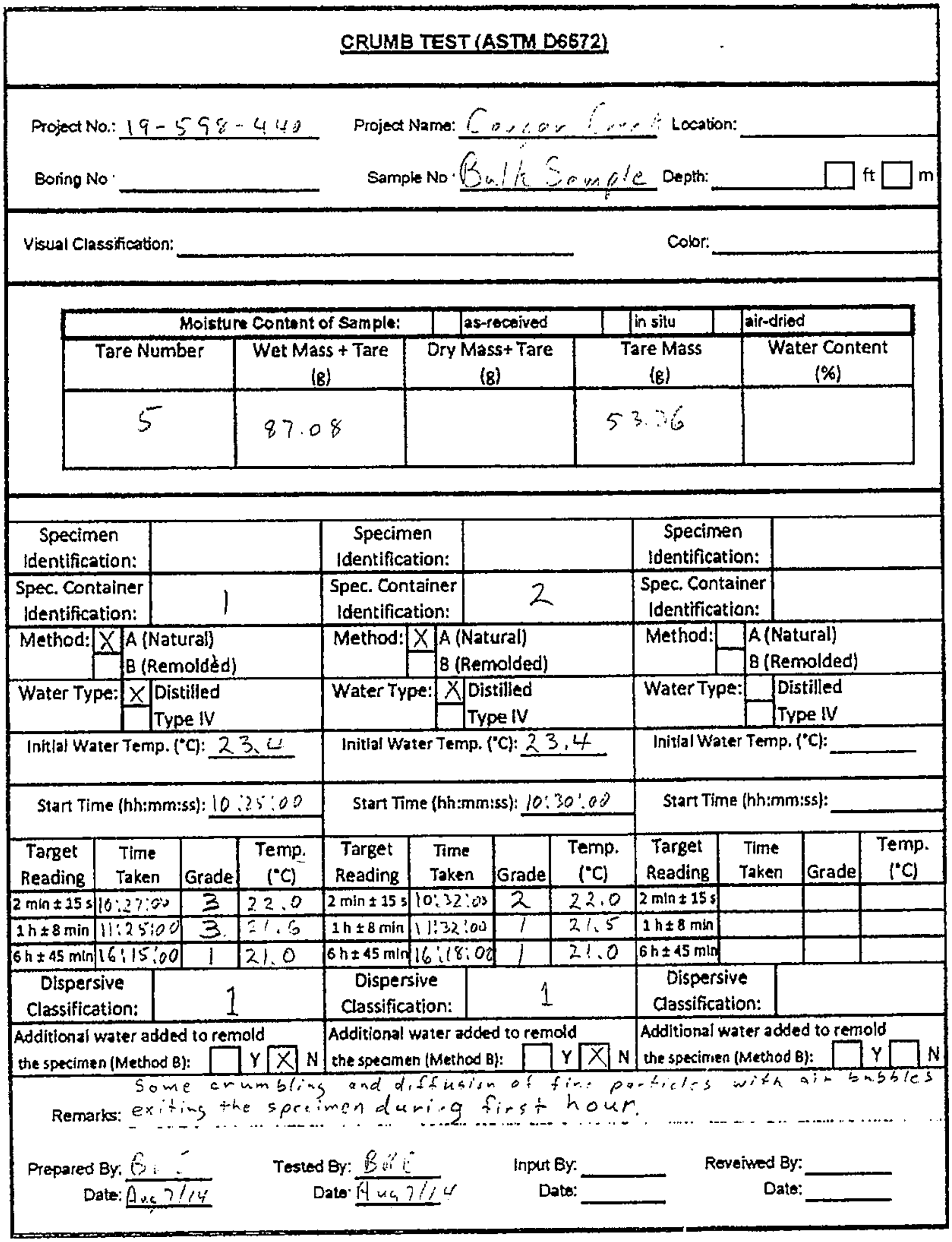
NOTES:

[1] Surficial (fines) phase degrades to mud

[2] Initially (2 min to 1 hr): "intermediate" to "dispersive". After 24 hrs: "non-dispersive"

[3] "Non-dispersive"

[4] Photos included at the end of this Appendix



CRUMB TEST (ASTM D6572)

Project No.: 19-598-440 Project Name: Carson Creek Location: ____

Boring No: ____ Sample No: Bulk Sample Depth: ____ ☐ ft ☐ m

Visual Classification: ____ Color: ____

Moisture Content of Sample:	☐ as-received	☐ in situ	☐ air-dried	
Tare Number	Wet Mass + Tare (g)	Dry Mass+ Tare (g)	Tare Mass (g)	Water Content (%)
5	87.08		53.06	

Specimen Identification:		Specimen Identification:		Specimen Identification:	
Spec. Container Identification:	1	Spec. Container Identification:	2	Spec. Container Identification:	
Method:	☒ A (Natural) ☐ B (Remolded)	Method:	☒ A (Natural) ☐ B (Remolded)	Method:	☐ A (Natural) ☐ B (Remolded)
Water Type:	☒ Distilled ☐ Type IV	Water Type:	☒ Distilled ☐ Type IV	Water Type:	☐ Distilled ☐ Type IV
Initial Water Temp. (°C):	23.4	Initial Water Temp. (°C):	23.4	Initial Water Temp. (°C):	
Start Time (hh:mm:ss):	10:25:00	Start Time (hh:mm:ss):	10:30:00	Start Time (hh:mm:ss):	

Target Reading	Time Taken	Grade	Temp. (°C)	Target Reading	Time Taken	Grade	Temp. (°C)	Target Reading	Time Taken	Grade	Temp. (°C)
2 min ± 15 s	10:27:00	3	22.0	2 min ± 15 s	10:32:05	2	22.0	2 min ± 15 s			
1 h ± 8 min	11:25:00	3	21.6	1 h ± 8 min	11:32:00	1	21.5	1 h ± 8 min			
6 h ± 45 min	16:15:00	1	21.0	6 h ± 45 min	16:18:00	1	21.0	6 h ± 45 min			

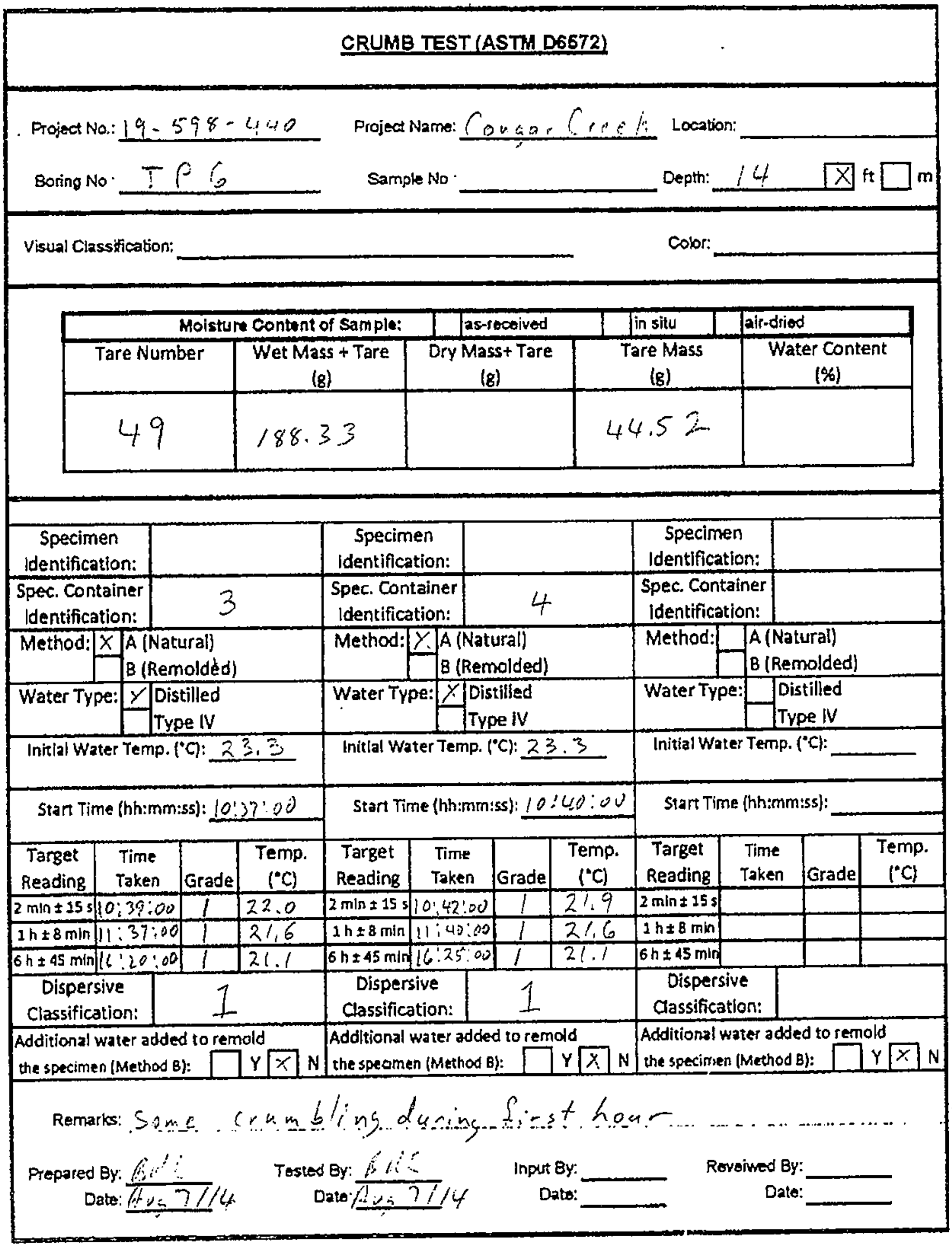
Dispersive Classification:	1	Dispersive Classification:	1	Dispersive Classification:	
Additional water added to remold the specimen (Method B):	☐ Y ☒ N	Additional water added to remold the specimen (Method B):	☐ Y ☒ N	Additional water added to remold the specimen (Method B):	☐ Y ☐ N

Remarks: Some crumbling and diffusion of fine particles with air bubbles exiting the specimen during first hour.

Prepared By: B C Tested By: BCE Input By: ____ Reveiwed By: ____

Date: Aug 7/14 Date: Aug 7/14 Date: ____ Date: ____

FIG. X1.1 Example of a Crumb Test Data Sheet



CRUMB TEST (ASTM D6572)

Project No.: 19-598-440 Project Name: Cougar Creek Location: ____

Boring No: TP6 Sample No: ____ Depth: 14 ☒ ft ☐ m

Visual Classification: ____ Color: ____

Moisture Content of Sample:	☐ as-received	☐ in situ	☐ air-dried	
Tare Number	Wet Mass + Tare (g)	Dry Mass+ Tare (g)	Tare Mass (g)	Water Content (%)
49	188.33		44.52	

Specimen Identification:		Specimen Identification:		Specimen Identification:	
Spec. Container Identification:	3	Spec. Container Identification:	4	Spec. Container Identification:	
Method:	☒ A (Natural) ☐ B (Remolded)	Method:	☒ A (Natural) ☐ B (Remolded)	Method:	☐ A (Natural) ☐ B (Remolded)
Water Type:	☒ Distilled ☐ Type IV	Water Type:	☒ Distilled ☐ Type IV	Water Type:	☐ Distilled ☐ Type IV
Initial Water Temp. (°C):	23.3	Initial Water Temp. (°C):	23.3	Initial Water Temp. (°C):	
Start Time (hh:mm:ss):	10:37:00	Start Time (hh:mm:ss):	10:40:00	Start Time (hh:mm:ss):	

Target Reading	Time Taken	Grade	Temp. (°C)	Target Reading	Time Taken	Grade	Temp. (°C)	Target Reading	Time Taken	Grade	Temp. (°C)
2 min ± 15 s	10:39:00	1	22.0	2 min ± 15 s	10:42:00	1	21.9	2 min ± 15 s			
1 h ± 8 min	11:37:00	1	21.6	1 h ± 8 min	11:40:00	1	21.6	1 h ± 8 min			
6 h ± 45 min	16:20:00	1	21.1	6 h ± 45 min	16:25:00	1	21.1	6 h ± 45 min			

Dispersive Classification:	1	Dispersive Classification:	1	Dispersive Classification:	
Additional water added to remold the specimen (Method B):	☐ Y ☒ N	Additional water added to remold the specimen (Method B):	☐ Y ☒ N	Additional water added to remold the specimen (Method B):	☐ Y ☒ N

Remarks: Some crumbling during first hour

Prepared By: ____ Date: Aug 7/14

Tested By: ____ Date: Aug 7/14

Input By: ____ Date: ____

Reviewed By: ____ Date: ____

FIG. X1.1 Example of a Crumb Test Data Sheet

#2

JAR SLAKE TEST

Project: COUGAR CREEK
Project No.: 13-593-440
Read by: HKH

Sample #	Moisture	Test Water	Start Day	Start Time
WALL	Natural [✓ Oven-Dried]	Creek [✓ Distilled]	23 JUL 14	16:20

Obs. First 10 mins. (include initial pH) 5

dropped in water, immediate release of fines sand, bubbles
sample appears to be one piece of gravel only

Obs. 10 - 30 mins.

no visible change from 10 mins

Obs. 24 hrs. (include final pH) 5

17:20 + Photo

no apparent change when compared to photo at 30 mins

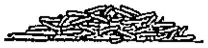
sample was a single piece of gravel, no significant amount broke off (sand grains only)

Jar Slake Index

[✓ 1] Degrades to a pile of flakes or mud
2 Breaks rapidly, forms many chips, or both
3 Breaks slowly, forms few chips, or both
4 Breaks rapidly, develops several fractures, or both
5 Breaks slowly, develops few fractures, or both
6 No change

Altern. Jar Slake Category (Santi)

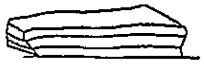
1. MUD - degrades to a mud-like consistency.



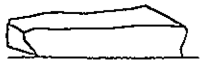
2. FLAKES - sample totally reduced to flakes. Original outline of sample not discernible.

3. CHIPS - chips of material fall from the sides of the sample. Sample may also be fractured. Original outline of sample is barely discernible.

4. FRACTURES - sample fractures throughout, creating a chunky appearance.



5. SLABS - sample parts along a few planar surfaces.



6. NO REACTION - no discernible effect.

Figure 1. Proposed modified jar slake test categories.

#3²

JAR SLAKE TEST

Project: COUGAR CK.
Project No.: 13-598-4440
Read by: HKH

Sample #	Moisture	Test Water	Start Day	Start Time
WALL	Natural [✓ Oven-Dried]	[✓ Creek] Distilled	23 JUL 14	16:20

Obs. First 10 ~~mins. (include~~ initial pH) 6-7

dropped in w. spoon, immediate release of fines, bubbles (less than #2.)

Obs. 10 - 30 mins.

no visible change from 10 mins

Obs. 24 hrs. (include final pH) 6-7

17.20 + Photo

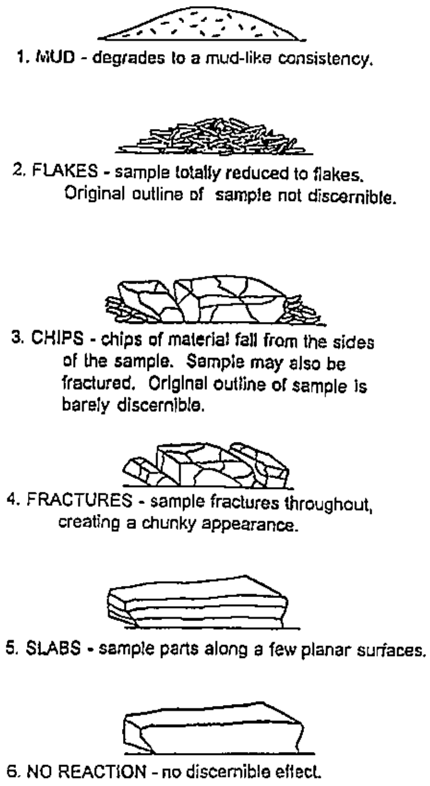
no apparent change when compared to photo at 30 mins

about 10% of sample broke off easily when washed

Jar Slake Index

[✓ 1] Degrades to a pile of flakes or mud
2 Breaks rapidly, forms many chips, or both
3 Breaks slowly, forms few chips, or both
4 Breaks rapidly, develops several fractures, or both
5 Breaks slowly, develops few fractures, or both
6 No change

Altern. Jar Slake Category (Santi)



1. MUD - degrades to a mud-like consistency.
2. FLAKES - sample totally reduced to flakes. Original outline of sample not discernible.
3. CHIPS - chips of material fall from the sides of the sample. Sample may also be fractured. Original outline of sample is barely discernible.
4. FRACTURES - sample fractures throughout, creating a chunky appearance.
5. SLABS - sample parts along a few planar surfaces.
6. NO REACTION - no discernible effect.

Figure 1. Proposed modified jar slake test categories.

#35

JAR SLAKE TEST

Project: COUGAR CREEK
Project No.: 13-538-4460
Read by: HKH

Sample #	Moisture	Test Water	Start Day	Start Time
TP-6 14 ft	Natural Oven-Dried	Creek Distilled	23 JUL 2014	16:20

Obs. First 10 ~~mins.~~ (include initial pH) 5

dropped in w. spoon, immediate release of coarser particles (sand?) which settled
no fines released

Obs. 10 - 30 mins.

no visible change from 10 mins

Obs. 24 hrs. (include final pH) 5 17:20 + Photo

no apparent change when compared to photo at 30 mins

able to break ≈30% of original sample w. fingers, no significant effort - remainder unbreakable w. fingers

Jar Slake Index

[✓ 1]	Degrades to a pile of flakes or mud
2	Breaks rapidly, forms many chips, or both
3	Breaks slowly, forms few chips, or both
4	Breaks rapidly, develops several fractures, or both
5	Breaks slowly, develops few fractures, or both
6	No change

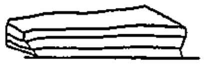
Altern. Jar Slake Category (Santi)

1. MUD - degrades to a mud-like consistency.

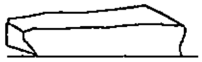
2. FLAKES - sample totally reduced to flakes. Original outline of sample not discernible.

3. CHIPS - chips of material fall from the sides of the sample. Sample may also be fractured. Original outline of sample is barely discernible.

4. FRACTURES - sample fractures throughout, creating a chunky appearance.



5. SLABS - sample parts along a few planar surfaces.



6. NO REACTION - no discernible effect.

Figure 1. Proposed modified jar slake test categories.

#36

JAR SLAKE TEST

Project: COUGAR CREEK
Project No.: 13-538-440
Read by: HKH

Sample #	Moisture	Test Water	Start Day	Start Time
TP-6 14ft	Natural [✓ Oven-Dried]	[✓ Creek] Distilled	23 JUL 14	16:20

Obs. First 10 mins. (Include initial pH) 6-7

dropped in w. spoon, immediate release of coarser particles (sand?), which settled
invisible fines

Obs. 10 - 30 mins.

no visible change from 10 mins

Obs. 24 hrs. (include final pH) 6-7 17:20+Photo

no apparent change when compared to photo at 30 mins
able to break only 10% of sample w. fingers, hard/unbreakable w. fingers

Jar Slake Index

[✓ 1]	Degrades to a pile of flakes or mud
2	Breaks rapidly, forms many chips, or both
3	Breaks slowly, forms few chips, or both
4	Breaks rapidly, develops several fractures, or both
5	Breaks slowly, develops few fractures, or both
6	No change

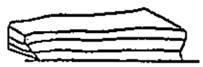
Altern. Jar Slake Category (Santi)

1. MUD - degrades to a mud-like consistency.

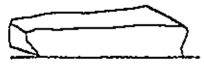
2. FLAKES - sample totally reduced to flakes. Original outline of sample not discernible.

3. CHIPS - chips of material fall from the sides of the sample. Sample may also be fractured. Original outline of sample is barely discernible.

4. FRACTURES - sample fractures throughout, creating a chunky appearance.



5. SLABS - sample parts along a few planar surfaces.



6. NO REACTION - no discernible effect.

Figure 1. Proposed modified jar slake test categories.

Photo 1: Crumb Test Sample 1 (Valley Wall) – Before Immersion

Photo 2: Crumb Test Sample 1 (Valley Wall) – After 24 hrs Immersion

Photo 3: Crumb Test Sample 2 (Valley Wall) – Before Immersion

Photo 4: Crumb Test Sample 2 (Valley Wall) – After 24 hrs Immersion

Photo 5: Crumb Test Sample 3 (TP14-06) – Before Immersion

Photo 6: Crumb Test Sample 3 (TP14-06) – After 24 hrs Immersion

Photo 7: Crumb Test Sample 4 (TP14-06) – Before Immersion

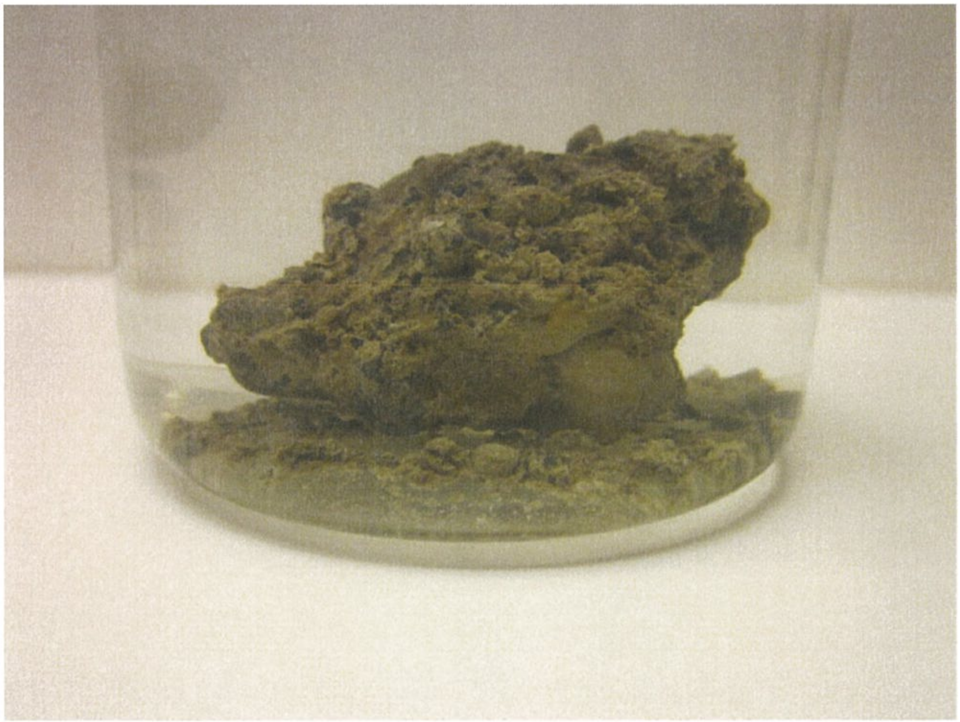


Photo 8: Crumb Test Sample 4 (TP14-06) – After 24 hrs Immersion

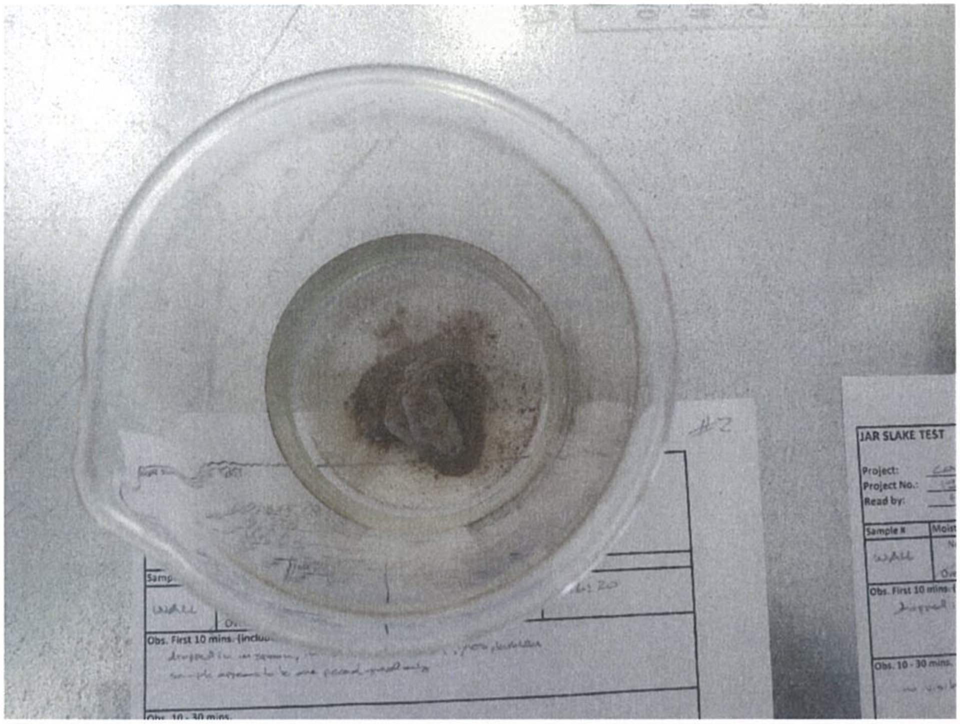


Photo 9: Jar Slake Test Sample #2 (Valley Wall) – Distilled Water, After 24 hrs Immersion

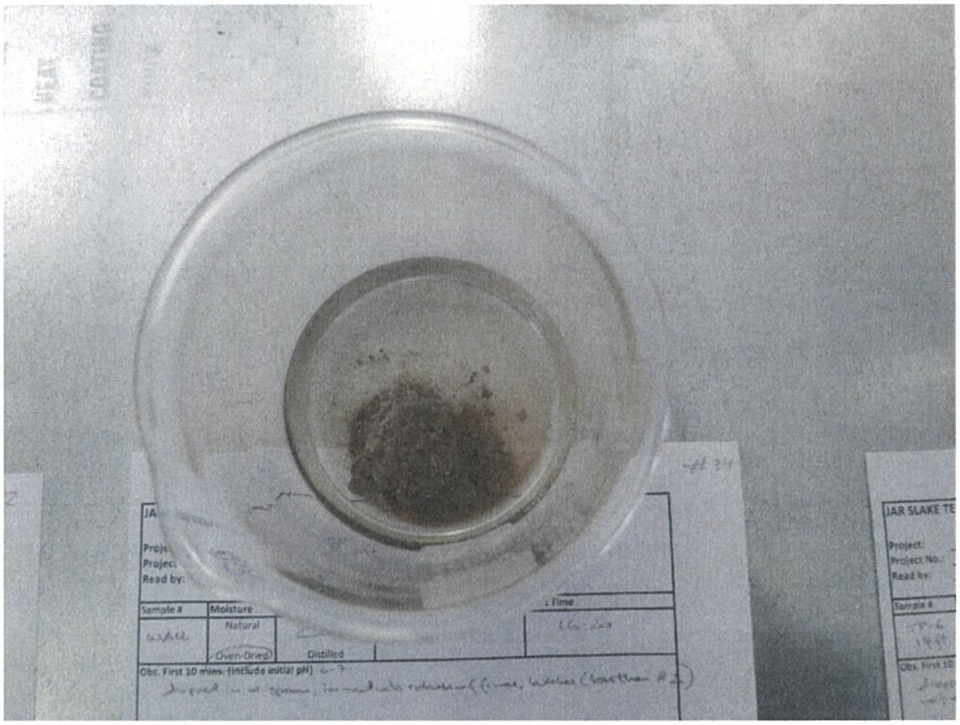


Photo 10: Jar Slake Test Sample #34 (Valley Wall) – Creek Water, After 24 hrs Immersion

Photo 11: Jar Slake Test Sample #35 (TP14-06) – Distilled Water, After 24 hrs Immersion

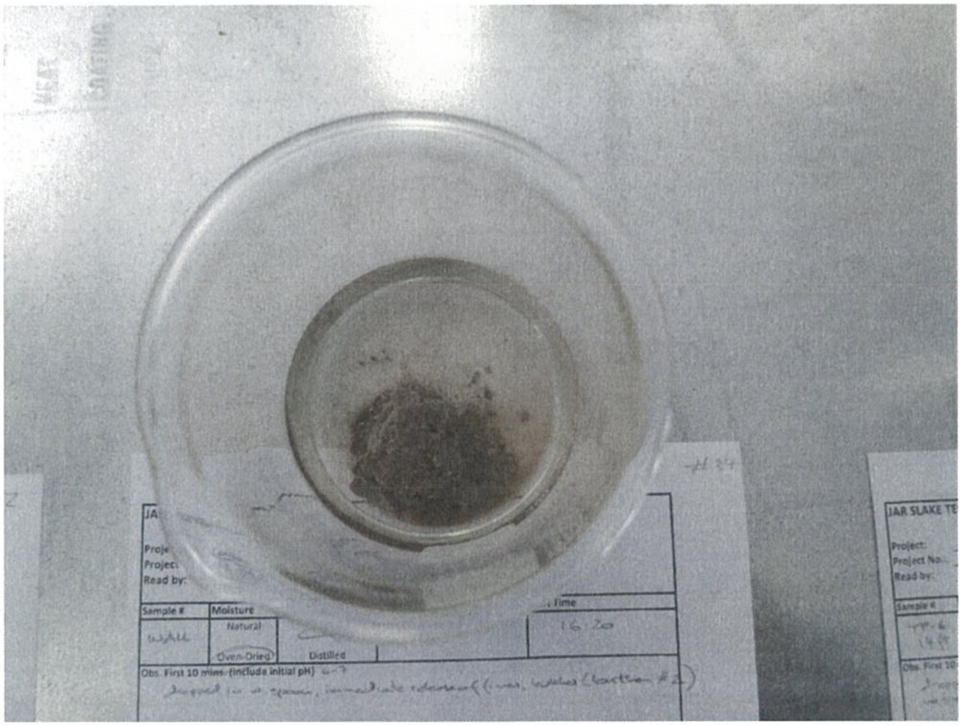


Photo 12: Jar Slake Test Sample #36 (TP14-06) – Creek Water, After 24 hrs Immersion

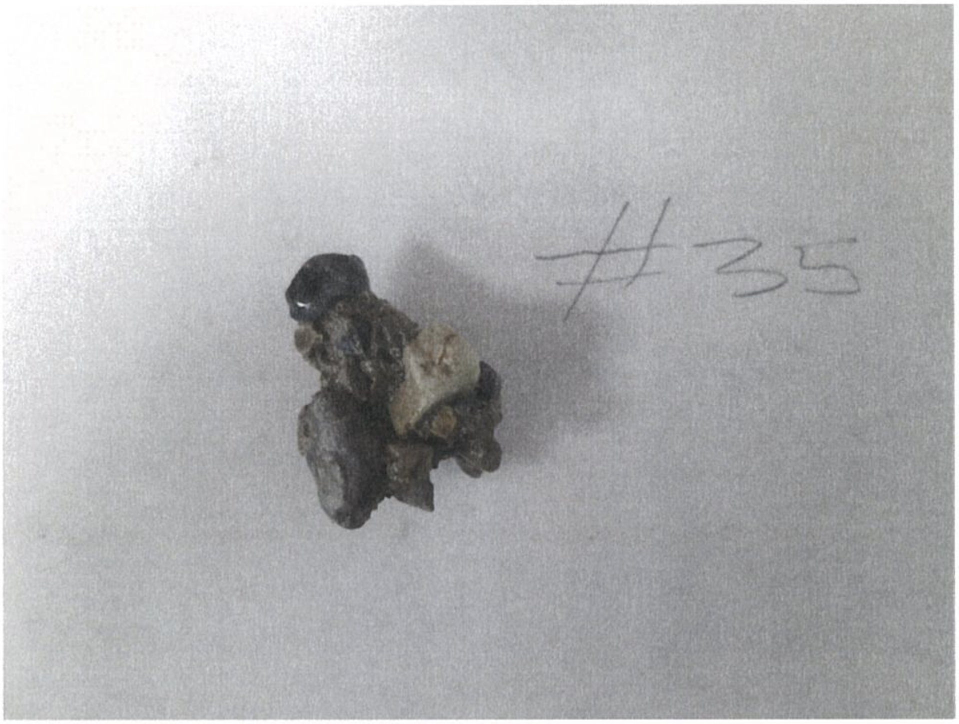


Photo 13: Jar Slake Test Sample #35 (TP14-06) – After Removal from Beaker + Washing

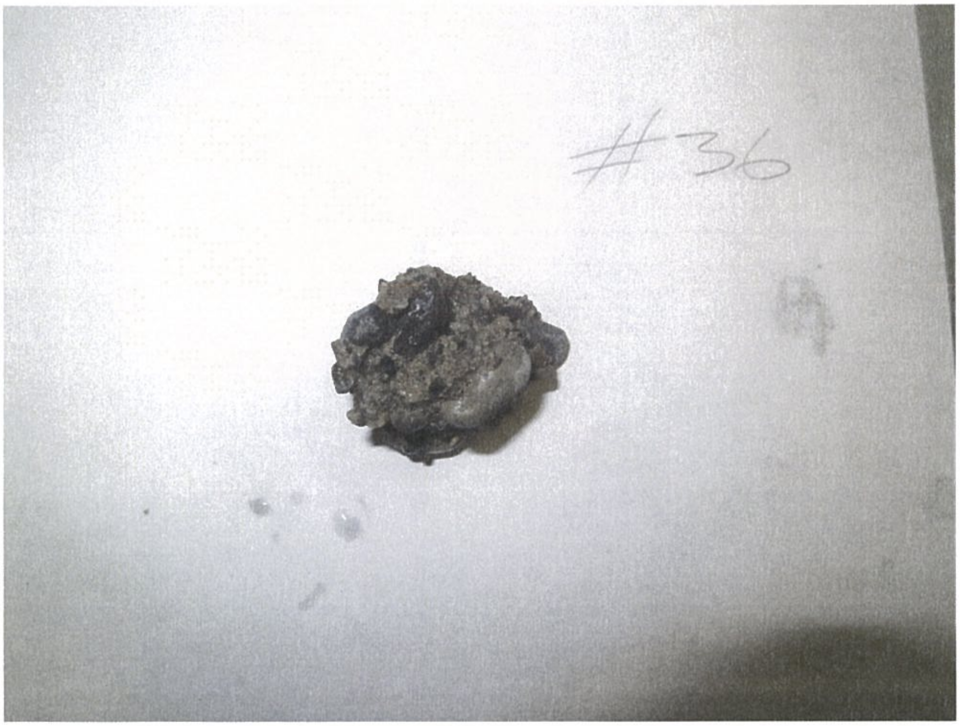


Photo 14: Jar Slake Test Sample #36 (TP14-06) – After Removal from Beaker + Washing

THURBER

WATER CREEK ANALYSIS

THURBER ENGINEERING LTD-CAL
ATTN: LINDSEY BLAINE
#180, 7330 FISHER ST SE
CALGARY AB T2H 2H8

Date Received: 21-JUL-14
Report Date: 28-JUL-14 14:03 (MT)
Version: FINAL

Client Phone: 403-253-9217

Certificate of Analysis

Lab Work Order #:	**L1489818**
Project P.O. #:	NOT SUBMITTED
Job Reference:	19-598-440
C of C Numbers:	14-403070
Legal Site Desc:	

Monica Gibson

Monica Gibson
Account Manager

ALS ENVIRONMENTAL ANALYTICAL REPORT

Sample Details/Parameters	Result	Qualifier*	D.L.	Units	Extracted	Analyzed	Batch
L1489818-1 GC-1							
Sampled By: HKH on 19-JUL-14							
Matrix: WATER							
Routine Potable Water							
Chloride (Cl)							
Chloride (Cl)	0.35		0.10	mg/L		21-JUL-14	R2899687
Fluoride							
Fluoride (F)	0.39		0.10	mg/L		21-JUL-14	R2899687
Ion Balance Calculation							
Ion Balance	94.9			%		28-JUL-14	
TDS (Calculated)	234			mg/L		28-JUL-14	
Hardness (as CaCO3)	208			mg/L		28-JUL-14	
Nitrate+Nitrite							
Nitrate and Nitrite (as N)	0.205		0.054	mg/L		28-JUL-14	
Nitrate-N							
Nitrate (as N)	0.205		0.050	mg/L		21-JUL-14	R2899687
Nitrite-N							
Nitrite (as N)	<0.020		0.020	mg/L		21-JUL-14	R2899687
Sulfate (SO4)							
Sulfate (SO4)	74.6		0.50	mg/L		21-JUL-14	R2899687
Total Metals in Water by ICPOES							
Calcium (Ca)-Total	56.3		0.10	mg/L		23-JUL-14	R2895614
Iron (Fe)-Total	<0.030		0.030	mg/L		23-JUL-14	R2895614
Magnesium (Mg)-Total	16.4		0.10	mg/L		23-JUL-14	R2895614
Manganese (Mn)-Total	<0.0050		0.0050	mg/L		23-JUL-14	R2895614
Potassium (K)-Total	0.61		0.50	mg/L		23-JUL-14	R2895614
Sodium (Na)-Total	<1.0		1.0	mg/L		23-JUL-14	R2895614
Turbidity							
Turbidity	0.36		0.10	NTU		21-JUL-14	R2892610
pH, Conductivity and Total Alkalinity							
pH	8.29		0.10	pH		22-JUL-14	R2894508
Conductivity (EC)	371		3.0	uS/cm		22-JUL-14	R2894508
Bicarbonate (HCO3)	171		5.0	mg/L		22-JUL-14	R2894508
Carbonate (CO3)	<5.0		5.0	mg/L		22-JUL-14	R2894508
Hydroxide (OH)	<5.0		5.0	mg/L		22-JUL-14	R2894508
Alkalinity, Total (as CaCO3)	140		5.0	mg/L		22-JUL-14	R2894508

* Refer to Referenced Information for Qualifiers (if any) and Methodology.

Reference Information

Test Method References:

ALS Test Code	Matrix	Test Description	Method Reference**
CL-CL	Water	Chloride (Cl)	APHA 4110 B-Ion Chromatography

This analysis is carried out using procedures adapted from APHA Method 4110 B. "Ion Chromatography with Chemical Suppression of Eluent Conductivity" and EPA Method 300.0 "Determination of Inorganic Anions by Ion Chromatography

F-IC-CL	Water	Fluoride	APHA 4110 B-Ion Chromatography

This analysis is carried out using procedures adapted from APHA Method 4110 B. "Ion Chromatography with Chemical Suppression of Eluent Conductivity" and EPA Method 300.0 "Determination of Inorganic Anions by Ion Chromatography

IONBALANCE-CL	Water	Ion Balance Calculation	APHA 1030E
MET-TOT-ICP-CL	Water	Total Metals in Water by ICPOES	EPA SW-846 3005A/6010B

This analysis is carried out using procedures adapted from "Standard Methods for the Examination of Water and Wastewater" published by the American Public Health Association, and with procedures adapted from "Test Methods for Evaluating Solid Waste" SW-846 published by the United States Environmental Protection Agency (EPA). The procedures may involve preliminary sample treatment by acid digestion using a hotblock (EPA Method 3005A). Instrumental analysis is by inductively coupled plasma - optical emission spectrophotometry (EPA Method 6010B).

N2N3-CALC-CL	Water	Nitrate+Nitrite	CALCULATION
NO2-CL	Water	Nitrite-N	APHA 4110 B-Ion Chromatography

This analysis is carried out using procedures adapted from EPA Method 300.0 "Determination of Inorganic Anions by Ion Chromatography". Nitrite is detected by UV absorbance.

NO3-IC-CL	Water	Nitrate-N	APHA 4110 B-Ion Chromatography

This analysis is carried out using procedures adapted from EPA Method 300.0 "Determination of Inorganic Anions by Ion Chromatography". Nitrite is detected by UV absorbance

PH/EC/ALK-CL	Water	pH, Conductivity and Total Alkalinity	APHA 4500H,2510,2320

All samples analyzed by this method for pH will have exceeded the 15 minute recommended hold time from time of sampling (field analysis is recommended for pH where highly accurate results are needed)
pH measurement is determined from the activity of the hydrogen ions using a hydrogen electrode and a reference electrode.
Alkalinity measurement is based on the sample's capacity to neutralize acid
Conductivity measurement is based on the sample's capacity to convey an electric current

SO4-CL	Water	Sulfate (SO4)	APHA 4110 B-Ion Chromatography

This analysis is carried out using procedures adapted from APHA Method 4110 B. "Ion Chromatography with Chemical Suppression of Eluent Conductivity" and EPA Method 300.0 "Determination of Inorganic Anions by Ion Chromatography

TURBIDITY-CL	Water	Turbidity	APHA 2130 B-Nephelometer

This analysis is carried out using procedures adapted from APHA Method 2130 "Turbidity". Turbidity is determined by the nephelometric method.

** ALS test methods may incorporate modifications from specified reference methods to improve performance.

The last two letters of the above test code(s) indicate the laboratory that performed analytical analysis for that test. Refer to the list below:

Laboratory Definition Code	Laboratory Location
CL	ALS ENVIRONMENTAL - CALGARY, ALBERTA, CANADA

Chain of Custody Numbers:

14-403070

Reference Information

Test Method References:

ALS Test Code	Matrix	Test Description	Method Reference**

GLOSSARY OF REPORT TERMS

Surrogates are compounds that are similar in behaviour to target analyte(s), but that do not normally occur in environmental samples. For applicable tests, surrogates are added to samples prior to analysis as a check on recovery. In reports that display the D.L. column, laboratory objectives for surrogates are listed there.

mg/kg - milligrams per kilogram based on dry weight of sample
mg/kg wwt - milligrams per kilogram based on wet weight of sample
mg/kg lwt - milligrams per kilogram based on lipid-adjusted weight
mg/L - unit of concentration based on volume, parts per million.
< - Less than.
D.L. - The reporting limit.
N/A - Result not available. Refer to qualifier code and definition for explanation.

Test results reported relate only to the samples as received by the laboratory.
UNLESS OTHERWISE STATED, ALL SAMPLES WERE RECEIVED IN ACCEPTABLE CONDITION.
Analytical results in unsigned test reports with the DRAFT watermark are subject to change, pending final QC review.

Quality Control Report

Workorder: L1489818 Report Date: 28-JUL-14

Client: THURBER ENGINEERING LTD-CAL
#180, 7330 FISHER ST SE
CALGARY AB T2H 2H8
Contact: LINDSEY BLAINE

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
CL-CL	Water							
Batch R2899687								
WG1919790-10 LCS								
Chloride (Cl)			100.1		%		90-110	21-JUL-14
WG1919790-2 LCS								
Chloride (Cl)			100.1		%		90-110	21-JUL-14
WG1919790-6 LCS								
Chloride (Cl)			100.0		%		90-110	21-JUL-14
WG1919790-1 MB								
Chloride (Cl)			<0.10		mg/L		0.1	21-JUL-14
WG1919790-5 MB								
Chloride (Cl)			<0.10		mg/L		0.1	21-JUL-14
WG1919790-9 MB								
Chloride (Cl)			<0.10		mg/L		0.1	21-JUL-14
WG1919790-12 MS		**L1489818-1**						
Chloride (Cl)			99.0		%		75-125	21-JUL-14
WG1919790-4 MS		**L1489694-15**						
Chloride (Cl)			N/A	MS-B	%		-	21-JUL-14
WG1919790-8 MS		**L1489694-28**						
Chloride (Cl)			N/A	MS-B	%		-	21-JUL-14
F-IC-CL	Water							
Batch R2899687								
WG1919790-10 LCS								
Fluoride (F)			100.4		%		90-110	21-JUL-14
WG1919790-9 MB								
Fluoride (F)			<0.10		mg/L		0.1	21-JUL-14
WG1919790-12 MS		**L1489818-1**						
Fluoride (F)			97.9		%		75-125	21-JUL-14
MET-TOT-ICP-CL	Water							
Batch R2895614								
WG1916659-2 CRM		**TMRM**						
Calcium (Ca)-Total			96.5		%		80-120	23-JUL-14
Iron (Fe)-Total			95.9		%		80-120	23-JUL-14
Magnesium (Mg)-Total			100.6		%		80-120	23-JUL-14
Manganese (Mn)-Total			97.5		%		80-120	23-JUL-14
Potassium (K)-Total			96.7		%		80-120	23-JUL-14
Sodium (Na)-Total			99.0		%		80-120	23-JUL-14
WG1916659-1 MB								
Calcium (Ca)-Total			<0.10		mg/L		0.1	23-JUL-14

Quality Control Report

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
MET-TOT-ICP-CL	Water							
Batch R2895614								
WG1916659-1 MB								
Iron (Fe)-Total			<0.030		mg/L		0.03	23-JUL-14
Magnesium (Mg)-Total			<0.10		mg/L		0.1	23-JUL-14
Manganese (Mn)-Total			<0.0050		mg/L		0.005	23-JUL-14
Potassium (K)-Total			<0.50		mg/L		0.5	23-JUL-14
Sodium (Na)-Total			<1.0		mg/L		1	23-JUL-14
WG1916659-5 MS		**L1490121-1**						
Calcium (Ca)-Total			113.9		%		70-130	23-JUL-14
Iron (Fe)-Total			111.0		%		70-130	23-JUL-14
Magnesium (Mg)-Total			113.6		%		70-130	23-JUL-14
Sodium (Na)-Total			N/A	MS-B	%		-	23-JUL-14
NO2-CL	Water							
Batch R2899687								
WG1919790-10 LCS								
Nitrite (as N)			104.1		%		90-110	21-JUL-14
WG1919790-9 MB								
Nitrite (as N)			<0.020		mg/L		0.02	21-JUL-14
WG1919790-12 MS		**L1489818-1**						
Nitrite (as N)			102.9		%		75-125	21-JUL-14
NO3-IC-CL	Water							
Batch R2899687								
WG1919790-10 LCS								
Nitrate (as N)			100.4		%		90-110	21-JUL-14
WG1919790-9 MB								
Nitrate (as N)			<0.050		mg/L		0.05	21-JUL-14
WG1919790-12 MS		**L1489818-1**						
Nitrate (as N)			98.1		%		75-125	21-JUL-14
PH/EC/ALK-CL	Water							
Batch R2894508								
WG1916536-11 LCS								
pH			7.01		pH		6.9-7.1	22-JUL-14
Conductivity (EC)			100.9		%		90-110	22-JUL-14
Alkalinity, Total (as CaCO3)			100.8		%		85-115	22-JUL-14
WG1916536-8 LCS								
pH			7.04		pH		6.9-7.1	22-JUL-14
Conductivity (EC)			99.2		%		90-110	22-JUL-14
Alkalinity, Total (as CaCO3)			99.5		%		85-115	22-JUL-14

Quality Control Report

Workorder: L1489818 Report Date: 28-JUL-14

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
SO4-CL	Water							
Batch **R2899687**								
WG1919790-10 **LCS**								
Sulfate (SO4)			100.1		%		90-110	21-JUL-14
WG1919790-9 **MB**								
Sulfate (SO4)			<0.50		mg/L		0.5	21-JUL-14
WG1919790-12 **MS**		**L1489818-1**						
Sulfate (SO4)			90.1		%		75-125	21-JUL-14
TURBIDITY-CL	Water							
Batch **R2892610**								
WG1915294-3 **DUP**		**L1489818-1**						
Turbidity		0.36	0.36		NTU	1.7	15	21-JUL-14
WG1915294-2 **LCS**								
Turbidity			94.0		%		85-115	21-JUL-14
WG1915294-1 **MB**								
Turbidity			<0.10		NTU		0.1	21-JUL-14

Quality Control Report

Legend:

Limit	ALS Control Limit (Data Quality Objectives)
DUP	Duplicate
RPD	Relative Percent Difference
N/A	Not Available
LCS	Laboratory Control Sample
SRM	Standard Reference Material
MS	Matrix Spike
MSD	Matrix Spike Duplicate
ADE	Average Desorption Efficiency
MB	Method Blank
IRM	Internal Reference Material
CRM	Certified Reference Material
CCV	Continuing Calibration Verification
CVS	Calibration Verification Standard
LCSD	Laboratory Control Sample Duplicate

Sample Parameter Qualifier Definitions:

Qualifier	Description
J	Duplicate results and limits are expressed in terms of absolute difference.
MS-B	Matrix Spike recovery could not be accurately calculated due to high analyte background in sample.
RPD-NA	Relative Percent Difference Not Available due to result(s) being less than detection limit.

Quality Control Report

Workorder: L1489818 Report Date: 28-JUL-14

Hold Time Exceedances:

ALS Product Description	Sample ID	Sampling Date	Date Processed	Rec. HT	Actual HT	Units	Qualifier
Physical Tests							
Turbidity							
	1	19-JUL-14	21-JUL-14 14:53	48	51	hours	EHTR
Anions and Nutrients							
Nitrate-N							
	1	19-JUL-14	21-JUL-14 12:50	48	49	hours	EHTR
Nitrite-N							
	1	19-JUL-14	21-JUL-14 12:50	48	49	hours	EHTR

Legend & Qualifier Definitions:

EHTR-FM:	Exceeded ALS recommended hold time prior to sample receipt. Field Measurement recommended.
EHTR:	Exceeded ALS recommended hold time prior to sample receipt.
EHTL:	Exceeded ALS recommended hold time prior to analysis. Sample was received less than 24 hours prior to expiry.
EHT:	Exceeded ALS recommended hold time prior to analysis.
Rec. HT:	ALS recommended hold time (see units).

Notes*:
Where actual sampling date is not provided to ALS, the date (& time) of receipt is used for calculation purposes.
Where actual sampling time is not provided to ALS, the earlier of 12 noon on the sampling date or the time (& date) of receipt is used for calculation purposes. Samples for L1489818 were received on 21-JUL-14 14:15.

ALS recommended hold times may vary by province. They are assigned to meet known provincial and/or federal government requirements. In the absence of regulatory hold times, ALS establishes recommendations based on guidelines published by the US EPA, APHA Standard Methods, or Environment Canada (where available). For more information, please contact ALS.

The ALS Quality Control Report is provided to ALS clients upon request. ALS includes comprehensive QC checks with every analysis to ensure our high standards of quality are met. Each QC result has a known or expected target value, which is compared against pre-determined data quality objectives to provide confidence in the accuracy of associated test results.

Please note that this report may contain QC results from anonymous Sample Duplicates and Matrix Spikes that do not originate from this Work Order.

ALS Environmental
www.alsglobal.com

Chain of Custody (COC) / Analytical Request Form

Canada Toll Free: 1 800 668 9878

L1489818-COFC

COC Number: 14 - 403070

Page 1 of 1

Report To
Company: Thurber Engineering
Contact: Lindsey Blaine
Address:
Phone: 403-253-9217

Report Format / Distribution
Select Report Format: ☑ PDF ☐ EXCEL ☐ EDD (DIGITAL)
Quality Control (QC) Report with Report ☑ Yes ☐ No
☐ Criteria on Report - provide details below if box checked
Select Distribution: ☑ EMAIL ☐ MAIL ☐ FAX
Email 1 or Fax lblaine@thurber.ca
Email 2 hheinz@thurber.ca

Select Service Level Below (Rush Turnaround Time (TAT) is not available for all tests)
R ☒ Regular (Standard TAT if received by 3pm)
P ☐ Priority (2-4 business days if received by 3pm)
E ☐ Emergency (1-2 business days if received by 3pm)
E2 ☐ Same day or weekend emergency if received by 10am – contact ALS for surcharge.
Specify Date Required for E2,E or P:

Invoice To Same as Report To ☑ Yes ☐ No
Copy of Invoice with Report ☑ Yes ☐ No
Company:
Contact:

Invoice Distribution
Select Invoice Distribution: ☑ EMAIL ☐ MAIL ☐ FAX
Email 1 or Fax lblaine@thurber.ca
Email 2

Project Information
ALS Quote #:
Job #: 19-598-440
PO / AFE:
LSD:

Oil and Gas Required Fields (client use)
Approver ID:
Cost Center:
GL Account:
Routing Code:
Activity Code:
Location:

ALS Lab Work Order # (lab use only) L1489819
ALS Contact: Monica Gibson
Sampler: HKH

Analysis Request
Indicate Filtered (F), Preserved (P) or Filtered and Preserved (F/P) below

ALS Sample # (lab use only)	Sample Identification and/or Coordinates (This description will appear on the report)	Date (dd-mmm-yy)	Time (hh:mm)	Sample Type	Routine Potability	Number of Containers
	GC-1	19-JUL-14		Water	✓	2

Drinking Water (DW) Samples[1] (client use)
Are samples taken from a Regulated DW System?
☐ Yes ☐ No
Are samples for human drinking water use?
☐ Yes ☐ No

Special Instructions / Specify Criteria to add on report (client Use)

SAMPLE CONDITION AS RECEIVED (lab use only)
Frozen ☐ SIF Observations Yes ☐ No ☐
Ice packs Yes ☐ No ☐ Custody seal intact Yes ☐ No ☐
Cooling Initiated ☐
INITIAL COOLER TEMPERATURES °C: 3°C
FINAL COOLER TEMPERATURES °C:

SHIPMENT RELEASE (client use)
Released by: L Blaine Date: 21-JUL-14 Time: 2:08pm

INITIAL SHIPMENT RECEPTION (lab use only)
Received by: Date: 21 Jul Time: 2:15

FINAL SHIPMENT RECEPTION (lab use only)
Received by: Date: Time:

REFER TO BACK PAGE FOR ALS LOCATIONS AND SAMPLING INFORMATION

WHITE - LABORATORY COPY YELLOW - CLIENT COPY

NA FM 0326e v08 Front/03 October 2013

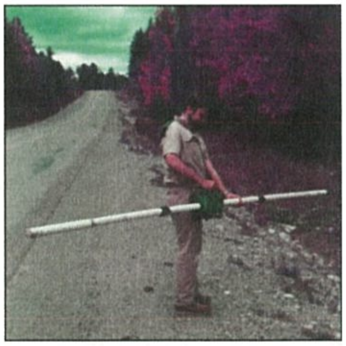
Failure to complete all portions of this form may delay analysis. Please fill in this form LEGIBLY. By the use of this form the user acknowledges and agrees with the Terms and Conditions as specified on the back page of the white - report copy.

[1] If any water samples are taken from a Regulated Drinking Water (DW) System, please submit using an Authorized DW COC form.

THURBER

APPENDIX D

DMT Geosciences (Geophysics) Report



Cougar Creek Geophysical Survey

Subsurface and Bedrock Investigation

Effective Date: September 19, 2014
Issue Date: September 19, 2014
File Number: CGAA.248

Prepared for:

Thurber Engineering Ltd.

Prepared by:

DMT Geosciences Ltd.
Calgary, AB, Canada
(APEGA Permit P-09454)

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ABBREVIATIONS

GPR	Ground Penetrating Radar
MASW	Multichannel Analysis of Surface Waves
UTM	Universal Transverse Mercator
Vs	Shear wave acoustic velocity
NAD83	North American Datum 1983
RMS	Root Mean Square

GLOSSARY

Shot	A shot is any active single input of seismic energy into the earth. The term shot is used whether created by a sledge hammer or explosives or any other
Array	Arrays are always referring to a collection of geophysical sensors spread out in a geometrically regular pattern, often a line.
First arrival time	The length of time a propagating P-wave takes to travel from its origin at the shot location to geophone in question.
Ground Roll	Ground roll is the wave that travels along the interface between the surface and the earth. The wave travels in the horizontal direction (along the surface) while the direction of motion is vertical. This classifies it as a shear wave.
Relative Permittivity	Permittivity is a measure of the resistance of a material to forming an electric field. Practically, it governs the speed that an EM wave will pass through a material. Relative permittivity is a unitless number that relates the permittivity of a material to the Permittivity of a vacuum.

1.0 INTRODUCTION

Cougar Creek was the site of flooding in June of 2013. As part of a larger mitigation effort, DMT Geosciences Ltd. was contracted by Thurber Engineering Ltd. to provide geophysical information as part of a precursor to design considerations for a possible debris flood retention dam on Cougar Creek.

1.1 Project Objectives

The purpose of this survey was to identify design considerations for the location of a possible dam on Cougar Creek. There were three main objectives for this survey:

- Map depth to bedrock along survey lines identified by Thurber
- Where possible, map stratigraphic boundaries above the bedrock
- Provide vertical profiles of shear-wave velocity at borehole locations

A secondary objective was to map the location of possible paleo-channels within the survey area.

1.2 Site Description

The Cougar Creek area is in the vicinity of Canmore, AB. The 15 hectare zone of investigation traverses the creek bed, up the banks, and along parts of the flood plain. The creek bed areas are open, but the tops of the banks are heavily forested. Figure 1-1 highlights the area of investigation and Figure 1-2 shows its proximity to the city of Canmore AB.

Figure 1-1: Cougar Creek aerial image outlining survey area (source Google Earth)

Figure 1-2: Expanded map of the town of Canmore AB with the survey area highlighted (source Google maps)

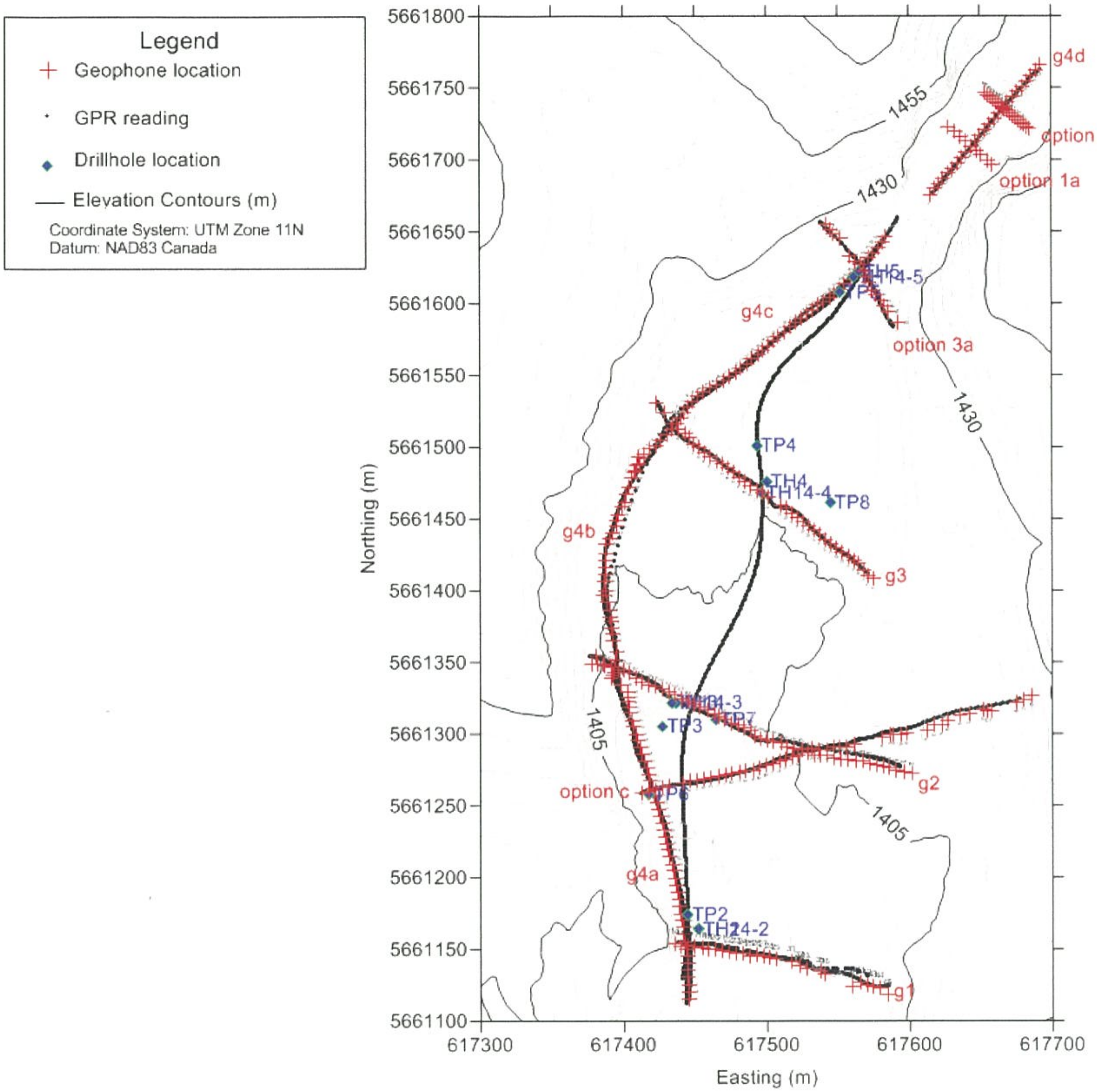


Figure 1-3: Map of survey areas showing survey locations. All location data used in this report is projected with UTM Zone 11 using the NAD83 Canada Datum

Figure 1-3 shows the survey location that is highlighted in Figure 1-1. All data in this report was processed and reported using the NAD83 datum with the UTM Zone 11 projection. Table 1-1 shows the geophysical methods used on each line.

Table 1-1: Table of methods used on each line

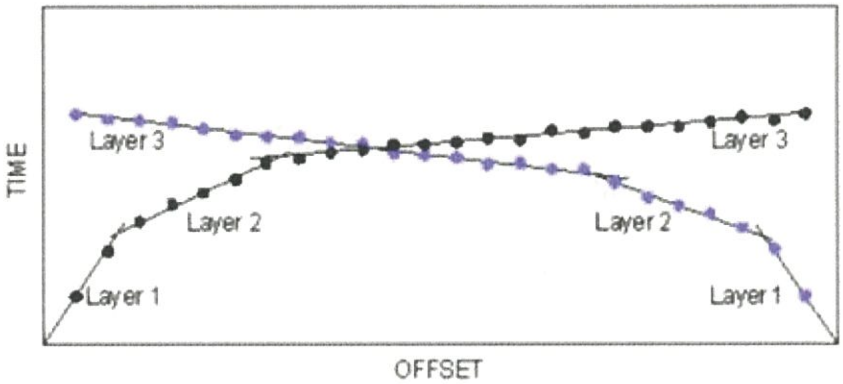
Line	**Refraction**	**MASW**	**GPR**
G1	Yes	No	Yes
G2	Yes	One profile	Yes
G3	Yes	No	Yes
G4	Broken up into four sections	No	Yes
Option C	Yes	No	Yes
Option 1a	Yes	No	No
Option 2a	Yes	No	No
Option 3a	Yes	No	Yes
Cougar Creek	No	Yes	Yes

2.0 METHODS

2.1 Seismic Refraction

Seismic refraction is commonly used to map depth to bedrock. Variations in acoustic velocity of the subsurface enable the mapping of earth layering and an interpretation of acoustic boundaries by measuring refracted seismic waves with respect to the known geometry of the seismic wave path.

Seismic Arrival Times



Layered Earth Model

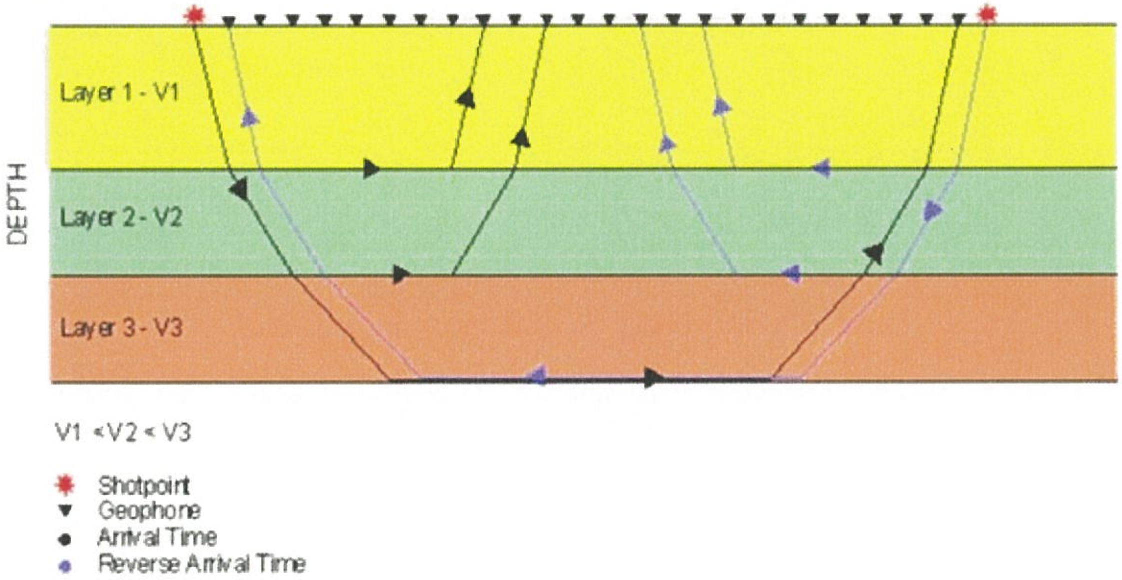


Figure 2-1: An illustration of the principles of seismic refraction. The top image displays the relationship between arrival time, and the distance of the geophone from the shot location

Figure 2-1 illustrates the principles of the seismic refraction method. A seismic event is produced by an acoustic source, usually activated at surface, with resulting arrival times recorded at receiver sites (geophones) located at known distances from the source. For the present study, refer to Table 2-1 for acquisition parameters used. Acoustic energy was imparted to the subsurface using a sledgehammer. Source locations were offset at either end of each spread and at every geophone station. The multiplicity of data thus collected enabled the use of computer-based algorithms to determine the variations of velocity with depth.

The depths of investigation in seismic refraction depend on the energy source, the array geometry, and the velocity variation in the subsurface and are generally in the order of 1/3 of the geophone array dimension. The success of the method is dependent upon the degree of contrast in acoustic velocity between the target layers. The method also requires that velocity increases with depth. Velocity reversals may, at times, result in layers being "hidden" and thus undetectable by the seismic refraction method.

The seismic velocities in overburden sediments generally do not present contrasts significant enough to allow the differentiation of clay, silt, sand and gravel. In the seismic profiles presented in this report, the nature of the overburden may be heterogeneous even though the seismic velocities may indicate a uniform layer. However this can be overcome by using other complementary geophysical methods.

2.1.1 Field Procedure

Geophones are placed into the surface at regular intervals along a line. The phones in the array are connected to a seismograph which records the vibrations of the earth. Specifically, the vibrations that are the result of a seismic event as its waves move through the earth.

For the Cougar Creek survey, a sledge hammer was used as the seismic source because of its flexibility in rough terrain, the fact that it does not require the ground to be disturbed, and because it can be used in a populated area. Sledge hammers provide a consistent, but relatively weak energy pulse. To compensate, multiple readings are made with the source at the same location in a process called stacking. Stacking helps to increase the signal to noise ratio as the signal is amplified while the random noise is cancelled out.

For each set up of the geophone array, multiple readings are collected varying the location of the shot. Shots are generally located next to geophones and are evenly spaced. When enough readings are collected, the array is moved, often with geophones in the new array overlapping locations of geophones from the previous array. Readings are collected again with multiple shot locations.

Table 2-1: Seismic refraction survey parameters

Line	Spread length (including rolls) (m)	Max spread length (excluding rolls) (m)	Geophone spacing (m)	Shot spacing (m)
G1	87	87	5	10 to 20
G2	235	235	5	15 to 20
G3	200	200	5	20
G4a	235	235	5	20
G4b	155	155	5	20
G4c	235	235	5	20
G4d	115	115	5	20
Option C	280	235	5	20
Option 1a	40	40	5	5
Option 2a	42.5	42.5	2.5	5
Option 3a	95	95	5	10

2.1.2 Elevation Data

Seismic data is sensitive to the elevations of the geophones and the shot source. A differential GPS system is used to achieve sub-metre accuracy vertically. Areas with low satellite coverage, as a result of geographic features such as trees or mountains, will have much lower accuracy. Many areas in this project site suffered from these issues. A digital terrain model provided by Thurber was used to correct this variant elevation data obtained with the differential GPS.

2.2 MASW

The MASW method evaluates the elastic properties (rigidity) of the near surface (~30 m deep, depending on survey parameters) using surface waves which are also known as the ground roll. Upon analysis of the propagation of the surface waves, the variations in the shear wave velocity (Vs) can be calculated below the survey area. The shear wave velocity is generally a direct indicator of the rigidity of the ground and therefore can be used to determine load bearing capacity for use in geotechnical and engineering applications. National Building Code (NBC) Site Classification values are derived by calculating the average shear wave velocity response from the top 30 m of an MASW sounding. These values, called Vs30 values, are used to assign an NBC Site Class between A and F.

The field procedure involves deploying a series of geophones on the ground in a straight line. The line of geophones is referred to as an MASW array or spread.

The ground roll measured can be generated by an active or passive source. For this project, we exclusively used a sledgehammer as an active source. A metal plate was placed on the ground and struck to send seismic energy into the earth.

A recording device called a seismograph records the vibrational signals from each of the geophones for several seconds. As the ground vibrations travel farther from their source they lose energy by dispersal and attenuation. The properties of the earth will also affect the frequency content of the surface waves. Numerical methods are employed to analyze the character of the ground roll including its energy loss and frequency, and a shear wave velocity profile of the shallow subsurface is developed. For each array set up, the profile developed represents the vertical region at the centre of the MASW array and is referred to as a sounding.

Longer MASW arrays will have a deeper depth of investigation. Smaller spacing between geophones will increase the vertical resolution of the profile. By moving the entire MASW array and recording another set of data, it is possible to generate a 2D profile along a line.

Table 2-2: MASW survey parameters

Line	Number of geophones	Geophone spacing	Sounding spacing
G2	24	1 m and 2 m	Only one sounding
Creek	24	2 m	Averaged 4 m

2.2.1 Field Procedures

There were two different approaches used to collect MASW soundings because of terrain restrictions. In the more difficult terrain, two soundings were collected on line G2. The geophones were set up similarly to the arrangement for refraction seismic. The two soundings were centred on the same location but with different geophone spacing, 1 m and 2 m. This was to get shallow resolution and increased depth of investigation. The second approach used a streamer of geophones that could be dragged along the surface by a truck. Unlike the fixed phones, the phones in the streamer did not need to be set by hand after they were in place. This allowed us to quickly move the entire array and collect multiple soundings along a line and get a 2D profile.

For each fixed geophone array, eight shots were taken on beyond the edges of the array, four on each side. The eight shots were all at different locations ranging up 12 m from the edge of the geophone array.

For the geophone streamer, one shot location was used for each geophone set up, always 4 m ahead of the direction of travel.

2.2.2 Processing

Computer software is used to analyze the dispersion of the surface waves. Through an inversion process of the raw data, a best fit of the field data is obtained. It begins with the field shot record which is used to create a measured dispersion curve. By means of an initial model, it generates a theoretical dispersion curve to fit the data. This iterative process is performed until the RMS error is reduced sufficiently while maintaining a realistic dispersion curve/earth model. The optimal dispersion curve is then converted into the final v_s model. The resulting shear wave data is plotted at the centre of the geophone array, and is referred to as a "1-D" (one-dimensional) MASW sounding.

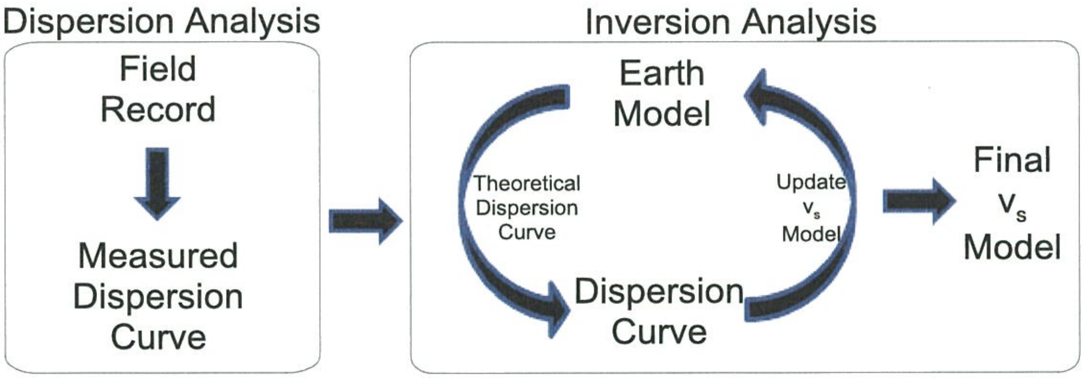


Figure 2-2: Basic MASW inversion process.

2.3 Ground Penetrating Radar (GPR)

Radio detection and ranging (radar) uses high frequency (10 MHz to 1000 MHz) electromagnetic (EM) waves to image the subsurface by precisely measuring the time taken by the emitted waves to reach an interface of contrasting electrical impedance and return to the surface. Two-dimensional profiles of the subsurface recorded by the GPR system are referenced to signal travel times. The conversion from travel time to depth requires the accurate determination of the velocity of the medium traversed, often by correlation with drill hole logs, the results of complementary geophysical methods and/or published velocities for various subsurface materials.

The velocity and attenuation of radar signals within the subsurface depend on the dielectric and conductivity properties of subsurface materials. Variations in the electrical properties of soils and rocks are usually associated with changes in grain size and/or water content which, in turn, cause part of the emitted signal to be reflected. The reflected signal is detected by the receiver where it is amplified, digitized and stored for subsequent data processing and interpretation.

GPR penetration depth is limited primarily by the conductivity of the subsurface. High proportions of clay material and/or total dissolved solids within the groundwater can severely reduce the effective exploration depth. Although depth penetration can often be increased by reducing GPR antenna frequency, vertical resolution is compromised accordingly. To optimize both penetration depth and horizontal resolution, preliminary testing of acquisition parameters specific to each survey environment is generally required. The correct choice of antenna frequency is paramount. The signal emitted by low-frequency antennas can penetrate the subsurface to relatively deep depths, but provide coarse, low-resolution results that lack detail. High-frequency antennas provide high resolution results but may not be able to penetrate very deeply into the subsurface.

Figure 2-3 Top - MALA 100 MHz RTA (Rough Terrain Antenna) and survey components. Bottom Left: Operator manually dragging a rough terrain antenna. Bottom Right: ATV dragging a rough terrain antenna.

A 100 MHz rough terrain antennae as shown in Figure 2-3 was used for all the GPR lines surveyed. This antenna provides a good balance of depth and resolution while also being rugged enough to work effectively in rough terrain.

2.3.1 GPR Processing and Interpretation

GPR data were processed using ReflexW, a well-known seismic and GPR processing package which enables a wide range of processing steps. Standard processing steps used on all GPR data included:

1. move start-time (in this case -35 ns)
2. subtract-mean(de-wow)
3. energy decay
4. average xy-filter (5 traces x 5 samples)
5. make equidistant.traces of length .05 m
6. Kirchhoff migration
7. average xy-filter (5traces x 5 samples)

GPR data may be interpreted in several ways. Distinct continuous reflections can often be attributed to specific lithologic boundaries, such as bedrock surface. However another approach is to group similar textures in the GPR sections into GPR "facies"[1,2]. In this study both interpretation techniques are used. Bedrock is identified as a continuous, or semi-continuous boundary, while sediments are divided into two GPR facies. Facies 1, characterized by short continuous reflections and numerous diffractions, is interpreted as more coarse grained sediments; Facies 2, characterized by a more washed out appearance with lower energy, is interpreted as containing a higher percentage of fines.

2.4 Test Holes

Subsurface information from drilling and test pits was provided by Thurber. Test pits are listed in Table 2-3. The bottoms of the test pits were almost always at the water table, but occasionally at a bedrock interface. Table 2-4 has a list of drill holes and their depth to bedrock.

Table 2-3: List of Test Pits including their depth and what interface is at their bottom

Test Pit	Depth (m)	UTM Easting (m)	UTM Northing (m)	Hole bottom
TP14-2	5.75	617445	5661174	Water table
TP14-3	4.5	617427	5661306	Water table
TP14-4	4.25	617493	5661501	Water table
TP14-5	4.5	617552	5661607	Bedrock
TP14-6	4.25	617417.5	5661258	Water table
TP14-7	3.5	617465	5661310	Bedrock
TP14-8	2.75	617544	5661461	Water table

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[1] Staggs, Julie; Young, Roger and Slatt, Roger, "Ground-penetrating radar facies characterization of deepwater turbidite outcrops" in The Leading Edge, September 2003, pp 888-891.

[2] Jol, Harry and Smith, Derald G., " Ground penetrating radar of northern lacustrine deltas", in Canadian Journal of Earth Sciences, Vol. 28, 1991. Pp 1939-1947.

Table 2-4: List of Drill holes including their depth to bedrock

Drill hole	Bedrock Depth (m)	UTM Easting (m)	UTM Northing (m)
TH14-2	11	617452	5661164
TH14-3	4.5	617434	5661322
TH14-4	9	617497	5661468
TH14-5	14.6	617561	5661618

3.0 RESULTS

3.1 Seismic Refraction

3.1.1 Data Quality

In general, the signal to noise ratio of the data was relatively high. Figure 3-1 shows an example of geophone traces from one shot on line G2. Background noise can be seen on the right most traces as signal that is arriving before the selected first arrival time. In this project, the main sources of noise were the City of Canmore and water flowing down Cougar Creek. Geophones that were planted near these sources will have a greater impact from the noise.

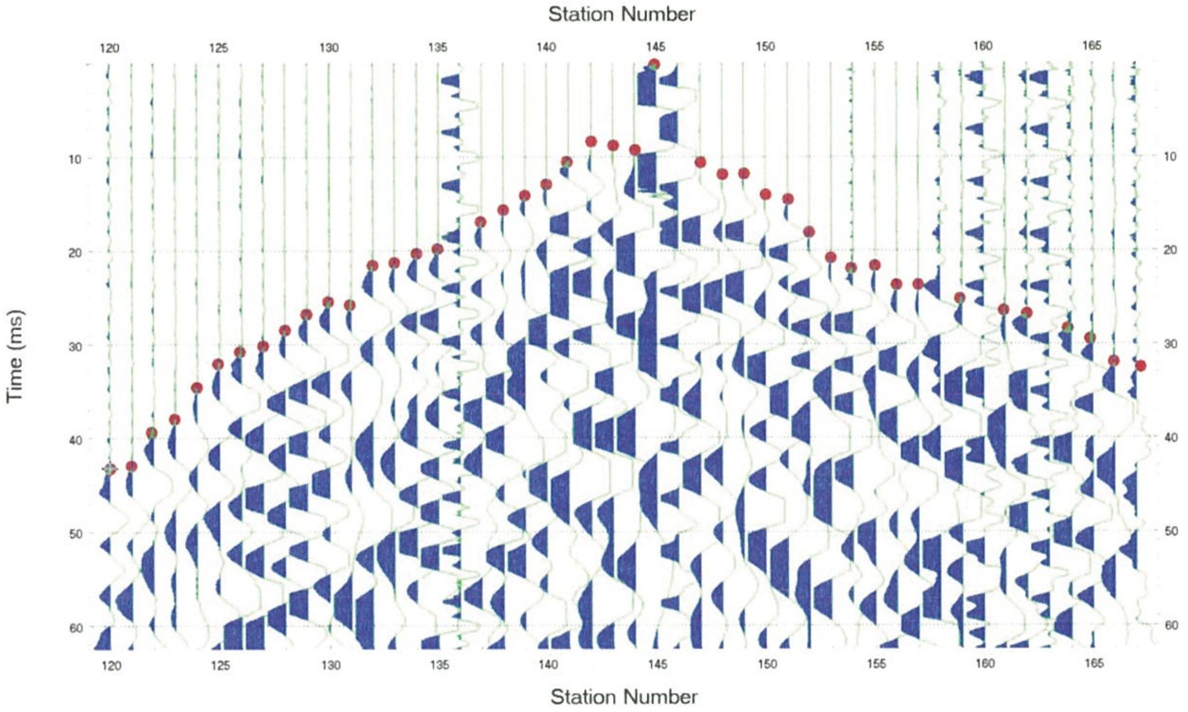

Figure 3-1: Geophone traces gathered for one shot. The red dots mark the selected first arrival time for each geophone.

3.1.2 Initial models

Our full tomographic inversion requires a starting model. Depending on the case, we either use a 1D velocity profile called a gradient model, or a 2D model built out of 2 or 3 layers referred to as a plus-minus model.

These different initial models give the final section a different character. Figure 3-2 shows the gradient initial model that was used on line G2 and Figure 3-3 shows the plus-minus model that was used on line G4a.

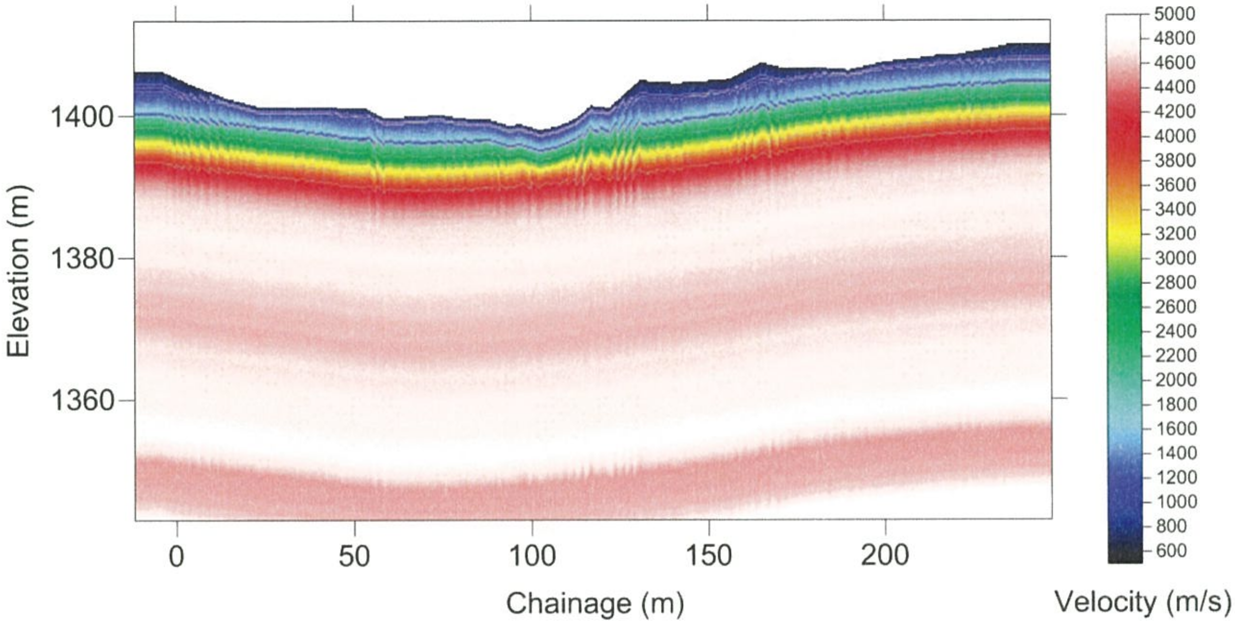

Figure 3-2: The gradient initial model used on line G2

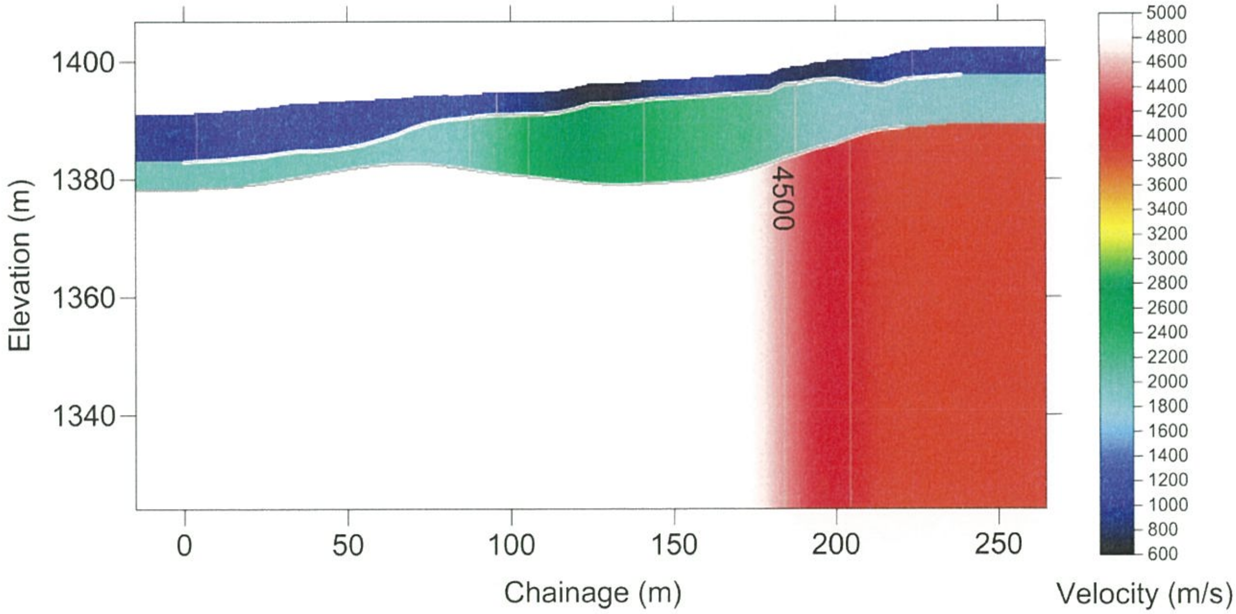

Figure 3-3: A plus-minus initial model for line G4a.

3.1.3 Final Models

The final seismic velocity models are generated by an iterative tomographic inversion algorithm (Rayfract). Figure 3-4 shows the velocity model generated for line Option C.

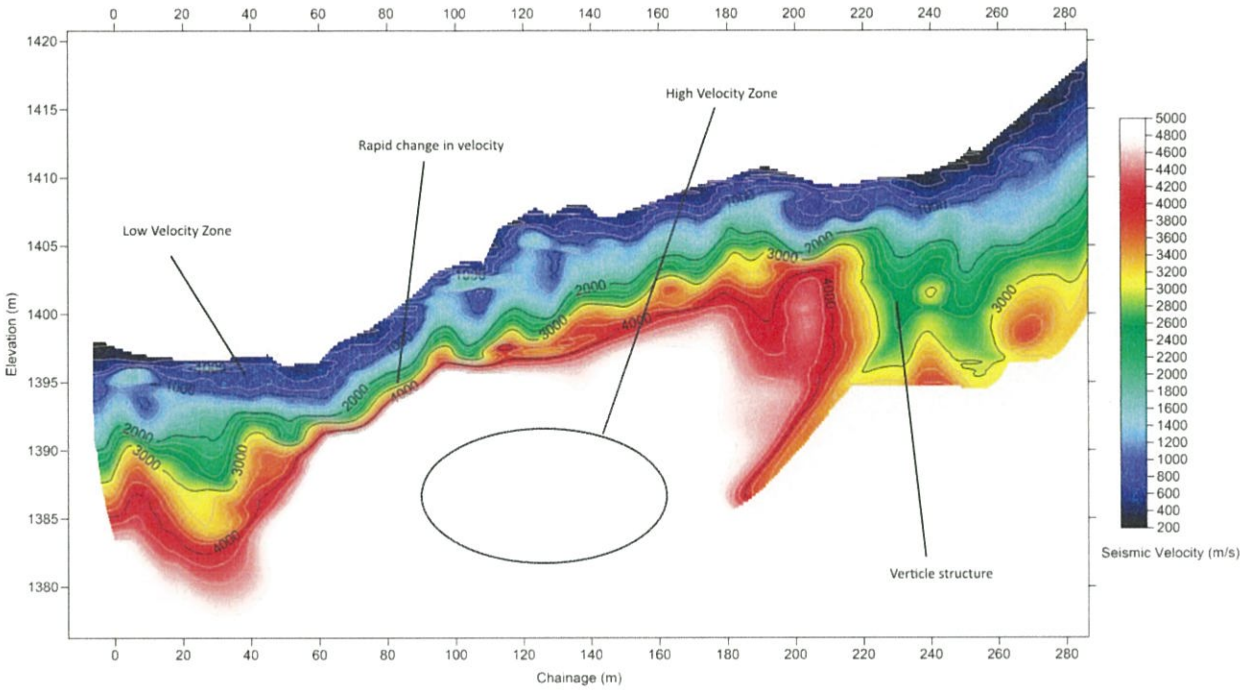

Figure 3-4: Velocity model on line Option C exhibiting likely bedrock in the high velocity zone and unconsolidated materials in the low velocity zone. This figure also exhibits vertical features on both sides.

The interpretation of seismic velocity models relies on some fundamental properties of the subsurface. Competent bedrock in this area has very high acoustic velocities, generally 3000 m/s or above depending on rock type. Fracturing and weathering can lower the velocity of the weakened bedrock. Unconsolidated materials generally have the lowest velocities. Saturated versus unsaturated sediments also have a large velocity contrast and water table was an important component of our results.

When there is a large difference in velocity between two subsurface bodies, this will manifest itself in the model as a region with a rapid special velocity change. Sharp lateral changes in velocity are classically very difficult to model but the tomographic inversion process is much better than other simpler methods at highlighting these structures.

Figure 3-4 shows low velocities in the near surface region interpreted as unconsolidated material. The high velocity zone bounded by a steep change in the velocity is likely consolidated bedrock. A paleo-channel feature can be interpreted in the trough in the high velocity on the left side of the figure. A strong vertical feature is visible on the right side of the figure.

3.2 GPR

Overall, the signal to noise ratio of the GPR data is very high. Depth of penetration varied between approximately 2 and 15 m. An example of the processed GPR data from the Cougar Creek line is shown in Figure 3-5.

Numerous reflections were seen in the GPR data. Diffractions, as indicated in Figure 3-5, are interpreted as areas with very coarse grained material such as gravels or cobbles. Areas with low GPR penetration are caused by increased fines content in the area. A bedrock boundary was interpreted in some places based on correlation with drill data. The boundary identified is discontinuous in some places and may be the result of a rough bedrock surface. Reflections in the region above the bedrock surface are interpreted as GPR facies. Two GPR facies have been identified in this survey area. Facies 1, characterized by short continuous reflections and numerous diffractions, is interpreted as more coarse grained sediments; Facies 2, characterized by a more washed out appearance with lower energy, is interpreted as containing a higher percentage of fines. Given the geophone separation used in seismic refraction, GPR provided detailed information on depth to bedrock when bedrock became very shallow

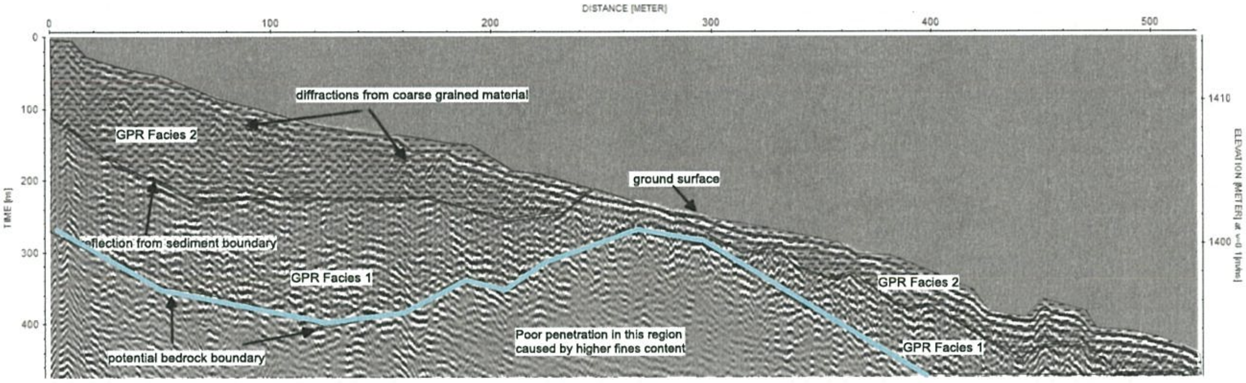

Figure 3-5: Example of a GPR line with interpretation. The line is along east side of Cougar Creek. GPR Facies 1 corresponds with areas of stronger reflections and diffractions; GPR Facies 2 corresponds with areas of lower energy or minimal reflections.

3.3 MASW

3.3.1 1D profile

A single 1D profile was collected near drillhole TH14-2. Its array was spread along line G1 and was centred at 617446 m E and 5661155 m N. This is 10 m away from the test hole. Figure 3-6 shows a graph displaying how the shear wave velocity changes with depth. The Vs30 is calculated by averaging the velocities up to 30 m deep.

Table 1-1 shows the shear wave velocities at depth as well as the averaged shear wave velocity up to the specified depths. The averaged velocity at 30 m is the Vs30. A Vs30 of 999.7 m/s gives it a "B" site classification.

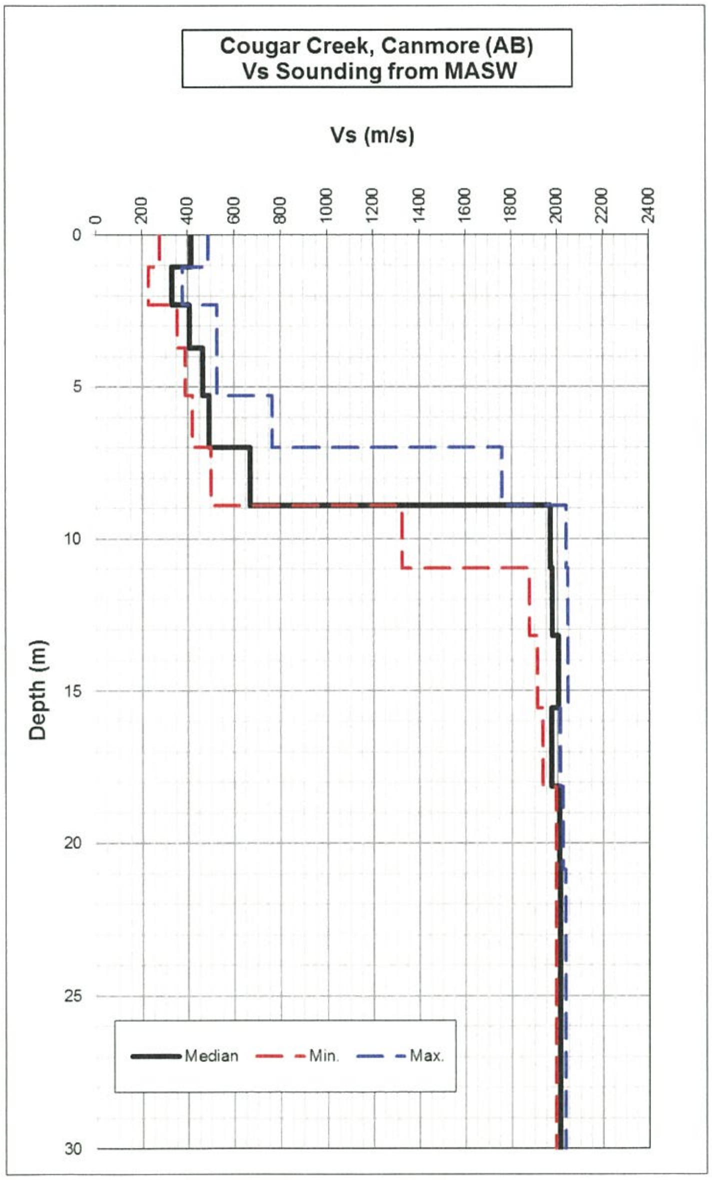

Figure 3-6: Plot of Vs versus Depth for 1D sounding near TH14-2.

Table 3-1: VS30 Calculation for 1D sounding near TH14-2

Depth (m)	Vs at a given depth (m/s)	Average Vs up to given depth (m/s)
0.00	414.0	
1.07	332.1	414.0
2.31	408.9	365.7
3.71	465.1	380.9
5.27	492.0	402.6
7.01	669.4	421.5
8.90	1970.5	457.6
10.96	1979.2	534.7
13.19	2003.8	609.8
15.58	1975.0	682.7
18.13	2007.1	752.0
20.85	2012.7	818.8
23.74	2012.7	882.5
26.79	2012.7	942.7
30.00		999.7
	Vs30 (m/s) =	999.7
	Site Class :	B *

3.3.2 2D profile

Figure 3-7 shows both the 2D MASW profile as well as its position relative to the test sites. A 1D section was extracted from the grid for each test site at the locations shown. The depth of investigation was much shallower with the second acquisition method so Vs30 values are unavailable. The velocity for specified depths is tabulated in Table 3-2 for all the test sites.

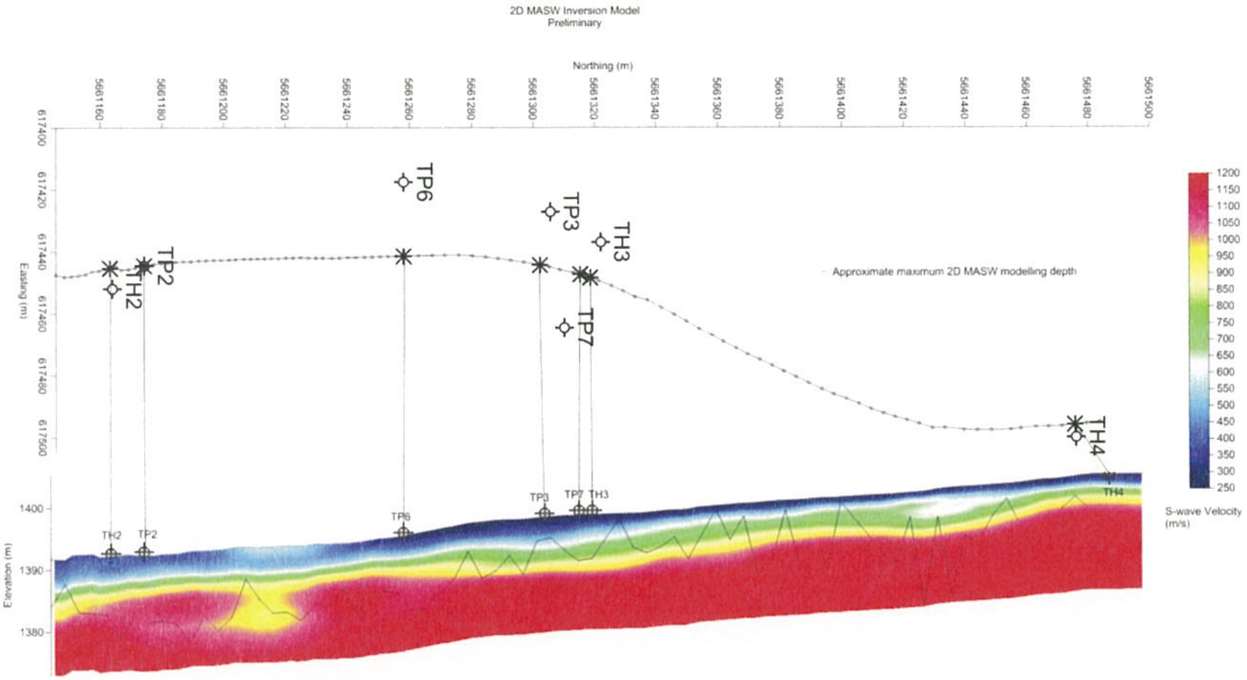

Figure 3-7: The top graph shows the position of the 2D MASW relative to the test sites. The bottom section is the 2D MASW velocity profile. The test sites are related on the section to where the profile data was extracted.

Table 3-2: Shear Wave velocity profiles for each test site

Depth (m)	Shear wave velocity profiles at depth (m/s)						
	TH14-2	TH14-3	TH14-4	TP14-2	TP14-3	TP14-6	TP14-7
0.00	415.3	229.5	252.9	389.6	252.9308	301.8	242.9
1.07	390.7	326.3	422.2	417.6	307.7	346.5	315.8
2.31	423.4	473.2	614.9	469.2	390.7	444.3	437.9
3.71	536.1	594.3	736.7	598.2	518.7	632.6	564.6
5.27	766.9	711.6	878.4	834.9	654.7	868.3	686.0
7.01	965.4	825.4	1054.5	1023.8	811.1	1014.3	815.8
8.90	1057.0	971.0	1235.6	1093.5	1004.1	1092.3	970.3
10.96	1113.7	1159.6	1334.3	1074.1	1174.6	1120.0	1159.5
13.19	1170.3	1255.1	1416.7	1110.1	1232.8	1165.4	1249.3
15.58	1223.4	1351.8	1485.6	1180.1	1322.7	1246.5	1344.4
18.13	1277.4	1449.5	1573.7	1248.2	1417.1	1328.1	1441.2

4.0 INTERPRETATION AND DISCUSSION

4.1 Line G1

Line G1 is the southernmost EW line in the survey area. The interpretation of this line can be found in Figure 6-1. The bedrock was interpreted based on the results of the seismic refraction survey and test hole TH14-2. The bedrock depth identified in this log corresponds with observed seismic refraction velocity values of approximately 3,500 m/s. Interpreted bedrock occurs at an approximate average elevation of 1380 m, however a distinctive bedrock elevation high is present at 617478 m E 5661147 m N where bedrock reaches an elevation of 1387 m.

The overburden has been divided into two GPR facies as discussed in section 3.2, above. Facies 1 occurs in the eastern section just above the bedrock and at surface on the western portion of the line.

The water table as surveyed on July 21st 2014 was interpreted based on a smoothed 1500 m/s contour from the seismic refraction survey along with results from drilling and test pits.

4.2 Line G2

The interpretation of Line G2 can be found in Figure 6-2. The bedrock was interpreted based on the results of the seismic refraction survey along with data from TH14-3 and TP14-7. The bedrock identified in TH14-3 corresponds with an observed seismic refraction velocity of 3500 m/s. Interpreted bedrock is highest in the east at an approximate elevation of 1402 m and slopes to the west. Bedrock outcrops at a chainage of 110 m and there is a relative low in the bedrock surface centred at a chainage of 14 m.

The overburden has been divided into two GPR facies as discussed in section 3.2, above. The majority of this area has been classified as Facies 1 with a small lens of Facies 2 occurring between chainage 145 m, and 202 m at a depth of 5 m.

The water table as surveyed on July 21st 2014 was interpreted based on a smoothed 1500 m/s contour from the seismic refraction survey along with results from drilling and test pits.

4.3 Line G3

The interpretation of Line G3 can be found in Figure 6-3. The bedrock was interpreted based on the results from the seismic refraction survey along with data from test hole TH14-4. The top of bedrock identified in test hole TH14-4 corresponds with a seismic velocity of

3500 m/s. Bedrock surface varies widely along this line between 1392 m and 1402 m in elevation. Bedrock highs occur at chainages of 9 m, 123 m, and 193 m.

The overburden has been divided into two GPR facies as discussed in section 3.2, above. Facies 1 occurs at surface to depths of between 0 m and about 13 m. GPR Facies 2 occurs in bedrock lows and overlying a bedrock high in the west of the line.

The water table as surveyed on July 22nd 2014 was interpreted based on a smoothed 1500 m/s contour from the seismic refraction survey along with results from drilling and test pits.

4.4 Line G4

As Line G4 is a particularly long and crooked line, it was sub divided into four sections for processing purposes: G4a in Figure 6-4, G4b in Figure 6-5, G4c in Figure 6-6, and G4d in Figure 6-7. However in the discussion below, Line G4 will be discussed as a whole.

The bedrock surface was interpreted based on the results from the seismic refraction survey along with data from test holes TH14-2 and TH14-5 as well as three test pits: TP14-2, TP14-5 and TP14-6. An average velocity contour of 3500 m/s was interpreted as competent bedrock. The bedrock surface elevations vary between 1377 m in the south and 1411 m in the north. While bedrock surface generally increases from south to north there are some undulations in the bedrock surface.

A number of zones with lower seismic velocities were noted within the bedrock. Low velocity zones may correspond with more highly weathered or fractured rock, or with a variation in bedrock type. The seismic weak zones occur at chainages 220 m and 390 m.

A very complex region occurs between chainage 520 m and 610 m. Bedrock rises rapidly at chainage 610 m, rising from approximately 1396 m to 1410 m forming a cliff like feature. The seismic velocities to the south of this feature vary widely from between 1500 and 3300 m/s. A borehole in this area indicates the presence of a limestone block within coarse sediments, indicating geologic complexity in the near-surface.

The water table as surveyed on July 23rd and 24th 2014 was interpreted based on a smoothed 1500 m/s contour from the seismic refraction survey along with results from drilling and test pits.

4.5 Line Option C

The interpretation of line Option C can be found in Figure 6-9. The bedrock was interpreted from the results of the seismic refraction and the GPR surveys while considering the results from Lines G2 and G4a which cross Option C.

The bedrock boundary was identified from the 3500 m/s velocity contour. On the west side at a chainage of 0 to 20 m a dashed boundary is drawn where we believe the bedrock diverges from the 3500 m/s contour. Edge effects on the inversion can bring in artifacts so the depth is taken from line G4a which is more reliable at this location. The bedrock on the east side also has a dashed section. The survey coverage in this area was lower so the boundary we do see in the seismic data is of lower confidence. It is not entirely clear where the bedrock transitions horizontally from the vertical feature.

The diagonally dashed section at the surface between 95 m and 180 m chainage represents an area that is likely made up of fractured bedrock and boulders. The seismic velocities are too low to be consolidated bedrock but are higher than most of the unconsolidated areas. Reflections in the GPR indicated possible bedrock boundaries and surface observations suggested possible bedrock outcropping.

The overburden has been separated into two GPR facies as discussed in section 3.2. Facies 1 is only located on the west side of the line near the surface between 0 m and 80 m chainage. The remaining overburden is characterized as Facies 2.

The water table as surveyed on July 22nd and 23rd 2014 was interpreted based on a smoothed 1500 m/s contour from the seismic refraction survey along with results from test pit TP14-6.

4.6 Line Option 3a

The interpretation of line Option 3a can be found in Figure 6-8. The bedrock was interpreted from the results of the seismic refraction survey, the drill data from TH14-5 and results from G4c which intersects the centre of line Option 3a.

This profile covers a very geologically complicated zone. The terrain is very steep on both sides, and drill results reveal a complex picture involving limestone slabs and coal. Line G4c, which bisects line Option 3a, also shows a complex environment with large lateral changes.

A bedrock boundary was identified from the 3500 m/s velocity contour that is very steeply dipping. Anomalous velocity structures were found and are highlighted in the figure. These are likely a result of the complex geology and 3D effects that the 2D inversion could not interpret.

The water table as surveyed on July 25th 2014 was interpreted based on a smoothed 1500 m/s contour from the seismic refraction survey.

4.7 Line Option 1a and 2a

The geophone arrays on Option 1a and 2a were too short and the depth of investigation didn't reach deep enough to provide any useful information. Figure 6-7 displays Line Option 1a and Line Option 2a as they are both bisected by G4d. The bedrock was not identified and the GPR facies were interpreted mostly based upon G4d. As a result, the interpretation is not overly compelling.

4.8 Line Cougar Creek

An extra GPR line was collected along the East side of Cougar Creek. Figure 6-10 displays an interpretation that relies only on the GPR data. GPR Facies 2 crosses the entire profile except when GPR Facies 1 appears at surface between 250-275m of chainage. GPR Facies 2 ranges between 7.5 m to 2.5m thick, getting thinner downstream. GPR Facies 1 fills the area between GPR Facies 2 and the probable bedrock boundary. Its thickness follows the profile of the bedrock boundary closure than GPR Facies 2.

5.0 CONCLUSION

Over the course of this project, eleven seismic refraction sections, eight GPR sections, one 1D MASW sounding, and one 2D MASW profile were completed. Overall, the data quality was good, easing processing. Seismic refraction was processed to produce acoustic velocity sections. GPR was processed to identify reflections and diffractions in the subsurface.

Many lines had straight forward interpretations with only some sections providing ambiguous or confusing results. Bedrock was generally located between 5 m to 15 m below the surface. The composition of the overburden was not clearly defined by the GPR, but different facies were identified.

Table 5-1 tabulates areas that may require special consideration for dam construction. These features include anomalous bedrock highs, possible weak zones, and complex geology.

Table 5-1: Areas with potential design considerations

Feature	Line	Chainage	Depth
Bedrock High	G1	90-120 m	7 m
Outcrop	G2	100-140 m	0 m
Bedrock Low	G2	0-60 m	15 m
Bedrock Low	G3	40-110 m	15 m
Potential weak zone	G4	200-240 m	14 m
Potential weak zone	G4	370-410 m	6m
Complex geology	G4	520-610 m	6m
Steep Bedrock	G4	600 -620 m	2-13 m
Steep Bedrock	G4d	40-90 m	9-17 m
Anomalous high velocity zone	G4d	60-75 m	13 m
Bedrock Low	Option C	0-50 m	16 m

Possible fractured rock or boulders	Option C	90-180 m	0-8 m
Steep bedrock	Option C	220 m	5-18 m
Undetermined bedrock boundary	Option C	220-280 m	12 m
Steep Bedrock	Option 3a	70-90 m	12 m
Anomalous velocities	Option 3a	30-80 m	6 m

6.0 APPENDIX

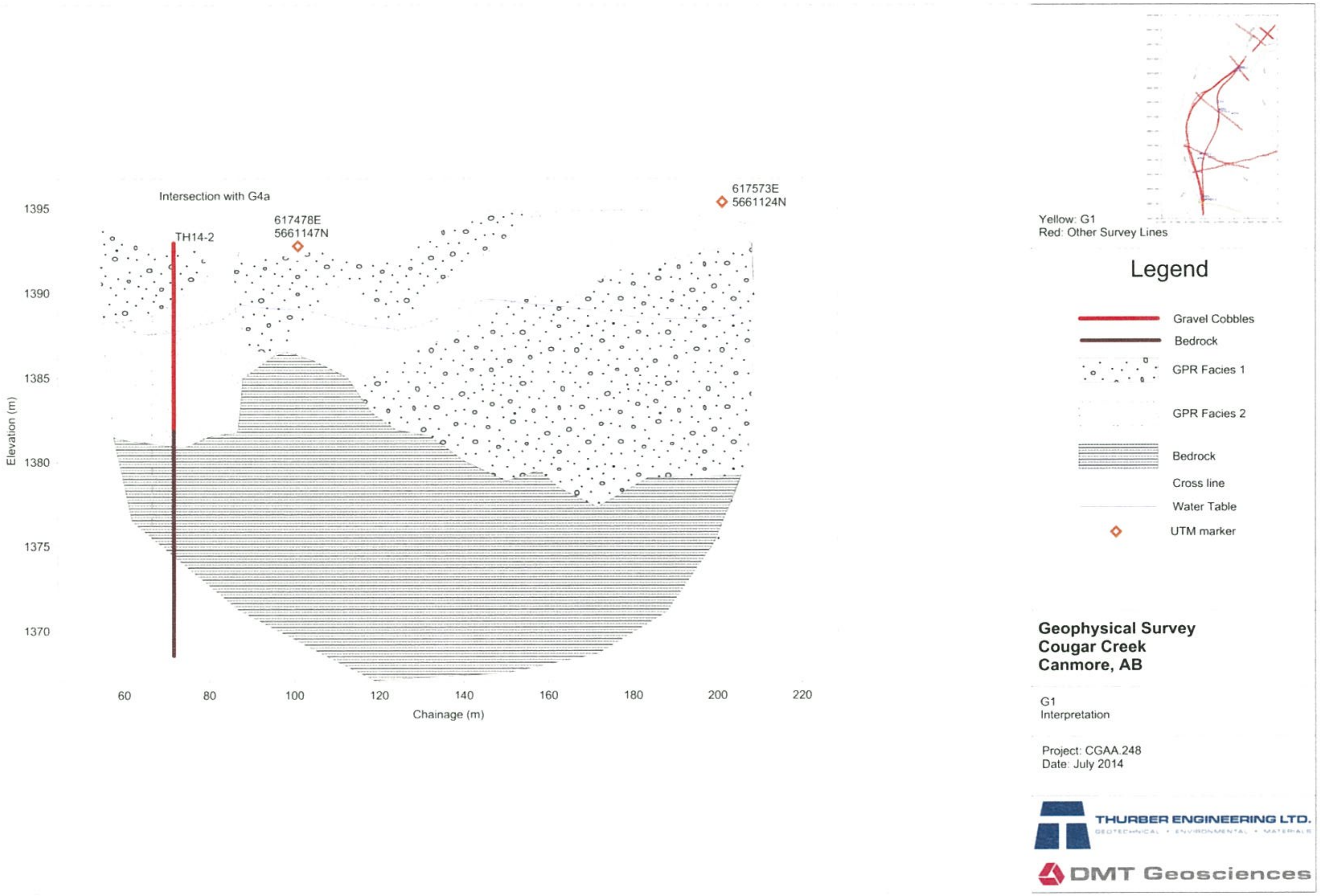

Figure 6-1: Interpretation for Line G1

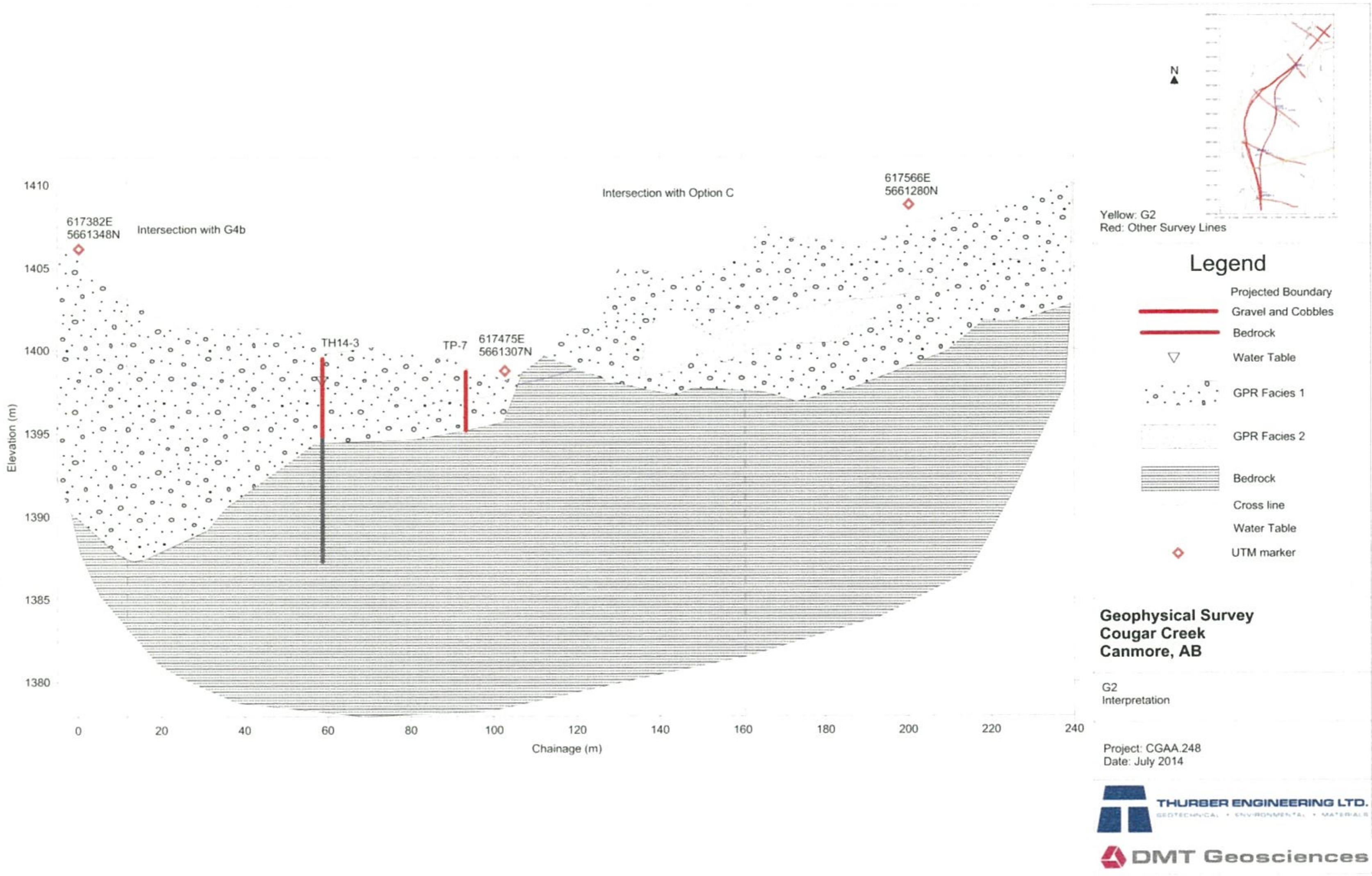

Figure 6-2: Interpretation for Line G2

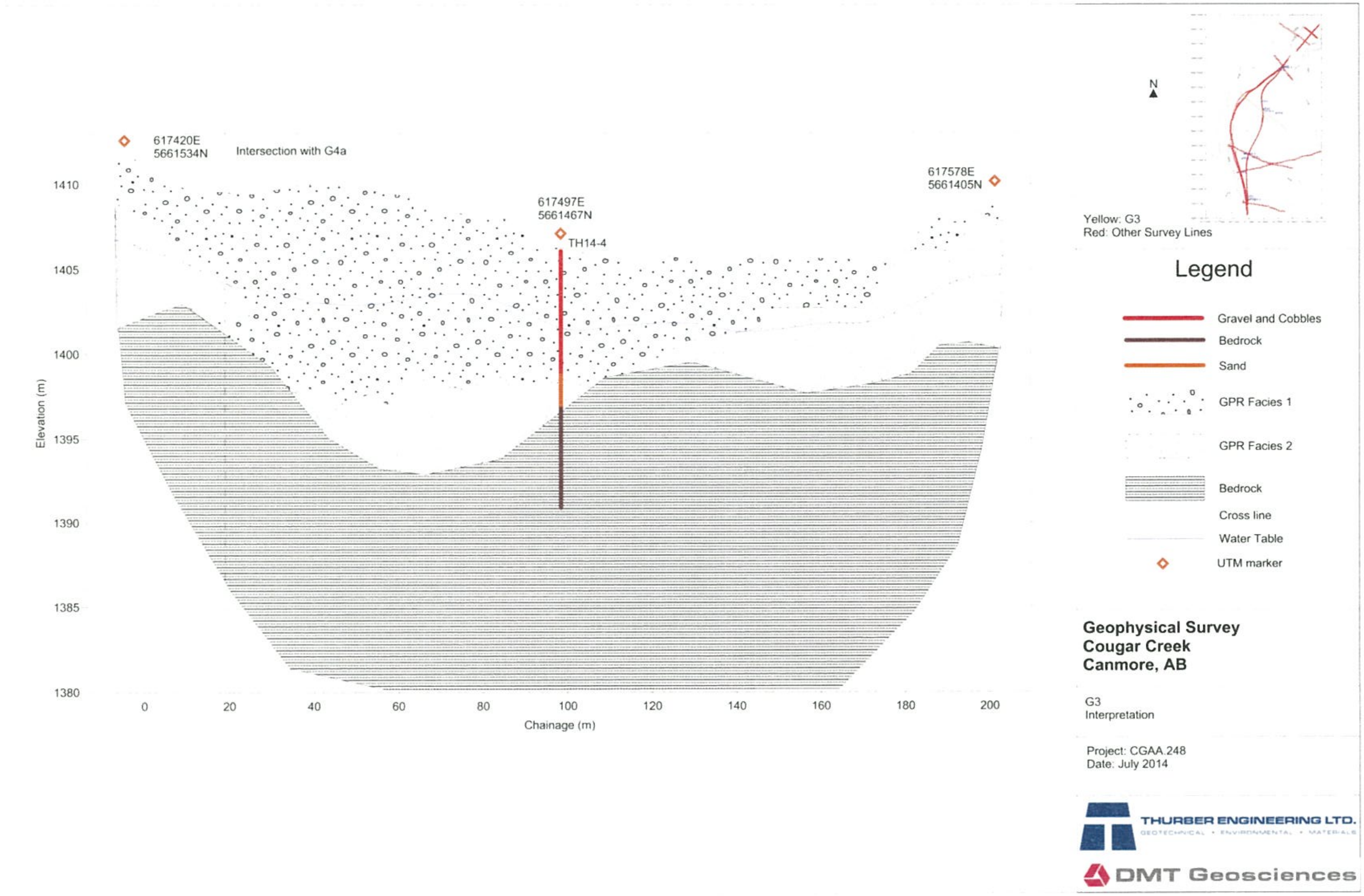

Figure 6-3: Interpretation for Line G3

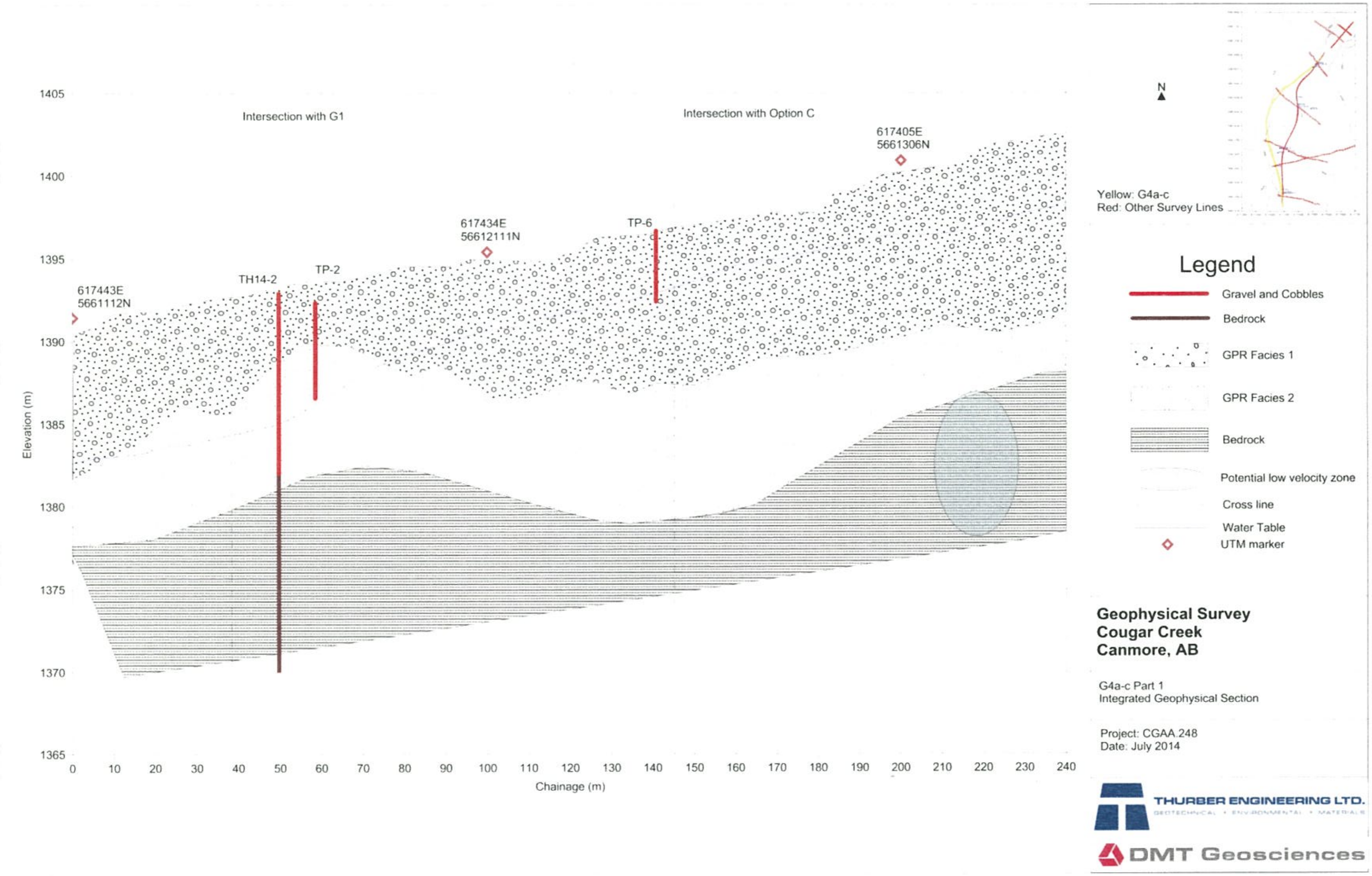

Figure 6-4: Interpretation for Line G4a-c Part 1

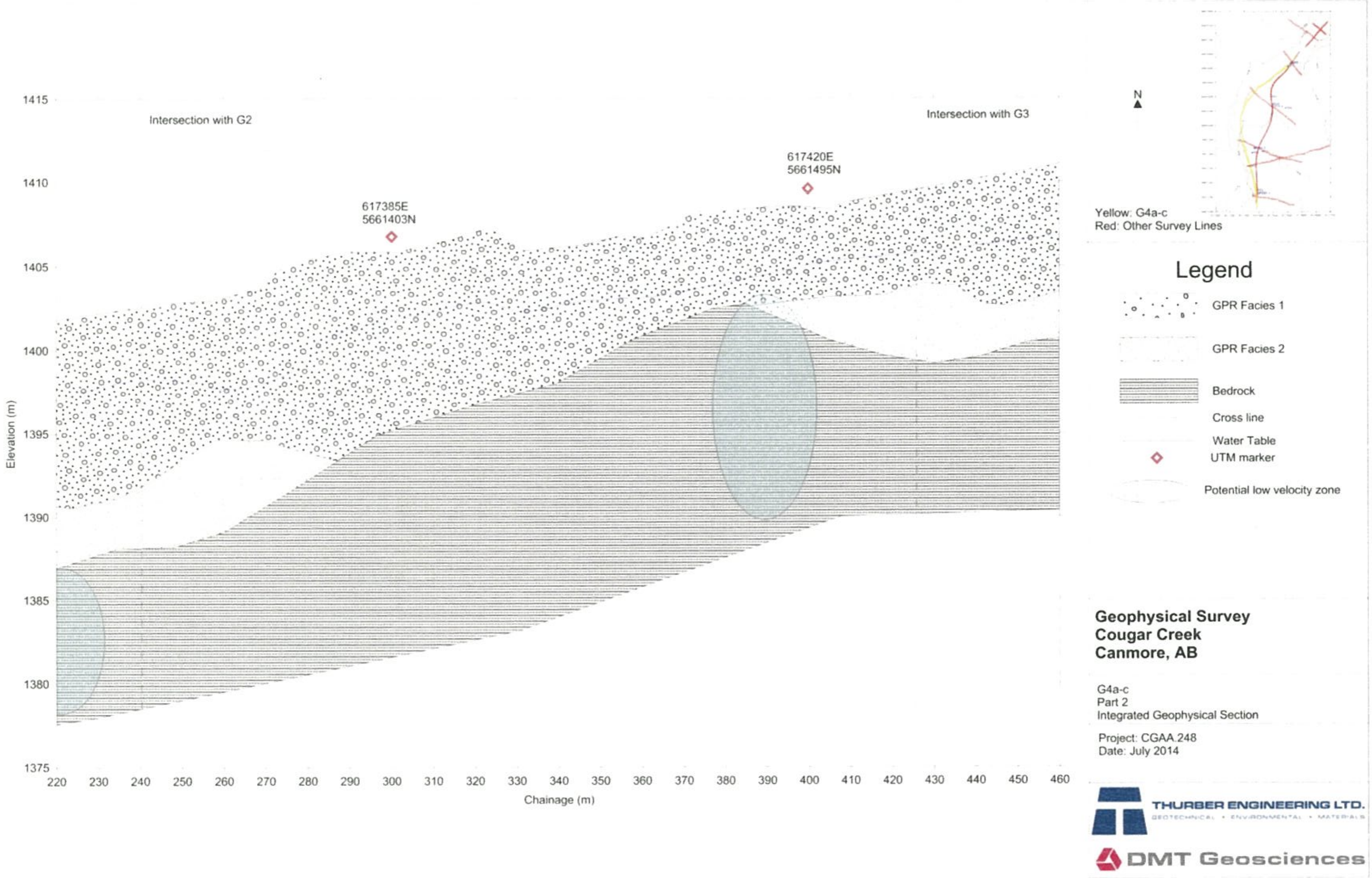

Figure 6-5: Interpretation for Line G4a-c Part 2

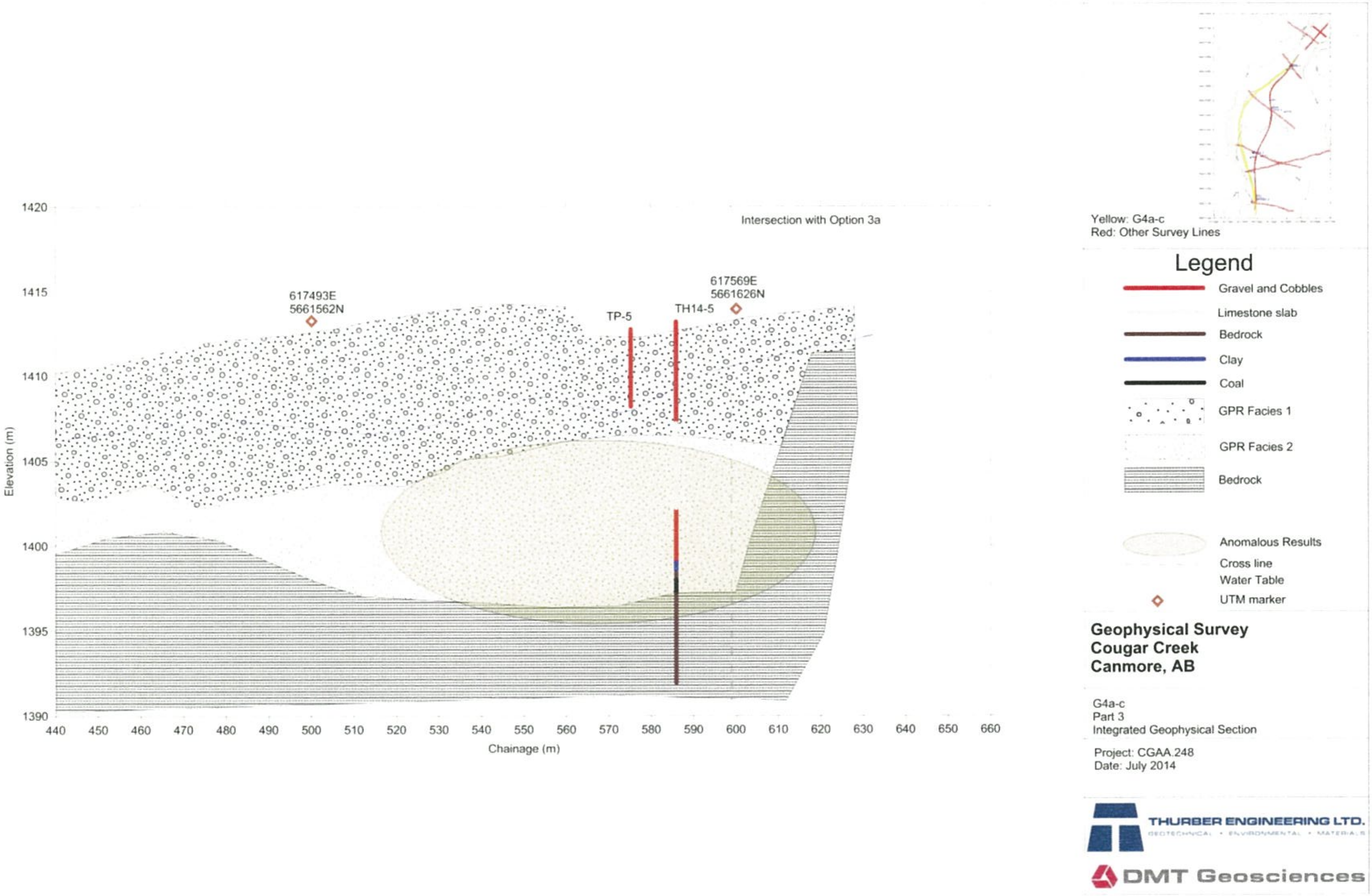

Figure 6-6: Interpretation of Line G4a-c Part 3

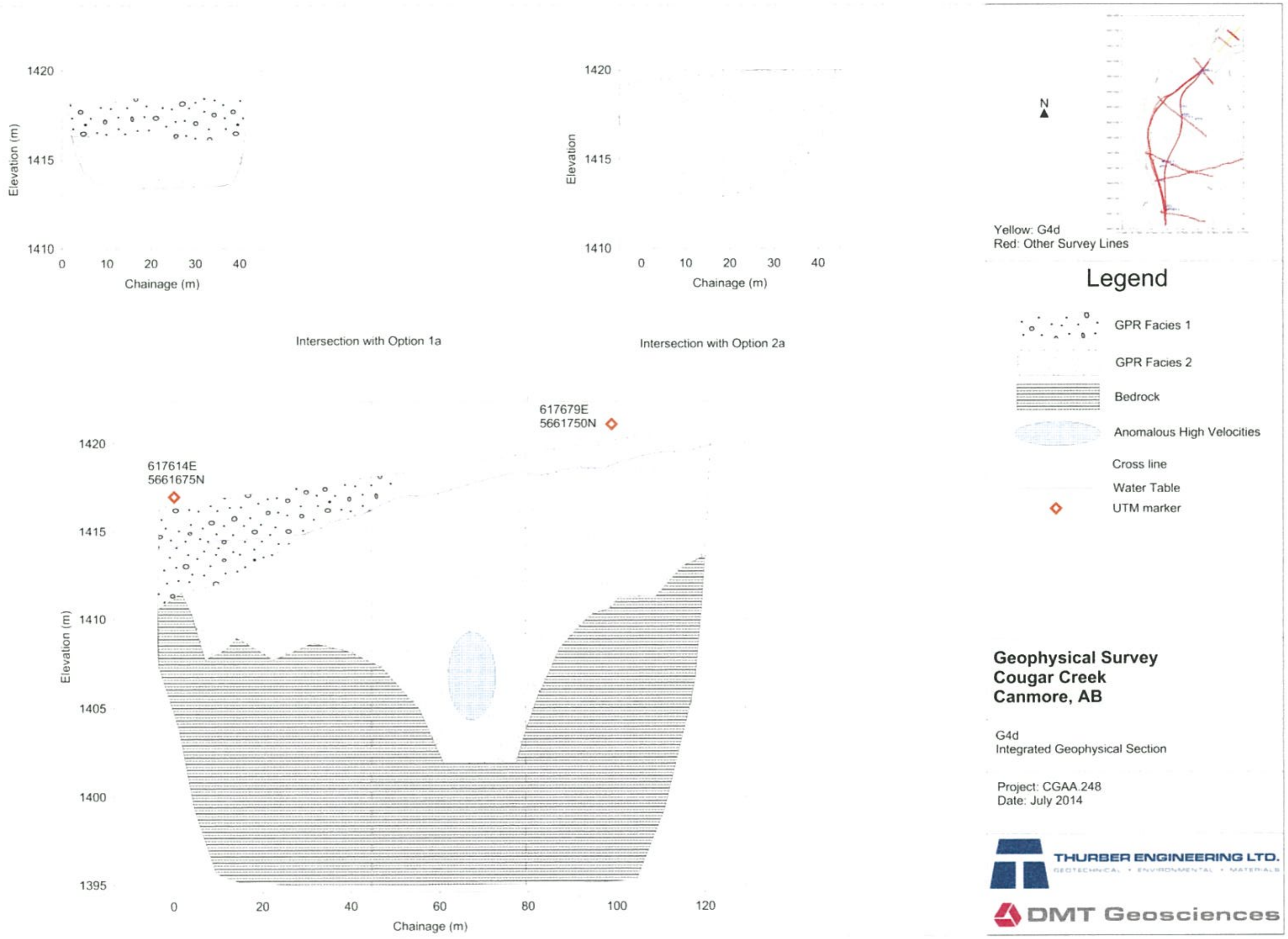

Figure 6-7: Interpretation for Line G4d Line Option 1 and Line Option 2

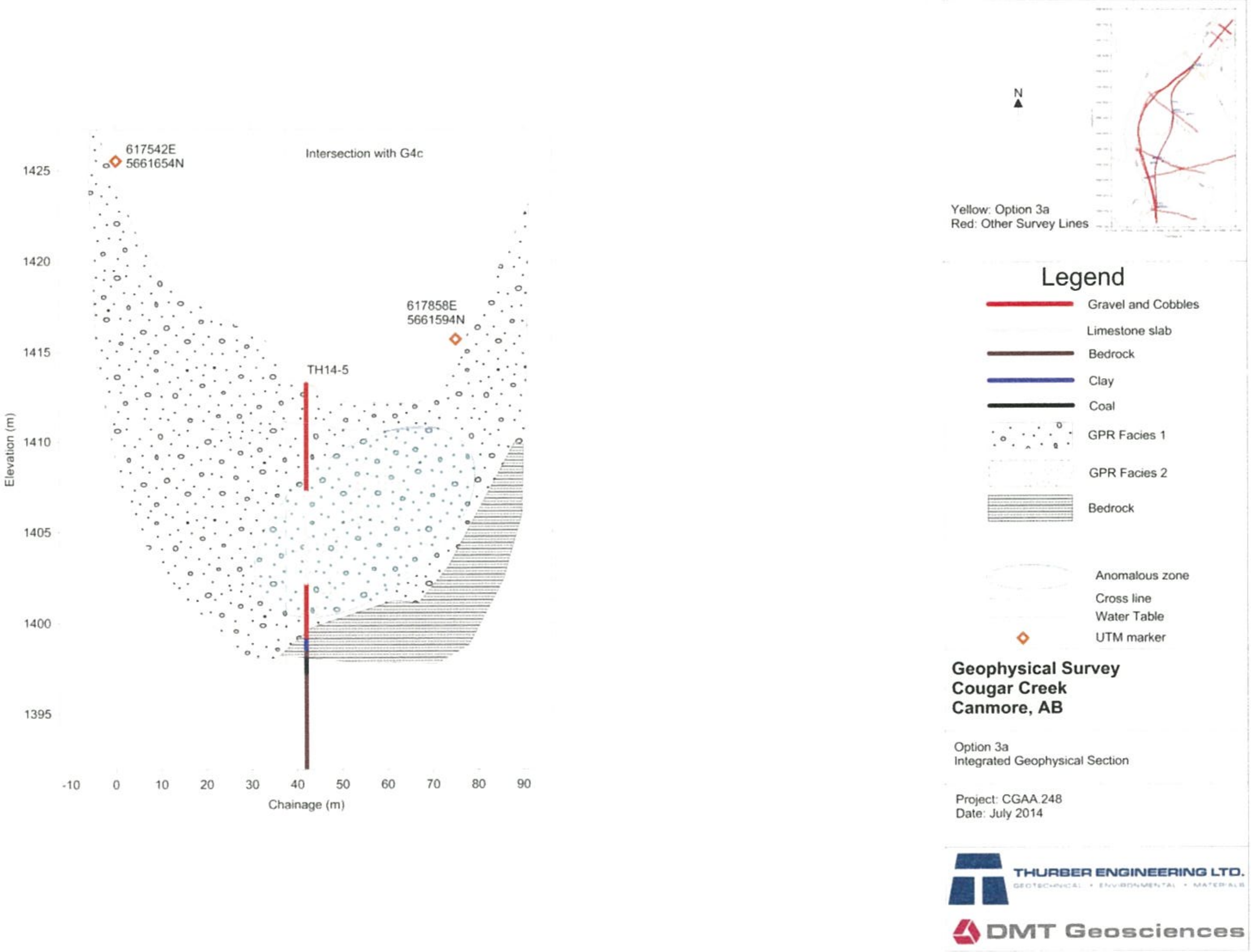

Figure 6-8: Interpretation for Option 3a

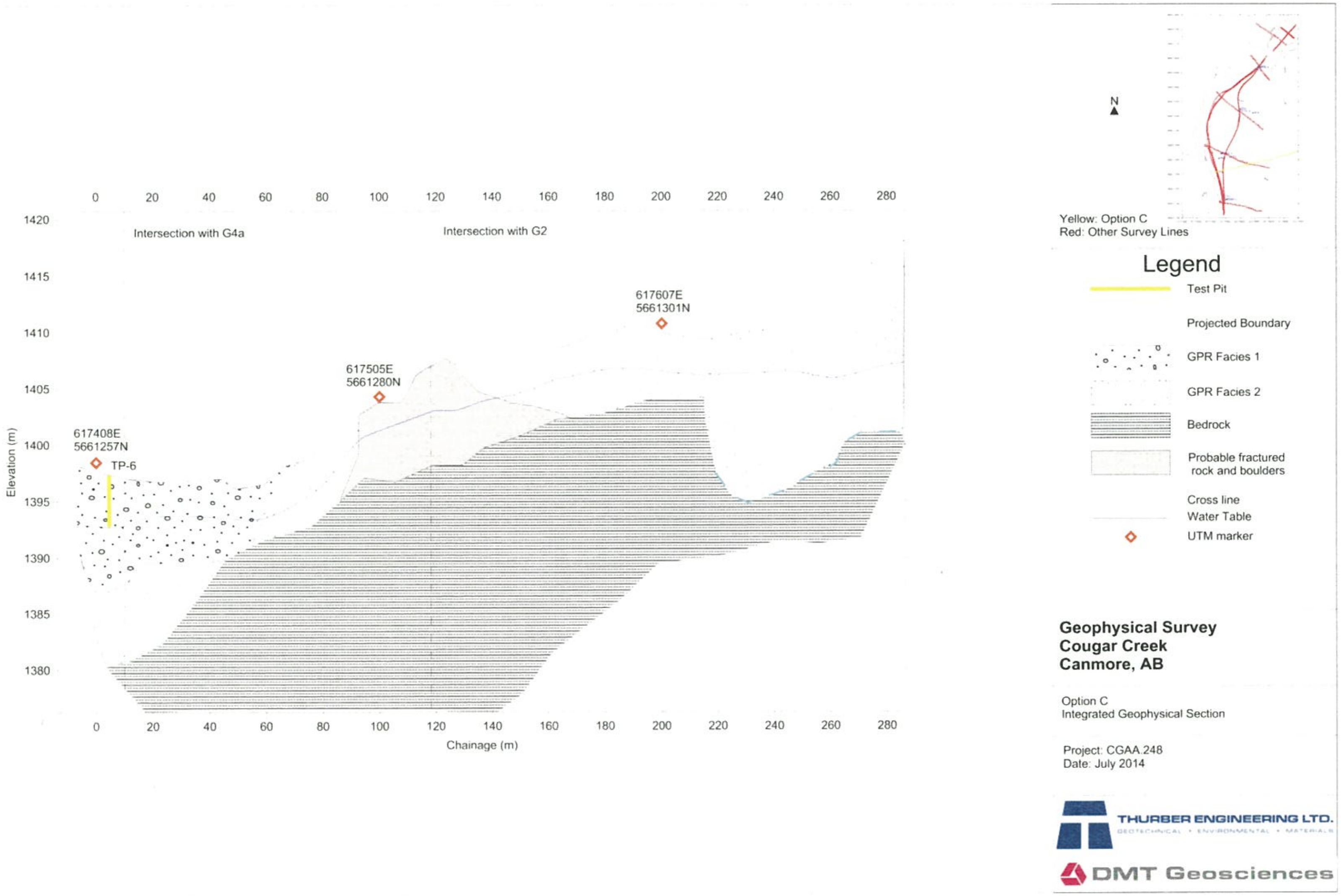

Figure 6-9: Interpretation for Line Option C

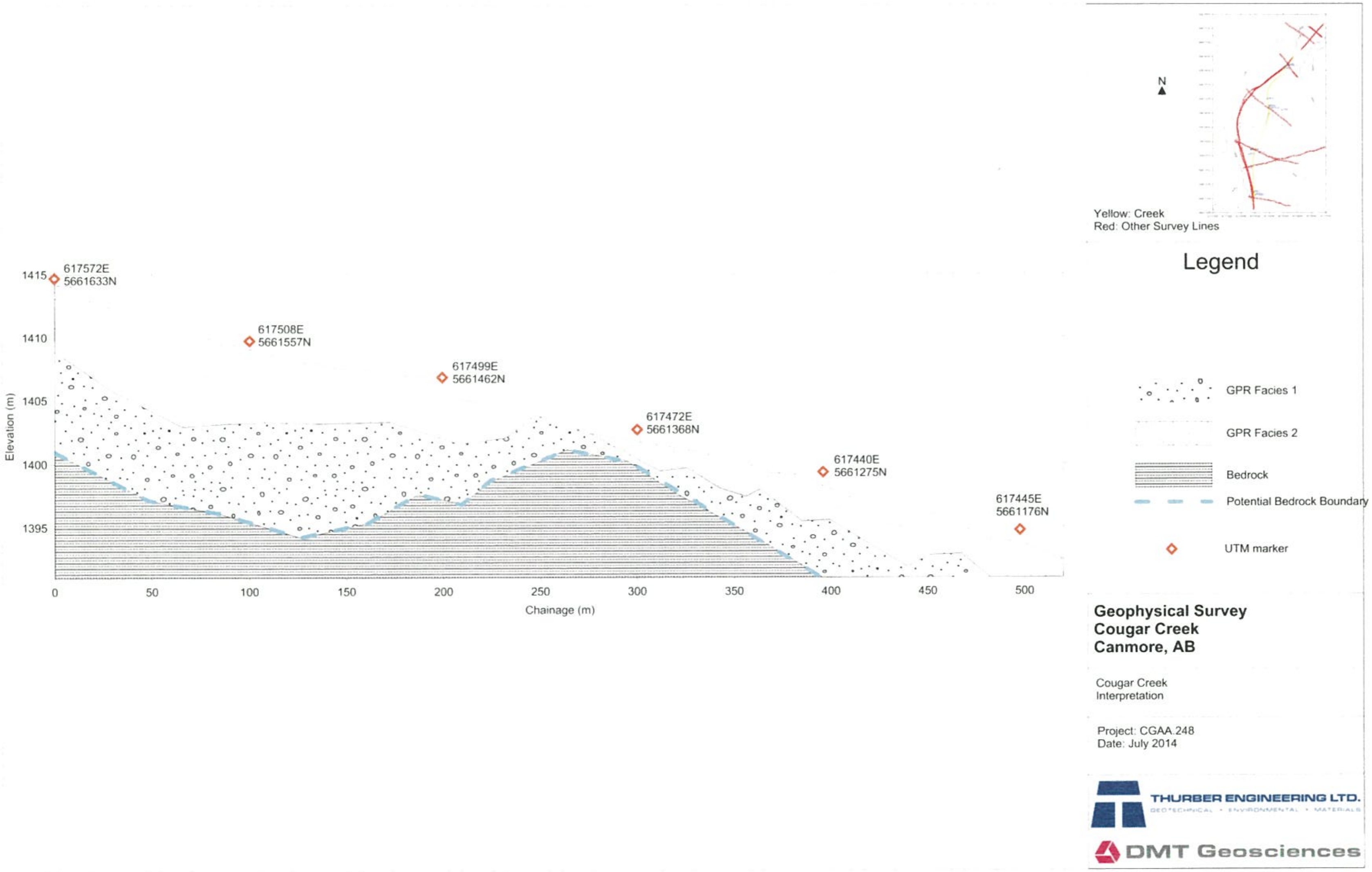

Figure 6-10: Interpretation for GPR line along the East side of Cougar Creek