Cariboo Regional District

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February 18, 2021

Sandra Griffiths
District Manager, Cariboo District
Ministry of Transportation and Infrastructure
301-640 Borland Street
Williams Lake, BC V2G 4T1

Dear Ms. Griffiths:

Re: Third Party Review – Quesnel-Hydraulic Road/Slide

The Cariboo Regional District was asked to commission a third party, independent geotechnical review of the Quesnel-Hydraulic Slide and its impacts on the possible repair/ restoration of Quesnel-Hydraulic Road.

Pursuant to the Regional District's Purchasing Policy, and a competitive proposal process, the Regional District retained Golder Associates LTD.

Golder Associates LTD completed the review and prepared the required report. That final report is attached to this letter.

We hope and trust that this independent report will provide some assurance to the local residents as to the assessment, planning and actions taken by the Ministry to address the situation on Quesnel-Hydraulic Road.

Yours truly,

John M. MacLean
Chief Administrative Officer

JM/ac

Attachment

REPORT

Independent Review of Feasibility of Temporary Access Quesnel-Hydraulic Road landslide

Quesnel, BC

Submitted to:

Larry Loveng, Manager Procurement

Cariboo Regional District
Suite D, 180 North 3rd Avenue
Williams Lake, BC
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Submitted by:

Golder Associates Ltd.

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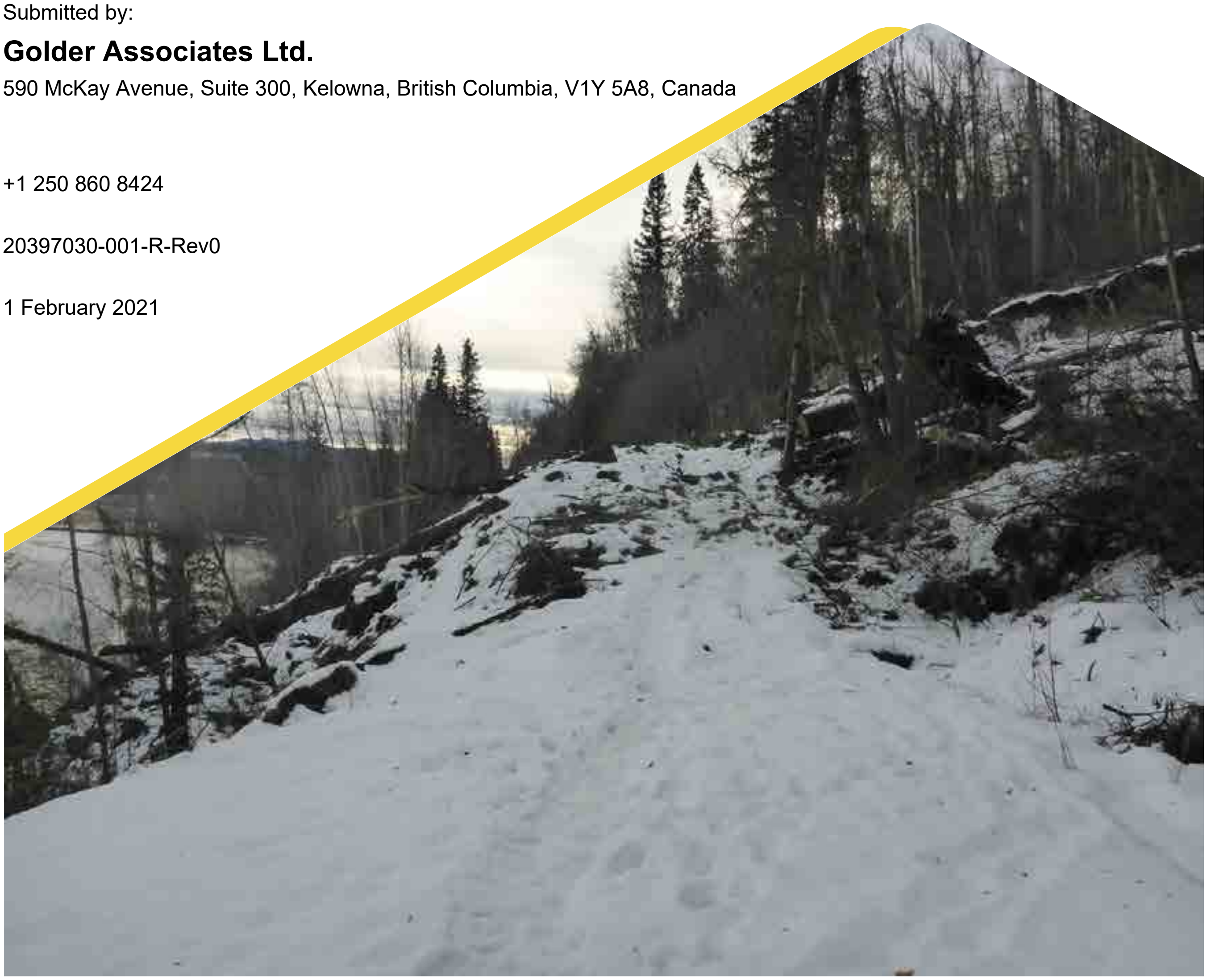
1 February 2021



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1.0 INTRODUCTION

As requested by the British Columbia Ministry of Transportation and Infrastructure (MoTI), the Cariboo Regional District (CRD) retained Golder Associates Ltd. (Golder) to conduct an independent geotechnical assessment of the Quesnel-Hydraulic Road landslide (Q-H Slide), located southeast of Quesnel at 20.3 km on Quesnel-Hydraulic Road. The purpose of the assessment was to review the active landslide for feasibility of a temporary access road through the slide and to provide a professional opinion on the current and future stability of the Q-H Slide site. The scope of work for the Golder's review can be found in Golder's proposal "Proposal for Independent Review of Feasibility of Temporary Access Quesnel-Hydraulic Road Slide, Quesnel, BC" dated 15 October 2020 (reference number: CX20397030-001-P-Rev0).

The scope of work for this assessment included a desktop study and a one-day field reconnaissance trip conducted by a member of Golder's geotechnical staff. This report does not include any subsurface geotechnical investigations, or investigations, analytical testing or assessments for possible soil and groundwater contamination, archaeological or biological considerations, hydrotechnical assessment or sediment control measures.

This report should be read in conjunction with the "*Important Information and Limitations of This Report*" (Appendix A). We specifically draw the reader's attention to this information, as it is essential for the proper use and interpretation of this report.

2.0 PROJECT UNDERSTANDING AND BACKGROUND INFORMATION

To complete the assessment, CRD has provided Golder with the following background information to review:

- GeoNorth Engineering Ltd. (GeoNorth). *Geotechnical Report, Quesnel Hydraulic Road Slides at km 16 and km 19.* File number K-1394. Report dated 31 March 2004.
- BGC Engineering Inc. (BGC). *Quesnel Hydraulic Road: Airborne Lidar Scanning Change Detection.* Project number 0272058. Project Memorandum dated 4 September 2020.
- BC Ministry of Transportation and Infrastructure (MoTI). *Independent Review of Quesnel-Hydraulic Road Slide, Quesnel, BC, Terms of Reference.* Letter dated October 7, 2020.
- Microsoft Excel file containing hub displacement monitoring measurements spanning form 18 April 2020 to 23 April 2020.

Additionally, Golder also reviewed the following background information:

- Air Photos from 1949 to 2006 obtained on loan from the University of British Columbia Geographic Information Centre Air Photo Library.
- Water well records of nearby water wells obtained from the Province of BC's Groundwater Wells and Aquifers Database. Accessed 22 January 2021. https://apps.nrs.gov.bc.ca/gwells/
- Geological Survey of Canada, Clague, John. *Quaternary Stratigraphy and History, Quesnel, British Columbia.* Published by Géographie physique et Quaternaire, vol. 42, no. 3, 1988, p. 279-288.

- Geological Survey of Canada, Tipper, H.W. *Glacial Geomorphology and Pleistocene History of Central British Columbia.* 1971 Bulletin 196
- Government of Canada. Real-Time Hydrometric Data Graph of Quesnel River near Quesnel (08KH006)[BC]. Accessed 22 January 2021. https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=08KH006
- Government of Canada. Past Weather and climate, Quesnel, British Columbia. Accessed 25 January 2021. https://climate.weather.gc.ca/climate_data/daily_data_e.html?hlyRange=2010-06-03%7C2021-01-24&dlyRange=2010-06-03%7C2021-01-24&mlyRange=%7C&StationID=48688&Prov=BC&urlExtension=_e.html&searchType=stnProv&optLimit=yearRange&StartYear=1840&EndYear=2021&selRowPerPage=25&Line=1256&lstProvince=BC&timeframe=2&Day=25&Year=2021&Month=1#

3.0 SITE DESCRIPTION

The Q-H Slide is located approximately 21 km southeast of Quesnel at 20.3 km on the Quesnel-Hydraulic Road. The road runs approximately parallel to the Quesnel river and is located on a hillside with a maximum grade of approximately 40%. The Quesnel-Hydraulic Road area has a history of landslide activity documented as early as 1978, most recently with the Q-H Slide closing a portion of Quesnel-Hydraulic Road in April 2020.

The geologic history of the site is a complex sequence of glacier advance and compression of the underlying soils, glacier retreat leaving ablation till, lake sediments and meltwater channels and subsequent downcutting by rivers and streams with landslides resulting in deposits of colluvium. In addition, following glacier retreat the ground surface is rebounding causing shearing and softening of the over-consolidated soils. Within the Quesnel area there is a history of many landslides due to the complex sequence of soils that have subsequently been down cut by rivers and streams.

4.0 ASSESSMENT METHODOLOGY

Golder's methodology for this assessment included a desktop review of available information, a one-day site reconnaissance, and global stability analyses of select sections through the slide area. The results of the assessment can be found in Sections 5.0 through 7.0.

5.0 DESKTOP REVIEW

Prior to the site reconnaissance, Golder conducted a desktop review of background information relating to the Q-H Slide site. The information reviewed included a collection of reports provided to Golder by MoTI, air photos obtained from the University of British Columbia archives, and water well construction records obtained from the BC Water Wells database. This section summarizes the findings of the desktop review.

5.1 GeoNorth Engineering Ltd. Report

GeoNorth (2004) conducted a geotechnical investigation and analysis of the landslide areas at approximately 18 km (referenced as the 16 km slide) and 20.3 km (referenced as the 19 km slide) along Quesnel-Hydraulic road. GeoNorth's 2004 report provided the following relevant information regarding the 19 km slide:

- Two drill holes were advanced in the 19 km slide area (TH03-3 and TH03-4) from 11 to 17 December 2003. TH03-03 was advanced to 30.4 metres below ground surface (mbgs) and TH03-4 was advanced to 46.7 mbgs.
  - Subsurface conditions below the road elevation at the 19 km slide site (TH03-3) are generally composed of 29 m of firm to stiff sandy clay and sandy silt soils of low to intermediate plasticity underlain by compact to dense sand with some gravel. Laboratory test results indicate the fines contents within the silt and clay was around 53%. The soils observed in TH03-4 (located upslope of TH03-3) were 17 m of loose to compact silty sand and gravel to silty sand with two 1.1 to 1.6 m thick layers of firm to stiff sandy silt at 6.2 and 12.6 mbgs. Laboratory tests on the silty sand indicate fines contents between 45% and 49%. The silty sand was underlain by 23 m of firm to stiff silty clay to clay of low to intermediate plasticity followed by a 2.8 m thick layer of stiff sandy silt. The borehole was terminated in very dense sand at 46.3 mbgs.
  - Slope inclinometer casing was installed to the total depth of both holes and vibrating wire piezometers were installed at 21.3 mbgs in TH03-3 and 36.2 mbgs in TH03-4. A standpipe piezometer was installed to 19.5 mbgs at TH03-4. No movement was recorded in the slope inclinometers and the water levels in the piezometers were reported to have not yet equalized.
  - A seep in the slope was observed during drilling (December 2003) at the culvert below the road grade. The seep was reported to continue to seep out of the slope on 24 March 2004 (report was issued 31 March 2004).
- The 19 km slide appears to be a post-glacial retrogressive slide composed of several smaller slides. The original failure was assumed to have happened between a few hundred and several thousand years ago.
- Regressive shallow surface failures at the north end of the 19 km slide were attributed to concentrations of runoff water acting on silt and clay soil. Movements affecting the road were attributed to both groundwater and erosion at the toe of the slope by the Quesnel River. Surface sloughs, in the case of silt, were attributed to frost action and slumping of saturated soil on thawing (Soliflution).
- A summary of a letter report written by G. Stock, PEng written 17 February 1978 that addressed historical slides observed along Quesnel-Hydraulic Road. The summary indicates "ongoing flow failures (that) appear to be a direct results of surface runoff" and seepage downslope in the road fill.
- Toe erosion was identified as the most significant factor causing the landslides. GeoNorth noted that managing slope drainage, protecting the toe from the Quesnel River and periodic road maintenance would be required to mitigate further landslides.

5.2 BGC Engineering Inc. Project Memorandum

BGC (2020) conducted an airborne LiDAR scanning (ALS) change detection analysis of the Q-H Slide site. BGC's memorandum provided the following relevant information:

- ALS datasets for the Q-H Slide site were compared between 12 May 2020 and 7 August 2020. Three profiles were analyzed with the following observations:
  - Profile A-A' (South end of Q-H slide site):
    - Localized failure on the outside edge of the highway
    - 2.0 m thick depositional area upslope of the highway between elevations 575 and 595 m
    - Active headscarp between 593 m and 600 m showing 2.0 m of subsidence
  - Profile B-B' (Middle of Q-H Slide site):
    - Approximately 2.0 m of erosion at the toe of the slope
    - Failure of the roadway
    - Headscarp between 620 m and 627 m showing 0.5 m of subsidence
  - Profile C-C' (North end of Q-H Slide site):
    - Greater than 2.0 m of deposition between 555 m and 570 m
    - Active headscarp between 572 m and 597 m showing 2.0 m of subsidence and greater than 2.0 m of material loss.
- The point cloud data from August was an order of magnitude lower in resolution compared to the May data, making detailed comparison of the two datasets difficult. BGC recommended additional LiDAR data be collected in the fall once the leaves were off the trees.

5.3 BC MoTI Letter and Related Drawings

MoTI (2020) delivered a letter to CRD requesting an independent geotechnical review of the Q-H Slide. The letter included a brief history of the slide, instructions for developing a scope for the independent review, and drawings and photographs of the Q-H Slide site and is shown in Appendix C. The slide history and photographs/drawings provided the following information:

- The slide is hypothesized to consist of up to seven (7) smaller slides labelled A (northern most slide) through G (southern most slide) as shown on the MoTI Figure 1 in Appendix C. There are 12 cracks (labelled 1 through 11, including crack #6 and #6-2) that have been identified throughout the slide area and marked with GPS waypoints as shown on the MoTI Figure 2 in Appendix C.
- Cracking in the roadway was observed near slides D and E on 15 April 2020. By 25 April 2020 the roadway had become unsafe for safe vehicle passage and was subsequently closed to traffic. On 1 May 2020 Slide B failed across the roadway with a second slide in the same area on 4 May 2020. Around 4 May 2020 Slide C accelerated, and the roadway dropped down by more than 2 m.

- Significant seepage zones were observed in Slide B throughout the summer, appearing to originate in a sand layer located above the roadway. Slides C, D, and E saw significant movement including up to 10 to 12 m of horizontal deformation and 10 m of vertical deformation in Slide E.
- MoTI completed two additional LiDAR flights to add to the flights discussed in BGC 2020 for a total of four flights. LiDAR flights were completed in the following months:
  - June 2020
  - August 2020
  - October 2020
  - November 2020

  No formal memo was provided for the change detection completed by MoTI. The change detection was completed using similar methods to those by BGC. The results of the change detection and orthophotos are presented in Appendix B. Figure 1 Shows the toe erosion compared between the different LiDAR scans.

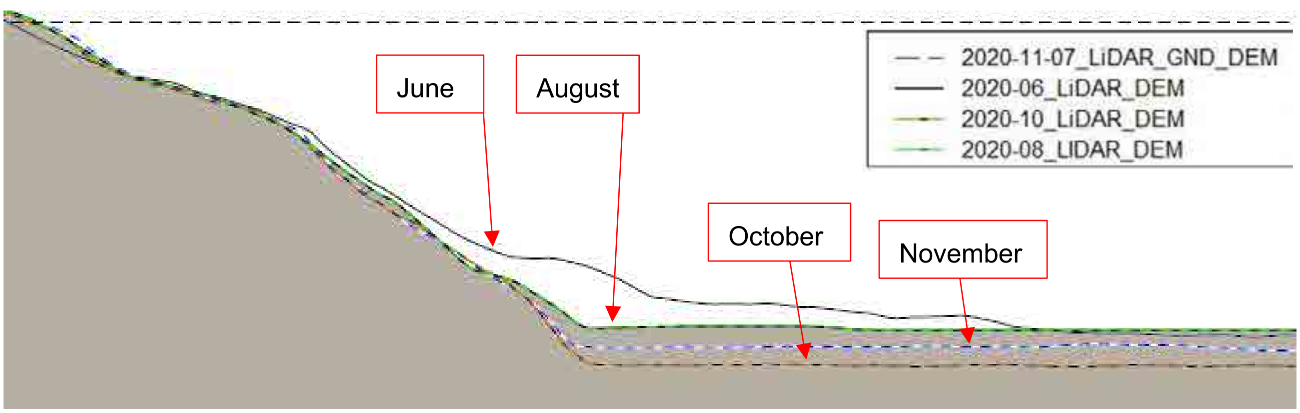

Figure 1: Toe Erosion by Quesnel River

Figure 1 shows the main landslide debris as present in June 2020 and then becoming eroded over the summer and fall of 2020. The slide debris/river bank is erroded about 10 m horizontally and up to 2 m or more vertically.

5.4 Hub Displacement Monitoring Measurements Records

MoTI provided Golder with a Microsoft Excel file containing hub displacement monitoring measurements spanning form 18 April 2020 to 23 April 2020. The data is only for a span of five days, it is apparent that the monitored area was progressing downhill at a rapid rate. Based on a note contained within the file, Golder undestands readings were ceased because the road was closed.

5.5 Air Photo Review

Air photos with dates ranging from 1949 to 2006 were obtained on loan from the University of British Columbia Geographic Information Centre Air Photo Library. Eleven sets of air photos were reviewed, some having a single photo, others were stereopairs. Where possible, air photos were examined using a stereoscope.

Table 1: University of British Columbia Geographic Information Centre Air Photos

Date	Flight Line	Approximate Scale	Photograph Number
19 Aug 1949	BC936:78-79	32,000	78-79
17 Aug 1957	BC2345	23,000	9-10
01 May 1963	BC5071	34,000	70-71
01 May 1968	BC5286	18,000	052
1972	BC5462	35,000	214-215
1977	30BC77013	22,000	062-063
1980	15BC80124	24,000	186
1985	30BC85008	16,000	040-041
1991	30BCC91061	17,000	284-285
1997	30BCC97116	19,000	43-44
2006	30BCC06004	23,000	144-145

Due to the relatively large scale of the air photos, moderate to locally moderately-steep slopes[1], and dense tree cover, interpretation of slope deformation was challenging. Air photos provide snapshots of specific points in time where changes in vegetation cover were visible, compared to earlier photos. Landslide activity can be inferred based on these observations, but as shown in BGC 2020, multiple headscarps are present along the project area and deformations may be occurring below the forest canopy, without significant loss in vegetation cover. Slides given alphabetical designation (A, B, C etc.) discussed below refer to MoTI's site plan ortho-aerial drawing, Figure 1, from MoTI 2020. For simplicity north refers to the general downstream or Quesnel-bound road direction, and south refers to the upstream direction.

The Quesnel-Hydraulic Road had been established by 1949 and appeared to be generally along the same alignment as present day. Dense vegetation, inferred to be mature trees, was visible between the road and the Quesnel River. Agricultural development was also underway with cleared land to the north and south of the site, as well as directly across the Quesnel River. No forestry roads or land development was evident upslope of the road along the project area. In 1957, a narrow track of thinned trees was noted in the project area with possible localized areas of erosion/scour along the riverbank and may be related to Slide B.

[1] Based on the Terrain Classification System for British Columbia (1997)

In 1963, the road clearing appears wider than in 1957, mainly in the downslope direction near Slide B. There may have been slide debris deposition across the roadway and spilling over the downslope shoulder. Slightly north of the slide area, at the “S-bend” in the road, the vegetation appears to be cleared downslope of the road, to the river. The cause of this clearing could not be determined. A small area of possible localized erosion due to river scour was identified near or upstream of Slide E. The “S-bend” and widened Slide B clearings were present in the 1968 photo with no other significant changes.

In 1972, a strip of cleared land was visible running parallel to the road, connecting agricultural properties up-and-downstream of the project area. The clearing was between the road and the river and the purpose of the clearing is unknown. No other relevant changes in vegetation cover were noted.

By 1985 photo, there appeared to be evidence of significant landslide that was not visible in the 1980 photo. A track, cleared of vegetation, could be seen on the downslope side of the road, running directly into the river. This main track was near the Slide B path identified by MoTI. No significant vegetation loss upslope of the road was identified; however, a gully feature was noted directly upslope of the inferred debris path. This gully feature appeared to drain a small wetland/pond area further upslope and south of the slide path. Other, smaller clearings downslope of the road, north of the Slide B path were visible. However, these clearings did not extend down to the river. Some clearing upslope of the road near the Slide A was noted, indicating potential recent slope deformation. An area of exposed soil upslope of the road, north of Slide A was visible, with debris noted downslope of the road. This specific area is inferred to be the exposed soil slope seen to the right of Slide A in MoTI’s Figure 1 in Appendix C.

By 1991 photo, the area downslope of the road appeared to be re-vegetated. No new signs of instability were visible. In 1997, the Slide A and B areas may have lost some vegetation cover upslope of the road, although no debris or vegetation loss was noted on or downslope of the road. The most recent photo available was from 2006 and generally indicated continued re-vegetation and mature tree development in the project area. No signs of vegetation loss or obvious indications of slope deformation were noted.

5.6 Groundwater Well Logs

Golder used the Government of British Columbia’s provincial Groundwater Wells and Aquifers database (https://apps.nrs.gov.bc.ca/gwells/) to view soil stratigraphy information for the general area surrounding the slide. Golder’s search revealed three groundwater wells were drilled within 1.9 km of the Q-H Slide:

- WTN 44445, located approximately 1.9 km south of the Q-H Slide and approximately 10 m above the floodplain elevation, was drilled to 48.77 mbgs. The well record indicates about 10.4 m of gravel and clay at the surface followed by 16.5 m of sand and clay underlain by 21.3 m of sand transitioning into a sand and gravel mixture at depth. The static water level is reported to be at 18 mbgs.
- WTN 52780 is located on the east side of the Quesnel River, approximately 0.8 km east of the Q-H Slide and is approximately at floodplain elevation. The well record indicates the well was drilled to 20.7 mbgs and encountered 4.5 m of topsoil with gravel and boulders followed by 12.5 m of sand loam until intersecting a gravel seam at depth. The static water level is reported to be at 7.6 mbgs.

- WTN 55171 is located approximately 1 km north of the Q-H Slide and approximately 30 m above the floodplain elevation and was drilled to 68.27 mbgs. The well record indicates about 9.1 m of brown clay followed by 1.5 m of brown clay and gravel, 27.4 m of brown sand and clay, and 26.5 m of grey clay underlain by water-bearing sand and gravel. The static water level is reported to be 39.6 mbgs.

The soils reported in the water wells are in general agreeance with the geologic setting and geologic history indicated in the surficial geology maps.

5.7 Surficial Geology, Glacial History and Site Stratigraphy

Quesnel is located near the center of the former Cordilleran Ice Sheet that previously covered central British Columbia during the Pleistocene epoch. The area experienced several sequences of glacial advance and retreat, with deglaciation characterized by frontal retreat and heavy outwash flows while glacial advances scoured deposited material and deposited layers of till. Quaternary stratigraphy, glaciation and surficial geology in the Quesnel area have been studied by Tipper (1971) and Clague (1988). Clague studied the stratigraphy in thick late Quaternary sediment exposures along the Fraser River and tributaries surrounding Quesnel to develop a model of past glaciation in the area. These studies identified fluvial and glaciofluvial sands overlain by thick fine grained glaciolacustrine deposits punctuated with tills, overlain by glaciolacustrine sediments likely deposited into an ice-dammed lake near the end of the Fraser Glaciation. Colluvial deposits were identified throughout the stratigraphic layers, deposited by landslides off valley walls triggered during various stages of glaciation (Clague, 1988).

The last glacial retreat marked the end of the Pleistocene and the start of the Holocene, approximately 11,700 years ago. The early Holocene was characterized glacial retreat, heavy glacial outwash flows and downcutting of Pleistocene deposits in a series of terraces along major drainages throughout the region that continues to this day.

The Q-H Slide site is located on the west bank of the Quesnel River within the river's historical meltwater channel. Glacier ice covering the site during the Pleistocene epoch flowed northerly from the Quesnel Highlands through the Interior Plateau (Tipper, 1971) and to the northern Rocky Mountains. This movement is evidenced by drumlins in the hills to the east and west of the Q-H site, shown on Figure 2. Prominent glacial grooves are also visible in the surrounding terrain, with both trending north to northwest.

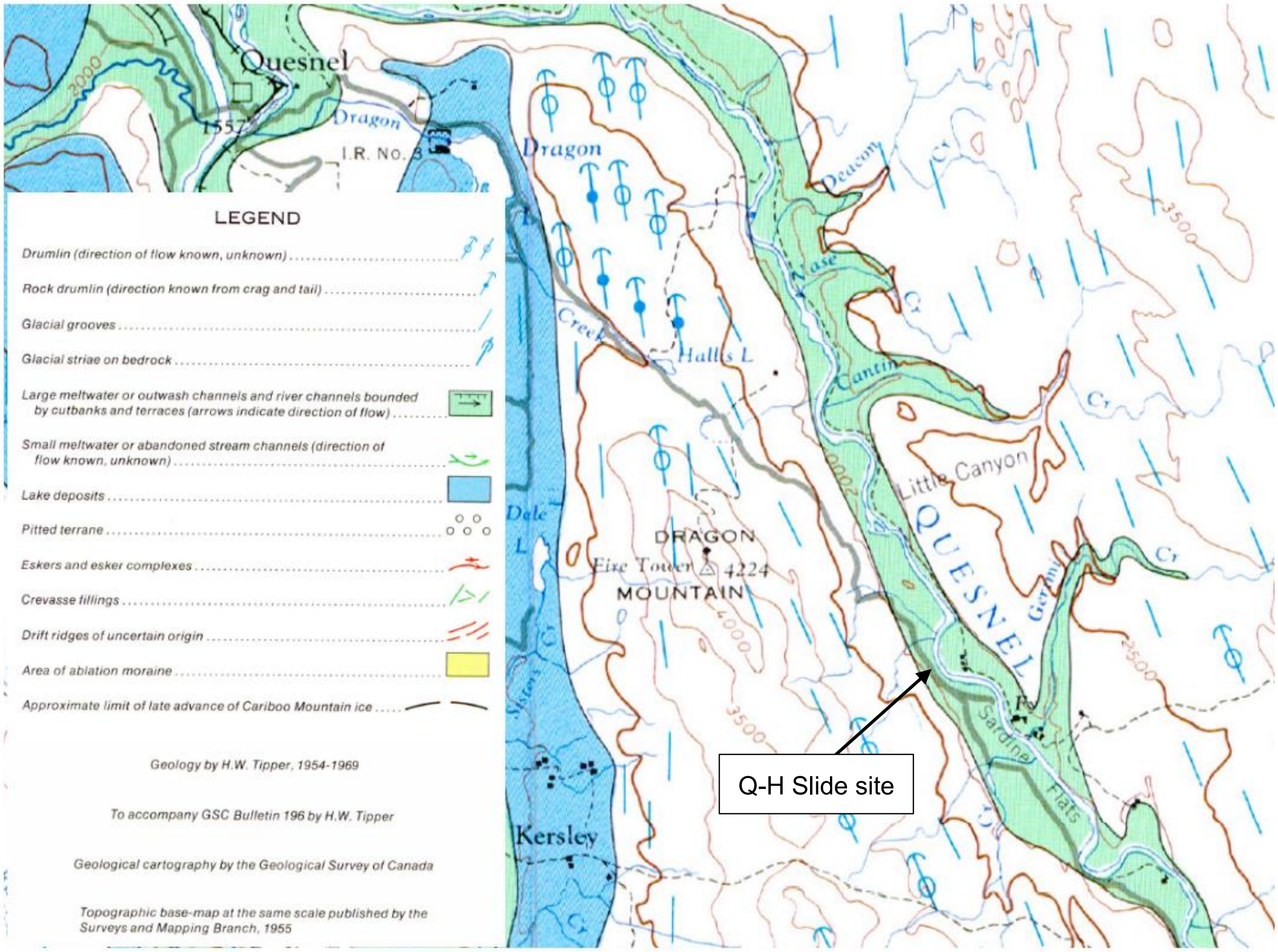

Figure 2: From Map 1290A, Surficial Geology – Quesnel, Tipper, 1971. Mapped at 1:250,000 scale

The Quesnel River currently occupies a broad outwash channel with banks rising to over 200 m above river level in places. No bedrock exposures were noted at the site and drillholes have been advanced in soils to depths of over 45 m in the bank around the Q-H Slide site with no bedrock observed.

5.8 Quesnel River Height and Flow Gauge

The Quesnel River gauge near Quesnel is located where Nyland Lake Rd crosses the Quesnel river approximately 3 km upstream and southeast of the Q-H Slide site. Bank to bank, the river is approximately 110 m wide at the gauge site and around 130 m wide including a large sand bar at the Q-H Slide site. Figure 3 shows the Quesnel River discharge and water level at the gauge site, as well as the statistical upper quartile discharge for the same dates over the 83-year gauge record.

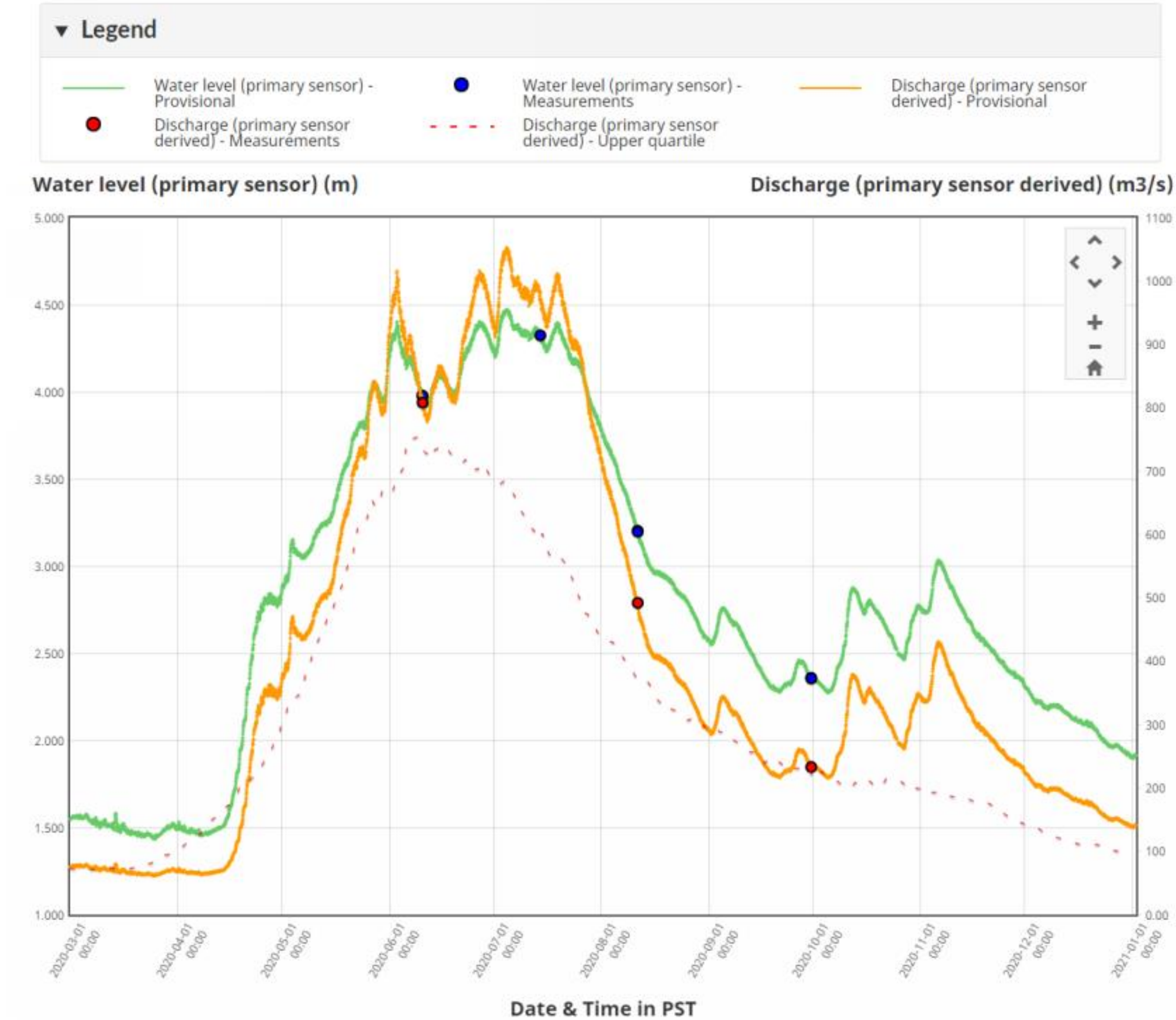

Figure 3: Quesnel River near Quesnel Discharge and Stage Hydrograph

Figure 3 shows that the Quesnel River was flowing well above the statistical upper quartile discharge from mid-April to September of 2020, and again from October 2020 into 2021. The river also experienced a large drop in flows from mid July to mid September, corresponding to a roughly 2 m drop in water level as measured at the gauge site. This drop in discharge is consistent with the seasonal freshet cycle. However, the increase in discharge in the fall of 2020 appears to be larger than normal as discharge over the 83-year gauge records do not show a corresponding fall increase before winter.

5.9 Quesnel Climate Data

Golder reviewed climate data at the nearby Quesnel airport weather station provided by Environment Canada. Figure 4 presents cumulative precipitation starting on 1 April 2020 through 31 December 2020 and the 30-year climate normals for the Quesnel A Weather station. Both the Quesnel and Quesnel A weather stations are located at the Quesnel Airport approximately 21 km northwest of the Q-H Slide site and at a similar elevation. The figure also presents daily mean temperature (°C) plotted against the secondary vertical axis. Slide events in April and May are marked with a vertical line, and the continuing deformation observed at Slide sites D and E following freshet drawdown are shown.

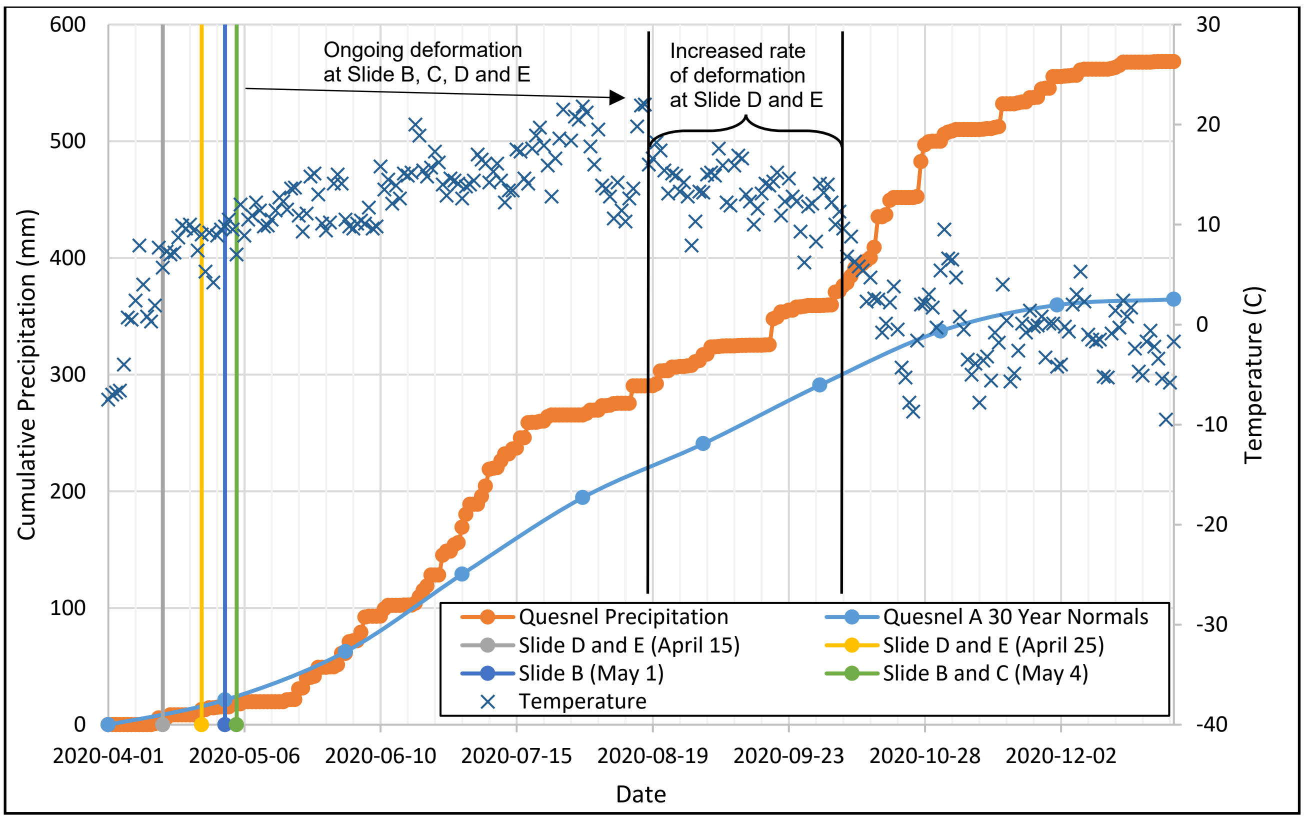

Figure 4: Quesnel Climate Data

Figure 4 shows mean daily temperatures climbing above freezing starting in the first week of April. This preceded cracking in the road shoulder at slide site D and E first observed on April 15th and assessed on April 18th. The assessment suggests the ground was still frozen in shaded areas as of April 18th but may have been beginning to thaw in more exposed locations.

Precipitation tracked the 30-year normal before increasing in late May. Heavy rainfall continued from late May into July, tapered from mid July through September, and increased again from October through November. This precipitation resulted in the high freshet and seasonally high fall discharges recorded at the Quesnel River near Quesnel gauge presented in Figure 3.

6.0 SITE RECONNAISSANCE

A site reconnaissance was conduced by Ben Singleton-Polster, PEng geotechnical engineer with Golder on 12 January 2021. To provide details on the naming convention from the MoTI and BGC work, Golder walked the site escorted by Warren Lemky, PEng of MoTI. Golder made visual observations of the slide site, took photographs and collected relative displacement measurements where possible. The intent of the site reconnaissance was to obtain an overall understanding of the site and to make observations of the soils and different slides noted in the MoTI mapping. Further, the reconnaissance was used to assist with slope stability model construction and to understand constraints to potential remedial options. Weather at the time of the inspection was overcast with above freezing temperatures resulting in some melting of the snow/ice on the ground.

The Quesnel-Hydraulic road was observed to have recent shoulder failures marked by cones near the farm entrance located to the north of the Q-H Slide. The Quesnel-Hydraulic road was blocked by a recent landslide located about 100 m north of the Q-H Slide. Warren reported that this landslide had occurred within the past month (mid December 2020 to mid January 2021). Golder traversed on foot on top of slide debris at the approximate level of the previous roadbed to the south end of the slide complex where some road shoulder failures were observed above the farmers field south of and near Slide G from MoTI Figure 1 and Section A from BGC. Photo 1 and Photo 2 show Slide B looking upslope and downslope respectively.

Photo 1: Slide B Looking Upslope at Hung up Material

Photo 2: Slide B Looking Down Slide Path at Toe of Slide in Quesnel River

Slide B on MoTI Figure 1 was observed in Photo 1 to have displaced a significant amount of debris into the Quesnel River as shown on Photo 2. Water with grey silt was observed flowing over the slide debris. Some saturated, very soft zones with sand and silt were noted, making travel over the debris difficult. Rounds of wood had been placed over the slide debris in spots indicating that the ground is/was very soft.

Slide E has grown and merged with Slide C, Slide D and the larger Slide F. Photo 3 shows the toe of Slide E in the Quesnel River. Soils exposed within the flank of Slide E appeared to be compact silty, clayey sand with some gravel.

Photo 3: Shows the Toe of Slide E

Golder traversed to the area of TH03-4 with installed slope inclinometer and piezometer as shown in Photo 4 below. It is understood that TH03-4 is located between Slide B and Slide E and may be within Slide F. However, the exact lateral extent of Slide F is not known.

Photo 4: TH03-4 Looking Downslope

Golder traversed upslope and an old back scarp was observed as shown in Photo 5.

Photo 5: Old Backscarp of Slide F

This old backscarp, understood to be the remnant of Slide F, may have been part of the mapping completed by MoTI (2020). Numerous old trails and drainage ditches were observed on the slope. It is possible that these old trails and drainage ditches follow old backscarps due to their orientation. These old trails and drainage ditches are assumed to be part of the historical works described by GeoNorth. Golder observed a wet area with some water ponded above slide B as shown in Photo 6 and Photo 7 which may be the location observed in Golder's air photo review.

Photo 6 Water on Slope **Photo 7: Water on Slope**

The water may have originated from melt upslope or be seepage and funnelled into a slight swale as shown in Photo 7.

Golder traversed to the area between Slide A and Slide B and observed trees split and cracked with between 0.4 m to 0.8 m of displacement observed in the split trees as shown in Photo 8 and Photo 9.

Photo 8: 0.4 m Split Tree **Photo 9: 0.8 m Split Tree**

From the area between Slide A and Slide B, the landslide paths were observed and the top of the “hung up material” observed in Photo 1 and shown on MoTI Figure 1. The “hung up material” was estimated to be approximately 8 m to 10 m below the main backscarp as shown in Photo 10. The soils observed above this “hung up material” appeared to be clay/silt overlain by sand. The clay/silt appeared to have some water on it and ice was observed within the sand indicating that likely water is flowing at the interface between the clay/silt and sand.

Photo 10: Slide B: Looking Downslope at Block of Debris and Possible Clay Layer

7.0 GLOBAL STABILTY ANALYSIS

Golder used Geostudio 2020 SLOPE/W software to develop a two-dimensional model of the Q-H Slide. Model sections were based on two cross sections provided to Golder by MoTI that were cut through Slide B and Slide E/F, as shown in Figure 5. The most recent LiDAR surface, obtained 7 November 2020, was used to create the ground surface of both model sections.

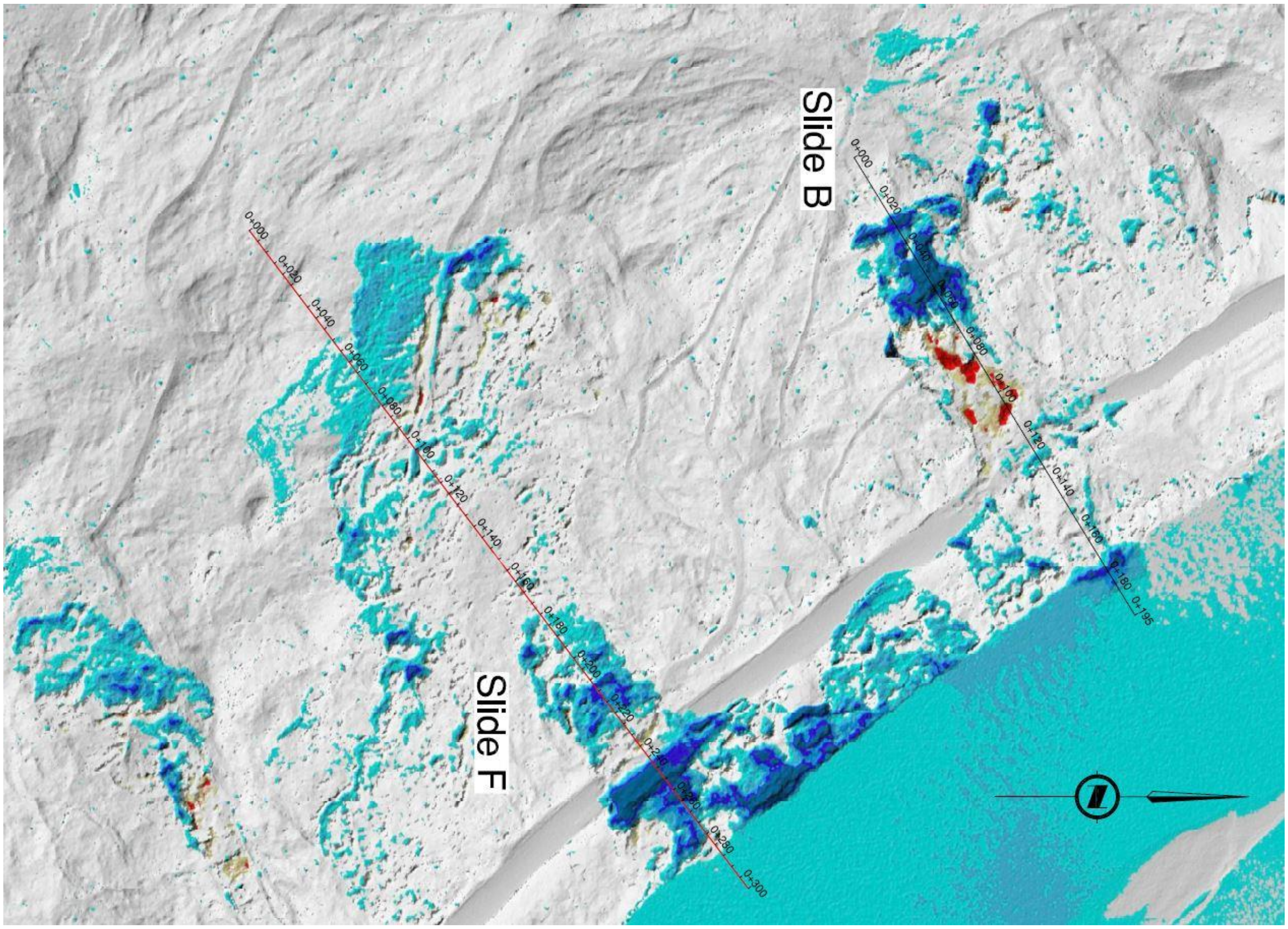

Figure 5: Plan of cut sections for slides F and B (Provided to Golder by MoTI on 26 January 2021)

Soil information used to develop Slide F model section was compiled based on historical data from test holes TH03-3 and TH03-4 reported in GeoNorth (2004). The test hole data was plotted downhole through the cross section and similar soil types were connected between boreholes. Where similar soils were not present between boreholes Golder assumed the stratigraphy “pinched out” throughout the entire horizontal distance between the two boreholes. The stratigraphy was assumed to be relatively horizontal both up and downslope of the boreholes because the geological history of the area indicates glacier retreat leaving ablation till, lake sediments and meltwater channel deposits. A sandy silt layer of firm to stiff consistency was drawn in the model at approximately 597 metres above sea level (masl) based on visual observations during the reconnaissance. Site-specific groundwater table elevations are not available at this time. A likely scenario of the phreatic surface was approximated to daylight at the observed seepage zone near the top of the slide (597 masl) and then persist underground throughout the rest of the slide area, daylighting again at river elevation. For the purposes of the model the water table is approximately equal to the phreatic surface. The Slide F model cross-section and stratigraphy can be seen in Figure 6.

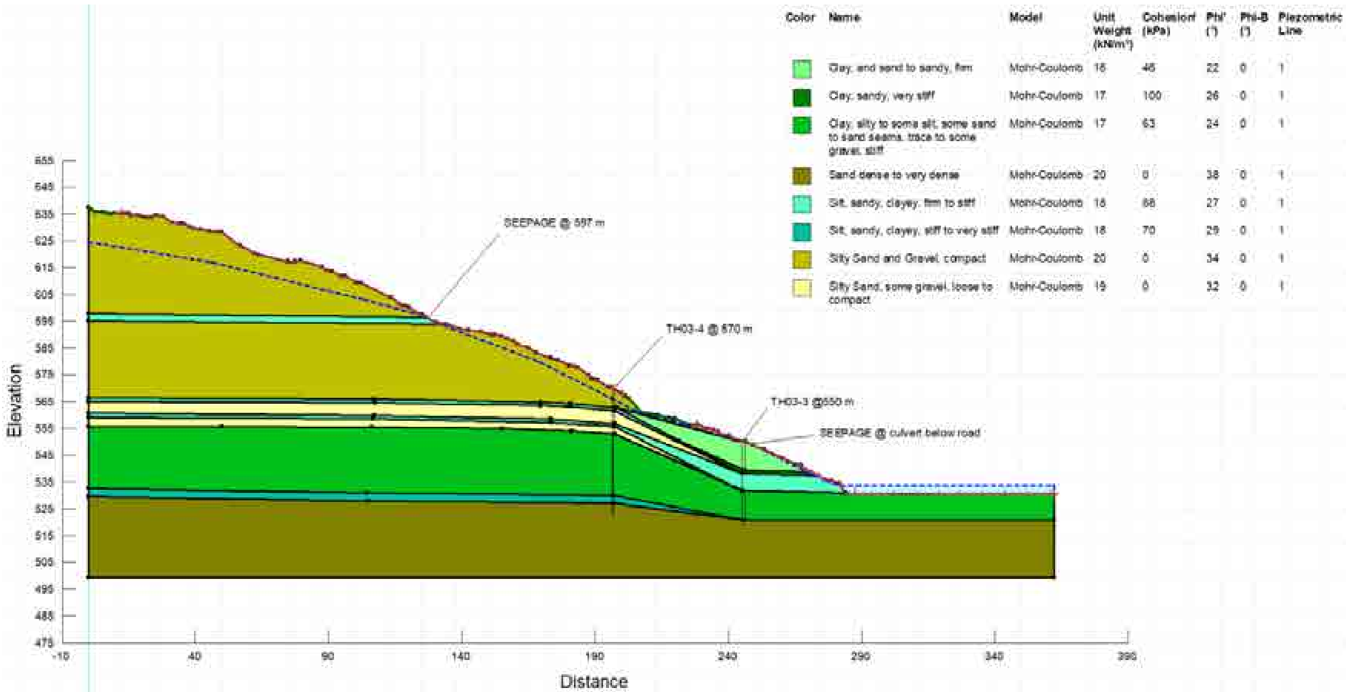

Figure 6: Slide F Model Section- Stratigraphy

Site-specific drillhole data was not available for Slide B. Therefore, the soil stratigraphy for the Slide B model was based on a projection of the stratigraphy from the Slide F model section. The Slide B model cross-section and stratigraphy can be seen in Figure 7

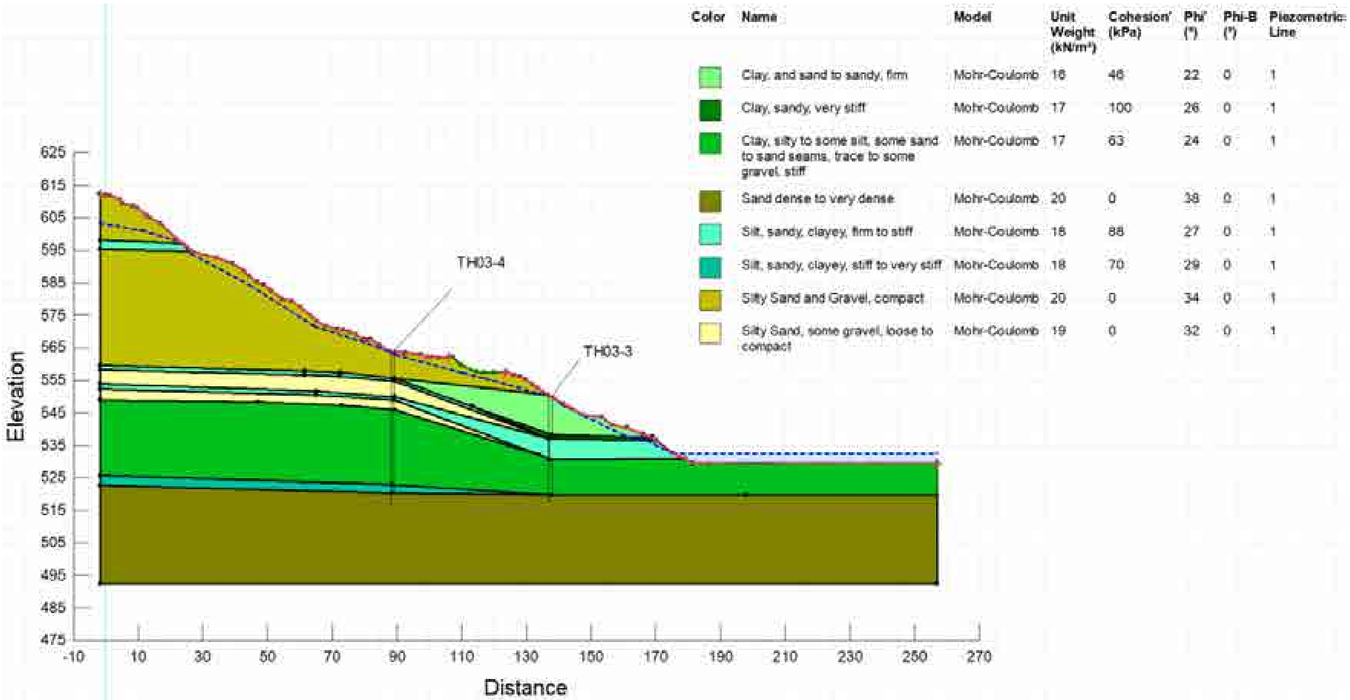

Figure 7: Slide B Model Section - Stratigraphy

Golder acknowledges the soils information available for the Q-H Slide at this time is limited and therefore the assumed stratigraphy in the model may or may not be representative of the actual ground conditions at the site. Furthermore, it is common, especially in areas of historical landslide activity, that soil conditions vary between and on either side of boreholes. Further geotechnical investigation and laboratory testing should be conducted to refine the model prior to design.

The different soil types within the model were modelled using a Mohr-Coulomb strength model (material strengths are based on a unit weight, cohesion, and internal friction angle). For the back analysis (base case), the input parameters were varied to obtain a factor of safety (FoS) of approximately 1.0. The FoS is a ratio that is calculated from the resisting forces of the soil over the driving forces of the soil. A FoS of 1.0 represents a "meta-stable" state whereby the driving forces and resisting forces are approximately equal. This back-analysis approach is a common analysis technique used to assess material model parameters for global stability analyses in geotechnical engineering. The material parameters that obtained an approximate FoS of 1.0 for the base case model sections can be seen in Table 2.

Table 2: Global Stability Model Input Parameters

Soil Name	Unit Weight (kN/m^3)	Cohesion (kPa)	Phi' (°)
Clay, and sand to sandy, firm	16	46	22
Clay, sandy, very stiff	17	100	26
Clay, silty to some silt, some sand to sand seams, trace to some gravel, stiff	17	63	24
Silt, sandy clayey, firm to stiff	18	88	27
Silt, sandy, clayey, stiff to very stiff	18	70	29
Silty Sand and Gravel, compact	20	0	34
Silty Sand, some gravel, loose to compact	19	0	32
Sand, dense to very dense	20	0	38

Once the material input parameters for a FoS of approximately 1.0 were defined, the model sections were run to calculate the FoS for various phreatic surface elevations, river water levels, and topographical conditions. River water level records from the Quesnel River Hydrometric station (station ID 08KH006) indicate the maximum water level of the Quesnel River within the past year was recorded at 4.48 m in July 2020 and the minimum water level was recorded at 1.43 m in late March/early April 2020. The water level increased significantly between April and June 2020. The first report of major recent slope movement on record was reported in April 2020 so an average water level for the period between April and May 2020 was used for the base case model. The Quesnel River water levels used in the model sections can be seen in Table 3.

Golder also observed the June 2020 LiDAR surface showed an accumulation of slide debris at the toe of the slope at Slide B. The debris appeared to have been eroded away by the river when the next LiDAR scan was obtained in October 2020. In order to simulate the change in FoS that occurs when the toe of a slope is removed, Golder modelled an eroded riverbank at the toe of the slope sections, immediately adjacent to the Quesnel River. The factors of safety obtained for each modelled scenario are shown in Table 3. The results of the analyses, including the modelled failure surfaces can be seen in Appendix D.

Golder also modelled a temporary road cut that consisted of a 2 horizontal to 1 vertical (2H:1V) road cut near the elevation of the current road. The results of the model for each model section can be seen in Table 3. Golder also considered the option of additional fill to raise the road grades. However, this fill would have to be placed on the existing slide debris that is metastable and would likely lead to localized small scale shoulder failures in the Quesnel River.

Table 3: Factor of Safety Summary

Model Section	Phreatic Surface Depth from Ground Surface (m)	Quesnel River Water Level (m)	Factor of Safety	% Change from Base Case
Slide F				
Base Case - April/May 2020	2 to 4	3.25	0.96	N/A
March/April 2020 (Min water level)	2 to 4	1.43	0.96	0
June 2020 (Peak water level)	0	4.48	0.89	-7
June to August 2020 (eroded toe of slope)	1 to 2	4.0	0.95	-1
Temporary road cut – near old road elevation	2 to 4	3.25	0.95	-1
Slide B				
Base Case - April/May 2020	2 to 4	3.25	1.03	N/A
March/April 2020 (Min water level)	2 to 4	1.43	1.03	0
June 2020 (Peak water level)	0	4.48	0.96	-7
June to August 2020 (eroded toe of slope)	1 to 2	4.0	1.00	-3
Temporary road cut – near old road elevation	2 to 4	3.25	0.99	-4

Golder has not modeled the combination of high-water levels, toe erosion and construction activities as these individually reduce the slope stability so would have a cumulative greater reduction in stability than any case on its own. The combination of high water levels, toe erosion and construction would bring the FoS below 1.0 and would be expected to cause active landslides at the site.

8.0 DISCUSSION

The following presents our summary comments and discussion on the background desktop review, site reconnaissance and slope stability analysis:

- GeoNorth reported that the initial slide likely happened several hundred to several thousand years ago. Documented history of slides are described in 1978 and 1980 prior to the work by GeoNorth in 2003 to 2004. Failures were partially attributed to surface runoff and toe erosion. Toe erosion was identified as the most significant factor. GeoNorth noted that managing slope drainage, protecting the toe from the Quesnel River and periodic road maintenance would be required for the road to remain serviceable.
- The air photo interpretation completed by Golder showed multiple, relatively small-scale slides to have occurred since the 1960s. A more significant set of landslides occurred between 1980 and 1985, which was followed by a period of relatively few landslide events until the most recent deformations in 2020.
- The published surficial geology mapping completed shows a sequence of till, lacustrine clay/silt and meltwater/fluvial sand and gravel deposits.
- The nearby groundwater well logs show a similar sequence of clay/silt, till and sand and gravel deposits. The groundwater level varies and there is some evidence of perched water.
- BGC completed a change detection using LiDAR data collected in May and August 2020 and noted movement of the bigger overall landslide and significant movement along three landslide tracts (Sections A, B, and C).
- MoTI completed additional change detection using LiDAR collected in October and November 2020 which showed similar movements of the overall landslide and along the three landslide paths (Slide B, E and G) with backscarps evident up to approximately 300 m horizontal distance from the river. In addition, significant toe erosion along the outside bend of the Quesnel River extending from the farmers field to the south of the Q-H Site near Slide G and extending to Slide B. The debris from Slide B that was deposited in the Quesnel River in May has generally be eroded by the Quesnel River by the November 2020 LiDAR as shown in Figure 1.
- Golder's field reconnaissance shows that the landslides are ongoing at the site. The slides do not appear to have stopped and there is additional soil on the slope that is at risk of coming down onto the road and into the Quesnel River. The timing and volume of soil that may come down and potentially enter the Quesnel River is currently unknown but is likely correlated with periods of high snow melt, rain and toe erosion by the Quesnel River during periods of high river levels.
- The modeling clearly shows that water levels within the slope are the biggest drivers of slope movement. The models with higher water levels show reduced stability and as the FoS is below 1.0 that landslides would actively occur. Toe erosion by high river levels and construction road cuts to facilitate access also has a marginal reduction in slope stability. Golder has not modeled the combination of high-water levels, toe erosion and construction activities as these will have a cumulative negative impact on the stability. The combination of high water levels, toe erosion and construction is expected to cause active landslides at the site.

9.0 OPINION ON CURRENT AND FUTURE STABILITY OF SITE

The CRD and MoTI have requested Golder to assess if a safe temporary access roadway can be constructed using only locally available dozer and excavator equipment from the hired equipment list without soil and debris entering the Quesnel River and within limited construction period. The 7 October 2020 MoTI Terms of Reference list a number of constraints that must be considered for construction of the roadway. A select list is documented below:

- The temporary access is to have a lifespan of between 1 to 2 years.
- The BC Ministry of Environment and Climate Change Strategy (MoE) prohibits any material from entering the river (either by natural or construction impacts) at any time during or after construction is started at the site. Any construction of a temporary access roadway can not adversely impact the Quesnel River. Any stabilization works should have no impact to the shoreline or impacts must be contained without discharge into the river.
- Temporary access road should meet a minimum global stability FoS of 1.1

Golder's professional opinion is that a temporary roadway cannot be constructed or safely used based on Golder's background review, site reconnaissance and stability analysis. Golder's stability analysis in Appendix D showed that under typical spring freshet conditions of melting snow and rainfall that the site stability will drop slightly and will be below a FoS 1.0 indicating additional landslides are likely. Golder's analysis calculated that reinstating the road by using locally available equipment and without impacting the Quesnel River resulted in a slight decrease in the FoS due to unloading of the toe area.

Golder's stability analysis showed that continued erosion by the Quesnel River would result in slightly reduced FoS and likely additional landslides. Figure 1 shows that landslide debris and toe erosion was significant over the period of June to August and then continues to the last LiDAR data in November. Landslide movement appears to be correlated with toe erosion as discussed in MoTI 2020 in Appendix B and shown in the Golder slope stability modelling in Appendix D. Typical toe erosion control measures such as riprap would involve encroachment into the Quesnel River and are not acceptable to MoE at the current time. Other erosion control measures such as a secant pile wall are not possible to construct with locally available equipment. Golder does not believe that it is possible to construct a road at this time, using the resources specified, given that the road needs to have a lifespan of 1 to 2 years. Simple grading earthworks within the slide mass are not sufficient to stabilize the slope. Protection of the toe from erosion by the Quesnel River is not feasible with the limitations indicated. Further, it is likely that some drainage scheme, in combination with toe protection and berming, will also be necessary to both increase the overall FoS and to minimize the occurrence of small localized failures.

10.0 RECOMMENDATIONS FOR FURTHER WORK

It may be possible to construct and maintain a road in this area. However, considerable effort, permits, investigation, analysis and design would need to be completed prior to any construction works. A brief discussion of the possible steps for further work is described below:

- Additional drilling and installation of inclinometers and piezometers. Drill holes would need to be installed at locations up slope from the existing drill holes. The drill holes would need to be very deep as GeoNorth 2004 notes that they may not have gone deep enough.
- Laboratory testing of samples of soil collected from the investigation to assess soil strength, grain size and material properties.
- Hydraulic engineering study to assess river erosion of toe and river movement nearby the site.
- A surficial and groundwater study is needed to characterize water within and over the slide mass and to identify potential water mitigation measures.
- Toe erosion mitigation design and permits/approvals from MoE.
- Alternately, assess options to reroute road to higher elevation around the slide area or to improve alternate access routes.

11.0 CLOSURE

We trust the foregoing is sufficient for your review and evaluation purposes. Please do not hesitate to call the undersigned if you have any questions or require clarification this report.

Golder Associates Ltd.

PROFESSIONAL
PROVINCE OF
B. F. SINGLETON-POLSTER
37218
BRITISH COLUMBIA
ENGINEER

Feb 2021

Ben-Singleton-Polster, PEng
Geotechnical Engineer

Glen Rutherford, PEng
Associate, Senior Geotechnical Engineer

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https://golderassociates.sharepoint.com/sites/136215/project files/6 deliverables/issued to client_for wp/20397030-001-r-rev0/20397030-001-r-rev0-crd landslide quesnel 01feb_21.docx

APPENDIX A

Important Information and Limitations of This Report

Standard of Care: Golder Associates Ltd. (Golder) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practising under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty, expressed or implied is made.

Basis and Use of the Report: This report has been prepared for the specific site, design objective, development and purpose described to Golder by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this report and are not applicable to any other project or site location. Any change of site conditions, purpose, development plans or if the project is not initiated within eighteen months of the date of the report may alter the validity of the report. Golder can not be responsible for use of this report, or portions thereof, unless Golder is requested to review and, if necessary, revise the report.

The information, recommendations and opinions expressed in this report are for the sole benefit of the Client. No other party may use or rely on this report or any portion thereof without Golder's express written consent. If the report was prepared to be included for a specific permit application process, then upon the reasonable request of the client, Golder may authorize in writing the use of this report by the regulatory agency as an Approved User for the specific and identified purpose of the applicable permit review process. Any other use of this report by others is prohibited and is without responsibility to Golder. The report, all plans, data, drawings and other documents as well as all electronic media prepared by Golder are considered its professional work product and shall remain the copyright property of Golder, who authorizes only the Client and Approved Users to make copies of the report, but only in such quantities as are reasonably necessary for the use of the report by those parties. The Client and Approved Users may not give, lend, sell, or otherwise make available the report or any portion thereof to any other party without the express written permission of Golder. The Client acknowledges that electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore the Client cannot rely upon the electronic media versions of Golder's report or other work products.

The report is of a summary nature and is not intended to stand alone without reference to the instructions given to Golder by the Client, communications between Golder and the Client, and to any other reports prepared by Golder for the Client relative to the specific site described in the report. In order to properly understand the suggestions, recommendations and opinions expressed in this report, reference must be made to the whole of the report. Golder can not be responsible for use of portions of the report without reference to the entire report.

Unless otherwise stated, the suggestions, recommendations and opinions given in this report are intended only for the guidance of the Client in the design of the specific project. The extent and detail of investigations, including the number of test holes, necessary to determine all of the relevant conditions which may affect construction costs would normally be greater than has been carried out for design purposes. Contractors bidding on, or undertaking the work, should rely on their own investigations, as well as their own interpretations of the factual data presented in the report, as to how subsurface conditions may affect their work, including but not limited to proposed construction techniques, schedule, safety and equipment capabilities.

Soil, Rock and Groundwater Conditions: Classification and identification of soils, rocks, and geologic units have been based on commonly accepted methods employed in the practice of geotechnical engineering and related disciplines. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Golder does not warrant or guarantee the exactness of the descriptions.

Special risks occur whenever engineering or related disciplines are applied to identify subsurface conditions and even a comprehensive investigation, sampling and testing program may fail to detect all or certain subsurface conditions. The environmental, geologic, geotechnical, geochemical and hydrogeologic conditions that Golder interprets to exist between and beyond sampling points may differ from those that actually exist. In addition to soil variability, fill of variable physical and chemical composition can be present over portions of the site or on adjacent properties. **The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report.** The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities (traffic, excavation, groundwater level lowering, pile driving, blasting, etc.) on the site or on adjacent sites. Excavation may expose the soils to changes due to wetting, drying or frost. Unless otherwise indicated the soil must be protected from these changes during construction.

Sample Disposal: Golder will dispose of all uncontaminated soil and/or rock samples 90 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client's expense. In the event that actual contaminated soils, fills or groundwater are encountered or are inferred to be present, all contaminated samples shall remain the property and responsibility of the Client for proper disposal.

Follow-Up and Construction Services: All details of the design were not known at the time of submission of Golder's report. Golder should be retained to review the final design, project plans and documents prior to construction, to confirm that they are consistent with the intent of Golder's report.

During construction, Golder should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Golder's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Golder's report. Adequate field review, observation and testing during construction are necessary for Golder to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Golder's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

Changed Conditions and Drainage: Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Golder be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Golder be employed to visit the site with sufficient frequency to detect if conditions have changed significantly.

Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Golder takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.

APPENDIX B

MoTI Orthophotos and Change Analysis

June 2020

October 2020

August 2020

November 2020

CLIENT

CARIBOO REGIONAL DISTRICT

CONSULTANT

GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	MOTI
DESIGN	B.SINGLETON-POLSTER
REVIEW	G.RUTHERFORD
APPROVED	G.RUTHERFORD

PROJECT

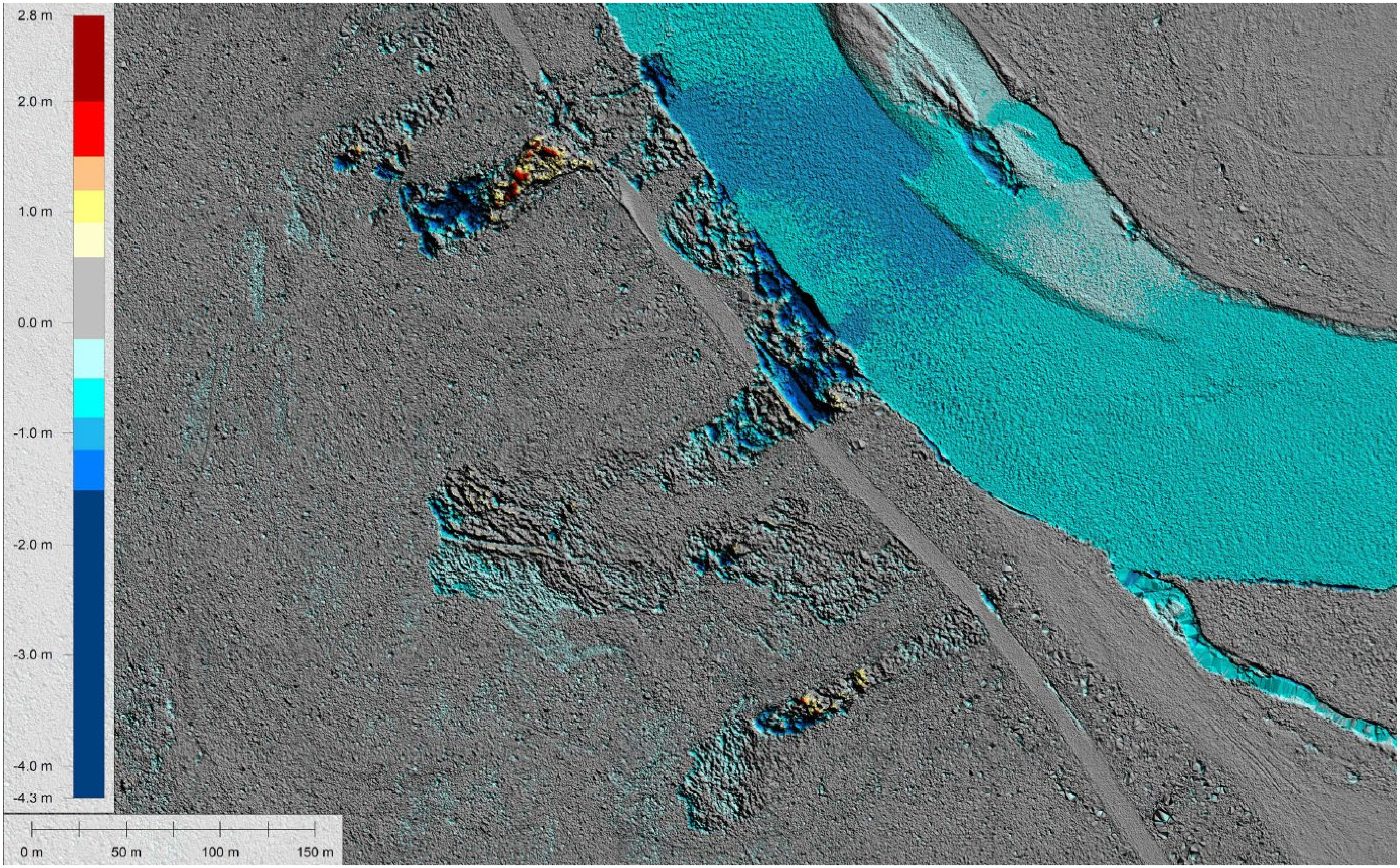
QUESNEL-HYDRAULIC ROAD SLIDE
QUESNEL, BC

TITLE

ORTHOPHOTOS
JUNE 2020 to NOVEMBER 2020

PROJECT No.	Phase	Rev	FIGURE
20397030	1000	0	B-1

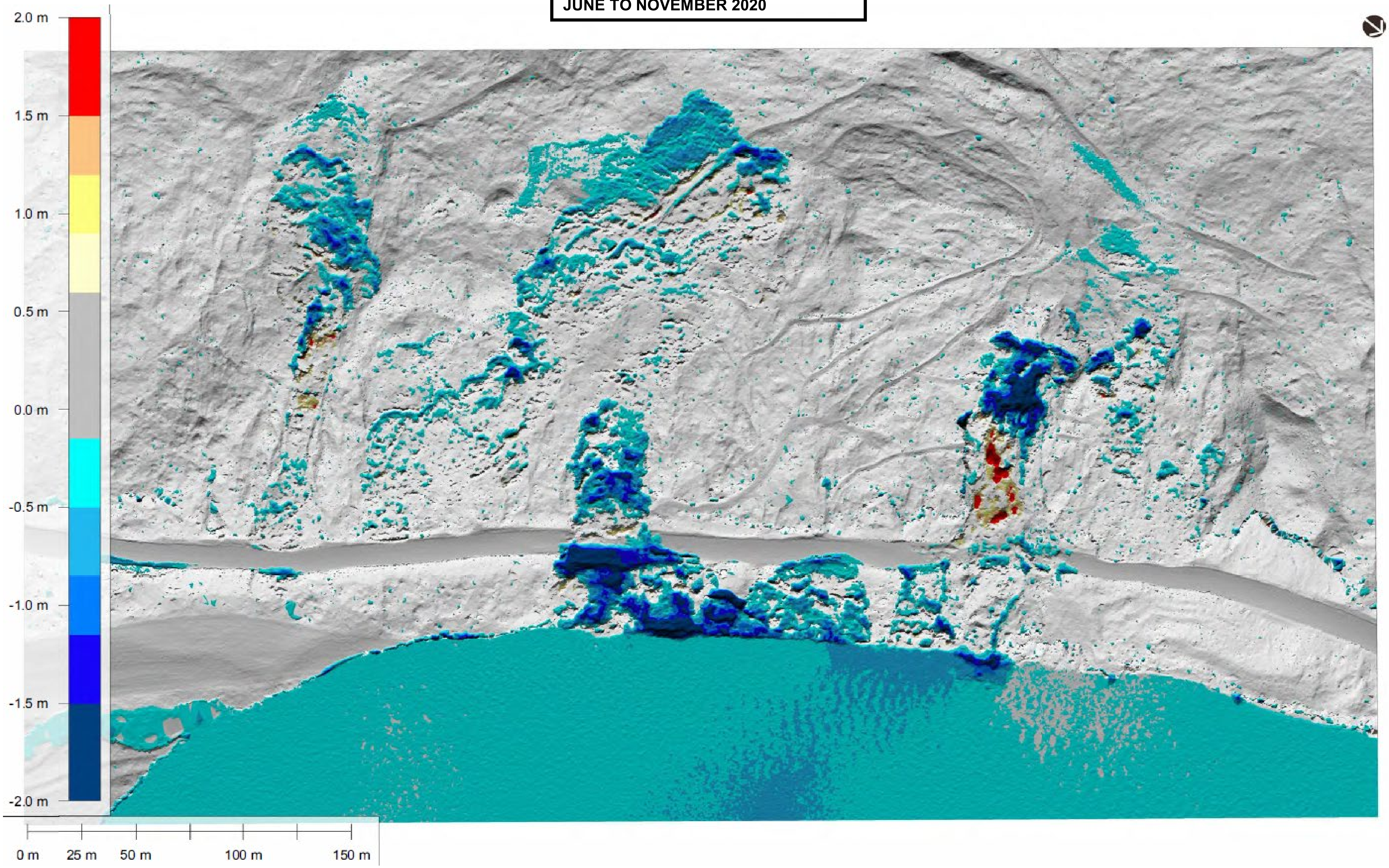
JUNE TO OCTOBER 2020



CLIENT	CARIBOO REGIONAL DISTRICT
PROJECT	QUESNEL-HYDRAULIC ROAD SLIDE QUESNEL, BC
CONSULTANT	GOLDER
YYYY-MM-DD	2021-01-29
PREPARED	MOTI
DESIGN	B.SINGLETON-POLSTER
REVIEW	G.RUTHERFORD
APPROVED	G.RUTHERFORD
TITLE	CHANGE ANALYSIS JUNE TO OCTOBER 2020

PROJECT No.	Phase	Rev	FIGURE
20397030	1000	0	B-2

JUNE TO NOVEMBER 2020



QUESNEL, BC

CONSULTANT

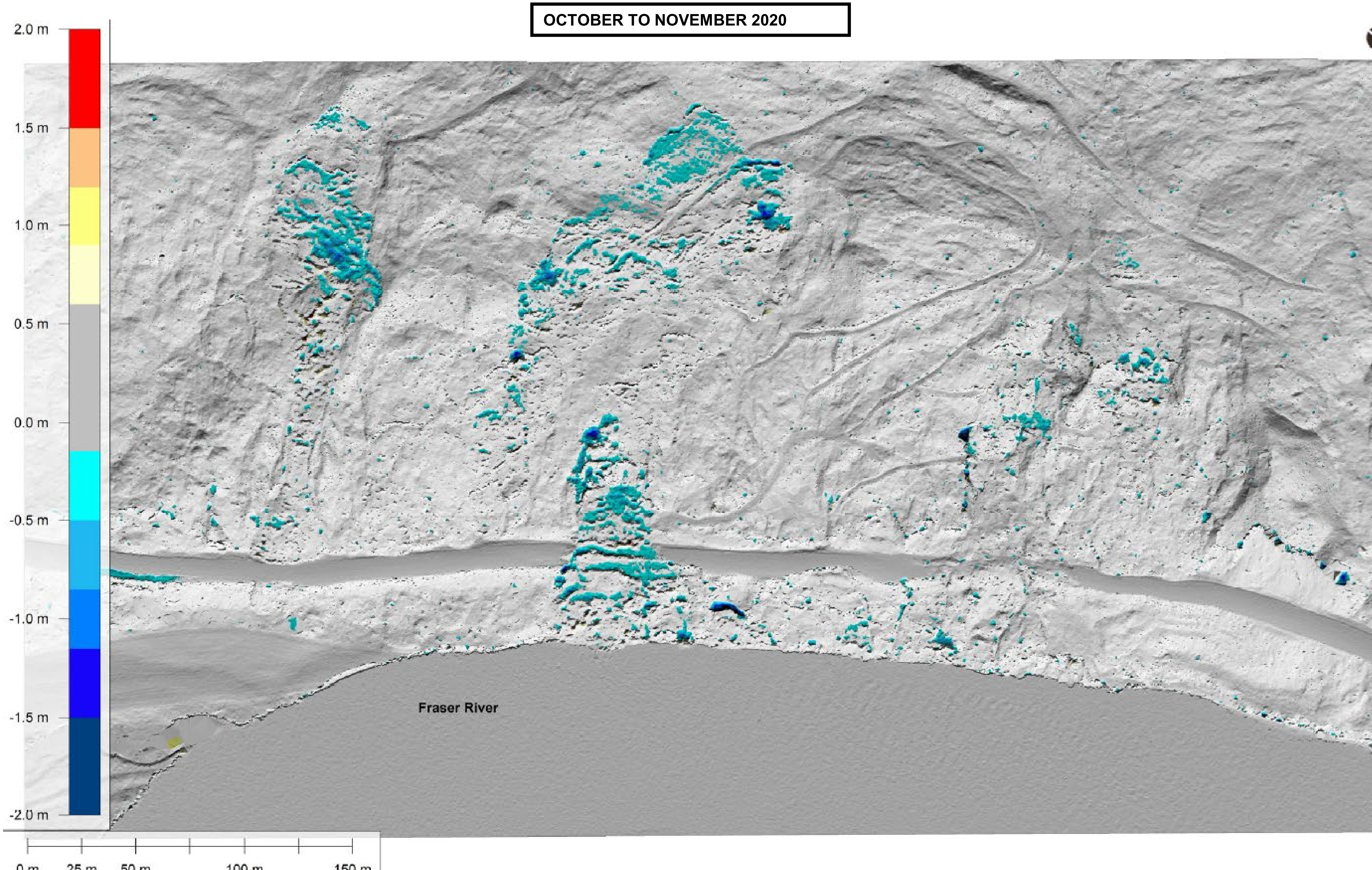
GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	MOTI
DESIGN	B.SINGLETON-POLSTER
REVIEW	G.RUTHERFORD
APPROVED	G.RUTHERFORD

TITLE

CHANGE ANALYSIS
JUNE TO NOVEMBER 2020

PROJECT No.	Phase	Rev	FIGURE
20397030	1000	0	B-3



QUESNEL, BC

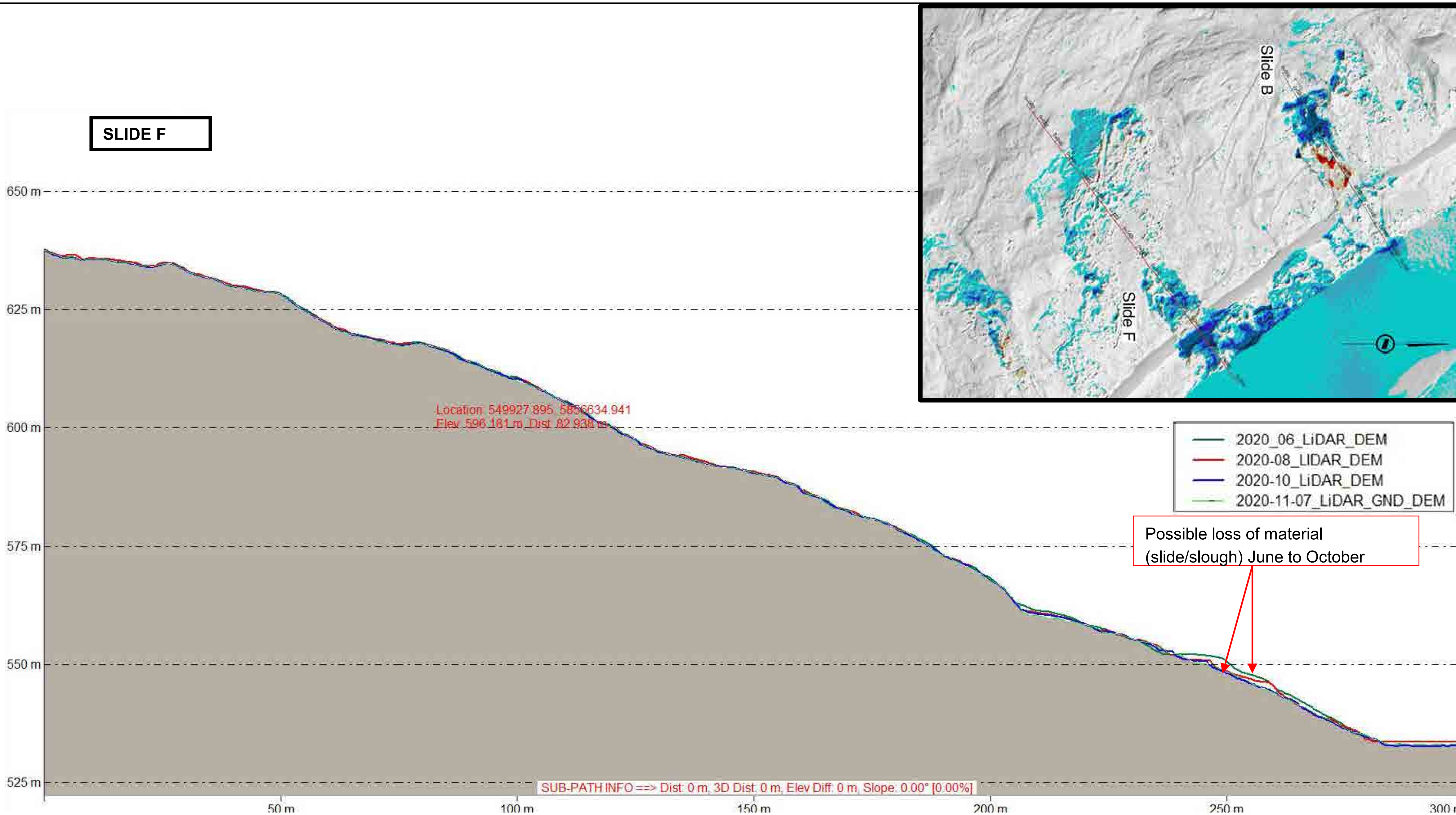
CONSULTANT

GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	MOTI
DESIGN	B.SINGLETON-POLSTER
REVIEW	G.RUTHERFORD
APPROVED	G.RUTHERFORD

TITLE
CHANGE ANALYSIS
OCTOBER TO NOVEMBER 2020

PROJECT No.	Phase	Rev	FIGURE
20397030	1000	0	B-4

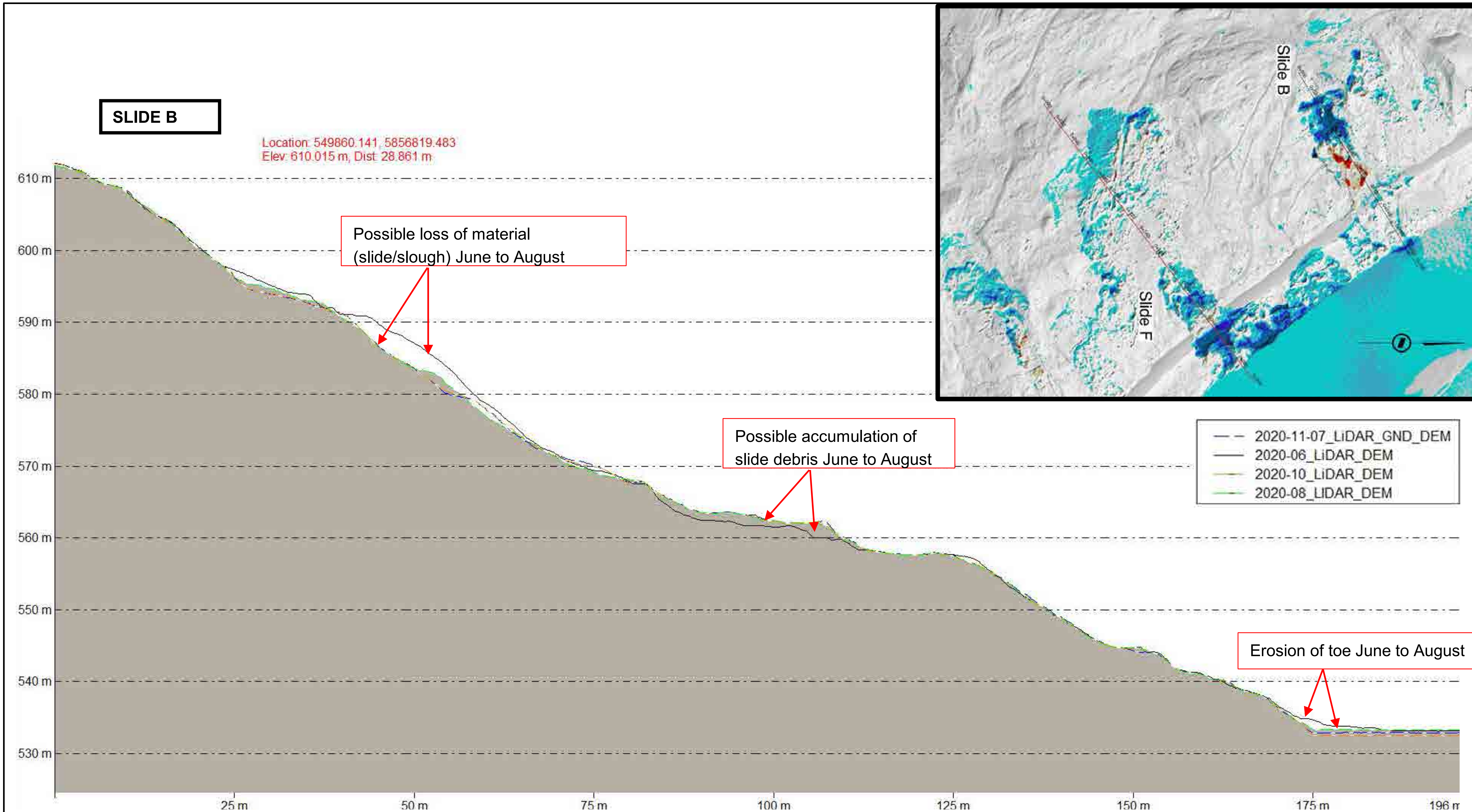


CLIENT	CARIBOO REGIONAL DISTRICT
CONSULTANT	GOLDER
YYYY-MM-DD	2021-01-29
PREPARED	MOTI
DESIGN	B.SINGLETON-POLSTER
REVIEW	G.RUTHERFORD
APPROVED	G.RUTHERFORD

PROJECT
QUESNEL-HYDRAULIC ROAD SLIDE
QUESNEL, BC

TITLE
CHANGE ANALYSIS
SLIDE F SECTION

PROJECT No.	Phase	Rev	FIGURE
20397030	1000	0	B-5



CLIENT

CARIBOO REGIONAL DISTRICT

CONSULTANT

GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	MOTI
DESIGN	B.SINGLETON-POLSTER
REVIEW	G.RUTHERFORD
APPROVED	G.RUTHERFORD

PROJECT

QUESNEL-HYDRAULIC ROAD SLIDE
QUESNEL, BC

TITLE

CHANGE ANALYSIS
SLIDE B SECTION

PROJECT No.	Phase	Rev	FIGURE
20397030	1000	0	B-6

APPENDIX C

MoTI Terms of Reference and Figures

October 07, 2020

Cariboo Regional District
Suite D, 180 N Third Avenue
Williams Lake, BC
V2G 2A4

Attention: John Maclean, Chief Administrative Officer

INDEPENDENT REVIEW OF QUESNEL-HYDRAULIC ROAD SLIDE, QUESNEL, BC

TERMS OF REFERENCE

Dear John,

The British Columbia Ministry of Transportation and Infrastructure (MoTI) has been requested by the residents impacted by the recent Quesnel-Hydraulic Road Slide (Q-H Slide) to conduct an Independent Geotechnical Assessment. The Q-H Slide occurred at 20.3 km along the roadway in early April of this year. MoTI requests that the Cariboo Regional District (CRD) coordinate this assessment as an impartial agency. The successful consultant is requested to review the background information that is available to the MoTI as well as the Terms of Reference and attached appendix information to assist with their scope development for this assignment.

1.0 BACKGROUND

The MoTI Geotechnical and Materials Engineering Group was called to the Q-H Slide on April 15, 2020 to assess shoulder cracking that had recently developed in proximity to Slide D and E, as indicated in Figure 1 attached. The assessment was carried out on April 18th, at which time the ground was still predominantly frozen within the shaded areas and the ditchline contained snow. It was noted that the cracking had extended from the outer shoulder into the roadway prism. It was noted that movements had also occurred above the roadway, with some material making its way onto the roadway from above. At that time, it was decided to keep the roadway open with increased patrols and invoke night time closures. A series of monitoring stakes were installed to observe if the failure was accelerating. Traversing upslope was dangerous during the initial assessment due to frozen ground and snow so limited information was gathered significantly above and below the roadway.

By April 25th, deformations to the slopes and the roadway surface were too great for continued safe vehicle passage and large cottonwood trees were falling onto the roadway. The roadway was closed to traffic at that time. Several additional upslope traverses were carried out in late April and May by MoTI geotechnical engineering staff once the frost and snow had melted from the area. The traverses indicated that the headscarp for Slide E was significantly farther upslope than originally anticipated or further headscarp retrogression had occurred. Scarps were also observed along the hillside that form part of Slides F, G and A. GPS tracks and waypoints of select observed cracks within the slide complex area were collected and are presented on Figure 2 attached. This information can be provided digitally for use during the assessment, if required. Areas of toe bulge deformation were noted at several locations along the roadway with signs of tearing at the roadway ditchline.

On May 1st a large upslope failure occurred at Slide B that crossed over the roadway and spilled down the embankment into the Quesnel River. A second pulse occurred again on May 4th. Saturated silty clay with sand and gravel mixed with organics and tree debris covered the roadway surface and a significant volume of debris entered the Quesnel River. It has not yet been determined if this failure extends below the road. At this same time, deformation began to accelerate at Slide C. The culvert outlet, spillway, and riprap began to fail towards the river as the culvert ruptured and the roadway dropped in excess of 2 m vertically.

Over the following summer months continued deformation occurred at Slides B, C, D, and E. Slide B was observed to have a series of significant seepage zones continuously draining into the slide from a sand layer at higher elevation. The seepage continues to flow through the slide and transport sediment into the Quesnel River.

When the river water elevation fell after an extended high-water flood season, a high precipitation summer season, and a late freshet which lasted into mid August, Slide D and E accelerated. Deformations at Slide E prior to the river dropping were roughly 3 to 4 m horizontally and 3 m vertically. After the freshet, 10 to 12 m of horizontal deformation and 10 m of vertical deformation were estimated. Most of the trees and vegetation within Slide D and E were displaced into the river over the summer freshet. Figure 3 shows a time series of photos taken at roughly the same location to observe deformation changes within Slides C, D, and E over the summer.

Ongoing deformation of various headscarps appears to have continued throughout the summer. During summer full foliation of the forest floor, displacement was difficult to observe. Two LiDAR flights have been completed at the site, one in early spring and one in late summer. BGC Engineering completed a change detection analysis (see attached in Appendix B) of the two LiDAR sets. Poor point data in the late summer data (due to heavy vegetation foliation) resulted in less than desirable output. Further LiDAR flights are planned to complete a second changed detection analysis later this fall after vegetation defoliation.

2.0 TERMS OF REFERENCE

The residents have requested an independent review of the Q-H Slide. A third-party engineering opinion is required on the possible construction of a temporary public access road that can be used to re-establish access over the coming year (all season road) while the MoTI assesses a permanent access plan. This assessment will need to consider the safety of the construction and maintenance crews as well as the travelling public utilizing the temporary access.

As noted in Section 1.0, several slide movement areas exist within the overall slide complex at the site (Refer to Figure 1). Individual slide area movements have varied from several meters to millimeters per day since April 15, 2020. Slide movements currently continue, and rates exhibit variation based on factors including Quesnel River erosion, Quesnel River water level, rainfall, snowmelt and groundwater flow egress into tension cracks. A catastrophic slope failure, Slide B, occurred on or about May 1, 2020 which rapidly displaced 60 m of road embankment length into the Quesnel River. The potential for similar future catastrophic events may exist. Site specific soil strength testing, slope indicator monitoring and porewater pressure data does not exist at the site and is not permitted to be carried out as part of the third-party review assignment (other than that gained from site reconnaissance visits).

The successful consultant should carry out their own land-based assessment of the site and review of available information such as LiDAR and previous reporting. Upon completion of their assessment, the consultant is requested to provide a professional opinion on the safety of the site. This opinion should address if construction of a temporary public roadway through the slide complex under existing conditions is considered possible. The temporary roadway should be able to be constructed using limited equipment and short timeframes as well as no further subsurface information other than what might be exposed during construction of the roadway. If the successful consultant deems a suitable safe access road is possible, they must be willing to sign off as Engineer of Record (EoR) for the proposed design and take all liability for the site that will be borne by the EBGC stamp and by their insurers. If it is determined by the successful consultant that the route is not safely passable within the limitations provided below, a professional opinion describing the details of the determination should be provided. The limitations for the assessment are provide below:

1. The assessment should be carried out based on available information provided in this letter or observed during the site reconnaissance. Limited historic borehole data is available from an incomplete assessment carried out by GeoNorth Engineering in the early 2000s (see attached in Appendix A).
2. The successful consultant should determine if a safe temporary access roadway can be constructed through the slide complex, using only dozer and excavator equipment readily available in the Quesnel area from the hired equipment list. The temporary access is to have a lifespan of between 1 to 2 years.
3. The remediated roadway would need to be constructed within one month following the assessment completion, including any mobilization and tree removal required to make the site safe for construction.
4. The Ministry of Environment prohibits any material from entering the river (either by natural or construction impacts) at any time during or after construction is started at the site. Any construction of a temporary access roadway can not adversely impact the Quesnel River. Any stabilization works should have no impact to the shoreline or impacts must be contained without discharge into the river.
5. All work should be carried out in accordance with all WCB requirements.
6. The vertical and horizontal alignment of Quesnel-Hydraulic Road can be modified slightly from pre-failure conditions but shall be passable by both personal vehicle and a commercial WB20 vehicle required to support the cattle industry. This requires that grades be no greater than 14 percent and a minimum road width of 5.0 m is maintained. Should a single lane configuration be selected, all site line requirements for oncoming vehicles shall be maintained.
7. If a temporary access road is determined to be constructible, it should meet a minimum global stability Factor of Safety (FoS) of 1.1, based on reasonable assumed soil properties and porewater pressures estimated from available information and modeling. Given the low FoS, limited openings, traffic control and/or field spotters may be required during public use of the roadway. Global stability shall encompass slopes both above and below the access roadway. Estimates of soil properties should be substantiated using back analysis of the existing site, assuming the existing slope geometry is near a FoS of unity or less. The slope stability analysis should assume worst case seasonal conditions.

Slope stability analyses and construction methodology shall be defensible to a level that the successful consultant is protected from potential liabilities related to future WCB and post-construction slope failures which may adversely impact workers, the public or environmental values (including vegetation, fish and aquatic habitat). Once site modifications based on the prescribed geotechnical recommendations have been carried out, all slope stability/sedimentation post-construction liabilities remain with the consultant on a forward-going basis. MoTI discussions with Environmental Regulators prior to this independent review indicate that any adverse impact to the Quesnel River will be deemed a chargeable offense.

3.0 DELIVERABLE AND TIMELINE

The requested deliverable from the successful consultant is a letter report summarizing the findings of the site reconnaissance and slope stability assessment. Based on consultant's observations and upon review of available information, the consultant shall provide a professional opinion on the slope stability of the site and whether a safe temporary all-season access roadway can be constructed through the site within the limitations provided above. If a temporary access roadway is considered possible, the proposed alignment should be illustrated in plan and all recommendations shall be substantiated with supporting analysis. Slope stability modeling for both the existing condition and the proposed new temporary access roadway shall be provided. Details are to be provided for geotechnical aspects of the Worksafe procedures deemed necessary for all construction aspects of the work (including equipment operation, site clearing and tree falling).

The above scope of services shall be carried out and a report received within 30 days of Authorization to Proceed with the works.

4.0 CLOSURE

We trust this provides the information you require. Should the consultant require any additional information, please have them submit their request to the CRD and we will provide whatever we have available upon request.

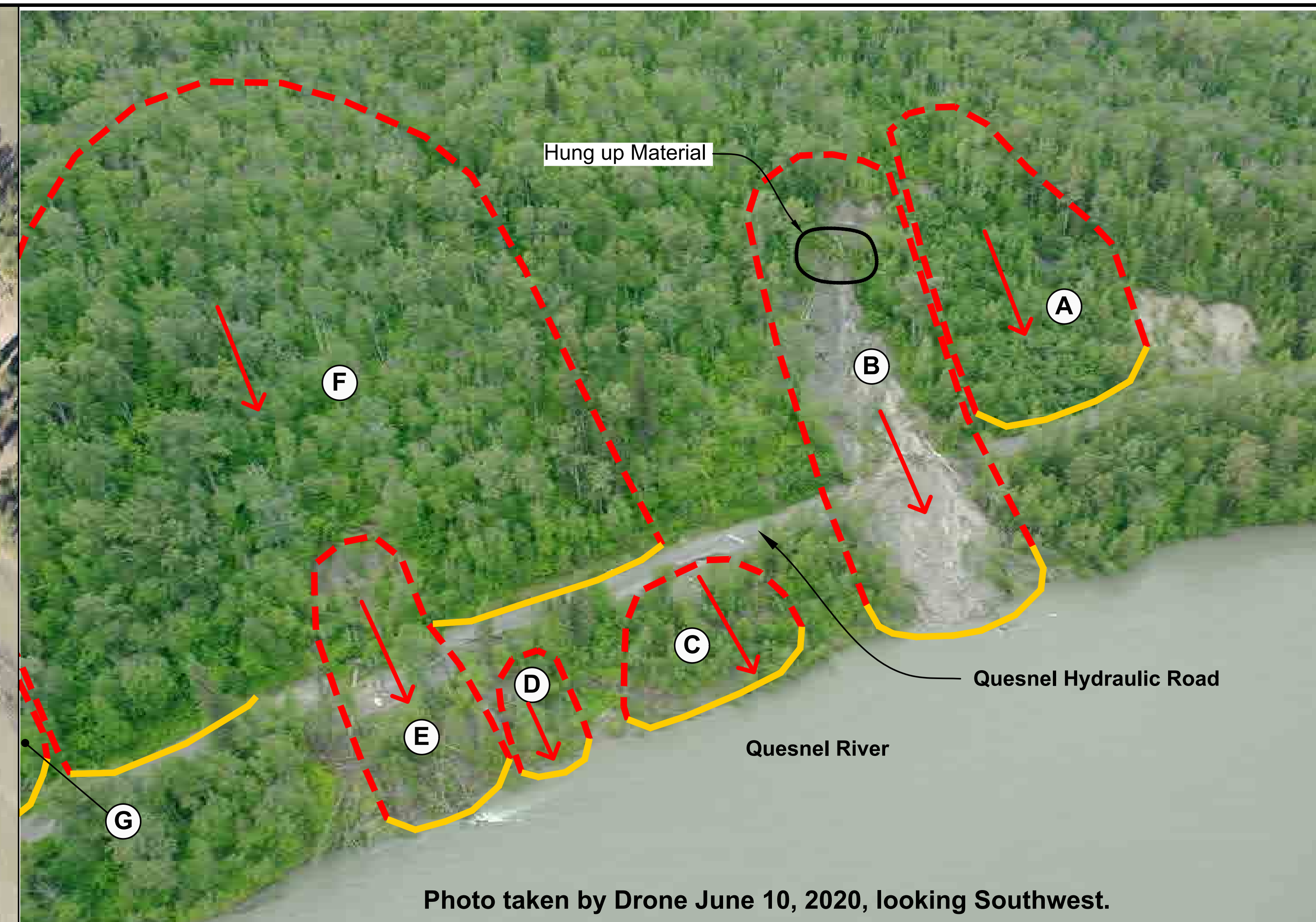
Yours very truly,

MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

Reviewed By:

Warren S. Lemky, P. Eng.
Senior Geotechnical Engineer

Tom Kneale, P. Eng.
Manager, Geotechnical Engineer



Legend:

- Approximate Slide Location
- Direction of Movement
- Approximate Toe Buldge
- Approximate extent of Historic Landslide Complex

Notes:

1. Ortho Image from LiDAR, flown May 12, 2020.
2. Drone Image June 10, 2020

Site Location:
UTM 10, N5856738, E550048

0m 30 60 90 120
1 : 3000

British Columbia
Ministry of Transportation and Infrastructure
Northern Region
Geotechnical and Materials Branch

SITE PLAN-ORTHO-AERIAL
QUESNEL-HYDRAULIC ROAD 20.3 Km SLIDE
SA18 - CARIBOO DISTRICT

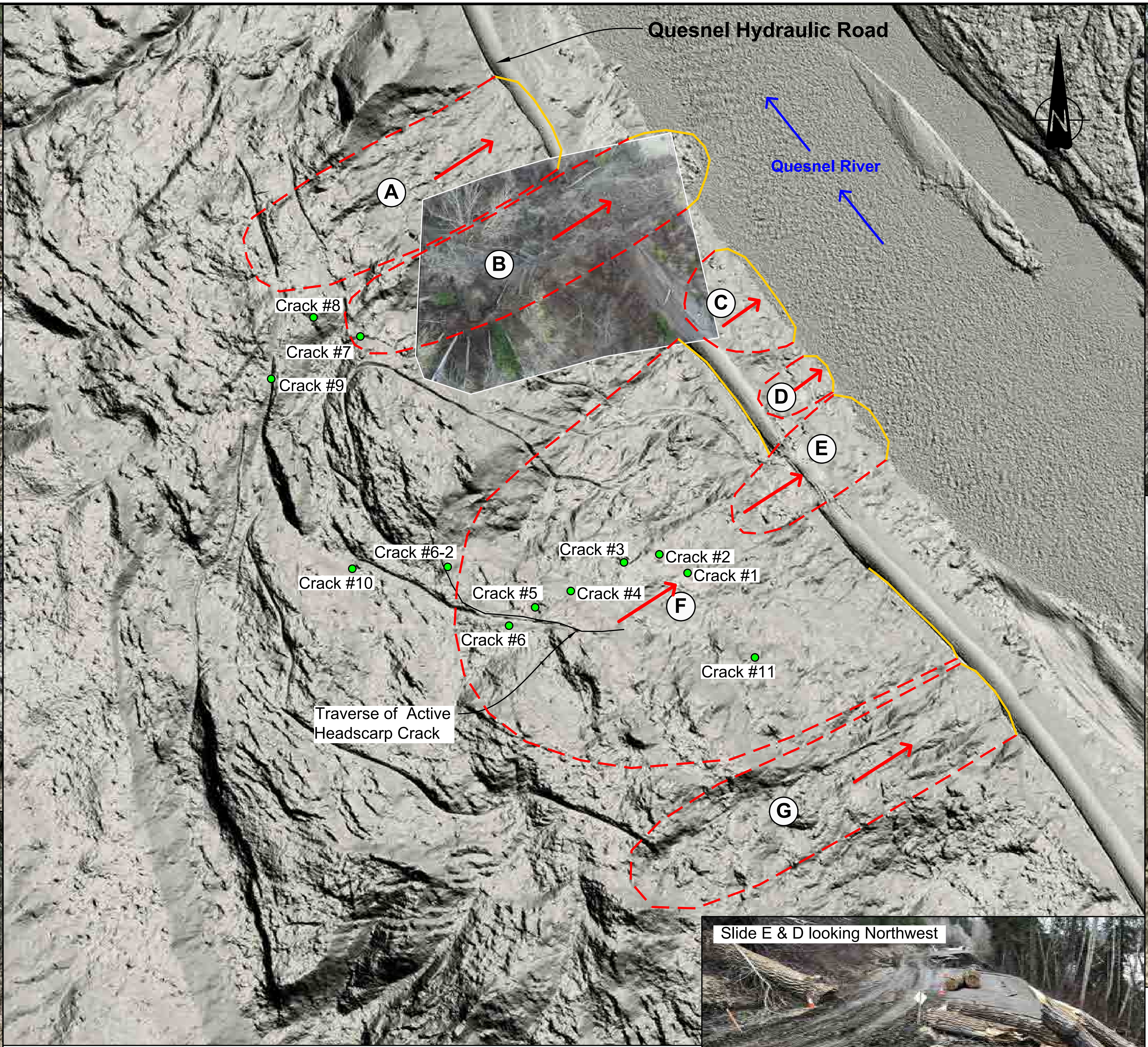
DRAWN BY: S.Ruiz	PROJECTION: UTM Zone 10		SCALE: AS SHOWN
CHECKED BY: W.Lemky	DATUM: NAD83		DATE: 16 September 2020
FILE No. 20.3kmslide_fig1_orthoobligue_2020-09-16.dwg	PROJECT No. 18-SS-1242	REG. NR	DRAWING No. Figure 1

This drawing was originally produced in colour.

Crack #5 looking Northwest

Crack #6 looking Southeast

Crack #6-2 looking Northwest



Slide D and E looking Southeast

Slide C looking Southeast

Slide E & D looking Northwest

Legend:

- Approximate Slide Location
- Direction of Movement
- Approximate Toe Buldge
- GPS Waypoint taken at Crack Location

Note: Hillshade Image from LiDAR, flown May 12, 2020. Image in Slide B from drone flight May 2020.

Site Location:
UTM 10, N5856738, E550048

0m 20 40 60 80 100
1 : 2500

Ministry of Transportation and Infrastructure
Northern Region
Geotechnical and Materials Branch

SITE PLAN- LiDAR-WAYPOINTS
QUESNEL-HYDRAULIC ROAD 20.3 Km SLIDE
SA18 - CARIBOO DISTRICT

DRAWN BY: S.Ruiz	PROJECTION: UTM Zone 10		SCALE: AS SHOWN
CHECKED BY: W.Lemky	DATUM: NAD83		DATE: 16 September 2020
FILE No. 20.3kmslide_fig2_siteplanwp_2020-09-16.dwg	PROJECT No. 18-SS-1242	REG. NR	DRAWING No. Figure 2

This drawing was originally produced in colour.

Picture taken
April 24, 2020

Picture taken
June 10, 2020

Picture taken
July 2, 2020

Picture taken
August 19, 2020

BRITISH COLUMBIA

Ministry of Transportation and Infrastructure
Northern Region
Geotechnical and Materials Branch

PHOTO TIME SERIES OF SLIDES C, D & E
QUESNEL-HYDRAULIC ROAD 20.3 Km SLIDE
SA18 - CARIBOO DISTRICT

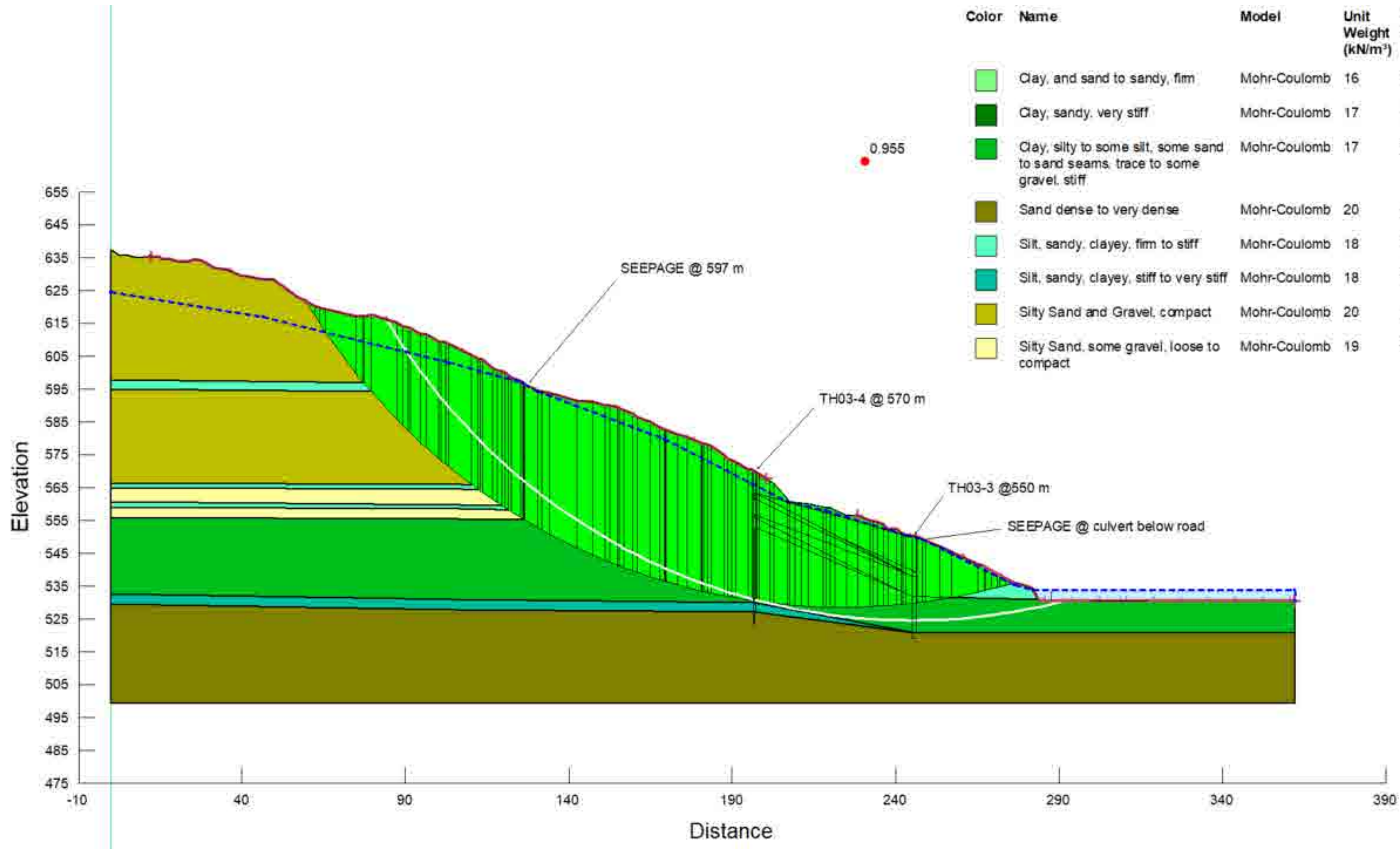
DRAWN BY: S.Ruiz	PROJECTION: UTM Zone 10	SCALE: AS SHOWN
CHECKED BY: W.Lemky	DATUM: NAD83	DATE: 16 September 2020

FILE No.	PROJECT No.	REG.	DRAWING No.
20.3kmslide_fig3_slidephotos_2020-09-16.dwg	18-SS-1242	NR	Figure 3

This drawing was originally produced in colour.

APPENDIX D

Global Stability Analysis Model Results



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	Clay, and sand to sandy, firm	Mohr-Coulomb	16	46	22	0	1
	Clay, sandy, very stiff	Mohr-Coulomb	17	100	26	0	1
	Clay, silty to some silt, some sand to sand seams, trace to some gravel, stiff	Mohr-Coulomb	17	63	24	0	1
	Sand dense to very dense	Mohr-Coulomb	20	0	38	0	1
	Silt, sandy, clayey, firm to stiff	Mohr-Coulomb	18	88	27	0	1
	Silt, sandy, clayey, stiff to very stiff	Mohr-Coulomb	18	70	29	0	1
	Silty Sand and Gravel, compact	Mohr-Coulomb	20	0	34	0	1
	Silty Sand, some gravel, loose to compact	Mohr-Coulomb	19	0	32	0	1

CLIENT
CARIBOO REGIONAL DISTRICT

PROJECT
QUESNEL-HYDRAULIC ROAD SLIDE

CONSULTANT
GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	G.BLACK
DESIGN	G.BLACK
REVIEW	B.SINGLETON-POLSTER
APPROVED	G.RUTHERFORD

TITLE
SLIDE F – BASE CASE

PROJECT No.	PHASE	Rev	FIGURE
20397030	1000	0	C-1

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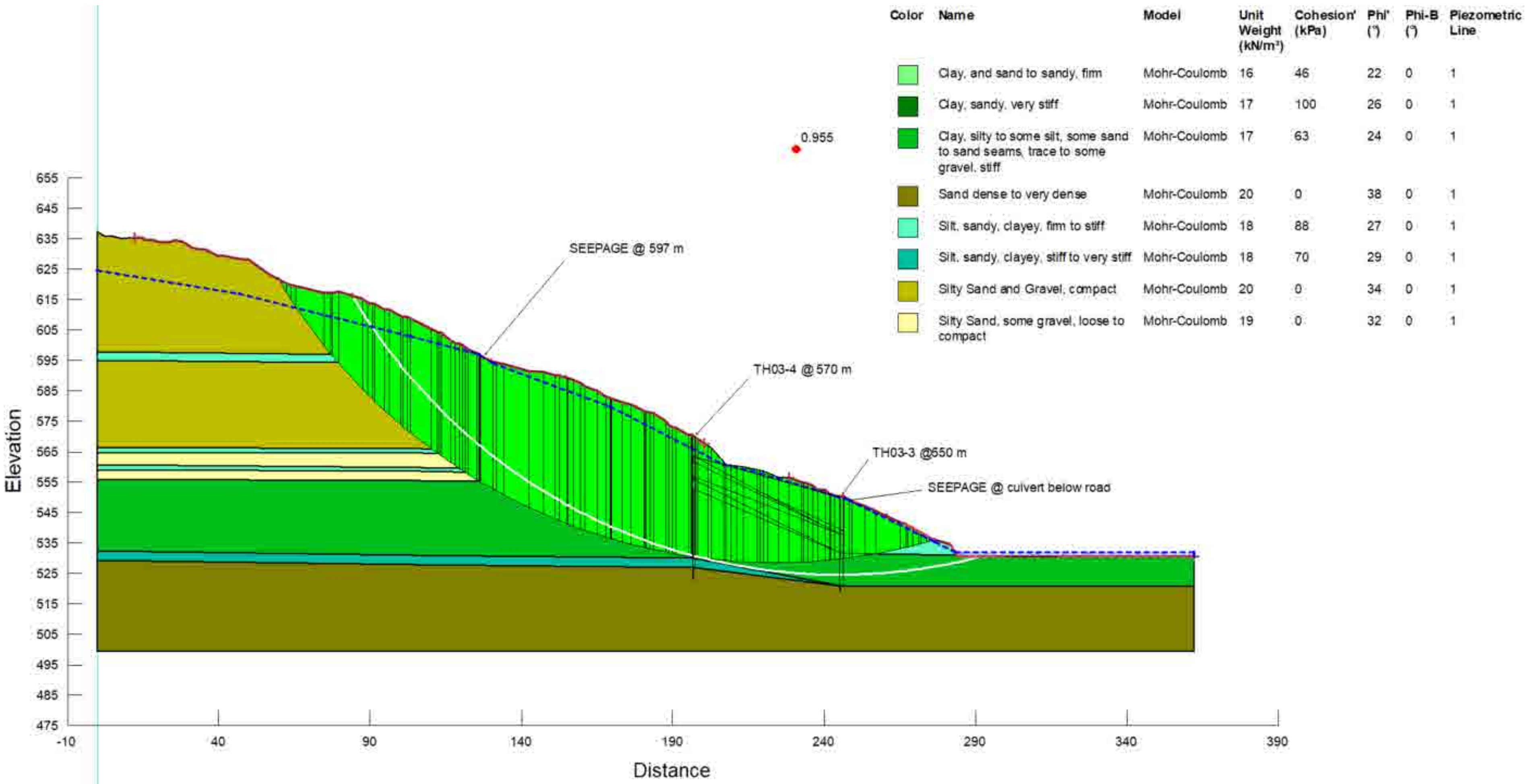

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	Silty Sand and Gravel, compact	Mohr-Coulomb	20	0	34	0	1
	Silty Sand, some gravel, loose to compact	Mohr-Coulomb	19	0	32	0	1

CLIENT
CARIBOO REGIONAL DISTRICT

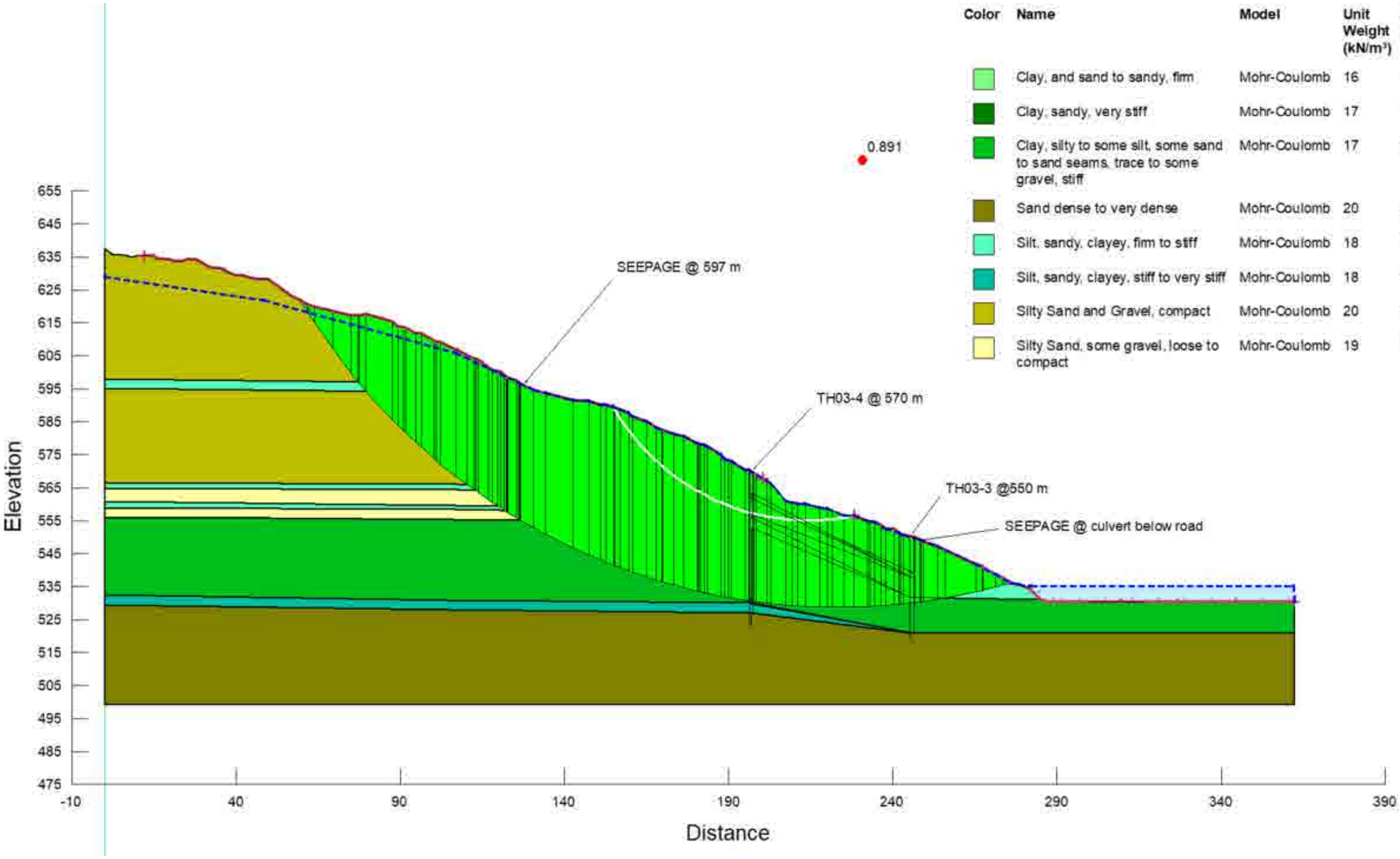
PROJECT
QUESNEL-HYDRAULIC ROAD SLIDE

CONSULTANT
GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	G.BLACK
DESIGN	G.BLACK
REVIEW	B.SINGLETON-POLSTER
APPROVED	G.RUTHERFORD

TITLE
SLIDE F – MINIMUM RIVER LEVEL

PROJECT No.	PHASE	Rev	FIGURE
20397030	1000	0	C-2



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CLIENT
CARIBOO REGIONAL DISTRICT

PROJECT
QUESNEL-HYDRAULIC ROAD SLIDE

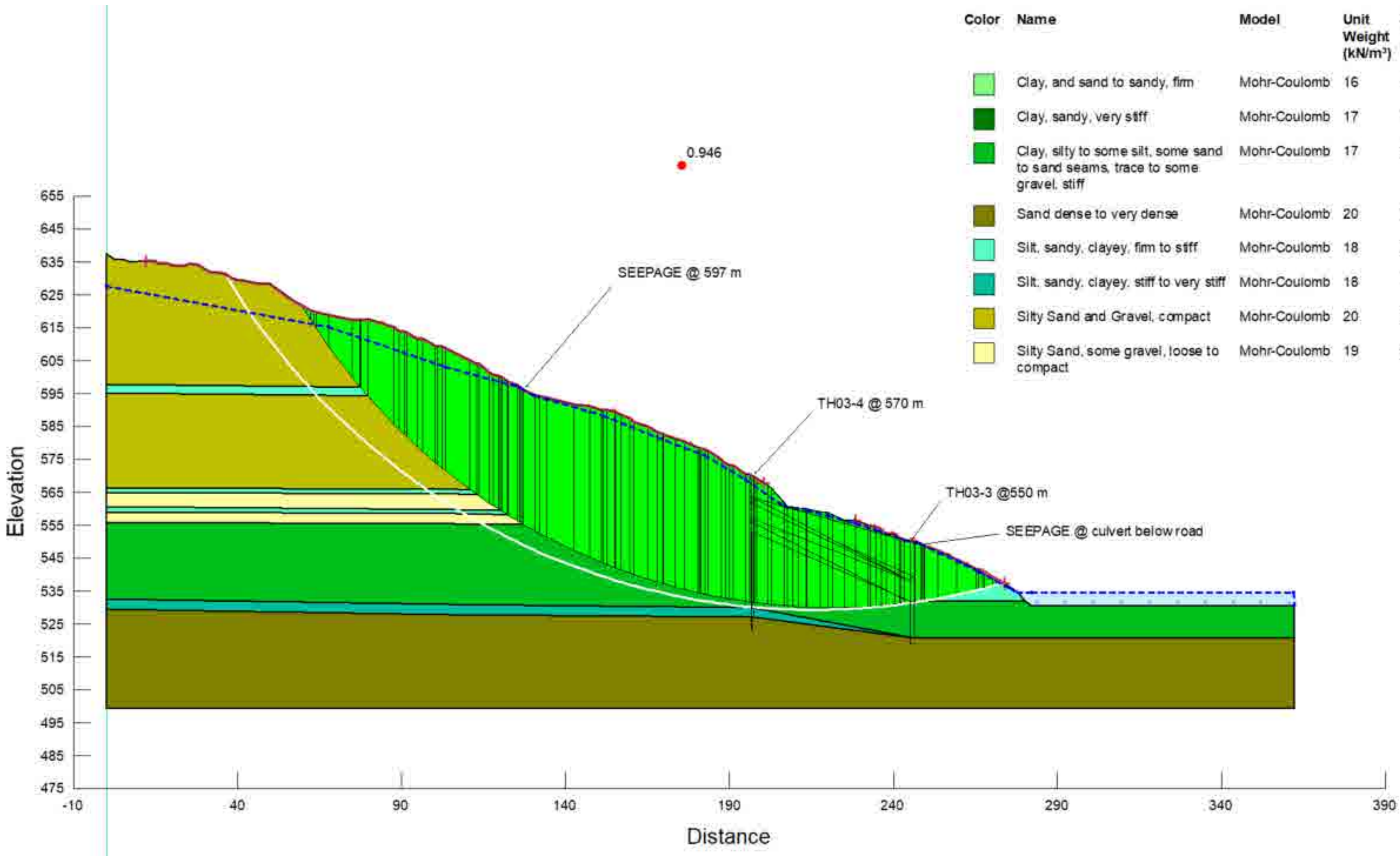
CONSULTANT

GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	G.BLACK
DESIGN	G.BLACK
REVIEW	B.SINGLETON-POLSTER
APPROVED	G.RUTHERFORD

TITLE
SLIDE F – MAXIMUM RIVER LEVEL AND HIGH PHREATIC SURFACE

PROJECT No.	PHASE	Rev	FIGURE
20397030	1000	0	C-3



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CLIENT
CARIBOO REGIONAL DISTRICT

PROJECT
QUESNEL-HYDRAULIC ROAD SLIDE

CONSULTANT
GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	G.BLACK
DESIGN	G.BLACK
REVIEW	B.SINGLETON-POLSTER
APPROVED	G.RUTHERFORD

TITLE
SLIDE F – TOE EROSION

PROJECT No.	PHASE	Rev	FIGURE
20397030	1000	0	C-4

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi-B (°)	Piezometric Line
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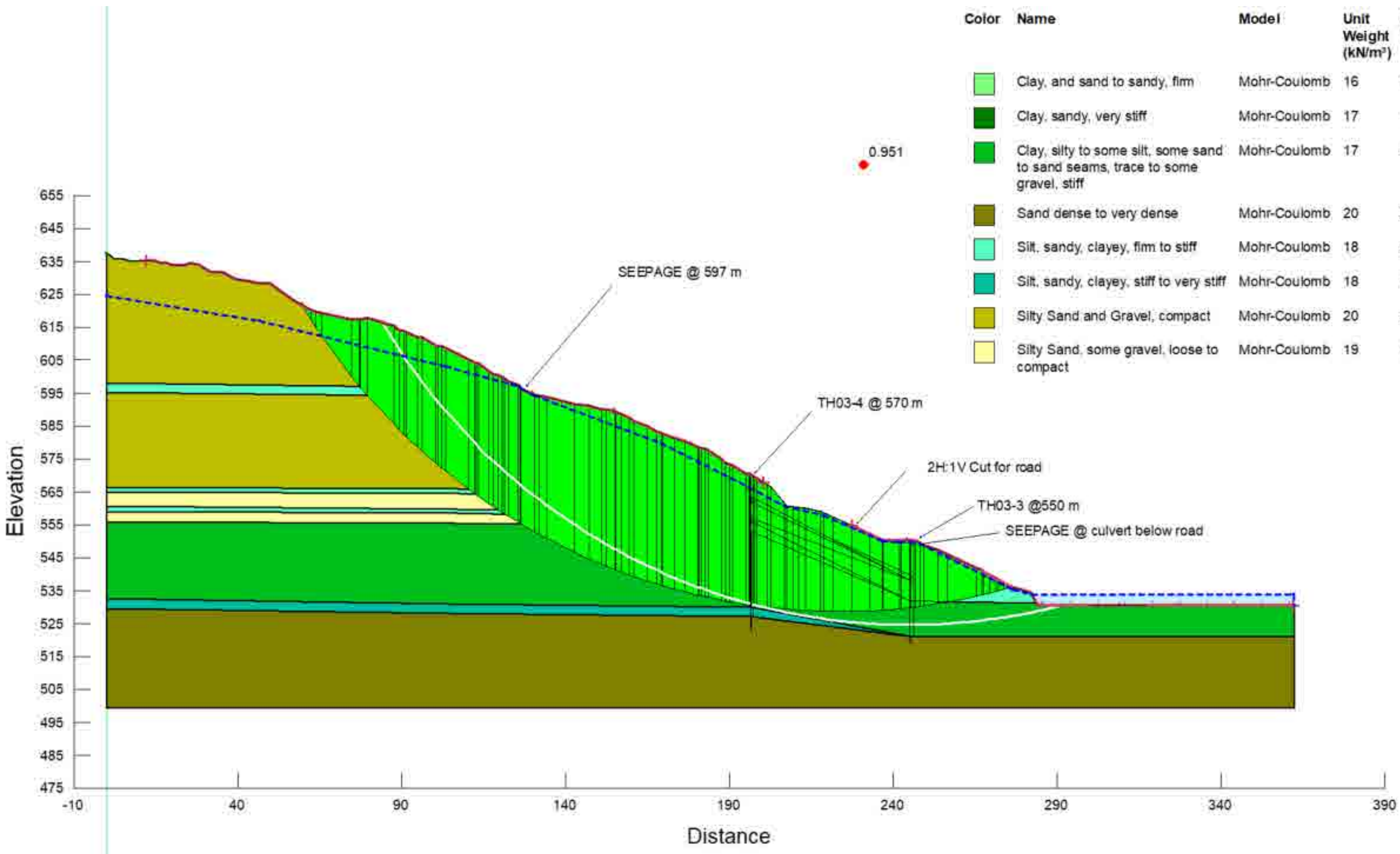
	Silty Sand and Gravel, compact	Mohr-Coulomb	20	0	34	0	1
	Silty Sand, some gravel, loose to compact	Mohr-Coulomb	19	0	32	0	1



CLIENT
CARIBOO REGIONAL DISTRICT

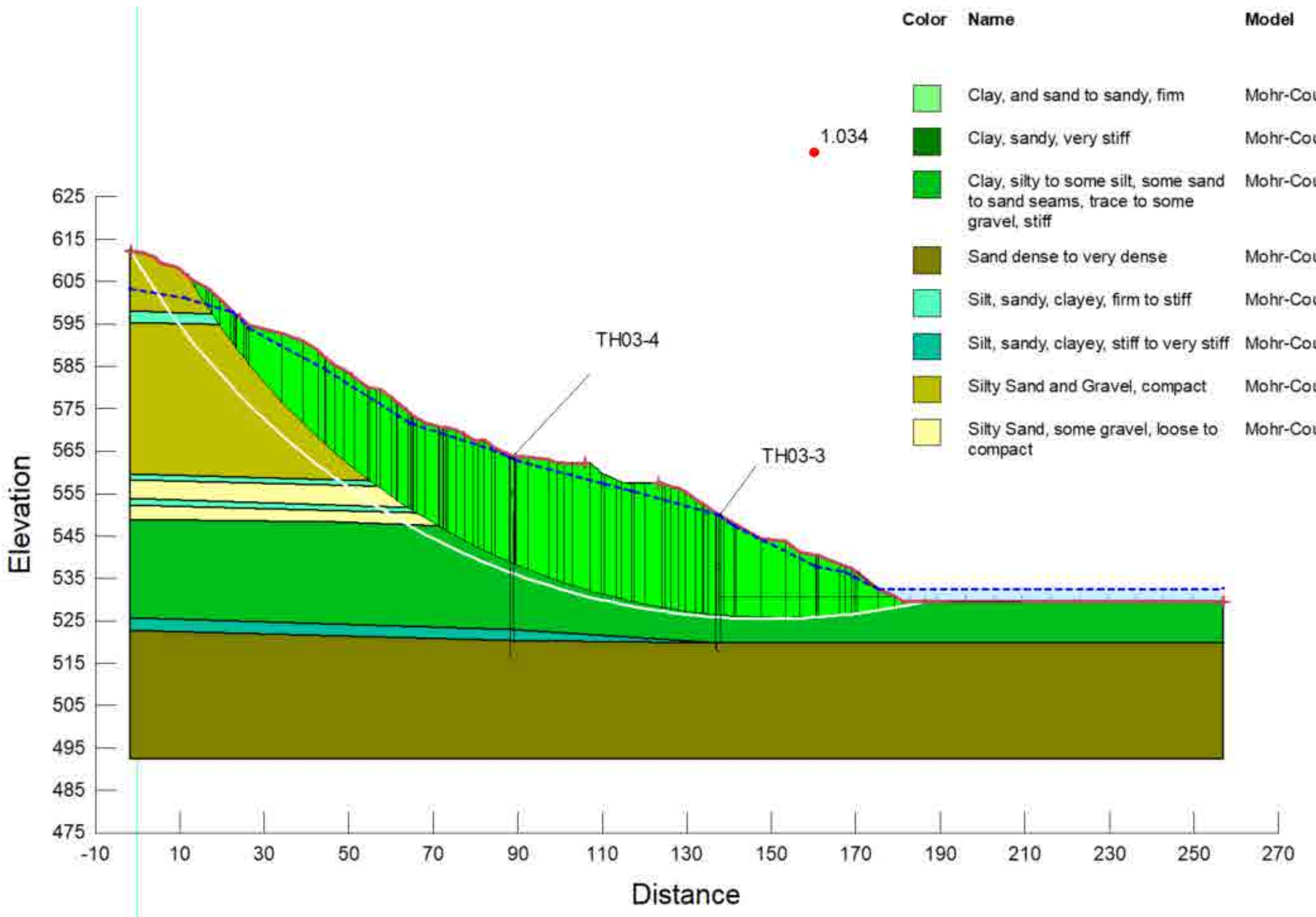
PROJECT
QUESNEL-HYDRAULIC ROAD SLIDE

CONSULTANT
GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	G.BLACK
DESIGN	G.BLACK
REVIEW	B.SINGLETON-POLSTER
APPROVED	G.RUTHERFORD

TITLE
SLIDE F – 2H:1V CUT FOR TEMPORARY ROAD AT OLD ROAD LEVEL

PROJECT No.	PHASE	Rev	FIGURE
20397030	1000	0	C-5



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	Silty Sand, some gravel, loose to compact	Mohr-Coulomb	19	0	32	0	1

CLIENT
CARIBOO REGIONAL DISTRICT

PROJECT
QUESNEL-HYDRAULIC ROAD SLIDE

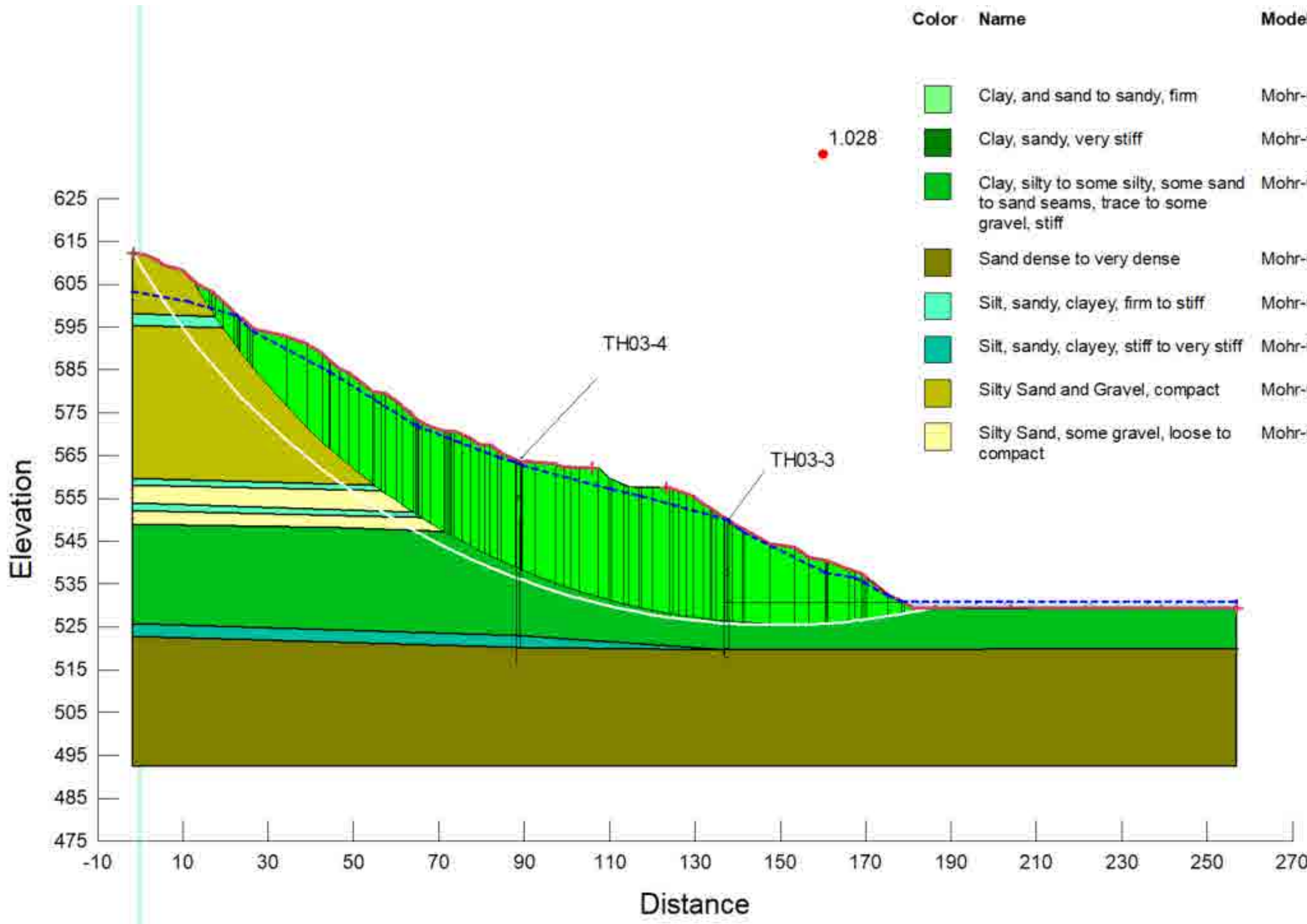
CONSULTANT

GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	G.BLACK
DESIGN	G.BLACK
REVIEW	B.SINGLETON-POLSTER
APPROVED	G.RUTHERFORD

TITLE
SLIDE B – BASE CASE

PROJECT No.	PHASE	Rev	FIGURE
20397030	1000	0	C-6



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CLIENT
CARIBOO REGIONAL DISTRICT

PROJECT
QUESNEL-HYDRAULIC ROAD SLIDE

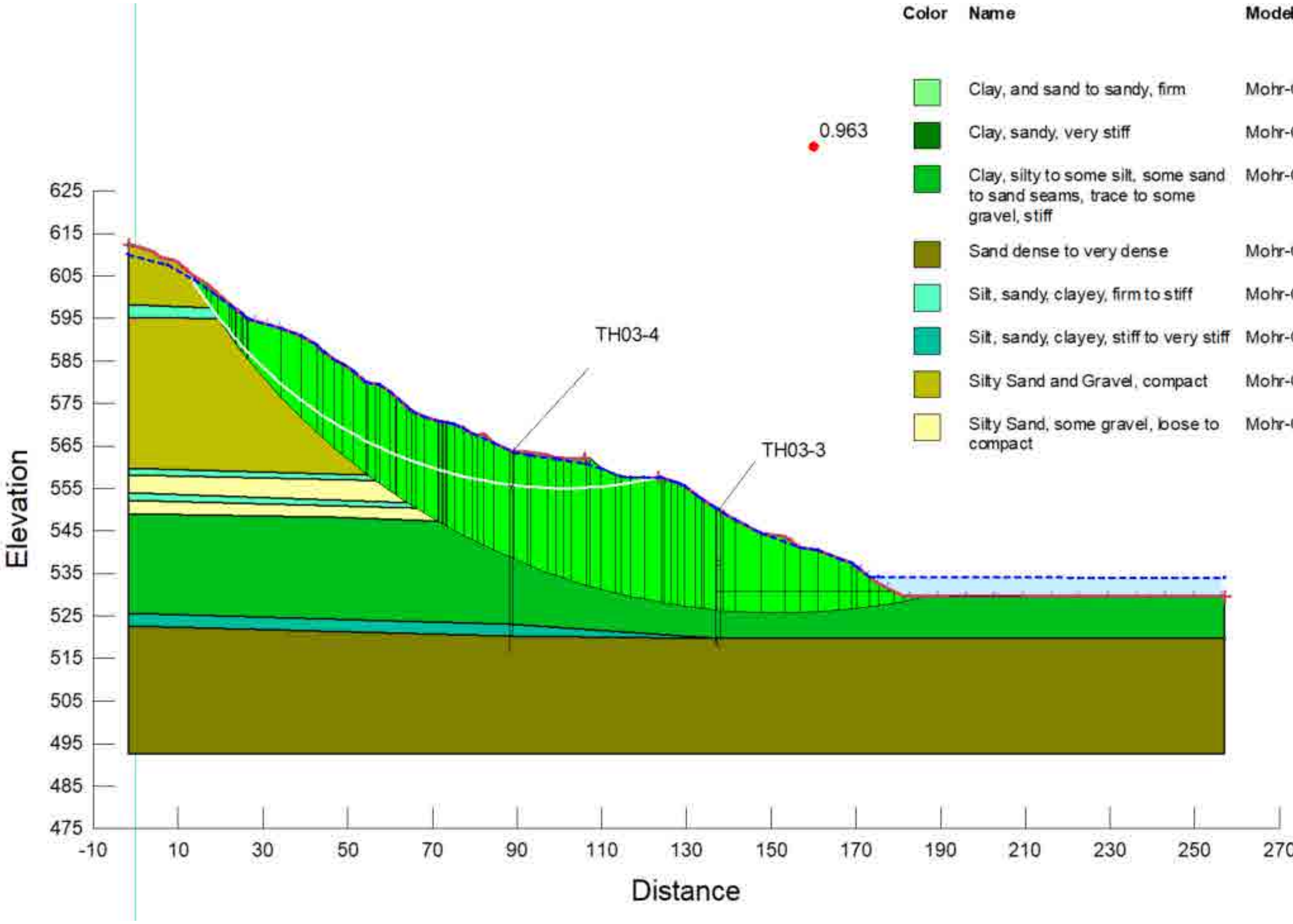
CONSULTANT

GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	G.BLACK
DESIGN	G.BLACK
REVIEW	B.SINGLETON-POLSTER
APPROVED	G.RUTHERFORD

TITLE
SLIDE B – MINIMUM RIVER LEVEL

PROJECT No.	PHASE	Rev	FIGURE
20397030	1000	0	C-7



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CLIENT
CARIBOO REGIONAL DISTRICT

PROJECT
QUESNEL-HYDRAULIC ROAD SLIDE

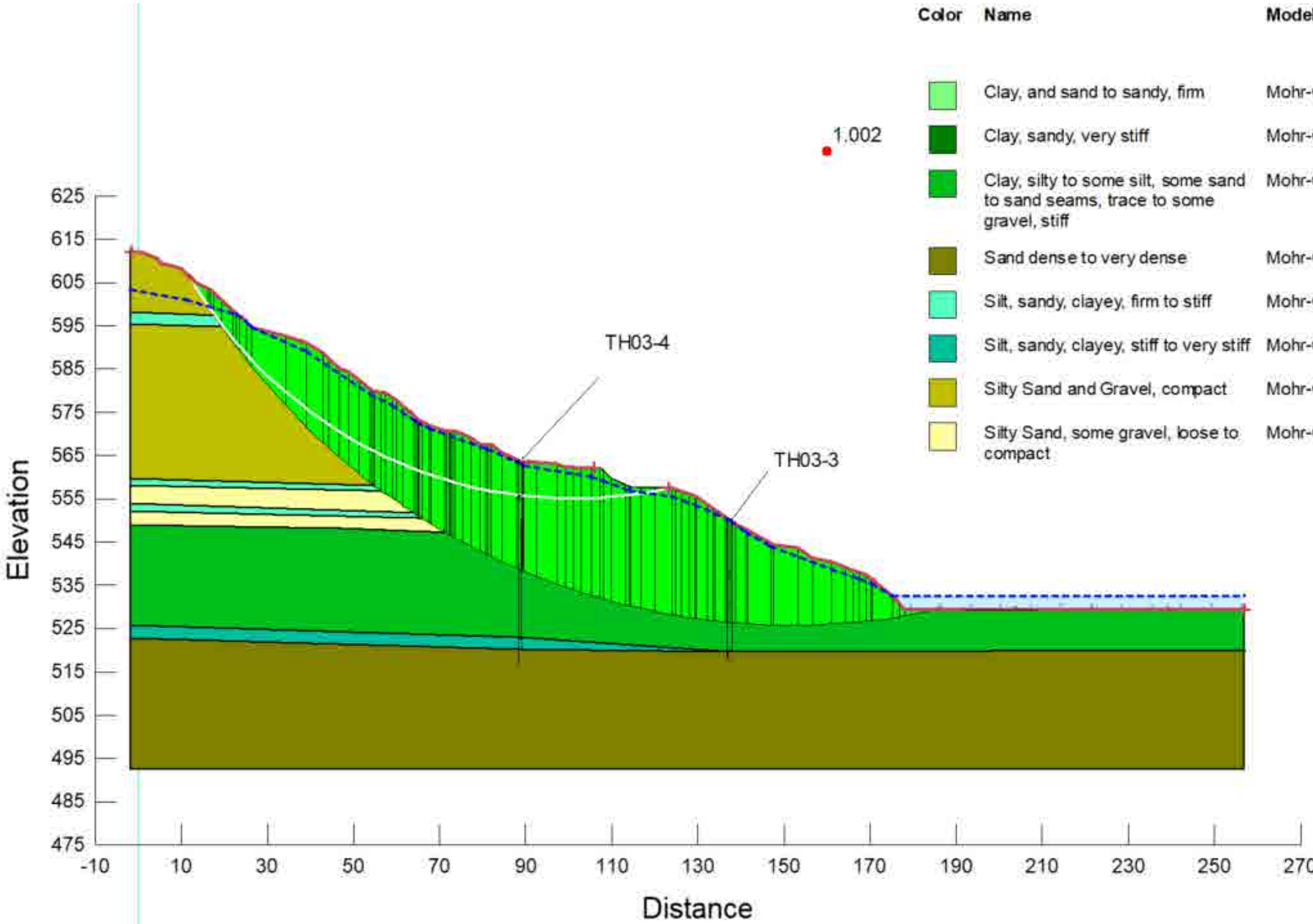
CONSULTANT

GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	G.BLACK
DESIGN	G.BLACK
REVIEW	B.SINGLETON-POLSTER
APPROVED	G.RUTHERFORD

TITLE
SLIDE B – MAXIMUM RIVER LEVEL AND HIGH PHREATIC SURFACE

PROJECT No.	PHASE	Rev	FIGURE
20397030	1000	0	C-8



Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi-B (°)	Piezometric Line
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CLIENT
CARIBOO REGIONAL DISTRICT

PROJECT
QUESNEL-HYDRAULIC ROAD SLIDE

CONSULTANT

GOLDER

YYYY-MM-DD	2021-01-29
PREPARED	G.BLACK
DESIGN	G.BLACK
REVIEW	B.SINGLETON-POLSTER
APPROVED	G.RUTHERFORD

TITLE
SLIDE B – TOE EROSION

PROJECT No.	PHASE	Rev	FIGURE
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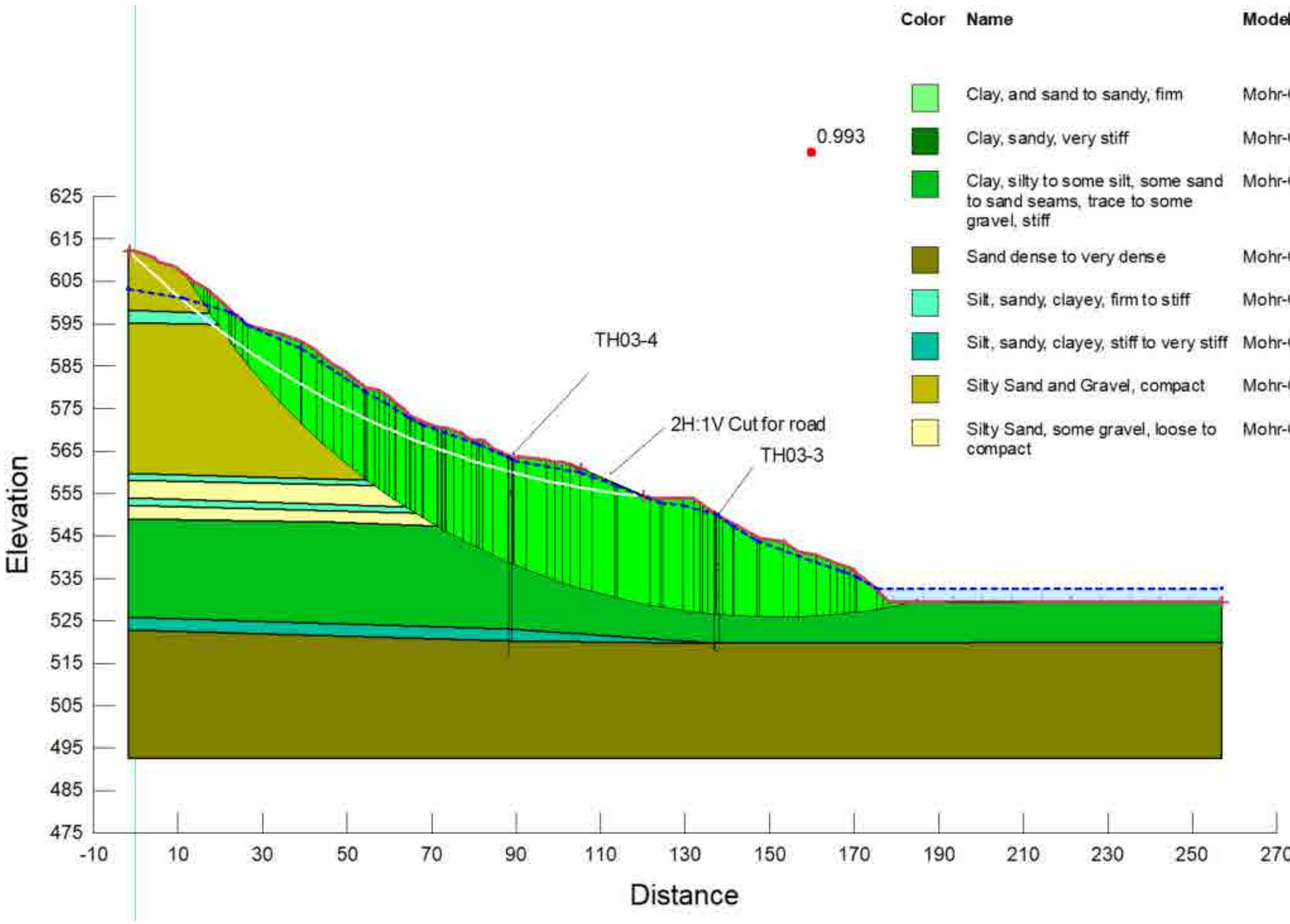

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CLIENT
CARIBOO REGIONAL DISTRICT

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DESIGN	G.BLACK
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APPROVED	G.RUTHERFORD

TITLE
SLIDE B – 2H:1V CUT FOR TEMPORARY ROAD AT OLD ROAD LEVEL

PROJECT No.	PHASE	Rev	FIGURE
20397030	1000	0	C-10

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