# Geohazard Assessment of the Old Fort Area



PRESENTED TO

**Peace River Regional District**

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## Revision History

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|---|---|---|
| June 24, 2021 | Rev 1 | Add Section 4.1.1, minor text edits |
| June 7, 2021 | Rev 0 | |

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## APPENDICES

# ACRONYMS & ABBREVIATIONS

| Acronyms/Abbreviations | Definition |
|---|---|
| Aquaterre | Aquaterre Consultants Inc. |
| BCGS | British Columbia Geological Survey |
| BGC | BGC Engineering Inc. |
| CDED | Canadian Digital Elevation Data |
| Deasan | Deasan Holdings Ltd. |
| DEM | Digital Elevation Model |
| EMPR | BC Ministry of Energy, Mines and Petroleum Resources |
| FLNRORD | BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development |
| FSJ | City of Fort St. John |
| GIS | Geographic Information System |
| Hardy | Hardy Associates (1978) Ltd. |
| LiDAR | Light Detection and Ranging |
| MoTI | BC Ministry of Transportation and Infrastructure |
| PRRD | Peace River Regional District |
| Tetra Tech | Tetra Tech Canada Ltd. |
| Site C | BC Hydro Site C Clean Energy Project |
| UAV | Unmanned Aerial Vehicle |

## LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Peace River Regional District and their agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than Peace River Regional District, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on the Use of this Document attached in the Appendix or Contractual Terms and Conditions executed by both parties.

# 1.0 INTRODUCTION

The Peace River Regional District (PRRD) retained Tetra Tech Canada Ltd. (Tetra Tech) to assess geohazards and flooding potential in the vicinity of the community of Old Fort, British Columbia.

This hazard assessment work was initiated by PRRD in response to a large slope failure event that occurred in the area in September and October of 2018. The original scope of work was outlined in Tetra Tech's proposal "Peace River Valley Geohazard Assessment Old Fort Area", dated November 5, 2019, and consisted of:

- Background data and literature review;
- Terrain mapping;
- Defining and mapping of instabilities;
- Hazard identification, mapping and ranking; and
- Flood/debris flood modelling of Bouffioux Creek

Reactivation of the slope failure occurred in June of 2020 during the course of the work. Tetra Tech provided emergency response services to the PRRD during the landslide remobilization event in June and July of 2020. The observations of this second event have been incorporated into this report.

For the purposes of defining the scope of work, the following terminology from Bobrowsky & Couture (2014) is presented below.

> ***Hazard:*** *potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environment resources.*
>
> ***Consequence:*** *outcome or potential outcome arising from a hazard, expressed qualitatively or quantitatively in terms of loss, disadvantage (or gain), damage, injury or loss of life; the effect on human well-being, property, the environment, other things of value, or a combination of these.*
>
> ***Risk:*** *a measure of the probability of severity of an adverse effect to health, property or the environment. Typically represented as the product of hazard and consequence.*

This report provides an assessment of potential geohazards that may occur within the Old Fort Study area and does not consider the possible consequences of hazard occurrence, or a measure of the risk to individual property, persons or the environment due to geohazard occurrence. As such, this report is limited to a **hazard assessment** according to the definitions presented above, and as defined in the original scope of work.

The hazard zonation maps included within this document are intended to provide a relative ranking of the potential for geohazard occurrence within individual polygon areas only. As discussed above, the hazard classification zones do not include potential consequences of geohazard occurrence, the vulnerability of elements within those classification zones or the level of risk associated with potential hazard occurrence within those zones. As such, the information provided in the hazard zonation mapping should not be interpreted as an equivalent to "risk" within the study area.

# 2.0 DATA SOURCES

Tetra Tech reviewed the following reports as part of the assessment:

- Westrek Geotechnical Services "Emergency Landslide Assessment, Old Fort, BC", dated November 21, 2018.
- BGC Engineering Inc. "Peer Review of Westrek Geotechnical Services Emergency Assessment of Old Fort Landslide", dated November 29, 2018.
- BGC Engineering Inc. "Site C Clean Energy Project, Volume 2 Appendix B Geology, Terrain and Soil, Part 1 Terrain Stability Mapping", dated November 21, 2012.
- Aquaterre Consultants Inc. "Hazard Assessment Report, Old Fort Subdivision, South of Fort St. John, British Columbia", dated January 23, 1986.
- Hardy Associates (1978) Ltd. "Stability Assessment, Old Fort Subdivision", dated June 13, 1982. Revised June 29, 1982.
- Thurber Consultants Ltd. "Site C Reservoir Shoreline Stability Assessment", dated April 1978.

The following spatial data was reviewed and used to complete the desktop analysis:

- Provided by the PRRD:
  - 2006 British Columbia Forest Service full feature and bare-earth LiDAR (LAS, XYZ and GeoTIFF files)
  - 2015 British Columbia Forest Service full feature and bare-earth LiDAR (LAS, XYZ and GeoTIFF files)
  - 2012 City of Fort St. John full feature and bare-earth LiDAR (LAS, XYZ and GeoTIFF files)
  - 2018 Ministry of Transportation and Infrastructure (MoTI) full feature and bare-earth LiDAR/Orthophotos for 2018 failure event (October 4, 5, 6, 8 and 9, 2018) (LAS, XYZ and ECW files)
  - Property boundaries and addresses for the area (ERSI Shapefile).
- Provided by Terra Remote Sensing Inc. (Terra) on behalf of MoTI:
  - 2020 MoTI full feature and bare-earth LiDAR/Orthophotos for 2020 failure event (June 20, 21, 22, 23, 25, 27, 29 and July 2, 5, 8, 2020) (LAS, XYZ and ECW files).

The following publicly available data was also reviewed to complete the desktop analysis:

- Digital Elevation Model (DEM) for British Columbia produced by GeoBC from Canadian Digital Elevation Data (CDED).
- Digital bedrock geology for British Columbia produced by the British Columbia Geological Survey (BCGS) (ERSI Shapefile).
- Digital surficial geology for British Columbia produced by the BCGS, the Geological Survey of Canada (GSC) and Geoscience BC (PDF).
- BC Water Resource Atlas drill logs (listed in Appendix A).
- Aerial photos on loan from the UBC Geographic Information Centre (listed in Appendix B).
- Google Earth satellite imagery dated: 7/30/2007, 6/29/2009, 3/15/2010, 6/7/2011, 5/27/2012, 6/27/2012, 7/11/2012, 5/18/2015, 6/25/2015, 7/16/2015, 4/25/2016, 7/29/2017, 9/22/2017, 5/10/2018, 5/20/2018, 5/21/2018, 7/4/2018, 7/24/2018, 9/18/2018, 10/26/2018, 4/24/2019, 6/14/2019, 8/12/2019, 9/17/2019, and 5/8/2020.
- Environment Canada Weather Station data: FORT ST JOHN A (Climate ID: 1183001) from 1942 to 2020.

# 3.0 BACKGROUND

## 3.1 Project Study Area

The community of Old Fort is located in northeastern British Columbia, south of the City of Fort St. John along the north bank of the Peace River. In the area the Peace River flows west to east, in a channel approximately 1.3 km wide, in a valley 230 m deep and 4 km wide at the crest. The community is bounded by Bouffioux Creek to the east, and BC Hydro's Site C Clean Energy project (Site C) to the west. Bouffioux Creek flows north to south, in a valley approximately 0.6 km wide at the crest and 120 m deep, which joins the Peace River immediately east of Old Fort.

There are other developments near the study area, outside of the jurisdiction of the PRRD. North of the study area is the City of Fort St. John (FSJ). A portion of FSJ's storm water drains into the study area. Several lagoons owned by FSJ, with a total footprint approximately 1,300 m by 600 m are located on the western crest of the Bouffioux Creek Valley. West of the lagoons, on the crest of the Peace River Valley is a borrow pit (Blair Gravel Pit) owned by Deasan Holdings Ltd. (Deasan), which is under the jurisdiction of the BC Ministry of Energy, Mines and Petroleum Resources (EMPR).

A lookout, to the west of the community, at the south end of 265 Road provides an elevated view of the community of Old Fort and the Peace River. The community is only accessible by vehicle via Old Fort Road. The community is also accessible by boat, or by a steep trail up the slope to the north of the community on the west side of Bouffioux Creek.

The community of Old Fort has approximately 150 residents. Part of the community of Old Fort is built on an alluvial fan at the base of Bouffioux Creek and the remaining community are spread along the south facing slopes adjacent to River Drive and Old Fort Road.

The study area generally covers the north slope of the Peace River Valley and the southern portion of the Bouffioux Creek Valley. The study area limits were determined based on information provided by PRRD and extended to the east and north in the vicinity of Bouffioux Creek based on the LiDAR coverage. The boundaries of the study area shown as the Area of Interest on Figure 1.

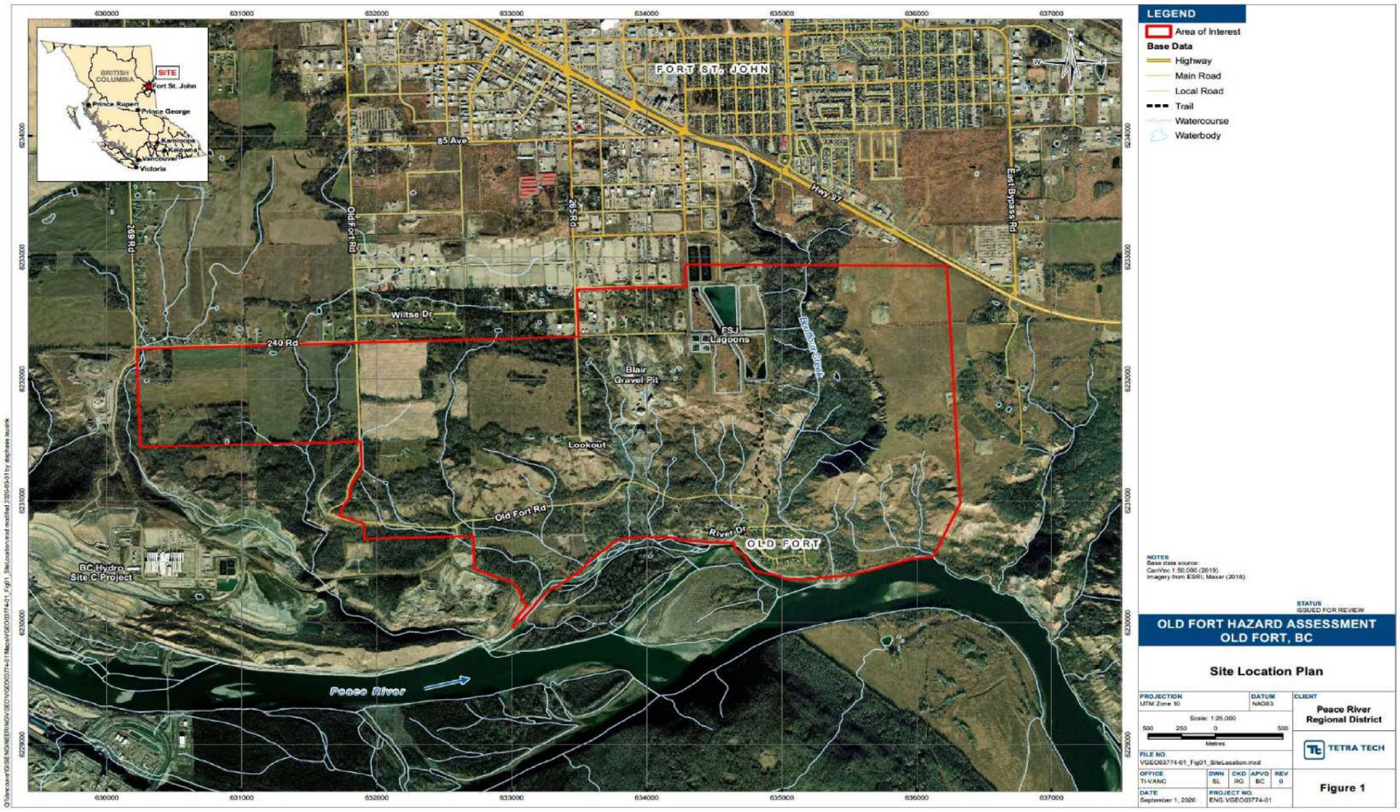


**Figure 1: Site Location**

## 3.2 Climate

The Environment Canada Fort St. John A weather station (Climate ID: 1183001) is located approximately 6.5 km away from the area of interest. Climate Normals from 1981-2010 are presented on Figure 2 below.

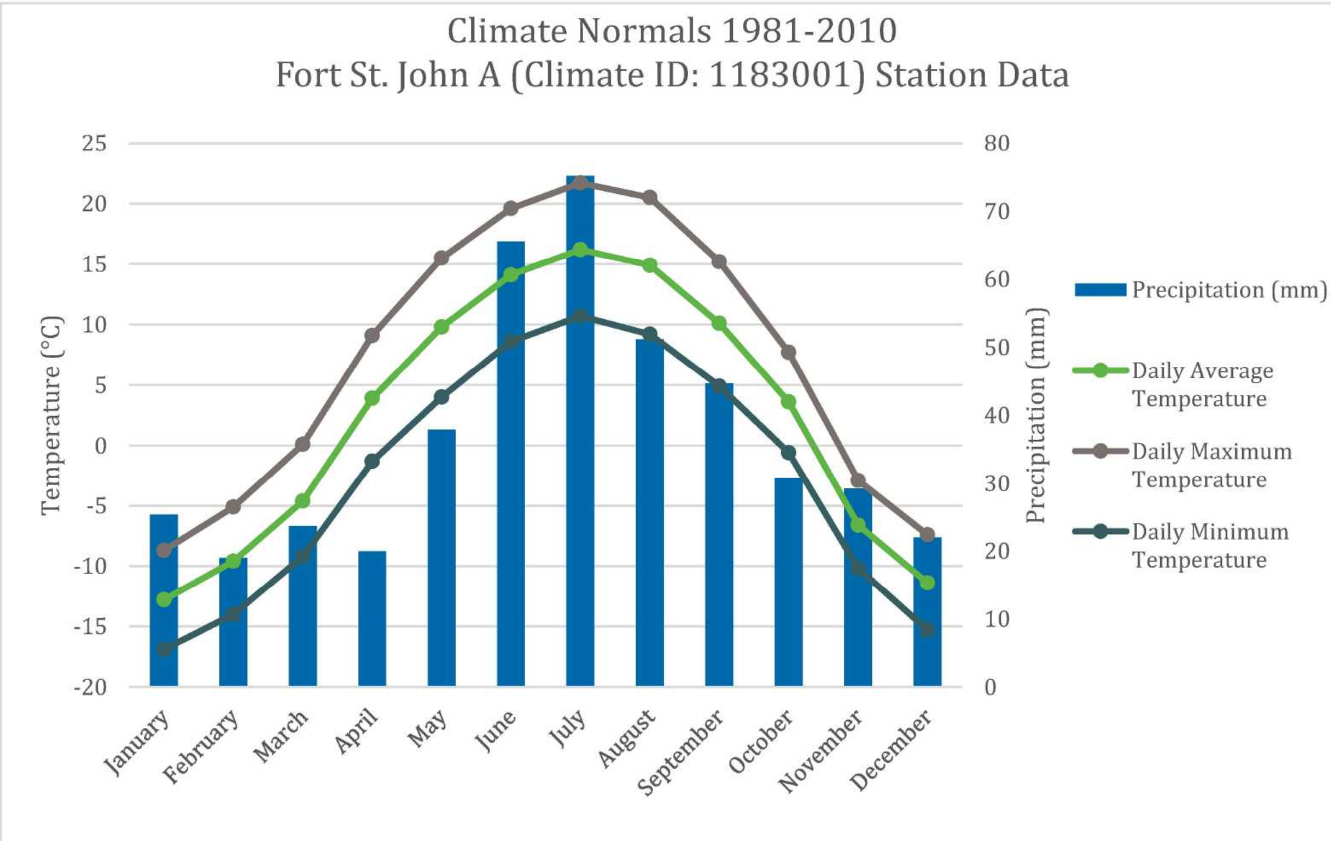


**Figure 2: Fort St. John Weather Station Climate Normals 1981-2010**

Peak monthly precipitation typically occurs during the late spring/early summer in June and July. On average, daily temperatures are below 0° for five months of the year. Old Fort is located within the Boreal White and Black Spruce biogeoclimatic zone of northeast BC, characterized by long and cold winters, and warm but short summers (Meidinger & Pojar, 1991).

Historical weather data from the Fort St. John A weather station from 1942 to 2020 was reviewed. Extreme temperatures ranged from -47.2 °C to 33.6 °C over the data record. The highest daily precipitation value within the record was 80.2 mm. 60.7 mm of precipitation was measured in the month of September prior to the 2018 Old Fort slope failure. This was the 15th highest total precipitation measured for September between 1942 and 2019. Overall, 2017 and 2018 had the 9th and 7th highest total annual precipitation recorded between 1942-2019 respectively. Precipitation data for the time period from May 13, 2020 to August 4, 2020 was unavailable.

Detailed assessment of future weather patterns and potential impacts to geohazards attributed to climate change was beyond the scope of this study. In a general sense, shifting weather patterns could result in changes to average and extreme temperatures, and frequency and/or intensity of precipitation. Where increased frequency or intensity of precipitation is anticipated to occur, potential impacts to geohazards in the region could include (but are not limited to):

- Increased surface water ponding and localized flooding;
- Increased frequency of slope failures due to increase of pore water pressures and erosion related to surface water flows;
- Increased shallow landslide events triggered by extreme rainfall events;
- Increased sediment load in watercourses due to erosion and landslide events;
- Increased flood and/or debris flood events; and
- Increased weathering and erosion rates of exposed bedrock surfaces.

## 3.3 Geological Setting

### 3.3.1 Surficial Geology

The Peace River valley was shaped and formed during the Quaternary Period by the advancement, stagnation and retreats of the Laurentide ice sheet from the east, and the Cordilleran ice sheet from the west. Two Cordilleran and three Laurentide glacial advances have been observed in the landforms and the surficial geology record of the area (Hartman and Clague, 2008). In general, the surficial geology of the area is made up of the following units:

- Infilled paleovalleys (former drainage/river channels) with interbedded sequences of fine-grained lacustrine deposits from lakes (silts and clays);
- Coarse-grained fluvial deposits from flowing water (sand, gravel and cobbles); and
- Till deposits from material that was in contact with glacial ice (mixture of fine- and coarse-grained materials).

The typical sequence of stratigraphy from oldest to youngest interpreted by Mathews (1978) is shown in Table 1 below.

### Table 1: Peace River Valley stratigraphy

| Stratigraphic Unit (Oldest to Youngest) | Thickness (m) | Origin/Comments | Modifications/Comments by Hartman and Clague (2008) |
|---|---|---|---|
| Interbedded sand, gravel, silt and clay | Variable | From early glacial activity overlying the bedrock. | - |
| Glacial till: mixture of fine- and coarse-grained material | 15 - 30 | Deposited from ice contact material during a glacial advance. | Separated into two distinct till units from separate glacial events. |
| Glaciofluvial deposits: well-sorted gravels | 23 - 30 | Deposited from meltwater during glacial retreat. Generally, found at elevations 50 m above the current Peace River. | On average, 13 m thick. |
| Glaciolacustrine deposits: silt with sandy layers | 90 – 120 | Deposited in a glacial lake, formed when ice-dams blocked drainage from the area. | Unit contains coarser sediments near the paleovalley walls. |
| Glacial till | Thin cap | Deposited from ice-contact material from the next glacial advance. | Silt and clay matrix generally containing less than 15% coarse material. |
| Fluvial/kame gravel deposits | 5 | Deposited from next glacial retreat. | Did not identify this layer. |
| Glaciolacustrine deposits: clay with fine gravel drop stones | 1 - 30 | Deposited when another glacial lake formed, when drainage was once again blocked by ice-dams during the most recent retreated of the Laurentide ice sheet. | Drop stones generally make up less than 5% of total volume. |
| Post-glacial fluvial/alluvial deposits: gravel and sand | Variable | Deposited from the modern Peace River and tributaries. Observed in the base and terraces of valleys. | - |
| Post-glacial colluvium deposits | Variable | Deposited from landslides/mass-wasting processes. | Diamictons are matrix supported and less compact than till deposits. |
| Post-glacial organic deposits | Variable | Formed by vegetation growing and infilling in low-lying areas, such as swamps and ponds. | - |

The modern Peace River Valley has eroded through these sediments and into the underlying bedrock. The modern valley is approximately 50 m deeper than the glacial paleovalleys (Hartman and Clague, 2008).

### 3.3.2 Bedrock Geology

Bedrock underlying the area consists of sedimentary rock sequences that are part of the Fort St. John Group. In general, the bedrock consists of shales and sandstones that gently dip to the northeast and east (Matthews, 1978). After formation, the bedrock was fractured and altered by tectonic activity (Sargent and Cornish, 1985).

Bedrock underlying Old Fort is mapped as the Lower Cretaceous Shaftesbury Formation described as marine shale and siltstone (Stott, 1982). The Shaftesbury Formation was described in more detail by Sargent and Cornish (1985) as “a sedimentary sequence of dark grey, silty shale interbedded with thin beds of siltstone, sandstone and shale”, containing silty lamination, concretion horizons and dipping to the northwest at about 1°. Due to the minerology of the Shaftesbury Formation rapid weathering and disintegration occurs if the bedrock is exposed to surface conditions (Cornish and Moore, 1985).

North of Old Fort below FSJ, the Upper Cretaceous Dunvegan Formation, described as sandstone, shales and conglomerates, overlies the Lower Cretaceous bedrock (Stott, 1982). The Dunvegan Formation is generally more resistant to erosional processes protecting the underlying Shaftesbury Formation (Mathews, 1978).

#### 3.3.2.1 Geotechnical Properties Encountered at Site C

Studies of the bedrock strength and material properties were performed for the Site C project, and the results are summarized in Cornish and Moore (1985) and Sargent and Cornish (1985). The studies suggested that a very low design strength should be used for modelling the bedrock and the bedrock may weaken when exposed to weathering processes, or if additional groundwater is introduced. Based on these studies the bedrock encountered at Site C exhibited the following properties:

- Many bedding plane fractures were observed in the bedrock. Some of these fractures were pre-sheared, some were discontinuous, and others were continuous over a large area. The following summarizes the layers which were theorized to govern foundation stability at Site C:
  - One continuous bedding plane fracture, thought to be derived from volcanic ash, was identified on the north bank of the Peace River. The fracture was infilled with 1 mm to 2 mm of sticky white clay and encountered near elevation 420 m. This layer had a measured peak friction angle of 10.8° to 13.3°, with a residual angle of 8.3° to 9.2°.
  - Stability of the south bank was thought to be governed by a contiguous fracture, infilled with clay at the base of a 1.7 m thick black shale bed near elevation 400 m to 410 m. This layer had a peak friction angle of 10.0° to 13.0°, a residual strength of 7.0° to 9.5°, with creep occurring at a friction angle of 6.9° during lab testing.
  - Underlying the Peace River, near elevation 380 m to 390 m a weak layer a few centimetres thick was encountered. This layer was also observed on both banks, but was much thinner, and perhaps less continuous. This layer had a measured peak friction angle of 14.6° and a residual angle of 7.7° to 8.5°
- Shear zones cross-cutting the bedding of the rock and dipping to the north and south were identified. These were generally found to contain sheared material with a thickness ranging from 5 cm to 300 cm. More shear zones were identified on the south bank than the north bank of the Peace River.
- The Peace River valley walls contain steep fractures that are interpreted to be relaxation fractures, resulting from stress relief of the valley wall bedrock during erosion and downcutting of the Peace River valley. At Site C these were found to extend 30 m into the south bank and 80 m into the north bank.
- Natural shale slopes in the Peace River valley were generally less than 75 m high and considered stable at angles shallower than 1.25H:1V.
- Cut slopes in the shale weathered and eroded quickly, with talus accumulating at the base of the slopes within three to seven years of excavation.
- Rock cores extracted from the ground disintegrated quickly. In a laboratory setting the shale and silty shale were observed to “deteriorate completely after air drying and two hours of water immersion” (Sargent and Cornish, 1985). This was not the case with siltstone samples which withstood multiple simulated weathering cycles.

## 3.4 Regional Slope Failures

The valley walls of the Peace River and its tributaries have undergone multiple, well-documented post-glacial landslide events. The slope crests of the steep valley walls are typically defined by scarps of previous landslide events which likely occurred during valley development (downcutting and widening). Prior to the Old Fort slope failures, the most recent large landslide affecting the Peace River was the Attachie Slide. The Attachie Slide occurred in 1973 and temporarily blocked the Peace River.

Work by Van Esch (2012) described and analyzed multiple large overburden and bedrock failure events along the Peace River valley between Hudson's Hope and FSJ. It was found that the sliding surface of compound slides generally occurred along weak clay layers in the overburden and bedrock. In some cases, as seen during the Old Fort slope failure events, the compound failures transitioned into earthflow run-out behaviour reaching the river where the toe of the landslide was then eroded.

Work by Severin (2004) found that the majority of landslides underlying the Old Fort area had multiple failure planes within the bedrock. A bentonitic layer was observed at the bottom of the river valley in which all analyzed slope failures within the area had failed along. The shale bedrock throughout the Peace River valley typically has several weak bentonitic layers at varying elevations.

It was theorized by Cornish and Moore (1985) that the same bedding plane fractures observed in the Site C foundation investigations were in the stratigraphic sequence at an elevation corresponding to the basal sliding surface that involved the failure of the Peace River Bridge in 1954.

## 3.5 2018 Old Fort Slope Failure

On September 30, 2018, a large slope failure occurred near the community of Old Fort, BC. In response to the 2018 slope failure event, the PRRD retained Westrek Geotechnical Services Ltd. (Westrek) to provide "emergency geotechnical support with regard to managing the imminent risk to public safety". The results were published in a report "Emergency Landslide Assessment, Old Fort, BC" dated November 21, 2018, (Westrek 2018). BGC Engineering Inc. (BGC) was retained by the PRRD to conduct a peer review of this assessment, and the findings were documented in a letter to the PRRD dated November 29, 2018 (BGC 2018). Results of this peer review appear to have been incorporated in Westrek's report.

According to the report completed by Westrek, the sequence of events for the main 2018 slope failure was as follows:

1. Landslide initiated September 30, 2018 within the Blair Pit. A large mass of underlying shale bedrock was mobilized during the initial failure.
2. Initial movements caused tension cracks within the shale ridge and shale cone. The initial movements triggered a channelized earthflow within the gully between the shale ridge and lookout.
3. The pavement structure of Old Fort Road began to heave on September 30, 2018.
4. The shale cone collapsed on October 1, 2018.
5. Old Fort Road was blocked on October 1, 2018.
6. The earthflow reached a back channel of the Peace River on October 8, 2018.

BGC estimated the toe of the earthflow displaced approximately 600 m between September 30 and October 25, 2018. The maximum velocity of the toe of the earthflow was estimated to be between 60-70 m/day based on point tracking data.

According to Westrek, the pre-existing west landslide (referred to as the translational earth/bedrock landslide by BGC) was remobilized several days after the initiation of the main 2018 slope failure. Tension cracks were observed by MoTI on October 2, 2018 and the landslide sheared the road surface and displaced in a south-southeast direction over the following days. Point tracking by BGC showed surficial displacements between 10 and 40 m depending on location. The west landslide damaged a house at 7605 Old Fort Road.

A landslide mass east of the shale ridge and rock slide within Blair Pit (referred to as the east landslide by Westrek) was remobilized as part of the 2018 slope failure. BGC referred to the larger area (the area between the ridge and Bouffioux Creek) as the Old Fort Landslide Complex and describes it as a multi-level landslide with an estimated volume as high as 18 $Mm^3$. According to Westrek, detectable movement ceased by October 6, 2018 with the toe of the landslide more than 200 m north of Old Fort Road.

Consequently, access to the community of Old Fort was cut off, and gas and electrical service were disrupted. Evacuation Orders and Alerts for specific properties were issued by the PRRD in response to the event, some of which remain in place.

## 3.6 2020 Old Fort Slope Failure

On June 18, 2020, remobilization of a portion of the 2018 slope failure occurred. In response to the 2020 Old Fort slope failure event, the PRRD retained Tetra Tech to provide emergency geotechnical support. The 2020 landslide field support focused on providing up to date observations and data to the PRRD during the slope failure event.

Based on field observations and communications with the PRRD and MoTI, the sequence of events for the 2020 slope failure was as follows:

1. Landslide remobilization occurred on June 18, 2020. Old Fort Road was closed on June 20, 2020 when movement rates made continued construction of temporary road access impractical.
2. On June 21, 2020, the graben within the Blair Gravel pit underwent additional vertical displacement. Debris from the main scarp failed into the gully and large west-east trending tensions cracks formed on the floor of the gravel pit. The ridge underwent additional deformation and ravelling, and debris was deposited on the west, south, and east sides of the ridge and onto the main earthflow mass.
3. Earthflow movements continued to progress until instabilities at the Blair Gravel Pit and ridge slowed.
4. Road re-construction began on July 8, 2020 after the earthflow mass showed multiple days of non-discernible movements
5. A temporary road was opened to local traffic on July 10, 2020. A smaller earthflow mass located immediately south of the ridge and east of the main earthflow continued to advance slowly during road construction; however, movements stopped prior to reaching road infrastructure.

During peak movement rates the earthflow exceeded 2 m/hour. Maximum surface displacements were an estimated 300 m and additional run-out material was deposited into the back channel blocked by the 2018 event. The landslide mass to the east of the ridge that moved in 2018 (referred to as the east landslide by Westrek) moved again in 2020, travelling a few metres further south/downslope of the 2018 toe. The west landslide failure did not appear to reactivate during the 2020 Old Fort slope failure event. The earthflow damaged road infrastructure and cut-off road access to the community of Old Fort.

The extent of the 2018 and 2020 landslide events is shown on Figure 3.

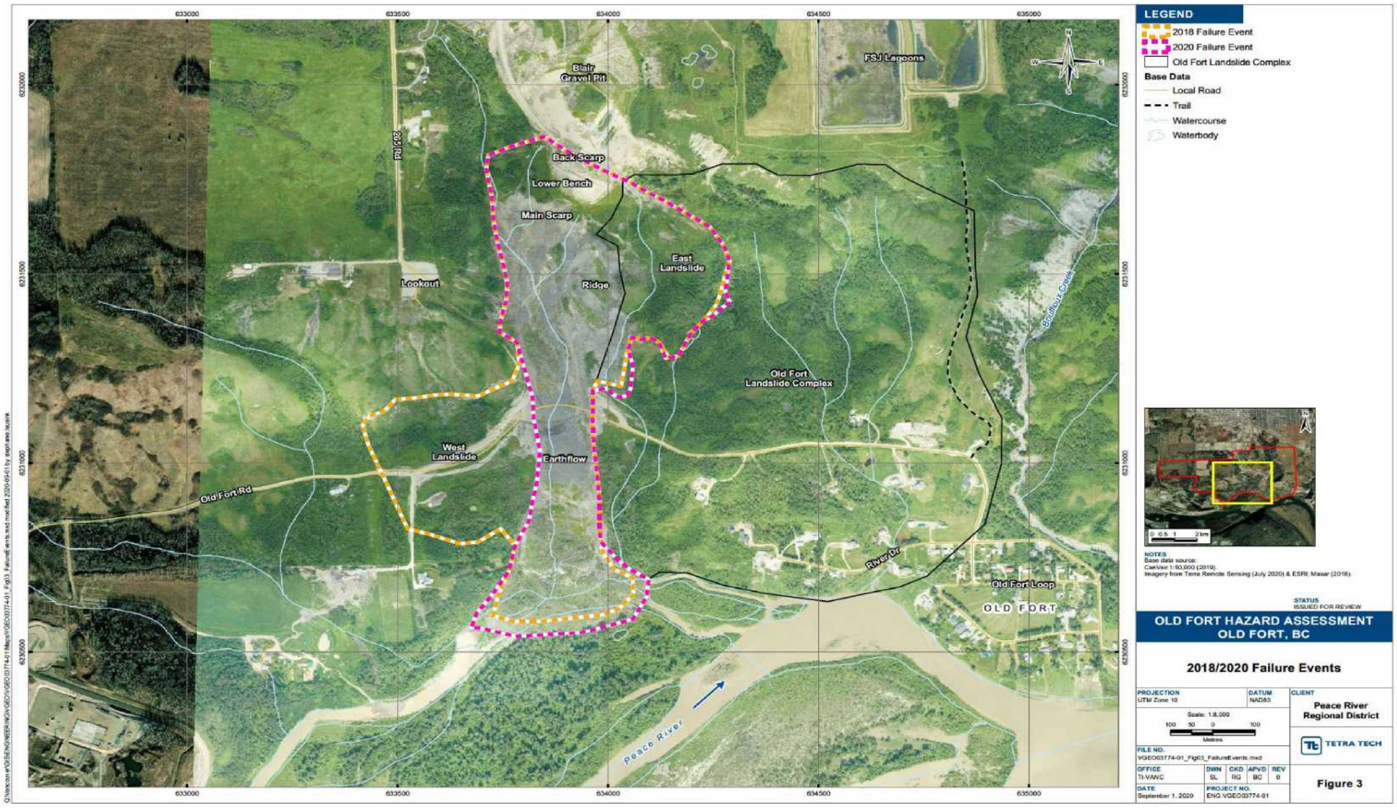


**Figure 3: 2018/2020 Failure Events**

# 4.0 DESKTOP AND FIELD REVIEW

## 4.1 Previous Hazard Assessment Work

At least two geotechnical assessments were completed in the Old Fort area prior to mobilization of the 2018 failure event. Hazard assessments were completed for the Old Fort subdivision in 1982 by Hardy Associates (1978) Ltd. (Hardy) , and in 1986 by Aquaterre Consultants Inc. (Aquaterre). The assessments by Hardy and Aquaterre included evaluation of geohazards which could affect the proposed development, and to aid the Peace River-Liard Regional District in determining whether changes to existing development bylaws and/or restrictive covenants should be considered at that time. Key observations, recommendations and conclusions from the Hardy and Aquaterre reports are briefly summarized in the following sections.

### 4.1.1 Hardy Report (1982)

The following key observations, conclusions, and recommendations from the Hardy (1982) report are presented below.

- The eastern portion of the subdivision was located on an alluvial fan which had developed as the delta of (Bouffioux) creek. Surficial materials west and north of the alluvial fan encompassing the west side of the subdivision were noted to be slide debris from an old slide. It was thought that the feature would generally “not demonstrate massive movement but may undergo shallow local slumping within the area and a slow creep type of movement”.
- Review of BC Hydro reports from the area suggested long-term slope stability would require slopes to be 5 Horizontal to 1 Vertical (5H:1V) or flatter. Many of the slopes within the subdivision were steeper than this, therefore minor movement could occur in localized areas of the subdivision.
- A stability analysis previously completed for the west wall of Old Fort Coulee (i.e. Bouffioux Creek west valley wall) recommended setback of the existing sewage lagoons, due to the potential for collapse of the valley walls and sudden rush of water from the lagoons emptying into Bouffioux Creek. Sudden failure of the lagoons was thought to be the “worst hazard to the Old Fort Subdivision” but should not occur if recommended setbacks were maintained.
- Slope failures into Bouffioux Creek causing stream blockage (e.g. landslide dams) and eventual overtopping and/or erosion leading to downstream flooding (e.g. outburst floods) was identified as a potential hazard to the Old Fort subdivision. It was postulated that a sudden release of water was unlikely unless a large failure resulted in storage of a large volume of water behind the landslide dam.
- Small slope failures along the left bank (facing downstream) of Bouffioux creek were causing the channel to migrate towards the right bank at the north end of the alluvial fan. An existing dyke was observed as a form of erosion protection; however, the dyke was constructed of local floodplain materials and therefore was not considered of large enough particle size to mitigate erosion under extreme flood events.
- Hardy recommended that “the area to the north of Old Fort Road to the intersection of River Road and north and east of River Road to the east of Old Fort Road should not be allowed to develop”. This area included:
  - Lots 1, 2, 3 Plan 26028
  - Lot 1, Plan 19260
  - Lot 7, Plan 14194
  - Frac. N1/2 17-83-18

- Lot 1, Plan 19260; Lot 7, Block 4, Plan 14194; and Frac. N1/2, 17-83-18 should not be developed due to the unstable slopes north and east of the creek, and the potential for severe erosion, extreme flood events and earthfalls that could occur from Bouffioux Creek and the adjacent slopes.
- Use of Lot A, Plan 19259 should be restricted due to the potential for periodic flooding and erosion, "depending on the amount of dyking installed to protect the property".
- All lots bordering on the Peace River should have restrictions on new building. A minimum setback of "30 m back from a point on the property that is defined as the point that slopes to the toe of the river bank at a slope no steeper than 2:1" should be applied to new buildings, due to the potential for erosion and instability of the river banks.
- Lots 1-9, Block 1, Plan 14194; Lots 1-4, Block 2, Plan 14194; and Plan 24449 were noted to be on slide debris. It was suggested that "no new rigid structures be constructed on these lots until it is proven that no movement is taking place. Further investigations will involve completing a drilling program on the slide area, to collect samples and install tiltmeters and piezometers to monitor any movements and groundwater conditions."
- Lots 1-8, Block 3, Plan 14194; Lots 1-6 and 8-15, Block 4, Plan 14194; Lots 1-7, Block 5, Plan 14194; and the large lot bounded by Old Fort Loop road "may be allowed to have unrestricted building permits at this time".
- A qualified geotechnical engineer should inspect any lot that has restrictions prior to allowing construction to proceed.

### 4.1.2 Aquaterre Report (1985)

The following key observations, conclusions and recommendations from the Aquaterre (1985) report are provided below.

**Old Fort Subdivision:**

- Hardy (as reported by Aquaterre) performed a hazard assessment in 1982 which was used as a basis for changes in development procedures and bylaws.
- It was recommended that no development be permitted on several lots close to Bouffioux Creek and steep slopes above it, including: Lot 1, Plan 19260, Lot 7, Block 4, Plan 14194, and the Area north and east of Lot A, Plan 19259 (i.e. Remainder of N1/2 17-83-18).
- Active river erosion and bank instability was occurring in the area of the park, and future erosion was anticipated for adjacent lots. Minimum horizontal setbacks of between 23 m and 30 m from the crest of the slope were recommended for several lots, subject to "regular monitoring of the riverbank migration and periodic revaluation of the setback recommendations". Minimum horizontal setbacks were recommended for:
  - Lots 1 to 4, Block 1, Plan 18222
  - Lots 1 to 7, Block 2, Plan 18222
  - Lots 1 to 4, Block 3, Plan 18222
  - Lots 1 to 3, Block 6, Plan 14194
  - Lot A, Plan 19259
- A minimum setback was not recommended for the lots within Block 2, Plan 14194. It was recommended that they have a site-specific study by a geotechnical engineer performed prior to construction. The recommended study would assess the stability of the slope based on the specific development plans.

- Further to the minimum setback limits provided, it was recommended that a qualified professional should prepare a report to assess riverbank hazards prior to construction of permanent structures on Lots 1 to 4 of Block 1, Plan 18222.
- Ministry of Highways placed a restrictive covenant on building Lots 1, 2 and 3 of Plan 26028 due to the observed undulating surfaces and steeper slopes. The covenant included statements that:
  - Constrained the location that buildings, improvements and structures could be built, constructed or placed on portions of each lot.
  - Restricted permanent excavations into the slope of the land to a maximum of 1.5 m depth.
  - Restricted blockage of natural drainage courses.
  - Required grading to be completed in a manner that would prevent ponding of water.

**Bouffioux Creek:**

- Slope instability along the slopes above Bouffioux Creek was observed along most of its length.
- Flooding events occurred in 1979 and 1980 causing the creek to block and avulsion (channel switching) to occur. Lot A, Plan 19259 was affected by the flooding events.
- Following the flooding events, FSJ began to perform annual inspections of the creek and cleaning of the creek channel north and east of the Old Fort subdivision.
- Channel widening and dike construction was performed in November 1983 under the direction of the Ministry of Highways and Ministry of Environment. Aquaterre concluded that the dike system would "definitely reduce the potential for creek meander and flooding", but that the dike system itself was not designed based on detailed studies of creek hydrology or a targeted level of mitigation/flood protection.
- Multiple lots were at risk in the event of a massive water/mud flow from the creek.

**FSJ Lagoons:**

- A stability study of the FSJ water lagoons was conducted in 1982 by Hardy who recommended draining the two cells nearest to the crest of the slope. The northeast lagoon was drained in 1982 and the southeast lagoon was planned to be drained in 1985.
- No stability analysis was performed on the slope south of/below the lagoons (i.e. slopes north of the Old Fort subdivision).

## 4.2 Aerial Photo Review

Aerial photos were obtained on loan from the UBC Geographic Information Center archives and reviewed in pairs using stereoscopic methods. Details of the aerial photo observations are summarized in Appendix B. In general, observed slope failures within the aerial photo record appeared to originate from undeveloped and developed areas. The largest slope failure in the aerial photo record was a failure at the south east end of the gravel pit (observed in the 1975 aerial photo), where debris flowed from the gravel pit along the east boundary of the ridge.

Note that the aerial photo review was delayed until after the field reconnaissance as the UBC archives were closed for several months due to the global pandemic. As such, observations made based on historic imagery were not ground-truthed during the field reconnaissance.

## 4.3 LiDAR Review

The LiDAR point cloud datasets provided to Tetra Tech were processed and viewed using Global Mapper software developed by Blue Marble Geographics (Version 21.1) and QGIS software developed by QGIS Development Team (Version 3.10.6-A Coruna). The LiDAR point cloud files (in XYZ and/or LAS format) were processed to create bare earth digital elevation models (DEMs) using the ground classified points. These DEM surfaces were used to examine the surface topography and interpret the surficial material types, and geomorphic processes present within the study area. Classification and visualization tools within the software allowed for identification of terrain and geohazards by highlighting changes in slope angle, aspect, and terrain roughness.

DEM surfaces were compared in Global Mapper to identify elevation differences between LiDAR datasets that indicate changes in the terrain surface topography such as landslides or mass-wasting processes, surface erosion, and anthropogenic activities such as excavation or grading.

## 4.4 Terrain Mapping

Terrain maps are often used by government or industry bodies for land use planning and policy development. Terrain mapping involves subdivision of an area into distinct sub-areas or polygons having similar characteristics based on surficial materials, landforms and/or geomorphological processes. Each polygon is labeled with a symbol consisting of a series of letters and punctuation, in a specific order, that represents the character of the terrain within the polygon. By labeling each polygon with a symbol, a large amount of information can be displayed efficiently within a small area on a single map.

In British Columbia two guidelines are commonly used to define standard symbols and methods used for terrain mapping. These include the “Guidelines and Standards to Terrain Mapping in British Columbia” by the Resource Inventory Committee (1996), and the “The Terrain Classification System for British Columbia Version 2” by Howes and Kenk (1997). A modified version of these guidelines was used for terrain mapping of the project study area. The terrain symbol legend used for this project is presented in Appendix D.

Review of spatial data and mapping of terrain polygons was completed using Global Mapper software. The area was mapped to a scale of 1:10,000 with a minimum classified polygon size of approximately 1 hectare. The following steps were used for viewing and interpreting the data:

- LiDAR bare earth point cloud datasets from 2006, 2012, 2015, 2018 and 2020 were processed to create digital elevation models (DEMs) and topographic contours.
- Hillshade (i.e., shaded relief) was applied to the DEMs to give the terrain a 3D appearance based on the suns relative position. Custom slope shaders were used to emphasize slope gradients, directions and subtle topographic changes in order to identify landforms, surficial expression and geomorphological processes.
- Orthophotos, satellite imagery and published mapping overlays were combined with the DEMs. The colours, textures, vegetation and variable water levels were reviewed with respect to underlying landforms to interpret surficial materials and geomorphological processes.
- The interpreted terrain polygons compared with published surficial geological maps from Matthews (1978) and Catto (1991), to check the interpreted surficial materials and geomorphological processes. Although these maps are at a smaller scale than the project study area mapping, they helped refine the interpreted terrain polygons.

There may be variations in surficial material and expression within individual polygons. As such, smaller features or changes within a polygon may exist that cannot be represented at the scale of mapping. The terrain map created from this desktop review is presented in Appendix D.

Landslide support duties restricted the amount of time that could be spent during the field rotations on the terrain mapping scope of work. Therefore, field verification was only completed for 26 of 84 (31%) terrain polygons, the majority of which were located in the vicinity of the 2020 slope failure and along Bouffioux Creek. Aerial photos and LiDAR were used as part of the terrain mapping exercise which typically require less field checking than the Resource Inventory Committee (1996) recommends for mapping completed without this data.

## 4.5 2020 Landslide Field Support

At the request of the PRRD, Tetra Tech travelled to the study area to provide emergency response support during the 2020 slope failure event. Tetra Tech personnel were on site between June 20 to June 25, June 27 to July 4, and July 7 to July 11, 2020. The 2020 landslide field support focused on providing up to date observations and data to the PRRD during the slope failure event. Reconnaissance of the area was performed daily to observe ongoing landslide behaviour and comment on potential impact to properties within the PRRD. Daily photos and observations were provided to the PRRD.

During the field emergency support rotations, Tetra Tech reviewed areas of interest related to the geohazard assessment scope of work. A traverse of the access trail south from the FSJ lagoons to Old Fort, west slopes above Bouffioux Creek and the lower reaches of Bouffioux Creek was completed. Observations of Bouffioux Creek were made before and after a storm event which caused damage to the existing dike infrastructure (Photos 38 and 46 in Appendix C). Detailed field notes and photographs were collected using cell phones and mobile Global Mapper software. The notes included observations of the topography, slope gradient, landforms, soil and bedrock exposures, hydrological conditions and vegetation indicators. Measurements were made using a handheld tape measure and inclinometer. Representative photographs are included in Appendix C.

# 5.0 GEOHAZARD ASSESSMENT

The term geohazard refers to geological or geomorphological events, processes or conditions that could potentially cause an undesirable consequence. Geohazards exists in the natural environment and are part of erosion and mass-wasting processes. The conditions that create or cause a geohazard event can occur gradually over time, or suddenly due to modifications to the surrounding environment. This can be caused by human activity, such as changing the geometry of a slope or natural drainage patterns, or from the natural processes such as stream erosion or intense precipitation. A geohazard event can also trigger secondary geohazards in a series of cascading events. For example, if a landslide occurs into a stream and dams or blocks the channel, stream flow may occur outside of the normal stream channel causing erosion and/or avulsion.

Geohazard maps can be used to identify potential landslide and erosive processes occurring in an area. Unlike terrain mapping, there is not a set geohazard guideline document typically used in BC, although there are guidelines regarding how professionals should assess landslides such as EGBC's "Guidelines for Legislated Landslide Assessments for Proposed Residential developments in BC" (2010). As such, a geohazard identification method and set of criteria is generally defined for each individual project based on site specific geological conditions, geohazard research and a combination of guidelines. For this assessment, geohazards were identified and classified using the following steps:

1. A landslide inventory map was created. The landslide inventory map shows polygons or defined areas where a landslide has occurred. The polygons are classified based on the activity level of the landslide determined from review of historical aerial photos and LiDAR data.

2. Geohazard susceptibility maps were created. The susceptibility maps show polygons or defined areas where terrain is susceptible to different types of geohazards, such as, rock slide, earthflow, debris slide, avulsion, among others.

3. Hazard zonation maps were created. The hazard zonation maps show polygons or defined areas classified according to qualitative hazard rating categories (high to low). The hazard zonation maps are based on the geohazard susceptibility and landslide inventory maps.

The methods used for these three steps are elaborated in the following subsections, with the produced maps provided in Appendix E, F and G. Note that the hazard zonation maps provide a relative ranking of the potential for geohazard occurrence within individual polygon areas only. The hazard classification zones do not include potential consequences of geohazard occurrence, the vulnerability of elements within those classification zones or the level of risk associated with potential hazard occurrence within those zones. As such, the information provided in the hazard zonation mapping should not be interpreted as an equivalent to "risk" within the study area.

The polygon boundaries presented in this report are based on interpretation of LiDAR data, ortho-imagery, historic aerial photographs, and information from available background reports. Limited field reconnaissance was conducted to check interpretations and confirm surficial materials at select locations, and no subsurface characterization was completed as part of this scope of work. As such, the polygon boundaries are considered approximate only, and are subject to considerable uncertainty particularly where more recent sediments, active geomorphic processes or human-caused disturbance potentially overlies and obscures the margins of older features at depth.

PRRD should be aware that other hazards, outside this scope of work, may exist within the Old Fort area. Examples of hazards not included in this assessment are:

- Seismically-induced hazards;
- Snow avalanche;
- Controlled or uncontrolled rapid releases of water from upstream dams;

## 5.1 Landslide Inventory

Landslides were identified and classified based on activity level to create a landslide inventory. The activity level can help define the spatial and temporal frequency of landslides over a region. A system generally used by industry for classifying landslide activity level is presented by UNESCO (WP/WLI, 1993), however this method is challenging to apply in the Peace River region as past landslides are likely to continue to move/deform at low or non-discernible rates due to the geology of the area (see Section 3.2). Consequently, a modified version of landslide activity levels, based on the UNESCO method, was used for this assessment and is outlined in Table 2. These descriptions of activity represent a preliminary assessment of frequency which could be refined further through additional investigations.

**Table 2: Landslide Activity Levels**

| State of Activity | Description of Activity |
|---|---|
| Very Active | Moved within the last 2 years (fall 2018 to fall 2020) |
| Active | Moved more than 2 years ago, but within the period of record of the LiDAR data and aerial photos (2 to 85 years ago) |
| Low Activity – Dormant | Moved prior to the period of record of the LiDAR data and aerial photos (> 85 years ago) |

The landslide inventory was developed based on the aerial photo review, LiDAR/Orthophoto review and field reconnaissance. Mapping of individual landslides was performed with the QGIS software. The inventory polygons include the source and run-out zones as a single landslide polygon. Individual landslide boundaries were identified in areas where relatively fresher (i.e., recent) landslide features could be identified (i.e., scarps, flanks, depletion/accumulation zones). Because most of the valley terrain has been subject to landslide and erosional processes, the inventory polygons contain some larger regions where distinct individual features could not be distinguished due to erosion, overprinting by more recent landslides, and/or anthropogenic activities.

Dating of the landslides to determine activity was limited to the timeframe of the aerial photos and LiDAR, approximately 85 years (1946-2020). Therefore, this inventory may not capture lower frequency events outside of the period of record. As such, additional assessment would be required to augment the landslide inventory for use as a frequency/likelihood parameter in a detailed risk assessment. The largest landslide events that occurred within the study area in the period of record were the 2018 and 2020 slope failures.

Landslide events identified in the aerial photo record are generally large and based on visual identifiers of movement such as changes to topography or vegetation. Smaller landslide events could be identified in the LiDAR data using change detection tools in the Global Mapper software program. Therefore, the landslides identified from the LiDAR data make up a higher quantity of the landslide inventory.

The landslide inventory polygons that were created to describe the state of activity of landslides within the study area are shown on the landslide inventory map in Appendix E.

## 5.2 Geohazard Susceptibility Mapping

Geohazard susceptibility mapping includes the classification (hazard type), spatial area and distribution of existing/potential geohazards within a study area (AGS 2007a). For this study geohazards were classified into three categories of small landslides, compound landslides and hydrotechnical hazards, which include subclassifications based on specific landslide behaviour and hazard types. The classification methods are based on observations of topography, surficial material, slope gradient, surface texture, evidence of previous failures (i.e. landslide inventory), and used criteria from the following sources:

- "Slope Movement Types and Processes" by Varnes (1978);
- "Landslide Types and Processes - Investigation and Mitigation" by Cruden and Varnes (1996); and
- "Varnes Classification of Landslide Types", by Hungr, Leroueil and Picarelli (2013).

The landslide inventory (presented in Section 5.1) and terrain mapping (presented in Section 4.4) helped guide geohazard susceptibility mapping. Detailed slope stability modelling was not part of the scope of work and was not performed as part of the susceptibility assessment. The specific geohazard definitions and method used for the mapping is described in the subsections below. The geohazards were mapped using the same mapping scale, software and techniques used for the terrain mapping described in Section 4.4. The geohazard susceptibility maps produced as part of this study are provided in Appendix F.

### 5.2.1 Small Landslides

The geohazard susceptibility maps for small landslides are shown on Figure F1. For the purpose of this assessment, the debris slide and earth slump/flow polygons were combined as small landslides because:

- The hazards are predominately related to small/shallow slope instabilities on the valley slopes;
- The hazards can be closely related in occurrence locations; and
- Based on the scale of mapping, it can be difficult to discern the landslide movement mechanics and materials to differentiate areas of differing susceptibility.

Debris slides in the area of interest typically occur on the valley slopes between the plateau and the terrace above the Peace River, and on the west slopes of Bouffioux Creek. Earth slump/flow failures typically occurs on the south facing slopes between the plateau and the terrace above the Peace River. Detailed mapping criteria and definitions of these hazard types are provided in the subsections below.

#### 5.2.1.1 Debris Slide

Debris slides involve the detachment of a thin sheet of predominantly coarse-grained soils (debris) from steep slopes. Generally, a shallow layer of weak or loose soil overlying a more competent soil or rock surface detaches and slides rapidly down slope. These slides are usually triggered by heavy precipitation, rain-on-snow activity, or changes in drainage patterns and slope geometry by anthropogenic disturbance or toe erosion. Rapid downslope movement of the debris may transform the debris slide into a debris avalanche on open slopes, or into a debris flow if the failure becomes confined in a drainage channel.

Debris slides were mapped based on the following conditions:

- Evidence of recent debris slide activity on similar slopes (such as deposits at the toe of the slope);
- Slopes steeper than about 30°; and
- Unconsolidated or weak soil and debris overlying competent soil or bedrock.

#### 5.2.1.2 Earth Slump/Flow

A failure of fine-grained cohesive soils that initiates as a shallow slump failure, then due to strength loss the remoulded material liquifies and flows downslope. Generally, initiates in soils with a high plasticity index. The process can repeat multiple times forming a retrogressive slide as the slumped material flows away reducing resistance forces at the toe of the initiating slide. These failures can be triggered by extreme precipitation events, seismic events, or changes in drainage, vegetation cover, slope geometry and loading conditions such as the placement of fill near the crest of slopes or removal of material from the toe, for example by river erosion.

Earth slump/flow failures were mapped based on the following conditions:

- Evidence of recent earth slump/flow failure activity on similar slopes (such as deposits at the toe of the slope);
- Slopes steeper than about 30°; and
- A weak soil or bedrock layer that could fail under certain circumstances such as elevated pore water pressure or a seismic event.

### 5.2.2 Compound Landslides

Varnes (1978) defined compound landslides as a landslide that exhibits two or more failure mechanisms. Within the study area compound slides were identified as large areas where combinations of earthflows, rock slides and earth slides have occurred. The geohazard susceptibility maps for compounds landslides are shown on Figure F2.

Large polygons within the study area were identified where compound slides have occurred in the past and are thus susceptible to similar failure events in the future. These areas likely contain pre-sheared planes of weakness in the bedrock, that may be re-triggered from surface loading or increases in water infiltration. Many of the compound landslides appear to include a translational basal surface (i.e., shear along clay seams, bedding fractures and/or weathered bedrock surfaces) and a rotational backscarp through intact bedrock, earth, and/or granular materials. In the case of the 2018 and 2020 landslides, failed debris deposited at the base of the borrow pit scarp and ridge and was then transported further by the earthflow.

Detailed susceptibility criteria and definitions of the failure types typically comprising the compound landslides in the study area are provided in the subsections below.

#### 5.2.2.1 Earthflow

Earthflows involve the flow-like movement of plastic fine-grained soils. Generally, occurs when the soil is ductile because the water content is close to the plastic limit. Earthflows can move at variable, changing speeds from 1 m/year to faster than 2 m per hour. The speed of flow can increase rapidly if the source/initiation zone is destabilized, for example if water is added to the slope crest due to changes in upslope drainage.

Earthflow failures were mapped based on the following conditions:

- Evidence of recent earthflow activity on similar terrain (such as areas of long/shallow landslide run-out).

#### 5.2.2.2 Rock Slide

Rock slides involve the movement of an intact rock mass on a surface. The rock mass experiences limited internal deformation and generally moves as a single piece. Rock slides involve the failure of large bedrock masses, typically over 1,000 $m^3$ in volume, which remain semi-intact during sliding. The rock mass typically fractures along a planar surface or combination of surfaces.

Rock slide failures were mapped based on the following conditions:

- Evidence of rock slide activity on similar slopes (such as slopes controlled by similar geology within the Peace River Valley);
- Steep rock slopes (>35°) with discontinuities capable of releasing rock masses;
- Weak discontinuity layers (shear zones, clay infilled bedding fractures); and
- A talus deposit at the base of the steep rock bluff indicating historic rock mass failures.

#### 5.2.2.3 Earth Slide

Earth slides involve the shallow to moderately deep-seated rotational failure of slopes comprised of fine-grained cohesive soils (silt and clay), or weak and highly weathered bedrock. The slide moves primarily by sliding on a basal shear surface, due to unfavourable slope angle, pore pressure, and/or strength conditions along the sliding surface. These failures can be triggered by extreme precipitation events, seismic events, or changes in drainage, vegetation cover, slope geometry and loading conditions such as the placement of fill near the crest of slopes or removal of material from the toe, for example by river erosion or anthropogenic activities.

Earth slide failures were mapped based on following conditions:

- Evidence of recent earth slide failure activity on similar slopes (such as deposits at the toe of the slope);
- Slopes steeper than about 30°; and
- A weak soil or bedrock layer that could fail under certain circumstances such as elevated water pressure or a seismic event.

### 5.2.3 Rockfall

Rockfall involves the detachment of smaller rock masses from rock outcrops or falls of boulders from steep colluvial or glacial till slopes where the individual blocks are deposited downslope through independent rolling and bouncing. Rockfall hazards may also occur where slopes are undermined by steep cuts or excavations. While less destructive than rock slides, rockfalls can damage surface structures through direct impact and can also impart cratering damage to buried facilities.

Rockfall was mapped based on the following conditions:

- Steep rock slopes (>35°) with discontinuities that could form discrete rock blocks that may release;
- Steep colluvial or glacial till slopes (>35°) containing large boulders; and
- Talus deposits at the base of the steep rock bluff indicating prior rockfall occurrence.

Rockfall in the area of interest is concentrated in areas of recent large-scale bedrock failures where fresh bedrock has been exposed (i.e. bedrock ridge and the scarp below the gravel pit). Otherwise, steep bedrock and colluvial slopes typically weather in place and are susceptible to failure by the mechanisms outlined in small and compound landslide sections.

The geohazard susceptibility map for rockfall is shown on Figure F3.

### 5.2.4 Hydrotechnical Hazards

Hydrotechnical hazards throughout the study area were mapped separately based on likely areas of susceptibility for each hazard. Debris floods and avulsion of Bouffioux Creek may occur and effect areas of the alluvial fan where part of the community of Old Fort resides. Gully erosion exists along crest of the upper slopes between the plateau and the terrace, and the upper slopes in Bouffioux Creek.

Lateral migration and scour potential exists along the north bank of the Peace River, the tributary streams in the east portion of the project area, and Bouffioux Creek near Old Fort. The Bouffioux Creek alignment is confined and has steep banks to the west and east, so large lateral migrations are unlikely, unless other failures occur and significantly alter the landscape. Ongoing scour and bank erosion are likely to continue to undercut the creek banks and cause localized instabilities.

The geohazard susceptibility map for hydrotechnical hazards are shown on Figures F4 through F6. Detailed susceptibility criteria and definitions of the hydrotechnical hazard types are provided in the subsections below.

#### 5.2.4.1 Debris Floods

Debris floods can be defined as “a very rapid, surging flow of water, heavily charged with debris in a steep channel” (Hungr et al. 2001).

Debris flood deposits extend further downslope than debris flows and deposit on shallower slope angles often less than 5° (Hungr et al., 2013). Debris floods tend to be less hazardous than debris flows, as velocities are lower therefore large boulders responsible for impact damage in debris flows are not mobilized (Pierson, 2005). Debris floods are usually triggered by intense rainfall events, which result in very large flows in streams, leading to entrainment of sediment. Debris floods can also be generated by sudden outburst of water due to failure of impoundments or flow barriers such as landslide dams or water retention structures. A debris flood may initiate as a debris flow, then transition to a debris flood where the waters reach a lower gradient slope.

Debris floods were mapped based on the following conditions:

- Steep stream channel with approximate gradient of 2° to 17°;
- Presence of an alluvial fan (indicating prior occurrence, sediment deposition zone);
- Substantial loose, erodible material available for transport; and
- Potential source of instability upstream, such as localized bank failures.

#### 5.2.4.2 Avulsion

Avulsion is when flow in a stream or river is diverted out of an established channel and flows in a new location. This can be caused by sediment deposition, lateral migration/scour, debris jams (for example log jams), beaver activity, ice jams, landslide damming or flood events. Avulsion is common on alluvial fans.

Avulsion was mapped based on the following conditions:

- A stream channel on an alluvial fan with areas of minimal confinement.
- The potential for a triggering event to occur such as a debris flow blocking the channel, or a flood event of large enough magnitude to overtop or erode and escape the channel banks.

#### 5.2.4.3 Gully Erosion

Gully erosion involves the erosion of steep slopes by water, such as concentrated surface runoff or drainage diversion. Sloughing and caving can also occur in established gully headwalls by the sudden discharge of groundwater from confined aquifers, potentially causing up to several metres of gully headwall retrogression over a few days. Gully erosion may expose highly erodible bedrock and cause localized undermining and loss of support.

Gullies are steep-sided, deeply incised features with characteristic steep headwalls, and a V-shaped channel section. Failure or overtopping of drainage control measures during extreme precipitation events, or redirection of water onto the terrace slopes could cause erosion or retrogression within existing gullies and/or formation of new gullies. Retrogressive failures on terrace slopes may also occur where surface water infiltration into the granular materials overlying glaciolacustrine sediments causes increased pore water pressures or high seepage gradients at the downstream slope face.

Gully erosion was mapped based on the following conditions:

- Steep-sided (>30°), deeply incised features with convex slope or channel profiles (flat over steep).

- Subject to surface water runoff or groundwater seepage from the face of a slope where fine-grained or glaciolacustrine sediments outcrop below granular materials.

#### 5.2.4.4 Lateral Migration/Scour

Lateral migration occurs when erosion of a bank of the stream or river causes the channel to shift laterally. This typically occurs at the outside bend or meander in a river, where the current is the fastest. This can occur slowly over multiple years, or rapidly during a flood event. As erosion removes the toe of the slope this can destabilize the slope triggering landslides and slope failures. This process can occur in coarse- or fine-grained soils, and the extent of the hazard depends on the channel morphology, bank materials, flow rate, sediment supply and presence of channel obstacles.

Scour is an erosive process where sediment is removed and transported from the bed of a stream or river. Scour is a natural process, but creates a hazard if it accelerates rapidly, which can destabilize the adjacent banks increasing the rate of lateral migration. This can occur where a channel is obstructed or constricted, for example bridge abutments, log jams, ice jams or landslide dams.

Lateral/migration scour was mapped based on the following conditions:

- Stream channels that are composed of erodible material (i.e., sediment or weak rock).
- Potential stream flows large enough to mobilize sediment within the channel (i.e., flood event of sufficient magnitude).

## 5.3 Hazard Zonation

A qualitative assessment of the geohazards at Old Fort was performed to rate the level of hazard across the study area. The hazard zonation polygons were created based on the geohazard susceptibility and landslide inventory maps to assign an estimated frequency and spatial extent of potential future geohazard events (AGS 2007a).

Based on guidance from AGS (2007a, 2007b), Porter & Morgenstern (2013) and Jackson, Bobrowsky & Bichler (2012), qualitative hazard descriptors were used to zone the study area in the rating polygons. Combined hazard zones (i.e., High/Moderate and Moderate/Low) were used in areas where uncertainty of the hazard level was present and further investigation would be required to refine the hazard zone boundaries. These zones are typically in areas where there is geomorphological evidence of past landslide activity, but the current/future state of instability is unknown.

An estimated frequency range (event return period) and magnitude (event size) are provided for the hazard zonation rating categories, based on the landslide inventory, terrain mapping, inferred subsurface conditions, and engineering judgement. Considerable uncertainty exists in the estimations for low frequency/high magnitude events due to the complexity of the identified hazard types, the limited available information of the subsurface soil, rock and groundwater conditions across the study area, and the lack of information for dating of events that have occurred outside of the approximately 85 year period of record. Given that the existing conditions and the conditions that led to initiation of previous events are relatively unknown, the degree to which potential modifications or changes to existing slope geometry, loading conditions and/or pore water pressures could affect future activity levels of the low frequency/high magnitude hazards is difficult to estimate.

The hazard zonation presented in this report was applicable at the time of the hazard study. Additional development activities or changes in level of understanding of individual landslide processes within the area may require that the hazard zonation be re-assessed and updated. Anthropogenic activities (i.e., land development) can also change underlying factors that could affect hazard zonation.

Hazard zoning classes are presented in Table 3 below. The hazard zonation maps of the study area are presented in Appendix G.

### Table 3: Hazard Zonation Ratings and Descriptions

| Rating | Description of Rating |
|---|---|
| High | Geohazards are judged to be high in potential magnitude and/or frequency. The chance of occurrence of an event is estimated to be on the order of a 10-year return period or less. |
| High/Moderate | Further assessment is required to refine the assignment to high or moderate hazard rating zone. |
| Moderate | Geohazards are judged to be moderate in potential magnitude and/or frequency. The chance of occurrence of an event is estimated to be between a 10-year return period and a 100-year return period. |
| Moderate/Low | Further assessment is required to refine the assignment to moderate or low hazard rating zone. |
| Low | Geohazards are judged to be low in magnitude and frequency. Chance of occurrence of an event is estimated to be on the order of a 100-year return period or greater. |

Additional information and comments regarding the hazard rating polygons shown on the hazard zonation maps are presented in Table 4 below.

### Table 4: Hazard Rating Polygons

| Hazard Rating Polygon | Landslide Inventory[1] | | | Geohazard Susceptibility Mapping[2] | | | | Hazard Rating[3] | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Very Active | Active | Low Activity - Dormant | Small Landslides | Compound Landslides | Rockfall | Hydrotechnical Hazards | | |
| 1 | - | - | - | - | - | - | ✓ | Moderate/Low | |
| 2 | - | - | - | - | - | - | - | Low | |
| 3 | - | - | - | - | - | - | ✓ | Moderate/Low | |
| 4 | - | - | - | - | - | - | - | Low | |
| 5 | - | - | - | - | - | - | - | Low | |
| 6 | - | - | - | - | - | - | - | Moderate/Low | Hazard area offset 50 m from slope crest. Possible retrogression of slope instabilities. |
| 7 | - | - | ✓ | ✓ | - | - | ✓ | High/Moderate | Geomorphic evidence of past landslide activity. Possible gully erosion and instability during high flow events. |
| 8 | - | - | ✓ | ✓ | - | - | ✓ | High | Geomorphic evidence of past landslide activity. Possible gully erosion and instability during high flow events. |
| 9 | - | - | ✓ | ✓ | - | - | - | High | Geomorphic evidence of past landslide activity. |
| 10 | - | - | ✓ | ✓ | - | - | ✓ | High | Geomorphic evidence of past landslide activity. Possible gully erosion and instability during high flow events. |
| 11 | - | - | ✓ | ✓ | ✓ | - | - | High | Geomorphic evidence of past landslide activity. |
| 12 | - | - | ✓ | ✓ | ✓ | - | ✓ | High/Moderate | Possible run-out zone for landslides initiating upslope. Geomorphic evidence of past landslide run-out. Possible avulsion or lateral migration of drainage channels. |
| 13 | - | - | - | - | - | - | ✓ | Moderate | Possible run-out zone for landslides initiating upslope. Possible avulsion or lateral migration of drainage channels. |
| 14 | - | - | - | - | - | - | ✓ | Moderate/Low | Possible avulsion or lateral migration of drainage channels. |
| 15 | - | - | - | ✓ | - | - | ✓ | High/Moderate | Hazard area offset 50 m from riverbank slope crest. Possible area effected by riverbank erosion/scour and slope instabilities. Possible avulsion or lateral migration of drainage channels. |
| 16 | - | - | - | ✓ | - | - | ✓ | High | Possible avulsion or lateral migration of drainage channels. |
| 17 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | High | Active landslide area. Small landslides have occurred through airphoto/LiDAR record. Compound landslide events in 2018 and 2020. Geomorphic evidence of small and compound landslide events outside of airphoto/LiDAR record. Possible gully erosion and instability during high flow events. Rockfall hazard near active landslide areas (scarp and ridge). |
| 18 | - | ✓ | - | ✓ | ✓ | - | - | High/Moderate | Gravel pit mining operations. Small landslides have occurred through airphoto/LiDAR record. |
| 19 | - | ✓ | ✓ | ✓ | ✓ | - | - | High/Moderate | Geomorphic evidence of small and compound landslide events outside of airphoto/LiDAR record. Possible run-out zone for landslides initiating upslope. Possible reactivation of larger compound landslides. |
| 20 | ✓ | ✓ | ✓ | ✓ | ✓ | - | ✓ | High | Small landslides and erosion have occurred along riverbank through airphoto/LiDAR record. |

| Hazard Rating Polygon | Landslide Inventory[1] | | | Geohazard Susceptibility Mapping[2] | | | | Hazard Rating[3] | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Very Active | Active | Low Activity - Dormant | Small Landslides | Compound Landslides | Rockfall | Hydrotechnical Hazards | | |
| 21 | - | - | ✓ | - | - | - | ✓ | Moderate | Geomorphic evidence of compound landslide events outside of airphoto/LiDAR record. Alluvial fan susceptible to hydrotechnical hazards from Buffioux Creek. |
| 22 | - | - | ✓ | - | ✓ | - | ✓ | High/Moderate | Water well records show evidence of landslide debris overprinted by alluvial deposits. Alluvial fan susceptible to hydrotechnical hazards from Buffioux Creek. Possible run-out zone for landslides initiating upslope. |
| 23 | ✓ | ✓ | ✓ | ✓ | ✓ | - | ✓ | High | Small landslides have occurred through airphoto/LiDAR record. Geomorphic evidence of small and compound landslide events outside of airphoto/LiDAR record. Possible gully erosion and creek bank instability during high flow events. |
| 24 | - | - | ✓ | ✓ | ✓ | - | - | High | Geomorphic evidence of small and compound landslide events outside of airphoto/LiDAR record. |
| 25 | ✓ | ✓ | ✓ | ✓ | ✓ | - | ✓ | High | Possible run-out zone for landslides initiating upslope or from creek banks. Area susceptible to hydrotechnical hazards (i.e. clear water and debris flooding) |
| 26 | - | - | - | ✓ | ✓ | - | ✓ | High/Moderate | Possible run-out zone for landslides initiating upslope. Possible flooding area. |
| 27 | - | - | - | - | - | - | - | Moderate | Hazard area offset 50 m from slope crest. Possible retrogression of slope instabilities. |
| 28 | - | - | - | - | - | - | - | Low | |

Notes:
1) Landslide inventory mapping methodology is presented in Section 5.1. The landslide inventory map for the project area is presented in Appendix E.
2.) Geohazard susceptibility mapping methodology is presented in Section 5.2. The susceptibility maps for the project area are presented in Appendix F.
3.) Hazard rating definitions are provided in Table 3, Section 5.3.

## 5.4 Discussion

Based on the hazard mapping and assessment discussed above, the following specific locations are located in areas identified as having a moderate to high hazard zone rating.

### 5.4.1 Bouffioux Creek

Bouffioux Creek originates at the Alaska Highway north of the area of interest. Water flows south through the confined Bouffioux Creek valley and the creek is redirected to the east by a dike at the north end of the alluvial fan where a portion of the Old Fort resides. The creek is confined by the toe of a slope to the north and by a 400 m long dike to the south. Gabion baskets are installed on the upper portion of upstream face of the dike. Bouffioux Creek flows to the south following the dike infrastructure and crosses a City of Fort St. John (FSJ) pipeline right-of-way where concrete lock-blocks and geotextile are installed for erosional and scour protection, it is unknown if these features were built based on hydrotechnical designs. At the end of the dike to the east, the creek flows south for approximately 450 m then joins the Peace River.

The west and east banks of Bouffioux Creek are actively being undercut by water flow. Erosion of the toes of the creek bank slopes creates destabilization and multiple creek bank failures have been observed throughout the available photo/LiDAR record. Debris slide failures originating from the steep slopes to the west of the creek have occurred multiple times with debris reaching the creek bed level. It is expected that mass-wasting of the creek banks and slopes will continue. A few areas of Bouffioux Creek are experiencing slope instabilities on both sides of the creek in the same location and may be more susceptible to blocking/damming the creek. There has been no discernible movement of the large compound slide on the east side of Bouffioux Creek in the period of record reviewed.

Damage to the dike infrastructure and lock blocks erosion protection of the lower reaches of Bouffioux Creek was observed during the field reconnaissance. The gabion baskets used for erosion protection on the upstream dike face have failed into the creek bed in several locations. Photos 38 and 46 in Appendix C show pre and post dike failure of a location adjacent to Old Fort. Concrete lock blocks and no-post barriers were observed in multiple locations throughout the stream bed, it is assumed they were transported by large water flows.

The inside bend of Bouffioux Creek in proximity to where the creek transitions from south flowing to east flowing adjacent to Old Fort is susceptible to slope instabilities. A small failure partially blocking the creek was observed when Tetra Tech was on-site in July of 2020 (see Photos 50 and 51 in Appendix C). The location of the dike erosion and small failure are shown on Figure 4 below. A larger failure at this location could dam the creek and cause overtopping of the dike resulting in flooding into the Old Fort.


**Figure 4: Bank Instability and Dike Erosion Locations**

The main ongoing hazard for Bouffioux Creek is a continued destabilization and failure of the Bouffioux Creek valley walls and bank slopes. It is possible a landslide event could temporarily block the creek channel and then release a large volume of water as a debris flood/outburst flood event. Reactivation of the large compound slide on the east slopes of Bouffioux Creek could block the creek resulting in a large volume of water being impounded and eventually a large outburst flood.

## 5.4.2 Old Fort Subdivision

### 5.4.2.1 Areas north of Old Fort Road

The steep slopes north of Old Fort Road and south of the FSJ lagoons show evidence of multiple landslide events based on topography/surface texture. Most of the recent events (within the airphoto/LiDAR record) have been shallow/small earth slump/flow events which have not reached populated areas.

Properties north of Old Fort Road are within a landslide run-out zone and appear to be built on landslide deposits. Ministry of Highways (now MoTI) placed a restrictive covenant on three (3) properties in 1980 on the north side of Old Fort Road (Aquaterre Consultants Inc., 1986). The western most property was never developed. The central and eastern most properties (6748 and 6736 Old Fort Road respectively) have permanent infrastructure on the properties. From BC Assessment the house at 6748 was built in 1980, and the house at 6736 was built in 2013 (www.bcassessment.ca accessed August 2020).

#### 5.4.2.2 Areas south of Old Fort Road/East of 2018/2020 Slope Failures

Areas adjacent to the 2018/2020 slope failure events are potentially within a run-out zone if/when the bedrock ridge and/or landslide east of the ridge fails again. Generally, the residential areas east of the 2018/2020 slope failures are built on hummocky terrain which is an indicator of landslide deposits. Although, active landslides in this area were not identified in the period of record reviewed from the aerial photos/LiDAR (85-years). Understanding the compound slide run-out behaviour/return period in this area would require further study.

##### 9813, 9681, 9641, 9473 River Drive

Aquaterre (1986) recommended all lots within Block 2, Plan 14194 have a specific study by a geotechnical engineer prior to construction of permanent structures. Block 2, Plan 14194 includes the following five riverfront lots:

- Lot 1: 9813 River Drive
- Lot 2: No permanent structure
- Lot 3: 9681 River Drive
- Lot 4: 9641 River Drive
- Lot 5: 9473 River Drive

It is unknown from the information provided if the recommended site-specific geotechnical studies were completed.

The house at 9681 River Drive (Lot 4) was built in 2012 (BC Assessment, August 2020) and is built on a mid-slope bench of the riverbank. The house at 9813 River Drive (Lot 1) was built in 2007 (BC Assessment, August 2020) and the house at 9641 River Drive (Lot 3) was built in 1984 (BC Assessment, August 2020). These houses are currently located beyond the riverbank slope and have offsets ranging from 5-10 m from the slope crest. Lot 2 currently has no permanent structure. 9473 River Drive (Lot 5) was built in 2000 (BC Assessment, August 2020) and is setback approximately 40 m from the slope crest.

Based on LiDAR data, a slope failure along the south facing slopes of the riverbank below 9813 River Drive initiated between 2012 and 2015, and additional failures and landslides occurred between 2015 and 2018. No discernible movement occurred between 2018 and 2020 LiDAR datasets. Areas affected by slope movements are shown on Figure 5 below. An additional area below 9641 River Drive and adjacent to 9681 River Drive is also highlighted as an area of possible bank instability based on surface texture of the slope.

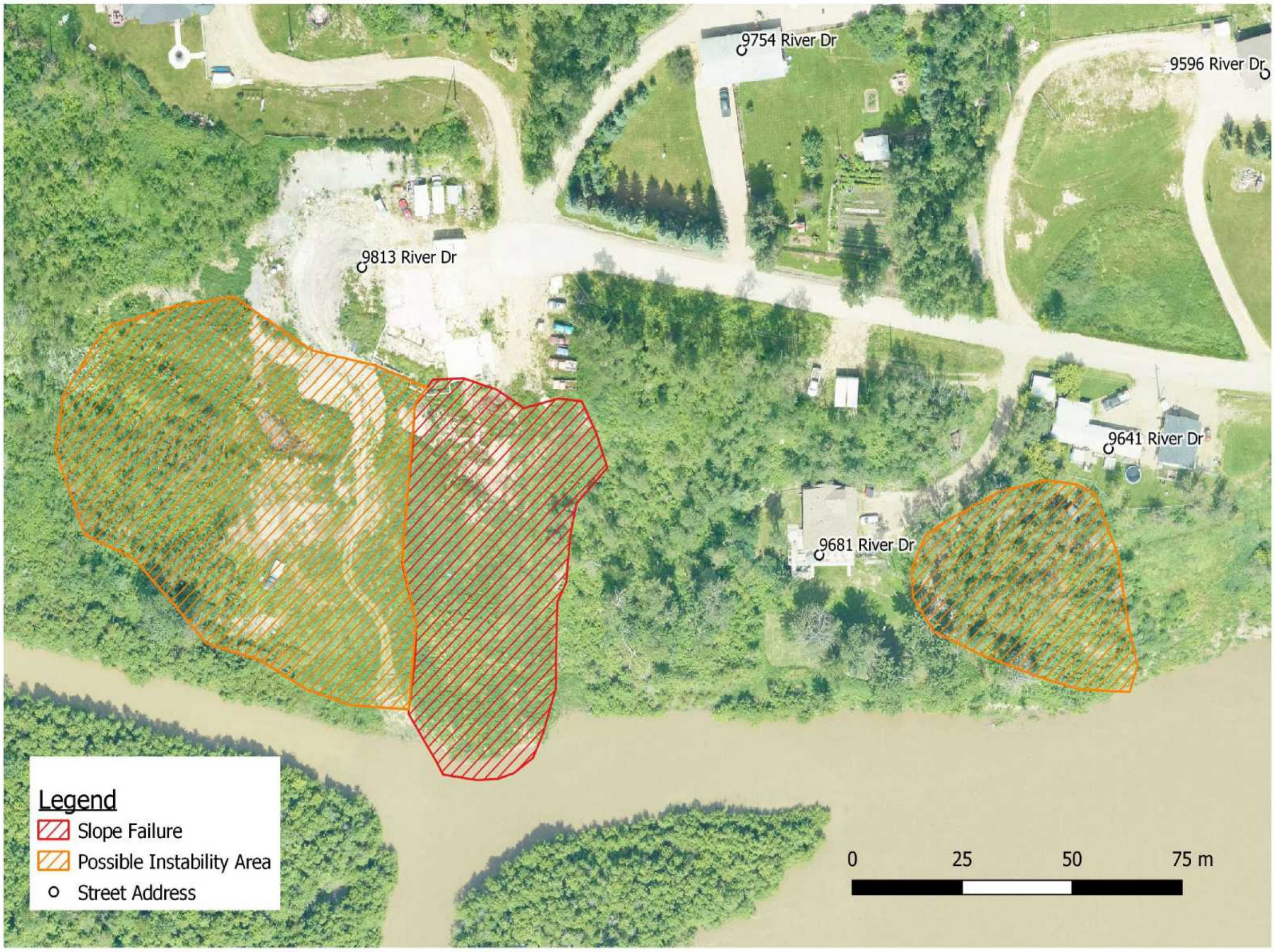


**Figure 5: River Drive Instabilities**

A gully has formed at the south west corner of 9473 River Drive lot. The gully was first visible on Google Earth imagery from 7/29/2017. Based on LiDAR data, the gully has regressed approximately 10 m between 2018 and 2020.

The 2015 LiDAR dataset shows a slope failure at the east end of the 9641 River Drive property at the location where a drainage path entered the Peace River. Google Earth imagery from 4/25/2016 shows site grading and possible slope repair and re-alignment of the drainage path at 9641 and 9473 River Drive. The drainage path was shifted 10 m to the east to the location of the current gully failure. Figure 6 below shows the location of the current gully failure and the location of the slope failure.


**Figure 6: Gully forming south of River Drive on Peace River slope**

Recent bank failure and erosion below and adjacent to the properties highlight the ongoing bank erosion and slope instability hazard. The Peace River back channel that was blocked by the 2018/2020 earthflow events rejoins the Peace River near this location. There is uncertainty in how the earthflow landslide dam may affect river flow or change erosion patterns below the lots on River Drive adjacent to the Peace River.

### 5.4.2.3 Areas West of 2018/2020 Slope Failures

The slopes west of the 2018/2020 slope failures have had small landslide failures throughout the aerial photo/LiDAR record. The slopes to the south and east of the lookout at the south end of 265 Road are actively deforming. Based on field observations, the failures are shallow and appear to deform during wet periods/high rainfall events. During the field support for the 2020 failure event, a shallow earth slump/flow was observed on the south facing slopes below a pond at 6786 265 Road (see Photo 31 in Appendix C). Further regression of this failure could cause the pond to breach which could impact the properties downslope. Figure 7 below shows the failure location.

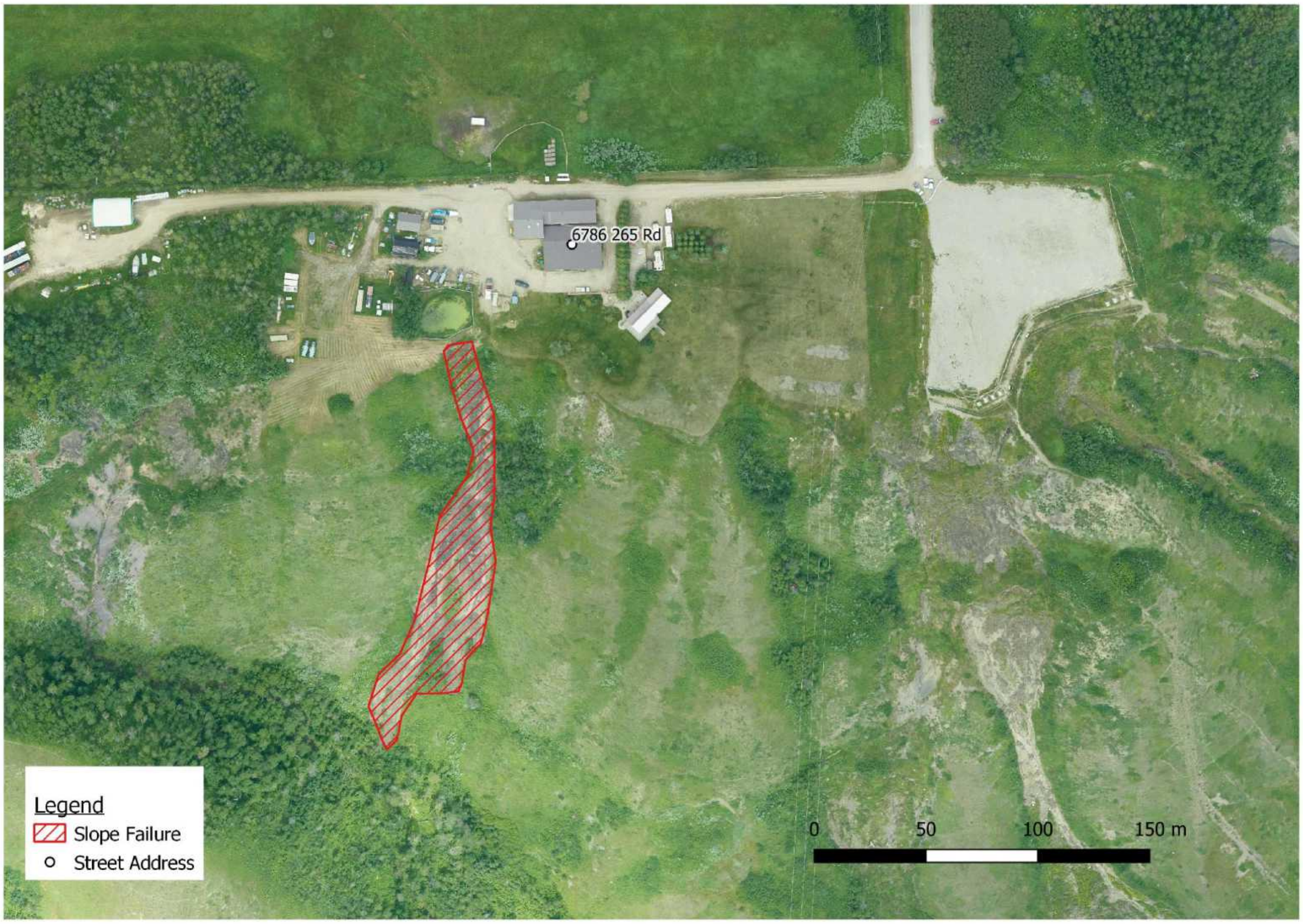


**Figure 7: Slope Failure below 6786 265 Road**

Further west of 2018/2020 failures there is evidence of small and large failures of the valley slopes. These slopes are considered to be Low Activity – Dormant as shown in the landslide inventory (Appendix E).

# 6.0 BOUFFIOUX CREEK FLOOD HAZARD ASSESSMENT

This section summarizes the results of the Bouffioux Creek flood modelling and hazard assessment. A memo detailing the flood modelling method, data sources, analysis and results is attached in Appendix H.

Tetra Tech performed flood modelling of Bouffioux Creek as part of this assessment. LiDAR data from October 2018 was combined with data from the High-Resolution Digital Elevation Model (HRDEM) produced by Natural Resources Canada to produce a topographic surface of the catchment that feeds into Bouffioux Creek.

Climatic data from Environment Canada weather station 1183000 – Fort St. John A, B.C. covering daily precipitation from 1973 to 2002 was used to produce intensity-duration-frequency (IDF) curves for the Fort St. John Area for 2, 5, 10, 25, 50, 100, and 200 year return periods. An SCS Type-II rainfall distribution was used to model the 200-year return period storm events to reflect conservative scenarios for the purpose of long-term planning, and it was found that a 12-hour storm event gave the greatest peak flow into the creek.

PCSWMM software (Version 7.2.2785) was used to model the hydrology of the catchment feeding into the Bouffioux Creek. A catchment of approximately 1,280 hectares was delineated. Given that the model aims to analyze major 1-in-200 year rain events, the larger subcatchments were mainly delineated based on topography produced by the high-resolution LiDAR data, with the more precise extents of the urban catchment being refined using stormwater system GIS data provided by FSJ. In concurrence with observations made in the 2004 Drainage Report for the Ministry of Transportation for the Alaska Highway No. 97 – Fort St. John Corridor Improvements, and the 2013 City of Fort St. John Stormwater Master Plan published by Urban Systems, it was found that the sizing of the existing storm sewer system of FSJ is not capable of fully conveying the major 1-in-200 year storm events into Bouffioux Creek, due to the existing storm pipe infrastructure acting as a bottleneck for the runoff and discharge into the creek. Therefore, the hydrological model is conservative as it assumes a scenario in which all storm runoff from FSJ is routed directly into the creek, rather than through the existing storm system. This scenario intends to represent a case in which FSJ's future storm water system is fully upgraded.

The inflow response was then input into the HEC-RAS 2D software (Version 5.0.7) to model the flow through the creek, with simulations being run for the full 12-hour storm duration, plus a 2-hour buffer at the end of the event to capture any residual effects. In the hydraulic model, the inflow volume was combined with a debris-bulking factor, which intends to reflect the collection of sediments, vegetation, and other debris in the stream due to erosion and sloughing along the path of the channel, thus bulking the volume of the flow in the stream. In this model, a debris-bulking factor of 2.0 was used. In physical terms, this represents a 100% increase in the volume of flow entering the creek, or in other words, 200% of the volume of clearwater (no debris) flow. The model was run at first with the assumption of clearwater only to be entering the creek, then again with the volume of inflow bulked by sediment.

It was found that no significant flooding occurs in the Old Fort Area for a clearwater (no debris) case. However, by including the effect of debris-bulking it was found that flooding occurs south of the dike alignment at the north end of Old Fort. The predicted flooding extents for the clearwater, and debris-bulked scenarios are shown below on Figure 8.

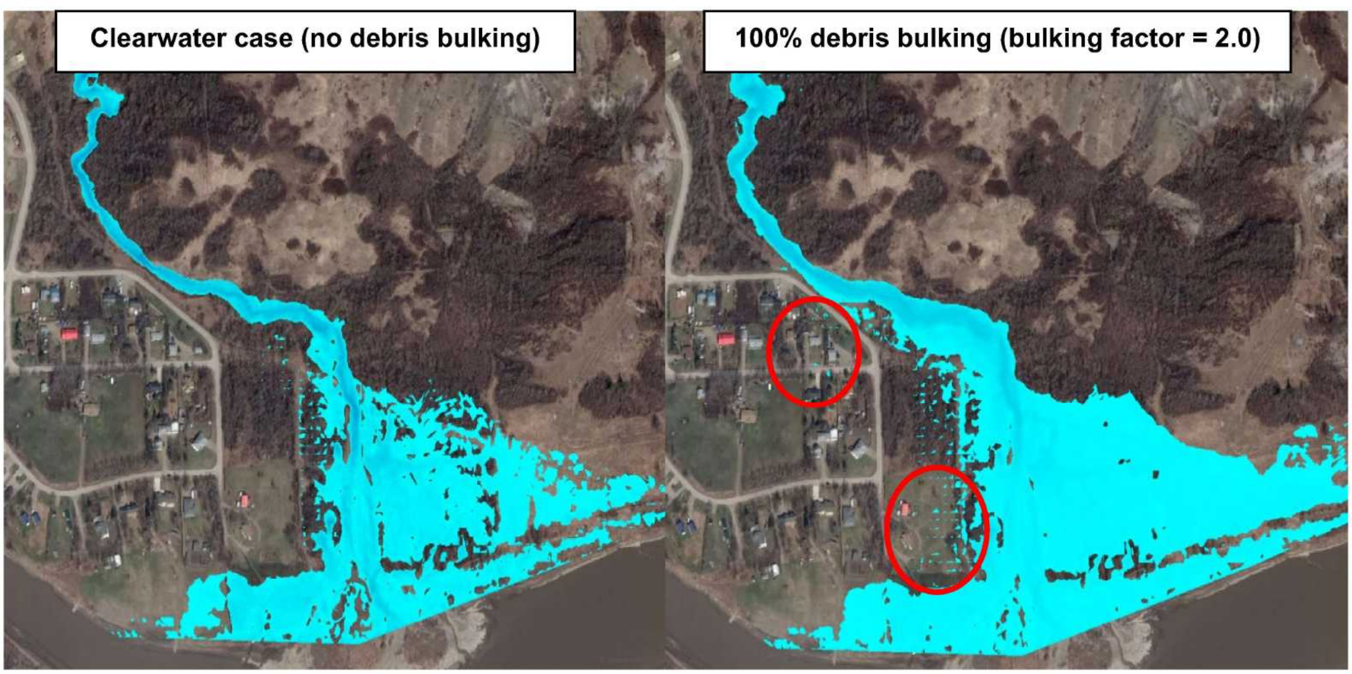


**Figure 8: Predicted flooding extents for the clearwater (left), and debris-bulked (right) cases in Old Fort**

In agreement again with the 2004 and 2013 Urban Systems reports, it is likely that this debris-bulked scenario will be the more likely case in the future, and may worsen over time as FSJ continues to develop and urbanize the upstream land, coinciding with the stormwater system upgrades which would increase discharge into the creek.

A memo detailing the flood modelling method, data sources, analysis and results is attached in Appendix H.

# 7.0 CLOSURE

We trust this document meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

File No. 704-ENG.VGEO3774-01
File No. 704-ENG.VGEO3774-01
File No. 704-ENG.VGEO3774-01

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# APPENDIX A

## WATER WELL ATLAS DATA

## Table A-1: Summary of BC Groundwater Atlas – Lower Wells

| Subgrade Description | Well Tag Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 39966 | 46054 | 55955 | 59676 | 83243 | 102681 | 113686 |
| Well Collar Elevation (masl) | 431 | 431 | 425 | 431 | 415 | 431 | 410 |
| Fine-Grained Soil (m) | 0 – 8 | 0 – 31 | 0 – 2 | 0 – 28 | - | - | 0 – 2 |
| Fine and Coarse Soil (m) | - | - | 2 – 20 | - | - | - | - |
| Coarse-Grained Soil (m) | 8 – 37 | 31 – 34 | 20 - 24 | 28 – 30 | 0 – 5 | 0 – 12 | 2 – 12 |
| Bedrock (m) | - | 34 | - | - | - | - | - |
| Total Depth (m) | 37 | 34 | 24 | 30 | 5 | 12 | 12 |

Notes:

1. Data from BC Water Well Atlas.
2. Well collar elevations from BCFS 2015 Lidar.
3. “Fine and Coarse Soil” is possible landslide debris.

## Table A-2: Depths of Encountered Lithology from BC Groundwater Atlas - Upper Wells

| Subgrade Description | Well Tag Number | | | | |
|---|---|---|---|---|---|
| | 16924 | 46593 | 80278 | 80284 | 102759 |
| Well Collar Elevation (masl) | 648 | 648 | 682 | 648 | 651 |
| Upper Fine-Grained Soil (m) | 0 – 20 | 0 – 12 | 0 – 4 | 0 – 17 | 0 – 14 |
| Upper Coarse-Grained Soil (m) | - | - | 4 – 32 | 17 – 21 | - |
| Lower Fine-Grained Soil (m) | - | - | 32 – 34 | 21 – 24 | - |
| Coarse Grained Soil (m) | 20 – 35 | 12 – 24 | 34 – 56 | - | 14 – 30 |
| Bedrock (m) | 35 – 99 | 24 – 137 | 56 - 99 | 24 – 92 | 30 – 49 |
| Total Depth (m) | 99 | 137 | 99 | 30 | 49 |

Notes:

1. Data from BC Water Well Atlas.
2. Well collar elevations from BCFS 2015 Lidar.

# APPENDIX B

## AERIAL PHOTO OBSERVATIONS

## Table B-1: Summary of Aerial Photo Review

| Number | Year | Approximate Scale | Comments |
|---|---|---|---|
| A8294 Photos 28-32<br>A8050 Photos 64-68 | 1945 | Scale not listed on scan or on GeoBC air photo index. Scale estimated as 1:20,000 | ▪ Borrow pit active; entrance to pit is along the east edge of drainage channel (to the west of the pit)<br>▪ No evidence of fresh failures within Old Fort Landslide Complex<br>▪ Hard to discern Bouffioux Creek drainage path adjacent to Old Fort, but the creek appears to follow alignment similar to modern day alignment. |
| BC1196 Photos 63-65 | 1950 | Scale not listed on scan or on GeoBC air photo index. Scale estimated as 1:38,000 | ▪ Low resolution<br>▪ No relevant changes from 1945 photos observed |
| BC1777 Photos 46-49 | 1953 | Scale not listed on scan or on GeoBC air photo index. Scale estimated as 1:32,000 | ▪ Farming in area now occupied by lagoons<br>▪ Farming on the plateau to the east of Bouffioux Creek |
| BC2171 Photos 35-37 | 1956 | Scale not listed on scan or on GeoBC air photo index. Scale estimated as 1:32,000 | ▪ Low resolution<br>▪ No relevant changes from 1956 photos observed |
| BC5042 Photos 137-139<br>BC5042 Photos 150-152 | 1962 | Scale not listed on scan or on GeoBC air photo index. Scale estimated as 1:36,000 | ▪ Mining operations extended to the east to the slopes south of the modern-day lagoon.<br>▪ Evidence of end dumping and/or failure of material below mining operation south of the lagoon.<br>▪ Clearing along pipeline right of way east of Old Fort |
| BC5165 Photos 85-87<br>BC5165 Photos 152-155 | 1965 | 1:32,000 | ▪ Failure (debris slide) of west slope of channel that is adjacent to the west side of the borrow pit.<br>▪ Possible damming of water within channel.<br>▪ A road was established to the head scarp of the failure. |
| BC5269 Photos 6-8 | 1967 | 1:32,000 | ▪ Possible roadworks or instability of Old Fort Road directly south of ridge. |
| BC7279 Photos 145-147<br>BC7279 Photos 40-43<br>BC7278 Photos 237-240 | 1970 | 1:16,000 | ▪ No longer any appearance of damming of the channel observed in the 1965 photos.<br>▪ South end of borrow pit has a large/steep excavation. Northern extent of the extraction pit appears to be in a similar location as the backscarp from 2018/2020 failures events. |
| BC5439 Photos 264-267 | 1971 | 1:32,000 | ▪ Construction of the FSJ lagoons. |
| BC5694 Photos 152-155 | 1975 | Scale not listed on scan or on GeoBC air photo index. Scale estimated as 1:45,000 | ▪ Large flow failure from the south-east side of the borrow pit (initiation appears to be within pit). Failure run-out is adjacent to the ridge, but does not impact any infrastructure.<br>▪ It appears that end dumped material in the pit mobilized as part of a larger flow failure. |

| Number | Year | Approximate Scale | Comments |
|---|---|---|---|
| BC7836 Photos 249-251<br>BC7836 Photos 298-301<br>BC7837 Photos 3-6 | 1976 | Scale not listed on scan or on GeoBC air photo index. Scale estimated as 1:20,000 | ▪ Clearer imagery of failure from south-east side of the borrow pit.<br>▪ Appears to be flow style failure. Run-out was contained by natural topography.<br>▪ Evidence of recent slope instability of the terrain east of the ridge based on tilted trees. |
| BC78043 Photos 29-35<br>BC78048 Photos 228-233 | 1978 | 1:20,000 | ▪ Debris slide on west bank of Bouffioux Creek. Location is approximately the same as observed in the field in 2020.<br>▪ Unclear of how much material flowed into the creek and if damming occurred. |
| BC81016 Photos 17-22<br>BC81016 Photos 79-84 | 1981 | 1:20,000 | ▪ An additional debris slide was observed north of the debris slide failure at the location on west bank of Bouffioux Creek.<br>▪ Failure on west side of borrow pit into drainage channel. Failure includes road and possibly effects buildings at the crest of the slope within the borrow pit.<br>▪ Material changes to the south bank of Bouffioux Creek observed, this could be evidence of flooding or debris floods at Bouffioux Creek or related to dike construction or dike vegetation clearing. No changes observed to the community/houses. |
| BC82032 Photos 130-132<br>BC82032 Photos 86-90<br>BC82032 Photos 97-100 | 1982 | 1:16,000 | ▪ North-south tension crack visible on west side of borrow pit (approximately 20 m long).<br>▪ East lagoon cell appears to be partially/fully drained. No visible breach of perimeter berm.<br>▪ Possible construction at the Old Fort Road gully crossing (area affected by 2018/2020 channelized earthflow) |
| BC86047 Photos 130-131 | 1986 | 1:60,000 | ▪ Scale too large to observe geohazard features. |
| BC87018 Photos 70-74<br>BC87018 Photos 80-85 | 1987 | 1:15,000 | ▪ Tension crack still visible on west side of borrow pit. No discernible changes.<br>▪ Debris slide failures on west bank of Bouffioux Creek observed in 1978/1981 photos has revegetated.<br>▪ Large excavations on east side of borrow pit. |
| 15BCB90002 Photos 64-70<br>15BCB90002 Photos 91-97<br>15BCB90002 Photos 128-132 | 1990 | 1:10,000 | ▪ Further lateral (south) expansion of road failure on west side of the gravel pit (run-out into channel), first observed in 1981.<br>▪ Tension crack near south end of borrow pit is not visible. Inferred that it was infilled.<br>▪ Earth slide failure of east wall of borrow pit. |
| 30BCC95043 Photos 44-48 | 1995 | 1:15,000 | ▪ No relevant changes from 1990 observations |
| 15BCB96095 Photos 97-99 | 1996 | 1:40,000 | ▪ No relevant changes from 1990 observations |

| Number | Year | Approximate Scale | Comments |
|---|---|---|---|
| 30BCC97159 Photos 204-209 | 1997 | 1:15,000 | ▪ Fresh clearing along pipeline right of way at the lower part of the slope (east of Old Fort and Bouffioux Creek alignment).<br>▪ Debris slide on the east bank of Bouffioux Creek (approximately across the creek of 1978/1981 debris slide failures)<br>▪ Scour of drainage paths on west slopes of Buffioux Creek. |
| 15BCC05129 Photos 49-51 | 2005 | 1:30,000 | ▪ South/east lagoons appear emptied/infilled. |
| 15BCC06023 Photos 135-138 | 2006 | 1:30,000 | ▪ No relevant changes from 2006 observations |

# APPENDIX C

## 2020 SITE VISIT PHOTOS

**Photo 1:** Tetra Tech meeting at the west flank of the earthflow at Old Fort Road with MoTI
June 20, 2020

**Photo 2:** Photo taken from on top of the earthflow looking east towards the bedrock ridge.
June 20, 2020

**Photo 3:** Old Fort Road being pushed to the south (note: tension cracks and earthflow bulge)
June 20, 2020

**Photo 4:** View of Old Fort Road displacement looking south from the look-out.
June 20, 2020

**Photo 5:** Overview of the back-scarp (borrow pit), main scarp (foreground) and ridge. Earthflow flowing left to right.
June 20, 2020

**Photo 6:** Close-up of the bedrock ridge.
June 20, 2020

**Photo 7:** Slope relaxation and deformation on the steep slopes near the south end of the look-out.
June 20, 2020

**Photo 8:** Slope relaxation and surface failures on the steep slopes on the south end of the look-out.
June 20, 2020

**Photo 9:** Picture from Old Fort Road, looking north/up to the look-out – scarp from 2018 west landslide failure.
June 21, 2020

**Photo 10:** Photo taken from on top of the earthflow looking up/north towards the main scarp and bedrock ridge.
June 21, 2020

**Photo 11:** Photo of house damaged by 2018 landslide.
June 22, 2020

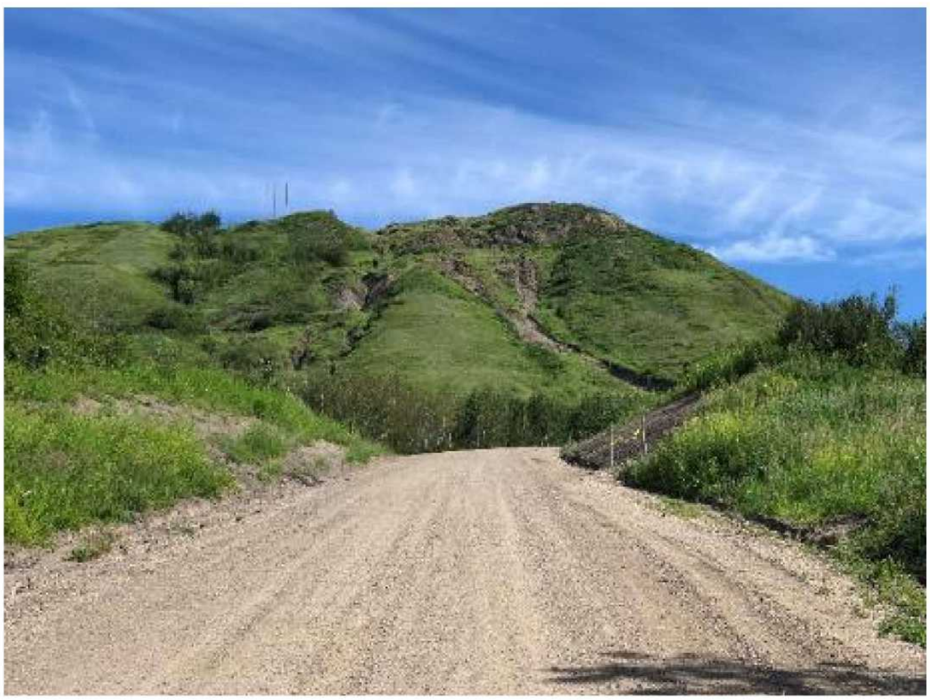


**Photo 12:** View of south facing slopes (below look-out). Multiple surface instabilities (shallow slump-flows).
June 22, 2020

**Photo 13:** Deep tension cracks (approximately 6' deep) on west boundary of west landslide which occurred in 2018.
June 22, 2020

**Photo 14:** Overview of the back-scarp (borrow pit), main scarp (foreground) and ridge. Earthflow flowing left to right.
June 22, 2020

**Photo 15:** Landslide terrain reconnaissance

June 23, 2020

**Photo 16:** Exposed soil (cracks) from surface deformation on east side of ridge
June 23, 2020

**Photo 17:** Backside of ridge – ridge was splitting and failing.
June 23, 2020

**Photo 18:** Tension cracks forming on south-east side of borrow pit platforms due to landslide deformation.
June 23, 2020

**Photo 19:** Overview of the back-scarp (borrow pit), main scarp (foreground) and ridge.
Earthflow flowing left to right.
June 24, 2020

**Photo 20:** Large tension crack crossing the length of the lower borrow pit bench.
June 24, 2020

**Photo 21:** Overview of the back-scarp (borrow pit), main scarp (foreground) and ridge.
Earthflow flowing left to right.
June 29, 2020

**Photo 22:** View of earthflow and Old Fort Road from viewpoint.
June 29, 2020

**Photo 23:** View of ridge from viewpoint.
July 2, 2020

**Photo 24:** View of lower bench in borrow pit (tension crack trends approximately west-east)
July 3, 2020

**Photo 25:** Ponded water in graben formed in borrow pit. MoTI GPS unit in pond around GPS unit.
July 3, 2020

**Photo 26:** Surficial water flows through the earthflow mass after high precipitation event.
July 3, 2020

**Photo 27:** Surficial slope instabilities adjacent to viewpoint.
July 7, 2020

**Photo 28:** Failure of block at main scarp.
July 7, 2020

**Photo 29:** Excavator removing garbage (car parts) from earthflow mass.
July 7, 2020

**Photo 30:** Overview of the back-scarp (borrow pit), main scarp (foreground) and ridge.
Earthflow flowing left to right.
July 7, 2020

**Photo 31:** Surficial flow failure on south facing slopes west of 2018/2020 landslide .
July 8, 2020

**Photo 32:** ATV road roughed across earthflow.
July 8, 2020

**Photo 33:** Start of construction of temporary access road over earthflow.
July 9, 2020

**Photo 34:** Temporary access road spans earthflow and began allowing 4x4 traffic into Old Fort.
July 10, 2020

**Photo 35:** Gabion baskets at west end of Bouffioux Creek dike.
June 22, 2020

**Photo 36:** Concrete no post barriers dumped into Bouffioux creek adjacent to residential area.
June 22, 2020

**Photo 37:** Gabion baskets partially in Bouffioux Creek near residential area (looking downstream).
June 22, 2020

**Photo 38:** Tetra Tech inspecting banks of Bouffioux Creek and dike (pre-failure at this location)
June 22, 2020

**Photo 39:** Diamicton (clay matrix) deposits exposed by erosion in Bouffioux Creek. June 22, 2020

**Photo 40:** Lock block armouring (partially failing) east of Old Fort in Bouffioux Creek. June 22, 2020

**Photo 41:** Lock block armouring (failing) east of Old Fort in Bouffioux Creek.
June 22, 2020

**Photo 42:** High creek flows in Bouffioux Creek following high precipitation event.
July 3, 2020

**Photo 43:** Debris in Bouffioux Creek near lock blocks east of Old Fort
July 3, 2020

**Photo 44:** Localized flooding and pile of debris at confluence of Bouffioux Creek and Peace River.
July 3, 2020

**Photo 45:** Localized flooding and debris accumulation at confluence of Bouffioux Creek and Peace River.
July 3, 2020

**Photo 46:** Bouffioux Creek bank and gabion basket failure (see Photo 38 for pre-storm picture).
July 8, 2020

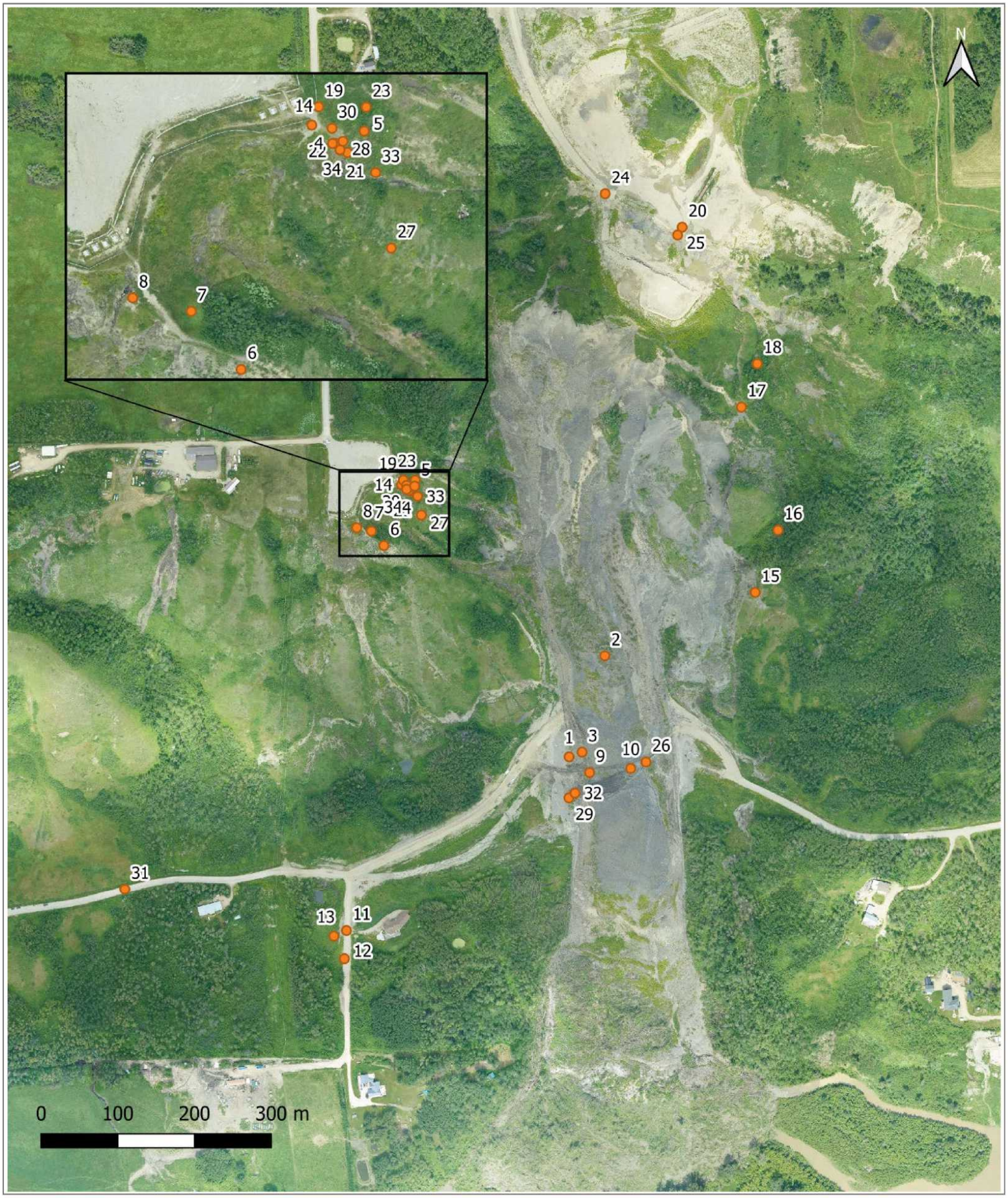
**Photo 47:** Additional failure of the concrete lock blocks in Bouffioux Creek east of Old Fort. July 8, 2020

**Photo 48:** Additional failure of the concrete lock blocks in Bouffioux Creek east of Old Fort. July 8, 2020

**Photo 49:** Debris Slide failure on west slopes of Bouffioux Creek.
July 10, 2020

**Photo 50:** Partial blockage/damming of Bouffioux Creek due to debris failure on the inside bend adjacent to Old Fort.
July 10, 2020

**Photo 51:** Partial blockage/damming of Bouffioux Creek due to debris failure on the inside bend adjacent to Old Fort.
July 10, 2020




## LEGEND

Photo Location

**NOTES**

Base data source:
Imagery from Terra Remote Sensing (July 2020)

**STATUS**

ISSUED FOR USE

**CLIENT**

**Peace River Regional District**

TETRA TECH

# OLD FORT HAZARD ASSESSMENT
# OLD FORT, BC

## Photo Locations
## Failure Event

| PROJECT NO. | DWN | CKD | APVD | REV |
|---|---|---|---|---|
| ENG.VGEO03774-01 | BC | AR | AR | 0 |

| OFFICE | DATE |
|---|---|
| EBA-VANC | JUNE 7, 2021 |

**Figure C1**


**LEGEND**

Photo Location

**NOTES**

Base data source:
Imagery from Terra Remote Sensing (July 2020)

**STATUS**

ISSUED FOR USE

**CLIENT**

**Peace River Regional District**

TETRA TECH

**OLD FORT HAZARD ASSESSMENT**
**OLD FORT, BC**

**Photo Locations**
**Bouffioux Creek**

| PROJECT NO. | DWN | CKD | APVD | REV |
|---|---|---|---|---|
| ENG.VGEO03774-01 | BC | AR | AR | 0 |

| OFFICE | DATE |
|---|---|
| EBA-VANC | JUNE 7, 2021 |

**Figure C2**

# APPENDIX D

## TERRAIN MAP

## TERRAIN SYMBOLS

**Simple Terrain Symbols:** Used when on surficial material is present within a polygon.

Example: Lb – Vs

- Surface Material: L
- Surface Expression: b
- Geomorphological process sub-type: s
- Geomorphological process (up to 3 may be assigned): V

**Composite Terrain Symbols:** Used when 2 or 3 terrain types are present within a polygon.

| | |
|---|---|
| Lb.Mb | Indicates that 'L' and 'M' are roughly equal in extent |
| Lb/Mb | Indicates that 'L' is greater in extent than 'M' (about 60:40) |
| Lb//Mb | Indicates that 'L' is much greater in extent than 'M' (about 80:20) |

**Stratigraphic Terrain Symbols:**

| | |
|---|---|
| Lb\|Mu | Indicates that 'Lb' Overlies 'Mu' |
| /Lb\|Mu | Indicates that 'Lb' Partially Overlies 'Mu' |

**Surficial Material Types:**

| | | | | | |
|---|---|---|---|---|---|
| C | Colluvium | R | Bedrock | LG | Glaciolacustrine |
| L | Lacustrine | M | Glacial Till | FG | Glaciofluvial |
| F | Fluvial | A | Active Floodplain | X | Anthropogenic |

**Surface Expressions**

| | | | |
|---|---|---|---|
| p | Plain (0-3˚) | v | Veneer (0-2 m thick deposit) |
| j | Gentle Slope (4-14˚) | b | Blanket (>2 m thick deposit) |
| a | Moderate Slope (15-26˚) | w | Variable thickness deposit |
| k | Moderate Steep Slope (27-35˚) | m | Rolling |
| s | Steep Slope (>35˚) | h | Hummocky |
| c | Cone (>15˚) | f | Fan (<15˚) |
| r | Ridge | u | Undulating |
| t | Terrace | | |

**Geomorphological Processes**

| | | | |
|---|---|---|---|
| R | Rapid landslide (runout zone) | V | Gully erosion |
| R'' | Rapid landslide (initiation zone) | F | Slow landslide (runout zone) |
| U | Flooding | F'' | Slow landslide (initiation zone) |

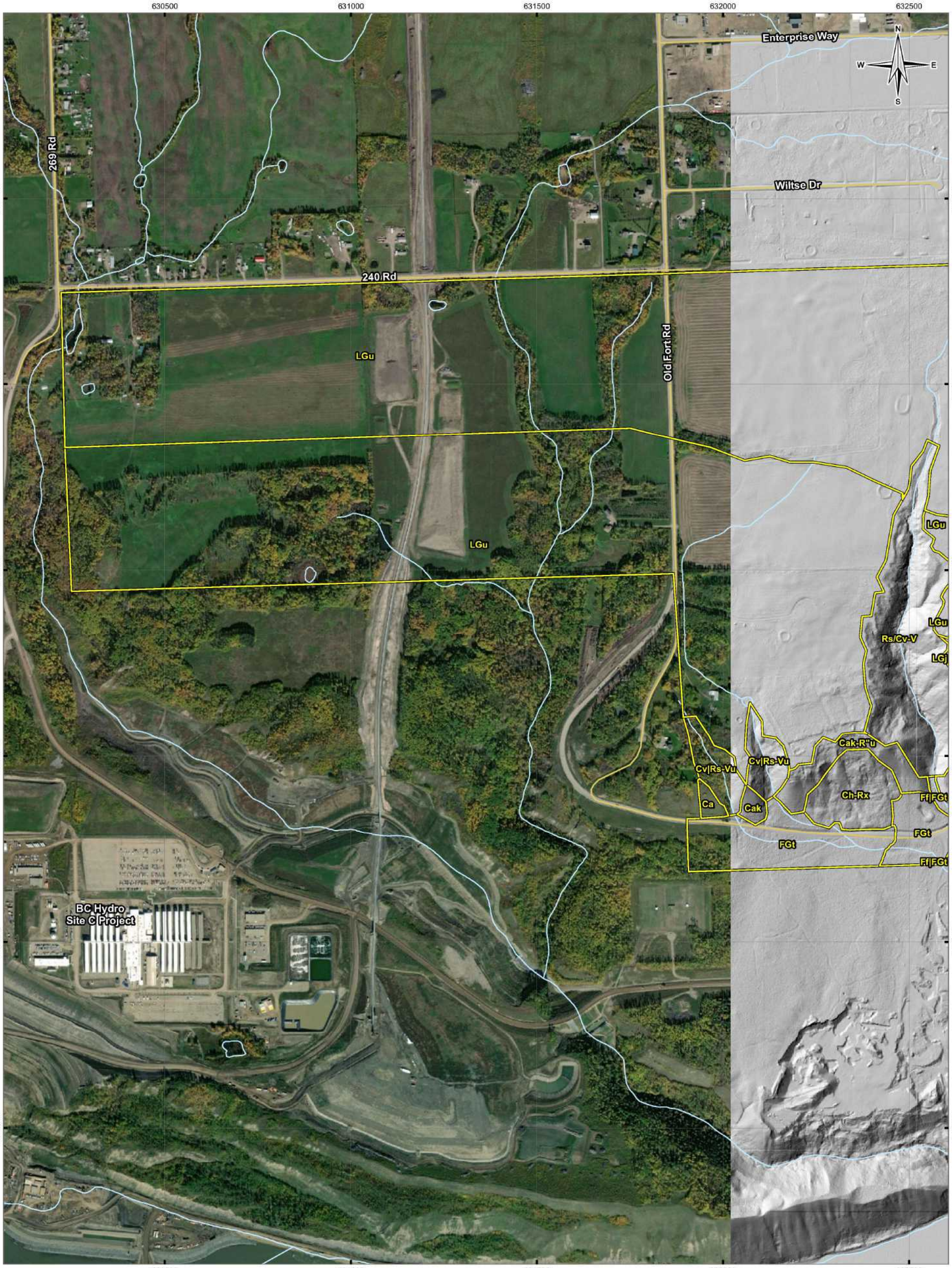
**Geomorphological Process Subtypes (may be combined)**

| | | | | | |
|---|---|---|---|---|---|
| b | Rockfall | m | Bedrock slump | r | Rock slides (Rr, R"r) |
| d | Debris flows | s | Debris avalanches | c | Soil Creep |
| e | Earthflow | a | Channel Avulsion | u | Surficial material slump |
| x | Slump-earthflow | | | | |

**Examples:**

| | |
|---|---|
| /Lb.Mv | Partial cover of a lacustrine blanket over a till veneer |
| Ra//LGb – VR"sd | Moderately sloped bedrock with <20% cover of a glaciolacustrine blanket; gullied with runout zones for debris avalanches and earthflow |

Q:\Vancouver\GIS\ENGINEERING\VGEO\VGEO03774-01\Maps\VGEO03774-01_FigD1_Terrain.mxd modified 6/8/2021 by stephanie.leusink




## LEGEND

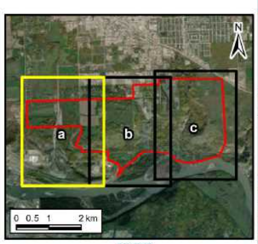
Terrain Polygon[1]

**Base Data**

Local Road

Watercourse

Waterbody




**NOTES**

1. Legend for the Terrain Symbols is provided in Appendix D.

Base data sources:
CanVec 1:50,000 (2019).
Hillshade from a combination of Terra Remote Sensing LiDAR (2020) & BC Forestry Service LiDAR (2015).
Imagery from ESRI; Maxar (2019).

**STATUS**
ISSUED FOR USE

## OLD FORT HAZARD ASSESSMENT
## OLD FORT, BC

### Terrain Classification

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | Peace River Regional District |

Scale: 1:10,000
200 100 0 200
Metres

FILE NO.
VGEO03774-01_FigD1_Terrain.mxd

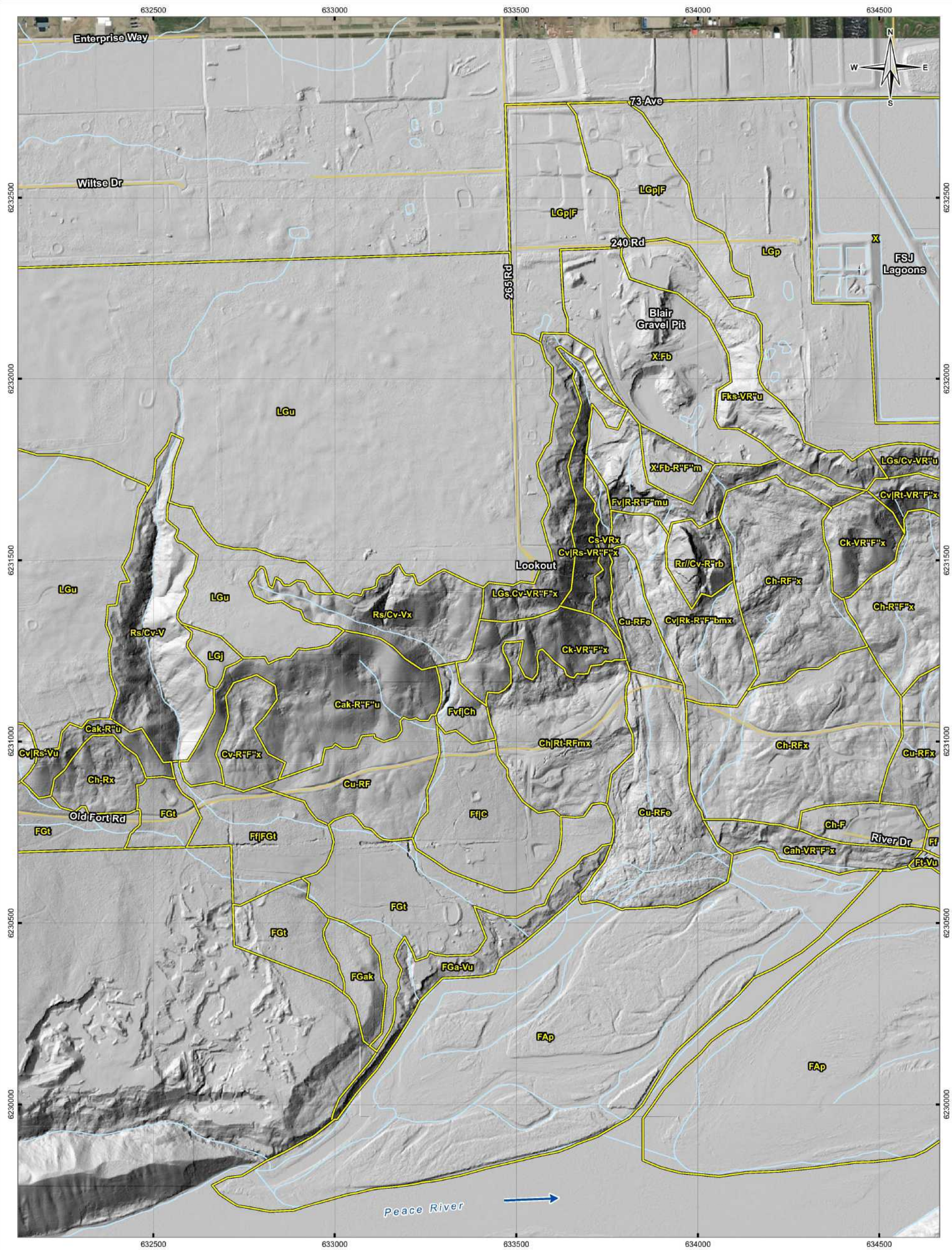
TETRA TECH

| OFFICE | DWN | CKD | APVD | REV |
|---|---|---|---|---|
| TI-VANC | SL | RG | BC | 0 |

| DATE | PROJECT NO. |
|---|---|
| June 7, 2021 | ENG.VGEO03774-01 |

**Figure D1a**

Q:\Vancouver\GIS\ENGINEERING\VGEO\VGEO03774-01\Maps\VGEO03774-01_FigD1_Terrain.mxd modified 6/8/2021 by stephanie.leusink




## LEGEND

Terrain Polygon[1]

**Base Data**

Local Road

Watercourse

Waterbody

**NOTES**

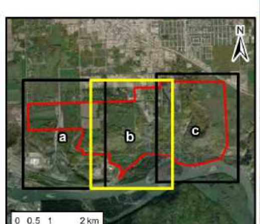
1. Legend for the Terrain Symbols is provided in Appendix D.

Base data sources:

CanVec 1:50,000 (2019).

Hillshade from a combination of Terra Remote Sensing LiDAR (2020) & BC Forestry Service LiDAR (2015).

Imagery from ESRI; Maxar (2019).




STATUS
ISSUED FOR USE

## OLD FORT HAZARD ASSESSMENT
## OLD FORT, BC

### Terrain Classification

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | Peace River Regional District |

Scale: 1:10,000

200 100 0 200

Metres

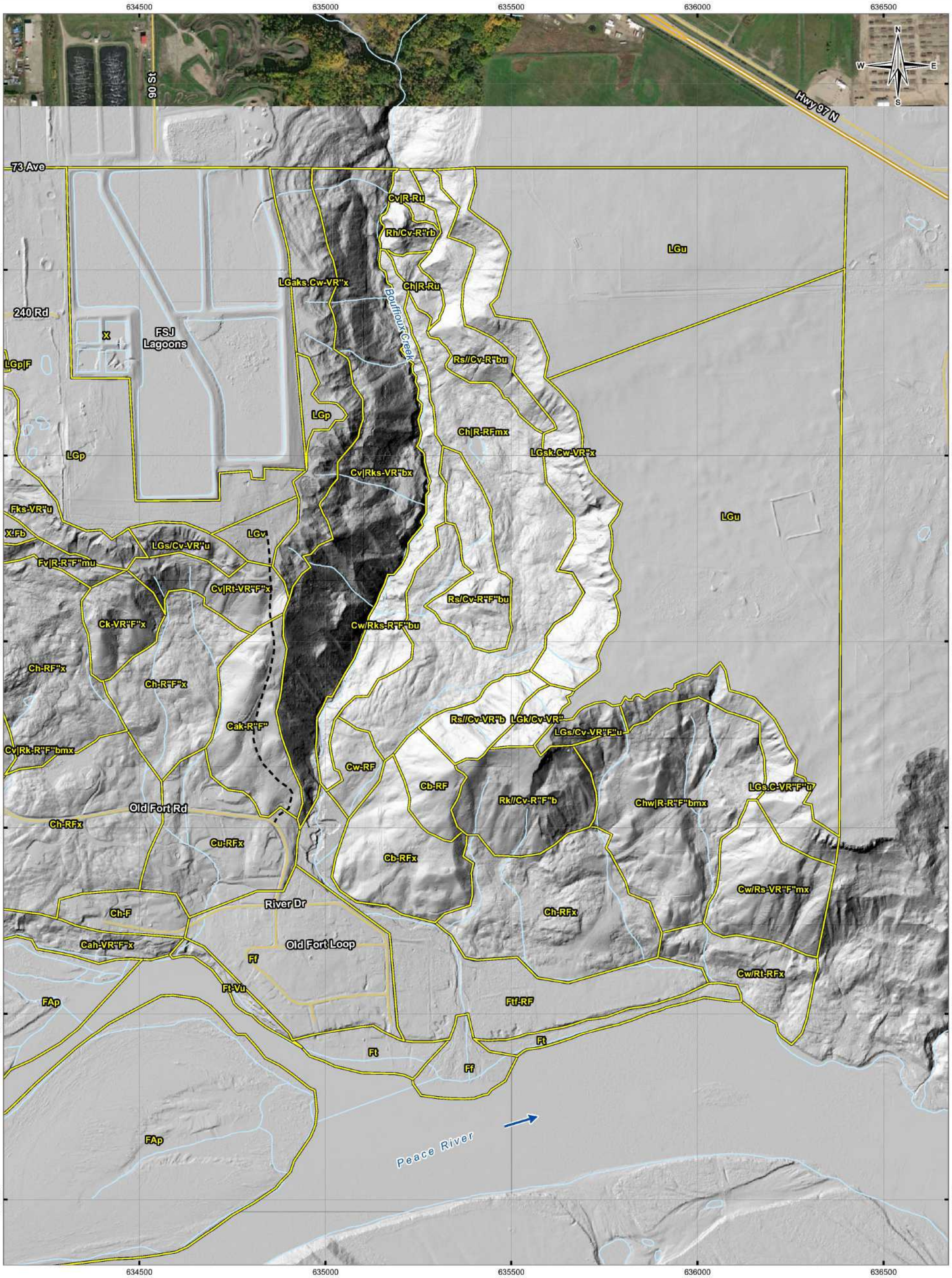
FILE NO.
VGEO03774-01_FigD1_Terrain.mxd

| OFFICE | DWN | CKD | APVD | REV |
|---|---|---|---|---|
| TI-VANC | SL | RG | BC | 0 |

| DATE | PROJECT NO. |
|---|---|
| June 7, 2021 | ENG.VGEO03774-01 |

TETRA TECH

**Figure D1b**




## LEGEND

Terrain Polygon[1]

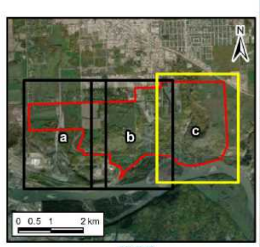
**Base Data**

- Highway
- Main Road
- Local Road
- Trail
- Watercourse
- Waterbody

**NOTES**

1. Legend for the Terrain Symbols is provided in Appendix D.

Base data sources:
CanVec 1:50,000 (2019).
Hillshade from a combination of Terra Remote Sensing LiDAR (2020) & BC Forestry Service LiDAR (2015).
Imagery from ESRI; Maxar (2019).




STATUS
ISSUED FOR USE

# OLD FORT HAZARD ASSESSMENT OLD FORT, BC

## Terrain Classification

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | Peace River Regional District |

Scale: 1:10,000
200 100 0 200
Metres

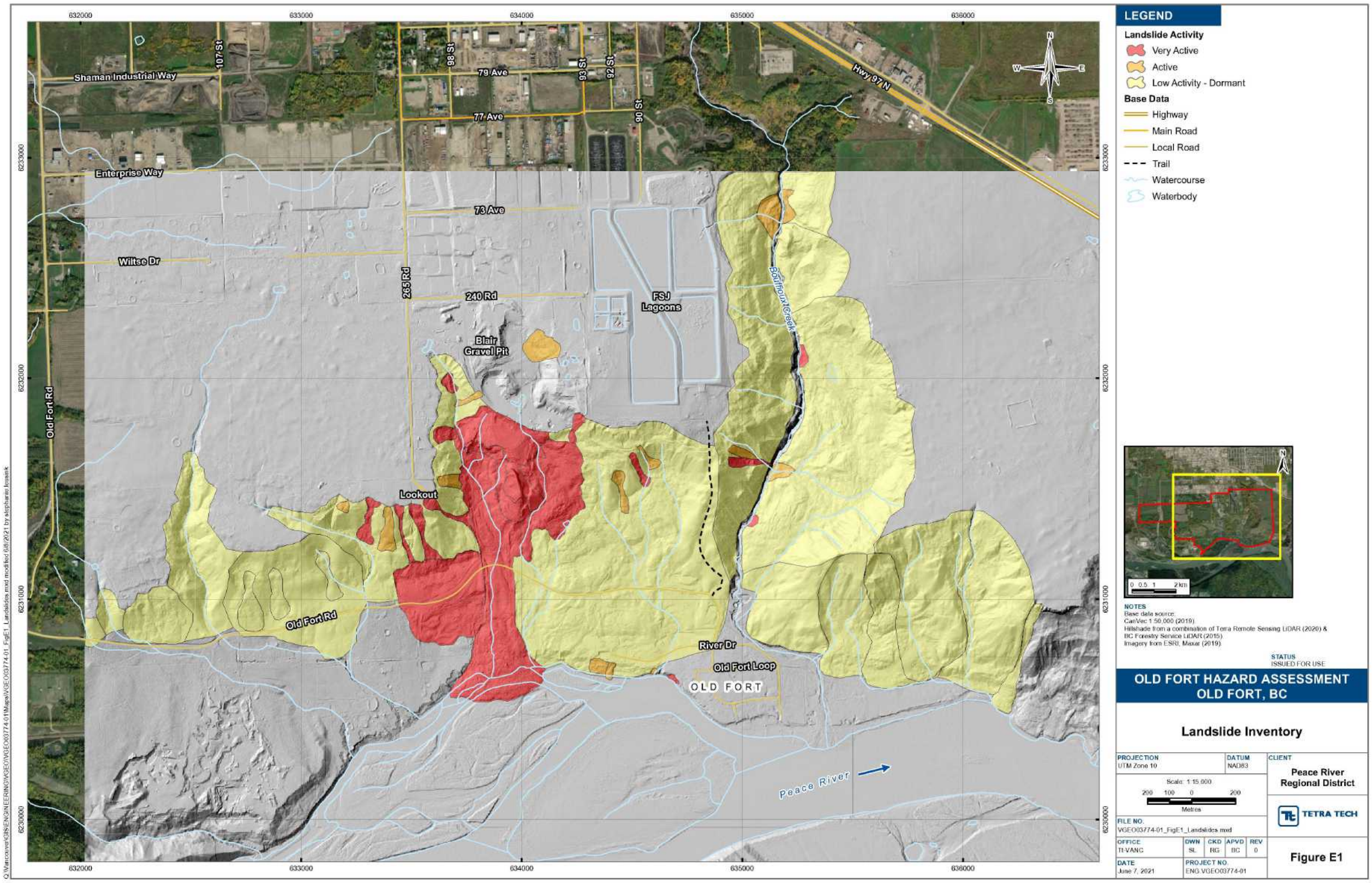
TETRA TECH

| FILE NO. | | | | |
|---|---|---|---|---|
| VGEO03774-01_FigD1_Terrain.mxd | | | | |
| OFFICE | DWN | CKD | APVD | REV |
| TT-VANC | SL | RG | BC | 0 |
| DATE | PROJECT NO. | | | |
| June 7, 2021 | ENG.VGEO03774-01 | | | |

**Figure D1c**

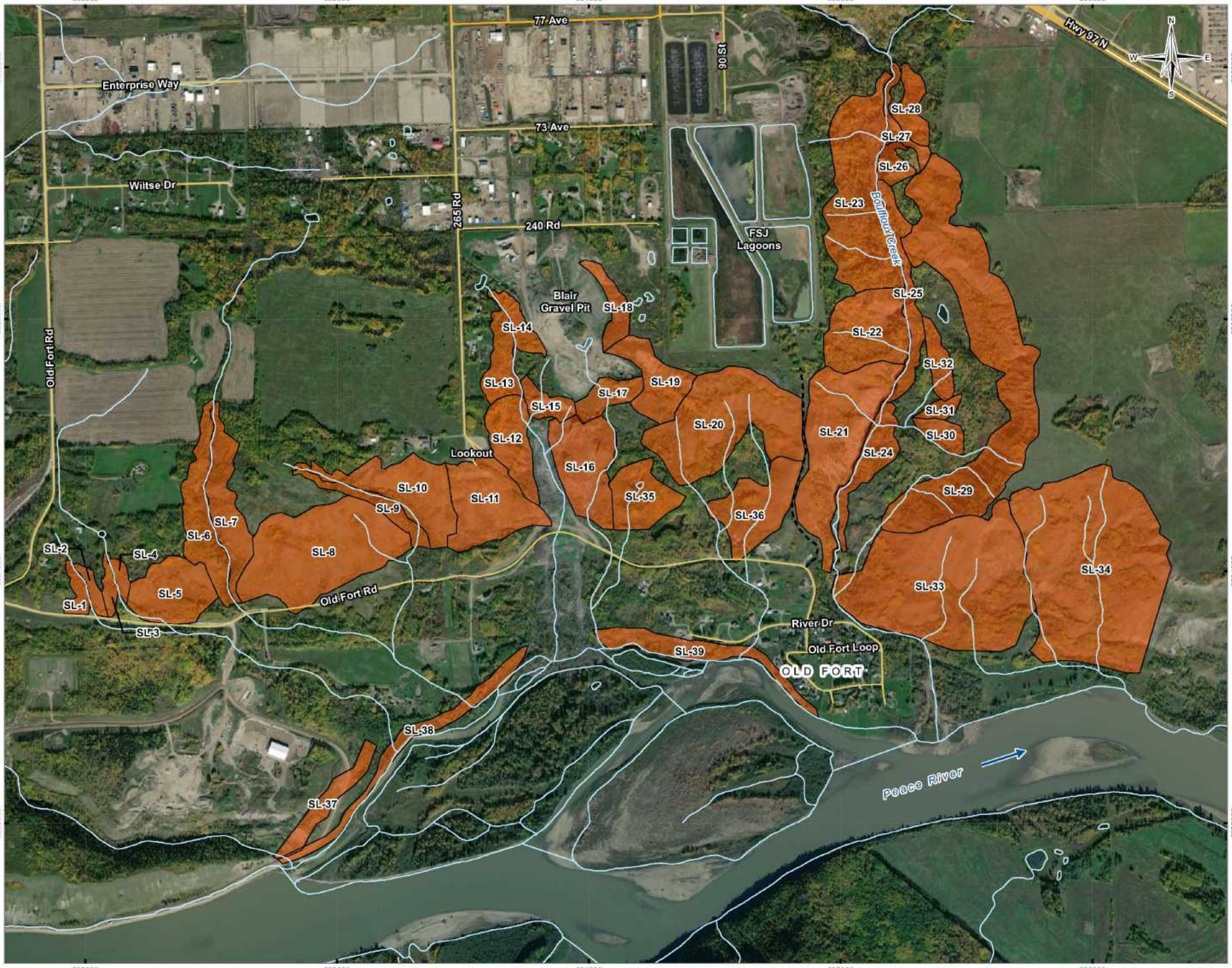
# APPENDIX E

## LANDSLIDE INVENTORY MAP


LEGEND
Landslide Activity
Very Active
Active
Low Activity - Dormant
Base Data
Highway
Main Road
Local Road
Trail
Watercourse
Waterbody
Shaman Industrial Way
107 St
98 St
79 Ave
93 St
92 St
90 St
77 Ave
Hwy 97 N
Enterprise Way
73 Ave
Wiltse Dr
265 Rd
240 Rd
FSJ Lagoons
Blair Gravel Pit
Bouffioux Creek
Old Fort Rd
Lookout
River Dr
Old Fort Loop
OLD FORT
Peace River
632000
633000
634000
635000
636000
6233000
6232000
6231000
6230000
NOTES
Base data source:
CanVec 1:50,000 (2019)
Hillshade from a combination of Tetra Remote Sensing LiDAR (2020) &
BC Forestry Service LiDAR (2015)
Imagery from ESRI, Maxar (2019)
STATUS
ISSUED FOR USE
OLD FORT HAZARD ASSESSMENT
OLD FORT, BC
Landslide Inventory
PROJECTION UTM Zone 10
DATUM NAD83
CLIENT Peace River Regional District
Scale: 1:15,000
200 100 0 200
Metres
FILE NO. VGEO03774-01_FigE1_Landslides.mxd
TETRA TECH
OFFICE TT-VANC
DWN SL
CKD RG
APVD BC
REV 0
DATE June 7, 2021
PROJECT NO. ENG.VGEO03774-01
Figure E1

# APPENDIX F

## GEOHAZARD SUSCEPTIBILITY MAPS




## LEGEND

**Geohazard Type**

- Debris Slide/Earth Slump-Flow (SL)

**Base Data**

- Highway
- Main Road
- Local Road
- Trail
- Watercourse
- Waterbody


**NOTES**
Base data source:
CanVec 1:50,000 (2019).
Imagery from ESRI; Maxar (2019).

**STATUS**
ISSUED FOR USE

# OLD FORT HAZARD ASSESSMENT
# OLD FORT, BC

## Geohazard Susceptibility
## Small Landslides

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | Peace River Regional District |

Scale: 1:15,000
200 100 0 200
Metres

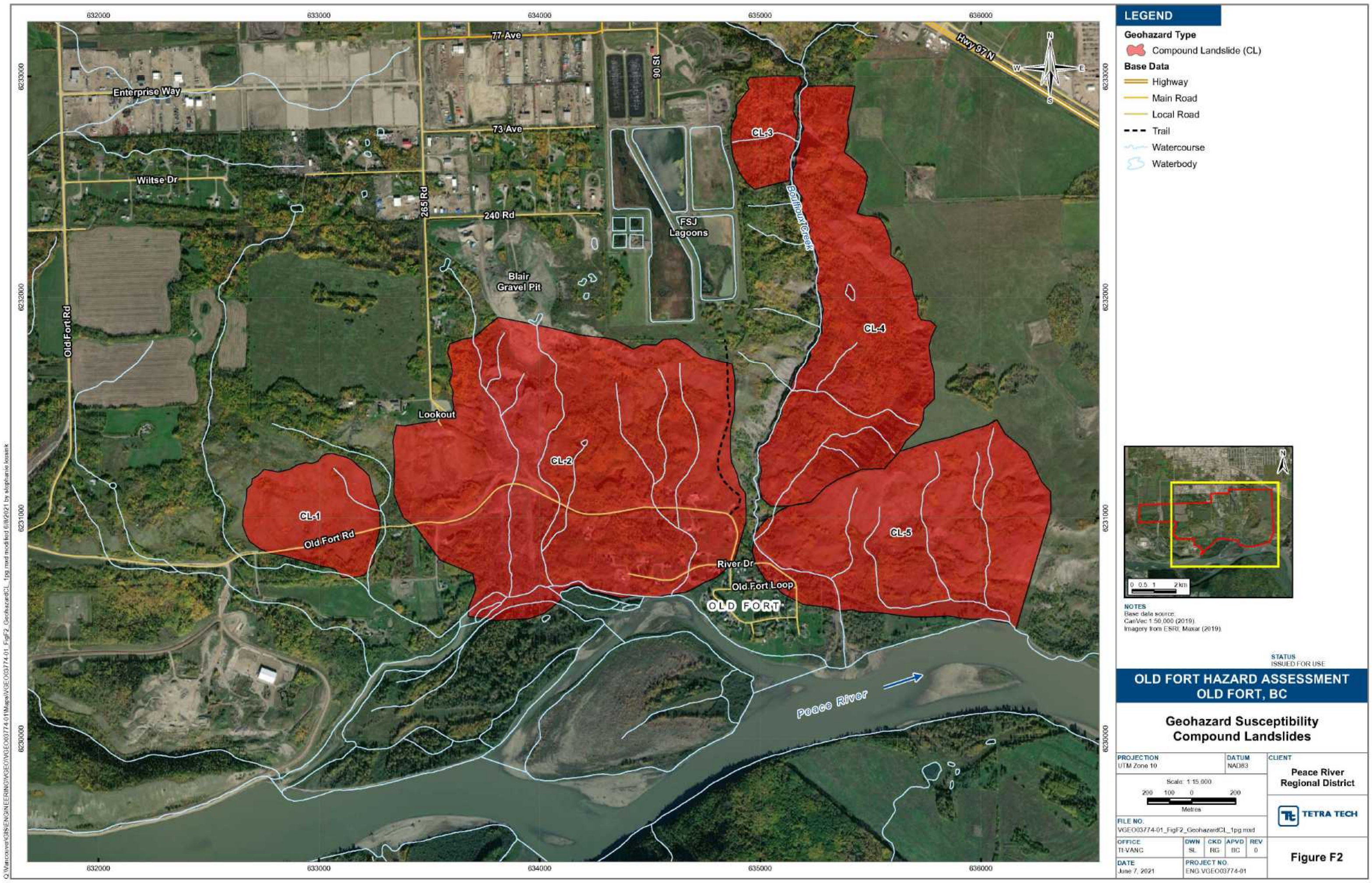
TETRA TECH

**FILE NO.**
VGEO03774-01_FigF1_GeohazardSmall_1pg_REV1.mxd

| OFFICE | DWN | CKD | APVD | REV |
|---|---|---|---|---|
| TI-VANC | SL | RG | BC | 1 |

| DATE | PROJECT NO. |
|---|---|
| June 24, 2021 | ENG.VGEO03774-01 |

**Figure F1**



LEGEND
Geohazard Type
Compound Landslide (CL)
Base Data
Highway
Main Road
Local Road
Trail
Watercourse
Waterbody
77 Ave
73 Ave
Enterprise Way
Wiltse Dr
240 Rd
265 Rd
90 St
Hwy 97 N
Old Fort Rd
FSJ Lagoons
Blair Gravel Pit
Lookout
Bouffant Creek
CL-1
CL-2
CL-3
CL-4
CL-5
River Dr
Old Fort Loop
OLD FORT
Peace River
NOTES
Base data source:
CanVec 1:50,000 (2019).
Imagery from ESRI; Maxar (2019).
STATUS
ISSUED FOR USE
OLD FORT HAZARD ASSESSMENT
OLD FORT, BC
Geohazard Susceptibility
Compound Landslides
PROJECTION
UTM Zone 10
DATUM
NAD83
Scale: 1:15,000
Metres
FILE NO.
VGEO03774-01_FigF2_GeohazardCL_1pg.mxd
OFFICE
TT-VANC
DWN SL
CKD RG
APVD BC
REV 0
DATE
June 7, 2021
PROJECT NO.
ENG.VGEO03774-01
CLIENT
Peace River
Regional District
TETRA TECH


Figure F2


**LEGEND**

**Geohazard Type**

Rockfall

**Base Data**

Highway

Main Road

Local Road

Trail

Watercourse

Waterbody


**NOTES**
Base data source:
CanVec 1:50,000 (2019)
Imagery from ESRI; Maxar (2019)

**STATUS**
ISSUED FOR USE

**OLD FORT HAZARD ASSESSMENT**
**OLD FORT, BC**

**Geohazard Susceptibility**
**Rockfall**

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | Peace River Regional District |

Scale: 1:15,000

200 100 0 200

Metres

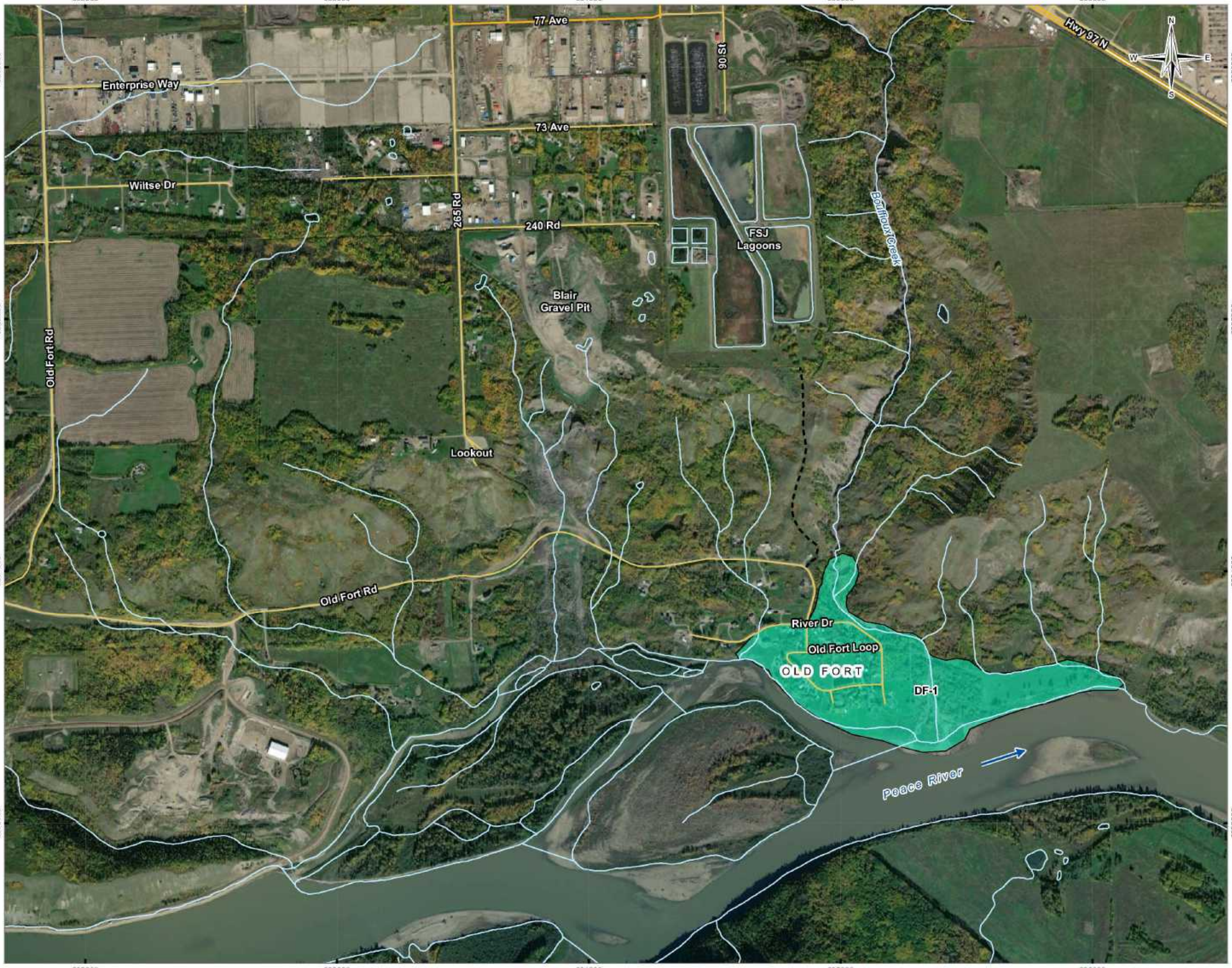
TETRA TECH

FILE NO.
VGEO03774-01_FigF3_GeohazardRF_1pg.mxd

| OFFICE | DWN | CKD | APVD | REV |
|---|---|---|---|---|
| TT-VANC | SL | RG | BC | 0 |

| DATE | PROJECT NO. |
|---|---|
| June 7, 2021 | ENG.VGEO03774-01 |

**Figure F3**




**LEGEND**

**Geohazard Type**

Debris Flood (DF)

**Base Data**

Highway

Main Road

Local Road

Trail

Watercourse

Waterbody


**NOTES**
Base data source:
CanVec 1:50,000 (2019).
Imagery from ESRI; Maxar (2019).

**STATUS**
ISSUED FOR USE

## OLD FORT HAZARD ASSESSMENT OLD FORT, BC

### Geohazard Susceptibility Debris Floods

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | Peace River Regional District |

Scale: 1:15,000
200 100 0 200
Metres

**FILE NO.** VGEO03774-01_FigF4_GeohazardDF_1pg.mxd

TETRA TECH

| OFFICE | DWN | CKD | APVD | REV |
|---|---|---|---|---|
| TI-VANC | SL | RG | BC | 0 |

| DATE | PROJECT NO. |
|---|---|
| June 7, 2021 | ENG.VGEO03774-01 |

**Figure F4**


**LEGEND**

**Geohazard Type**
- Avulsion (AV)

**Base Data**
- Highway
- Main Road
- Local Road
- Trail
- Watercourse
- Waterbody


**NOTES**
Base data source:
CanVec 1:50,000 (2019)
Imagery from ESRI, Maxar (2019)

STATUS
ISSUED FOR USE

**OLD FORT HAZARD ASSESSMENT**
**OLD FORT, BC**

**Geohazard Susceptibility**
**Avulsion**

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | Peace River Regional District |

Scale: 1:15,000
200 100 0 200
Metres

FILE NO.
VGEO03774-01_FigF5_GeohazardAV_1pg.mxd

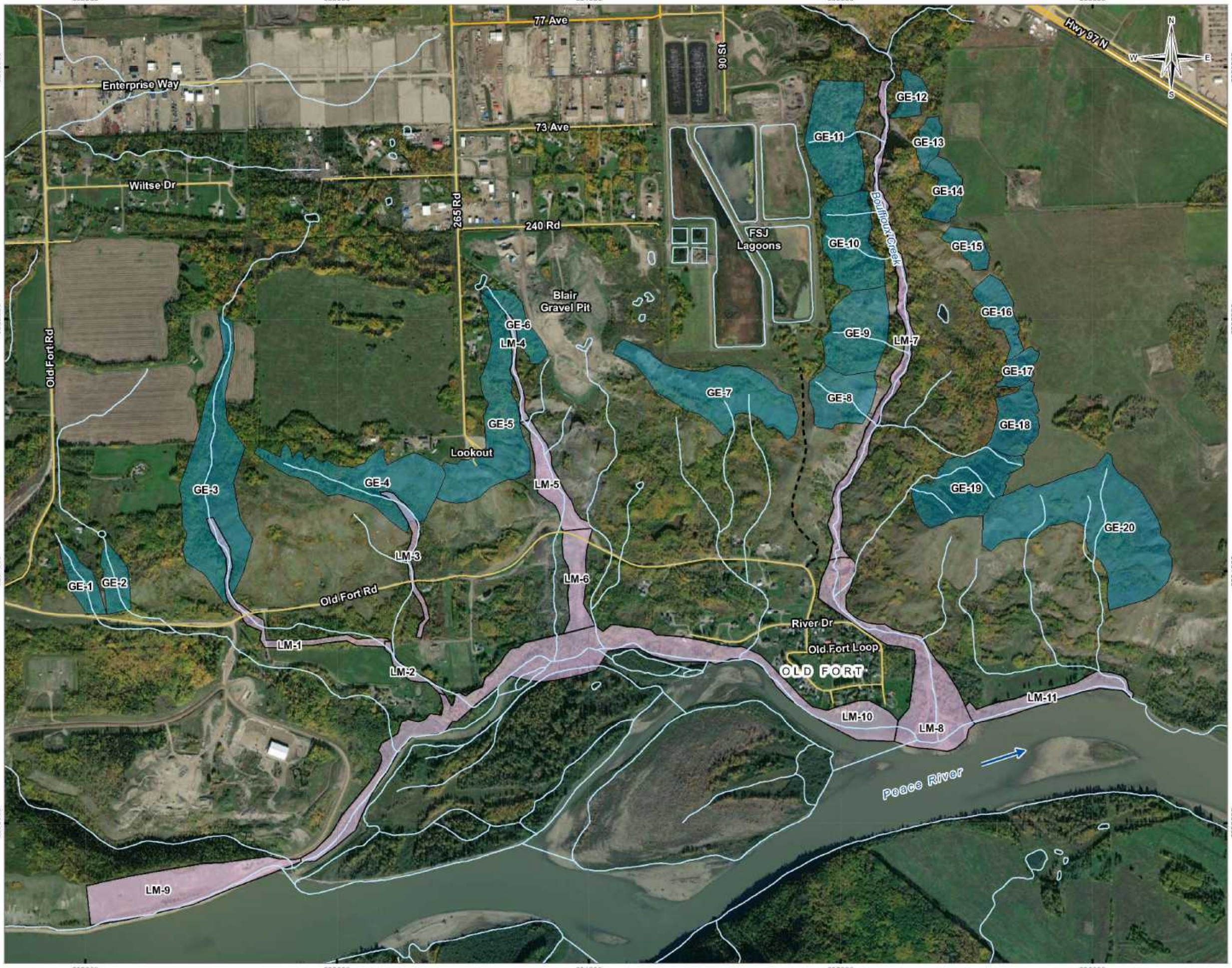
TETRA TECH

| OFFICE | DWN | CKD | APVD | REV |
|---|---|---|---|---|
| TT-VANC | SL | RG | BC | 0 |

| DATE | PROJECT NO. |
|---|---|
| June 7, 2021 | ENG.VGEO03774-01 |

**Figure F5**

Q:\Vancouver\GIS\ENGINEERING\VGEO\VGEO03774-01\Maps\VGEO03774-01_FigF5_GeohazardAV_1pg.mxd modified 6/8/2021 by stephanie.kowalik




**LEGEND**

**Geohazard Type**

- Lateral Migration/Scour (LM)
- Gully Erosion (GE)

**Base Data**

- Highway
- Main Road
- Local Road
- Trail
- Watercourse
- Waterbody


**NOTES**
Base data source:
CanVec 1:50,000 (2019)
Imagery from ESRI, Maxar (2019)

**STATUS**
ISSUED FOR USE

## OLD FORT HAZARD ASSESSMENT
## OLD FORT, BC

### Geohazard Susceptibility Lateral Migration/Scour and Gully Erosion

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | Peace River Regional District |

Scale: 1:15,000
200 100 0 200
Metres

TETRA TECH

| FILE NO. | | | | |
|---|---|---|---|---|
| VGEO03774-01_FigF6_GeohazardLMGE_fpg.mxd | | | | |
| OFFICE | DWN | CKD | APVD | REV |
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| June 7, 2021 | ENG.VGEO03774-01 | | | |

**Figure F6**

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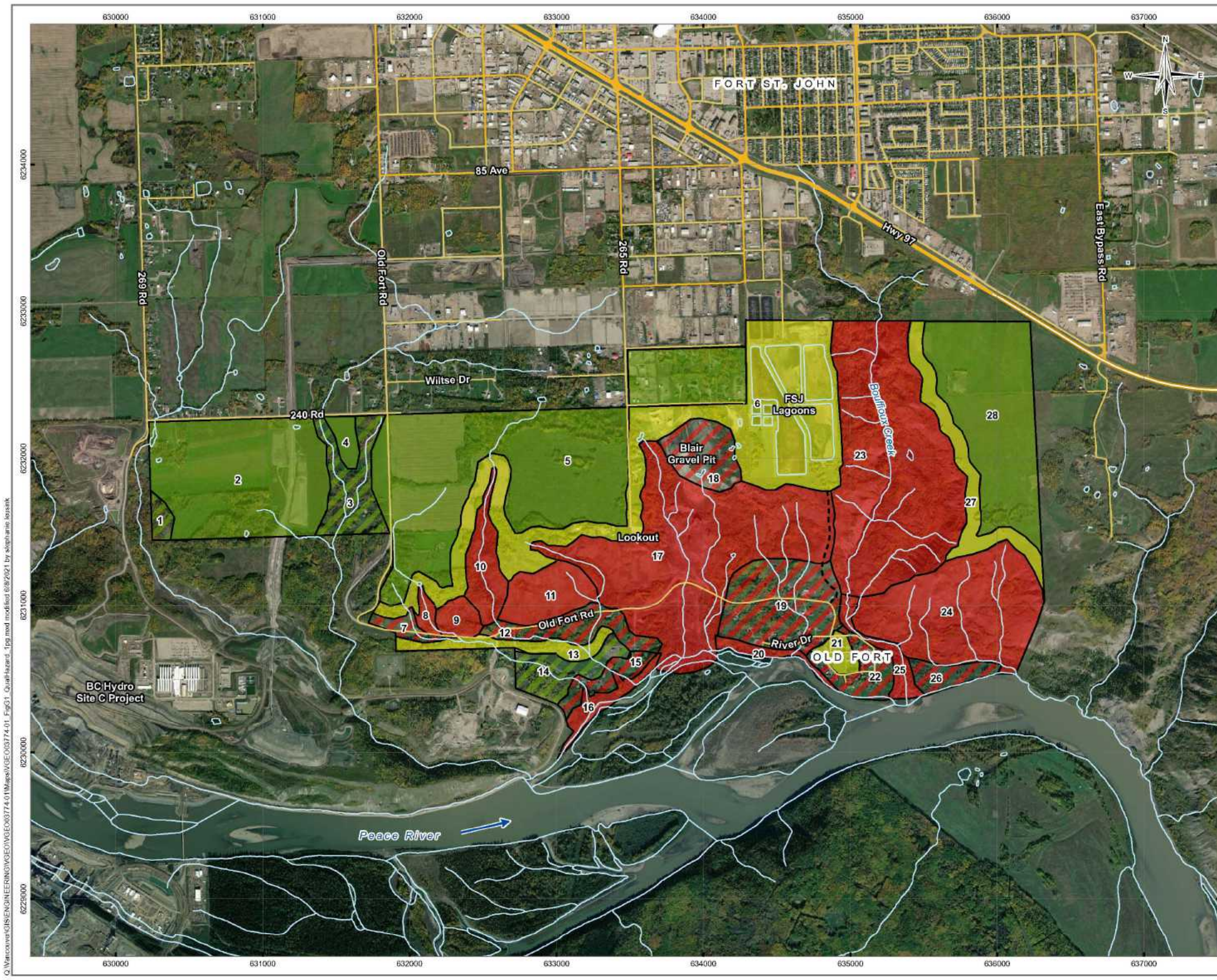
# APPENDIX G

## QUALITATIVE HAZARD ASSESSMENT MAP




**LEGEND**

**Qualitative Hazard Rank**

- High
- High/Moderate
- Moderate
- Moderate/Low
- Low

**Base Data**

- Highway
- Main Road
- Local Road
- Trail
- Watercourse
- Waterbody

**NOTES**
Base data source:
CanVec 1:50,000 (2019).
Imagery from ESRI; Maxar (2019).

**STATUS**
ISSUED FOR USE

## OLD FORT HAZARD ASSESSMENT
## OLD FORT, BC

### Qualitative Hazard Assessment

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | Peace River Regional District |

Scale: 1:25,000
500 250 0 500
Metres

| FILE NO. | | | | | |
|---|---|---|---|---|---|
| VGEO03774-01_FigG1_QualHazard_1pg.mxd | | | | | |
| OFFICE | DWN | CKD | APVD | REV | |
| TI-VANC | SL | RG | BC | 0 | Figure G1 |
| DATE | PROJECT NO. | | | | |
| June 7, 2021 | ENG.VGEO03774-01 | | | | |

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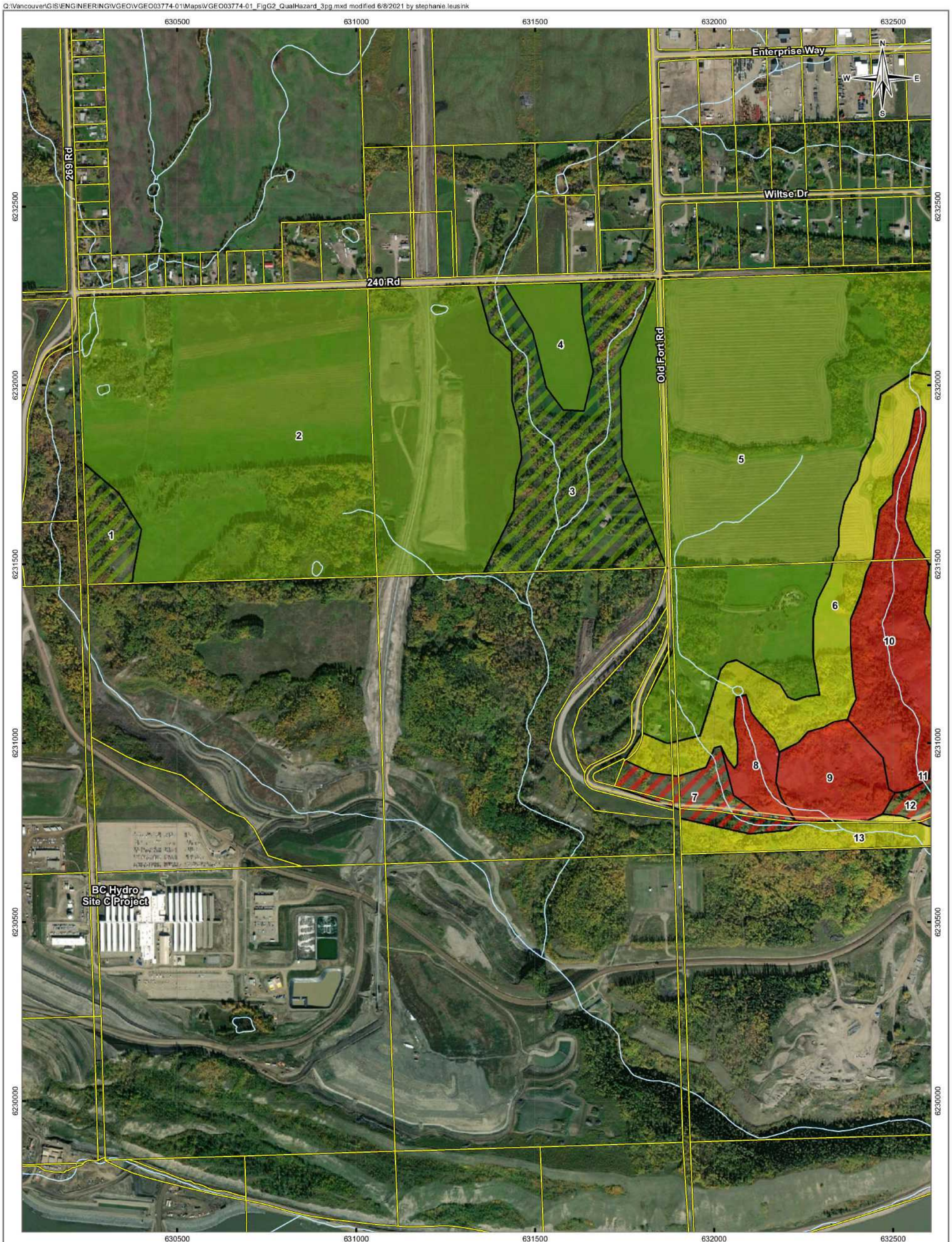



## LEGEND

Property Boundary

1 Hazard Rating Polygon

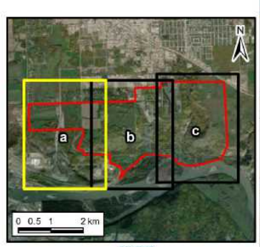
**Qualitative Hazard Rank**

- High
- High/Moderate
- Moderate
- Moderate/Low
- Low

**Base Data**

- Local Road
- Watercourse
- Waterbody

**NOTES**
Base data sources:
CanVec 1:50,000 (2019).
Imagery from ESRI; Maxar (2019).




STATUS
ISSUED FOR USE

# OLD FORT HAZARD ASSESSMENT
# OLD FORT, BC

## Qualitative Hazard Assessment and Property Boundaries

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | Peace River Regional District |

Scale: 1:10,000

200 100 0 200

Metres

FILE NO.
VGEO03774-01_FigG2_QualHazard_3pg.mxd

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| OFFICE | DWN | CKD | APVD | REV |
|---|---|---|---|---|
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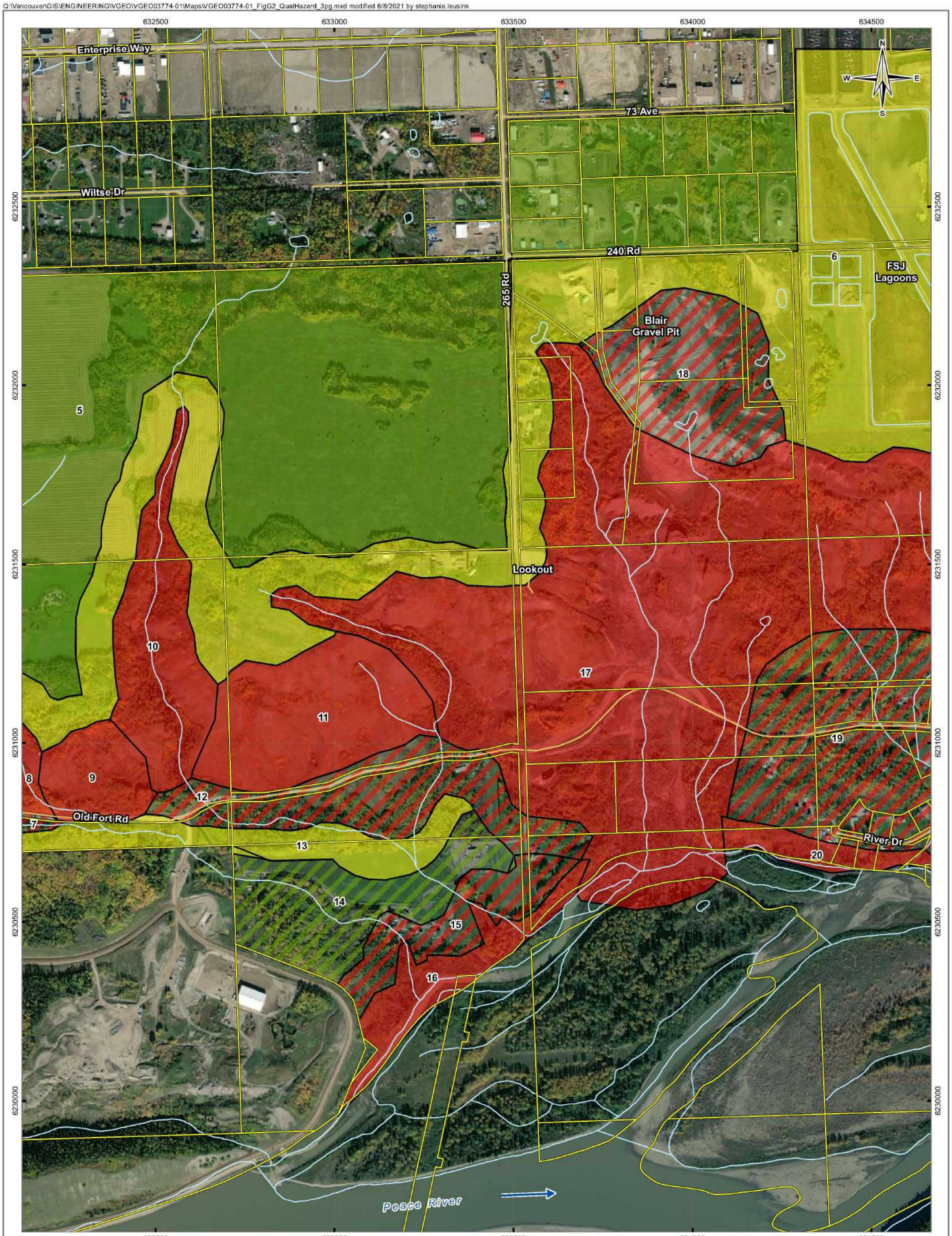
| DATE | PROJECT NO. |
|---|---|
| June 7, 2021 | ENG.VGEO03774-01 |

**Figure G2a**




## LEGEND

Property Boundary

1 Hazard Rating Polygon

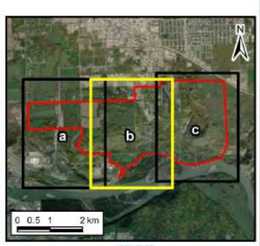
**Qualitative Hazard Rank**

- High
- High/Moderate
- Moderate
- Moderate/Low
- Low

**Base Data**

- Local Road
- Watercourse
- Waterbody

**NOTES**
Base data sources:
CanVec 1:50,000 (2019).
Imagery from ESRI; Maxar (2019).




STATUS
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## OLD FORT HAZARD ASSESSMENT
## OLD FORT, BC

**Qualitative Hazard Assessment and Property Boundaries**

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | Peace River Regional District |

Scale: 1:10,000
200 100 0 200
Metres

FILE NO.
VGEO03774-01_FigG2_QualHazard_3pg.mxd

TETRA TECH

| OFFICE | DWN | CKD | APVD | REV |
|---|---|---|---|---|
| TI-VANC | SL | RG | BC | 0 |

DATE: June 7, 2021
PROJECT NO.: ENG.VGEO03774-01

**Figure G2b**

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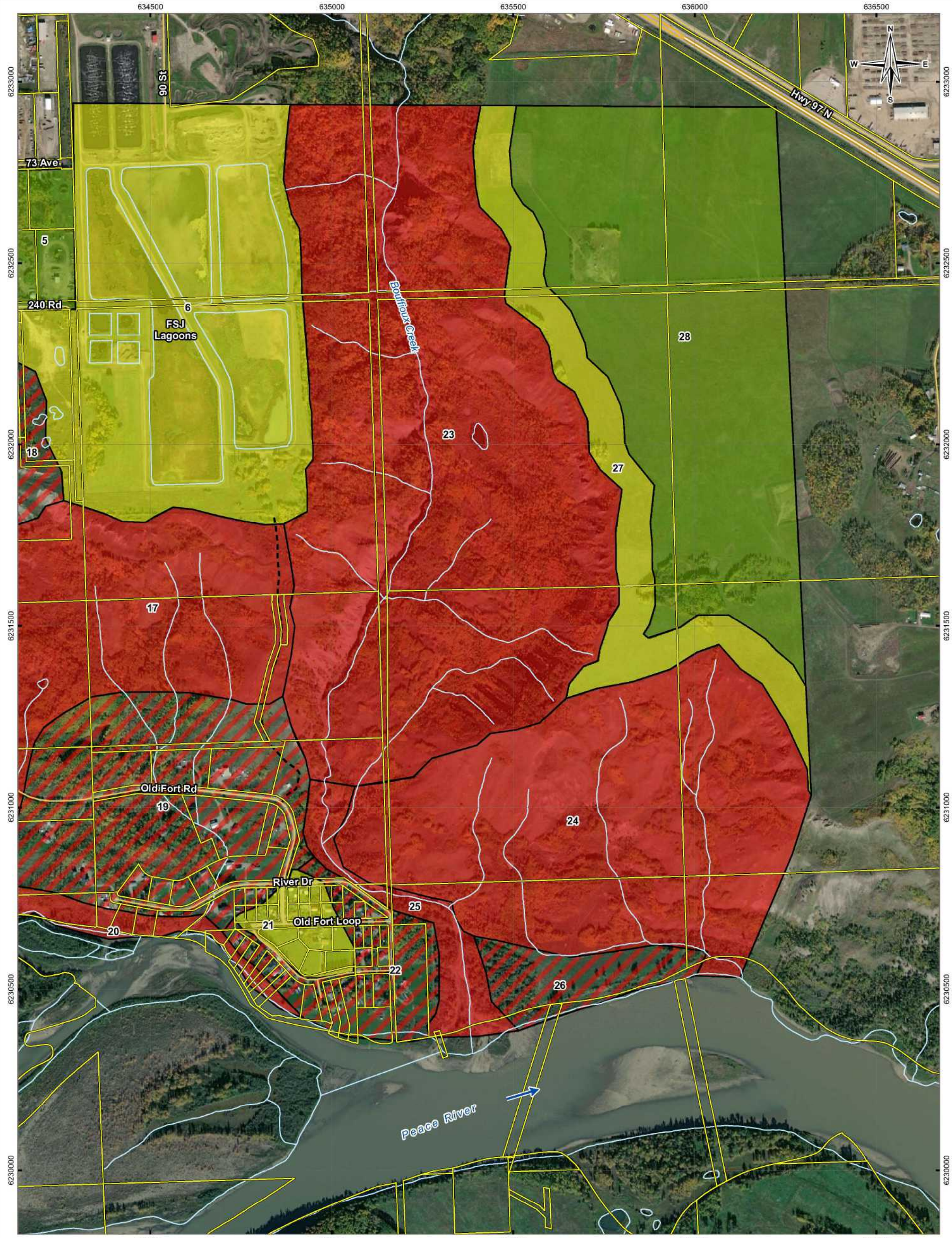
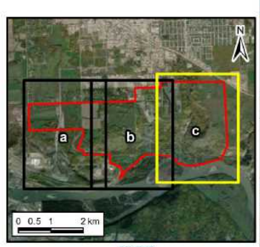



## LEGEND

| | |
|---|---|
| Property Boundary | **Base Data** |
| 1 Hazard Rating Polygon | Highway |
| **Qualitative Hazard Rank** | Main Road |
| High | Local Road |
| High/Moderate | Trail |
| Moderate | Watercourse |
| Low | Waterbody |

**NOTES**
Base data sources:
CanVec 1:50,000 (2019).
Imagery from ESRI; Maxar (2019).




STATUS
ISSUED FOR USE

# OLD FORT HAZARD ASSESSMENT
# OLD FORT, BC

## Qualitative Hazard Assessment and Property Boundaries

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | Peace River Regional District |

Scale: 1:10,000
200 100 0 200
Metres

FILE NO.
VGEO03774-01_FigG2_QualHazard_3pg.mxd

TETRA TECH

| OFFICE | DWN | CKD | APVD | REV |
|---|---|---|---|---|
| TI-VANC | SL | RG | BC | 0 |

| DATE | PROJECT NO. |
|---|---|
| June 7, 2021 | ENG.VGEO03774-01 |

**Figure G2c**

# APPENDIX H

## FLOOD HAZARD ASSESSMENT MEMO

# TETRA TECH

# TECHNICAL MEMO

ISSUED FOR USE

| | | | |
|---|---|---|---|
| **To:** | Trish Morgan<br>General Manager, Community Services,<br>Peace River Regional District | **Date:** | June 7, 2021 |
| **cc:** | | **Memo No.:** | 001 |
| **From:** | Marc Lau, E.I.T.<br>Dan Hajdukovic, Ph.D., P.Eng. | **File:** | 704-ENG.VGEO03774-01 |
| **Subject:** | Peace River Valley Geohazard Assessment Old Fort Area – Bouffioux Creek Flood Hazard Modelling | | |

## 1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was retained by the Peace River Regional District (the PRRD) to provide a geohazard assessment for the Old Fort Area in the Peace River Valley, British Columbia. This work was triggered by the PRRD, in response to the 2018 Old Fort Area landslide event. This technical memo addresses Tetra Tech's Flood/Debris Flood Modelling of Bouffioux Creek, including discussion on the two-dimensional flow model produced, the peak storm flow conditions used in the model, the effect of debris flow bulking, and recommendations based on the model results.

## 2.0 HISTORICAL REPORTS

Tetra Tech was provided with the City of Fort St. John's Stormwater Master Plan (Phase 1), published by Urban Systems in 2013 to address existing stormwater issues in Fort St. John triggered by a major flooding event on July 29, 2010. With respect to Bouffioux Creek, it was noted in an even earlier 2004 Urban Systems Drainage Report for the Ministry of Transportation for the Alaska Highway No. 97 – Fort St. John Corridor Improvements, that the creek continues to be at significant risk of erosion, and that development and urbanization of the Fort St. John Basin is further contributing to instability of the creek due to increased runoff, and thus increased discharge from the piped storm system into the creek. The 2013 Stormwater Masterplan also discusses how the development of Fort St. John led to the blockage of natural overland flow paths by urban features such as roads and sidewalks, while the existing stormwater management system was not fully able to reroute the collected runoff past these obstructions into the creek.

## 3.0 SURFACE AND CLIMATIC DATA

The PRRD provided Tetra Tech with light detection and ranging (LIDAR) data collected in October 2019 for an area roughly covering Fort St. John and Bouffioux Creek. This was combined with data from the High-Resolution Digital Elevation Model (HRDEM) produced by Natural Resources Canada to produce a topographic surface of the catchment that feeds into Bouffioux Creek.



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Climatic data from Environment Canada weather station 1183000 – Fort St. John A, B.C. covering daily precipitation from 1973 to 2002 was used to produce intensity-duration-frequency (IDF) curves for the Fort St. John Area for 2, 5, 10, 25, 50, 100, and 200 year return periods. For this model, climate change a. These IDF curves are displayed in Figure 1 – Fort St. John A, B.C. 1183000 IDF Curves on the next page. The 200-year return period storms were used in the hydrological model to reflect conservative scenarios for long-term planning.

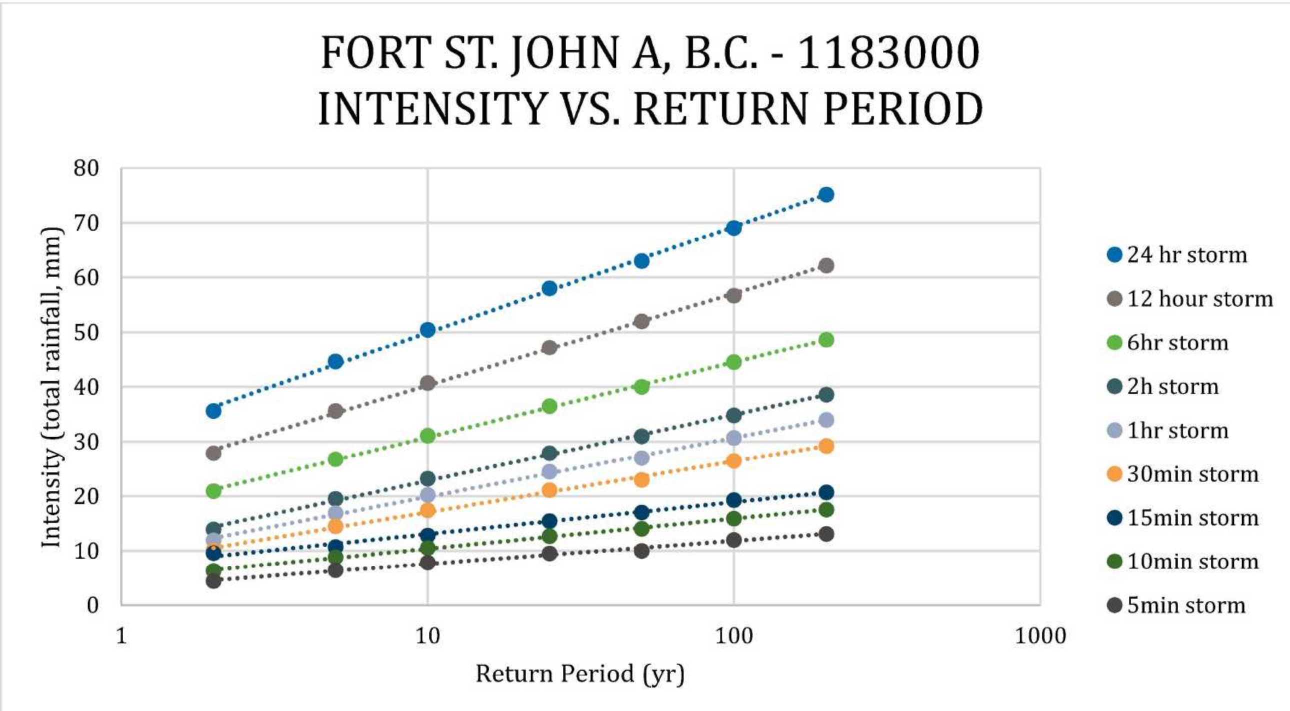


**Figure 1. IDF Curves for Fort St. John A, B.C. 1183000**

# 4.0 TWO-DIMENSIONAL FLOW MODEL

## 4.1 Hydrology Model

PCSWMM software was used to model the hydrology of the catchment feeding into Bouffioux Creek. A catchment of approximately 1,280 hectares was delineated, which included much of central and southern Fort St. John. Given that the model aims to analyze major 1-in-200 year rain events and conservatively estimates runoff to be directed directly into the creek, the larger subcatchments are mainly delineated based on topography produced by the high-resolution LIDAR data, with the more precise extents of the urban catchment being refined using stormwater system GIS data provided by the City of Fort St. John. Impervious area percentages, runoff coefficients, and depression storages were estimated using aerial imagery combined with PRRD zoning maps to estimate the approximate distribution of land cover for each subcatchment. The terrain model generated from the topographic data is shown below in Figure 2a, and the refined delineated catchment is shown Figure 2b.

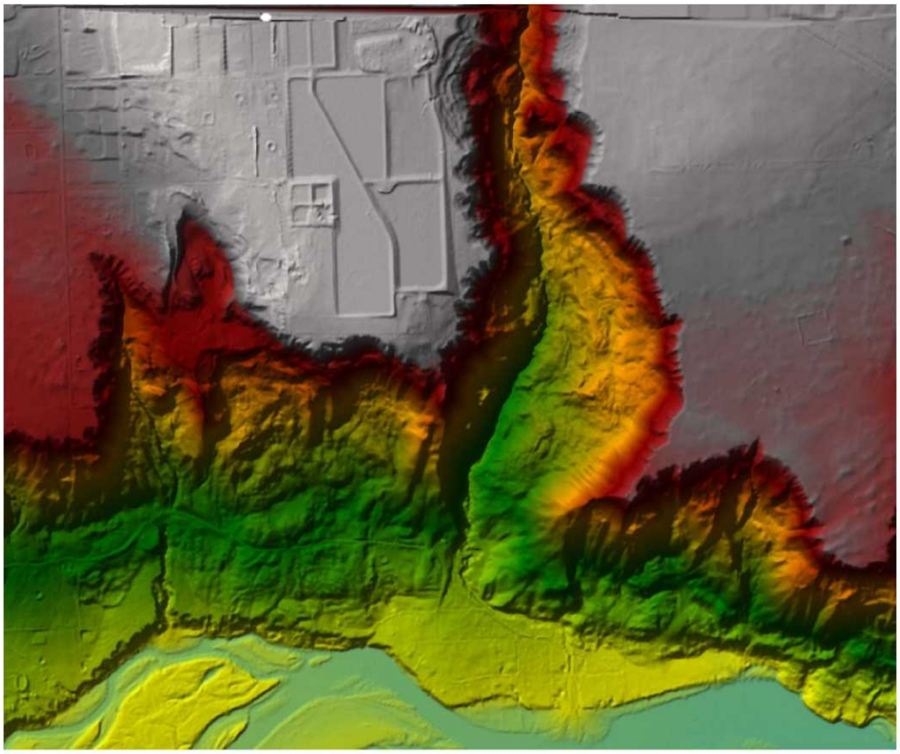

**Figure 2a. Terrain model of Bouffioux Creek**

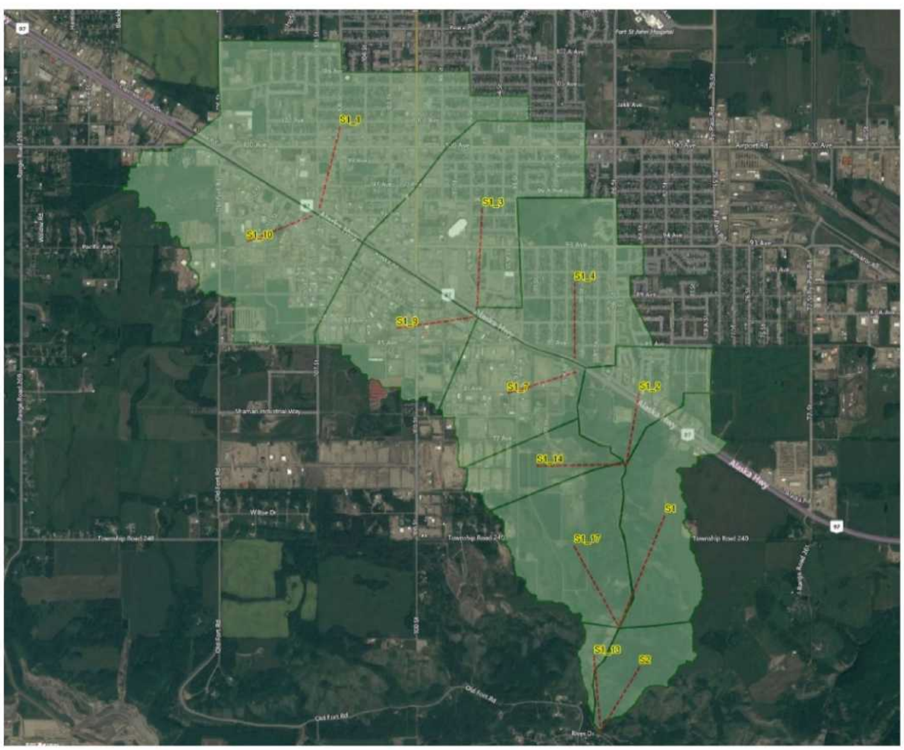


**Figure 2b. Subcatchment delineation for Bouffioux Creek**

An SCS Type II storm was used to model 200-year return period storm events for durations ranging from 5 minutes to 24 hours. It was found that a 12-hour storm event for a 200-year return period storm (approximately 62 mm of rainfall over 12 hours) gave the greatest peak flow into the creek. Below, Figure 3 displays the rainfall distribution of this event. Its shape represents a long duration storm with a sudden and severe peak, representing a scenario in which the baseflow in the creek is given time to reach a new sustained high during the storm, before a sudden and severe surge is introduced.

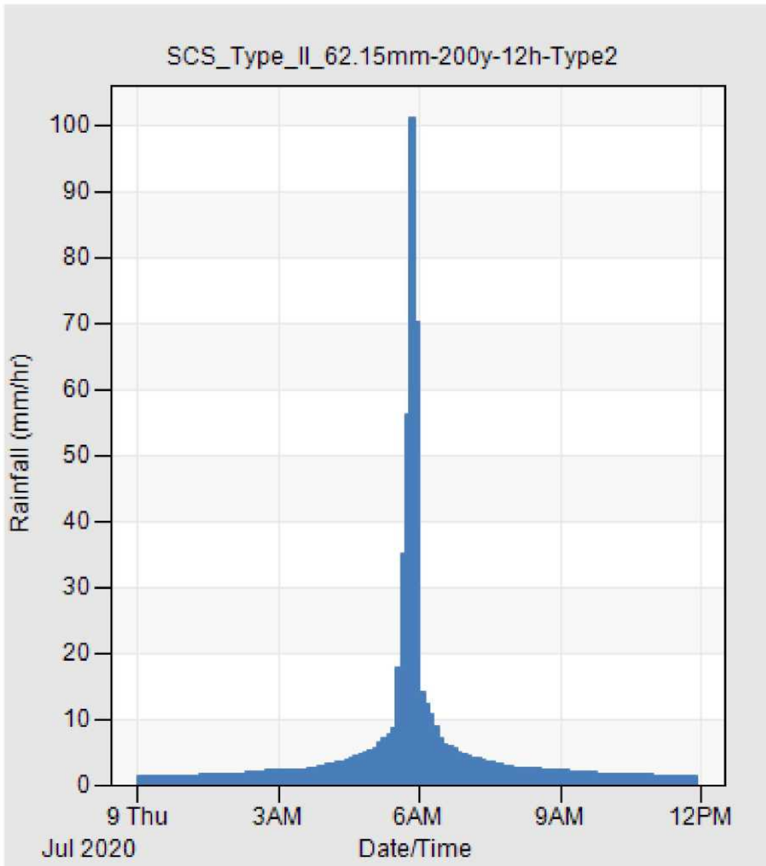


**Figure 3. SCS Type II 12-hr Rainfall Distribution for a 1-in-200 year storm event**

The rainfall event, and corresponding flow response into the creek, are shown below in Figure 4a. In agreement with observations made in the 2013 Urban Systems Stormwater Master Plan, it was found that the sizing of the existing storm sewer system of Fort St. John is not capable of fully conveying the major 1-in-200 year storm events into Bouffioux Creek, due to the existing storm pipe infrastructure acting as a bottleneck for the runoff and discharge into the creek.

Therefore, the hydrological model conservatively assumes a scenario in which all storm runoff from Fort St. John is routed directly into the creek, rather than through the existing storm system. This scenario intends to represent a case in which the City of Fort St. John's future storm water system is fully upgraded to route all possible storm runoff into the creek. The flow response of this scenario is shown in Figure 4b. The bottlenecking due to the existing storm infrastructure is significant, reducing the modelled discharge amount to the creek by more than 30%.

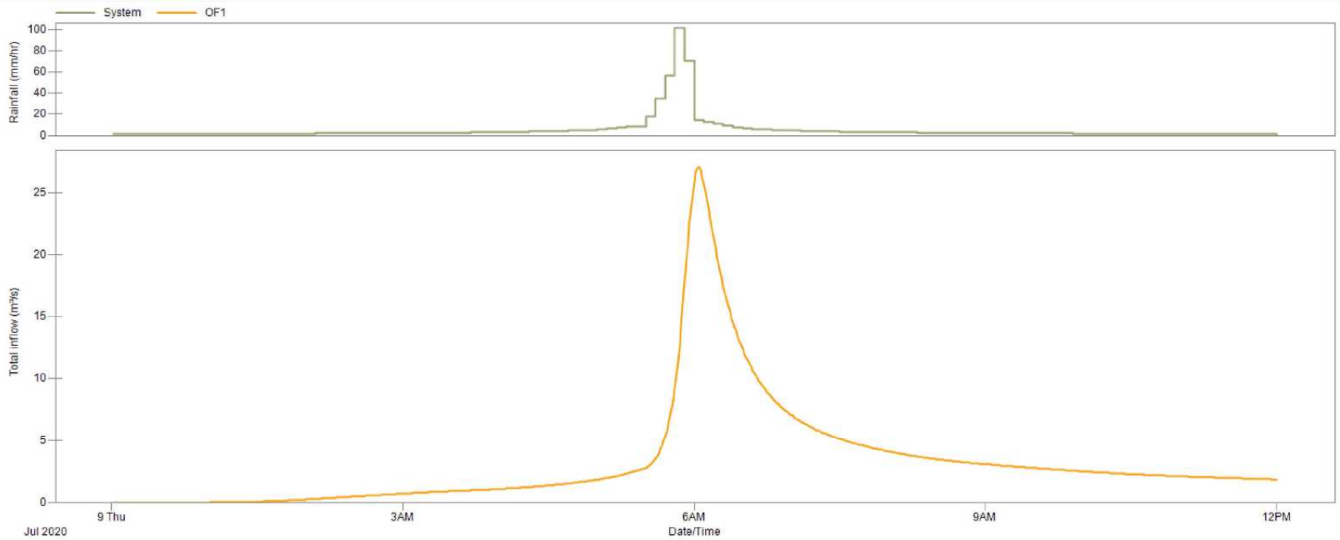


**Figure 4a. SCS Type II 12-hr Storm Event (1-in-200 year return period) flow response, with bottlenecking through existing storm pipe system**

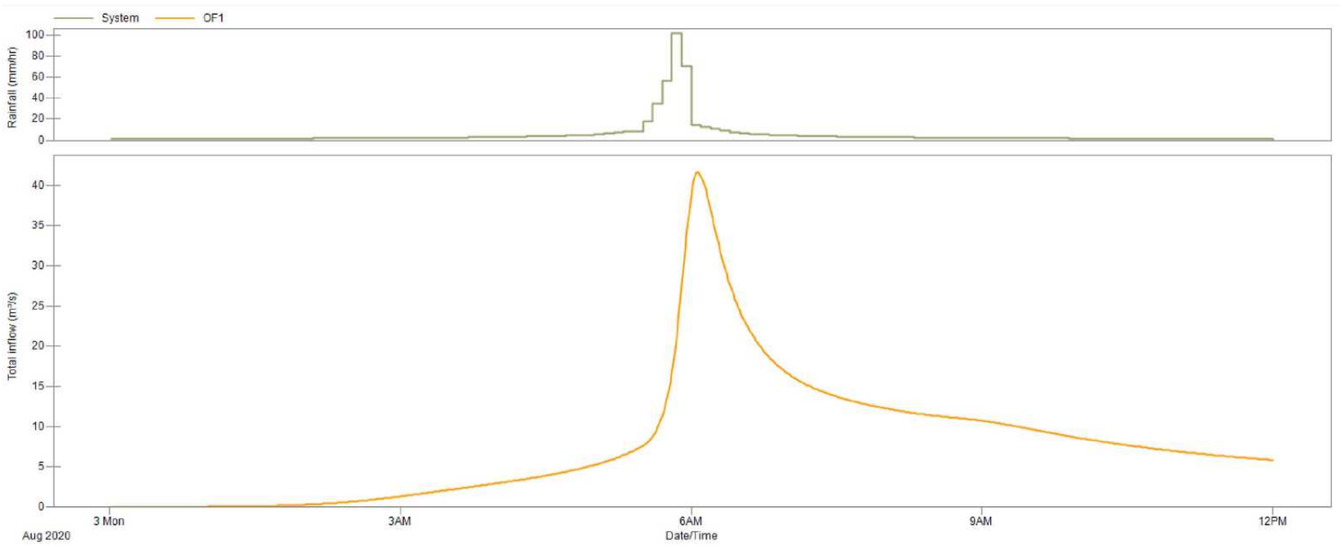


**Figure 4b. SCS Type II 12-hr Storm Event (1-in-200 year return period) flow response, with routing directly into Bouffioux Creek**

## Table 1: Hydrological Model Results

| Model Scenario | Runoff Routing | Max Inflow into Bouffioux Creek ($m^3/s$) |
|---|---|---|
| SCS Type II – 12 Hour (1:200 year return period) | Through existing storm system | 27.09 |
| SCS Type II – 12 Hour (1:200 year return period) | Routed directly into the creek | 41.75 |

## 4.2 Hydraulic Model

The more conservative direct-routing inflow scenario was then passed onto the HEC-RAS 2D software for hydraulic modelling of the flow through the creek. The flow response derived from the hydrological model was combined in HEC-RAS 2D with a steady, non-storm baseflow through the creek. This baseflow was estimated because there is not flow monitoring data for Bouffioux Creek. The inflow for the hydraulic model is shown in Figure 4c below.

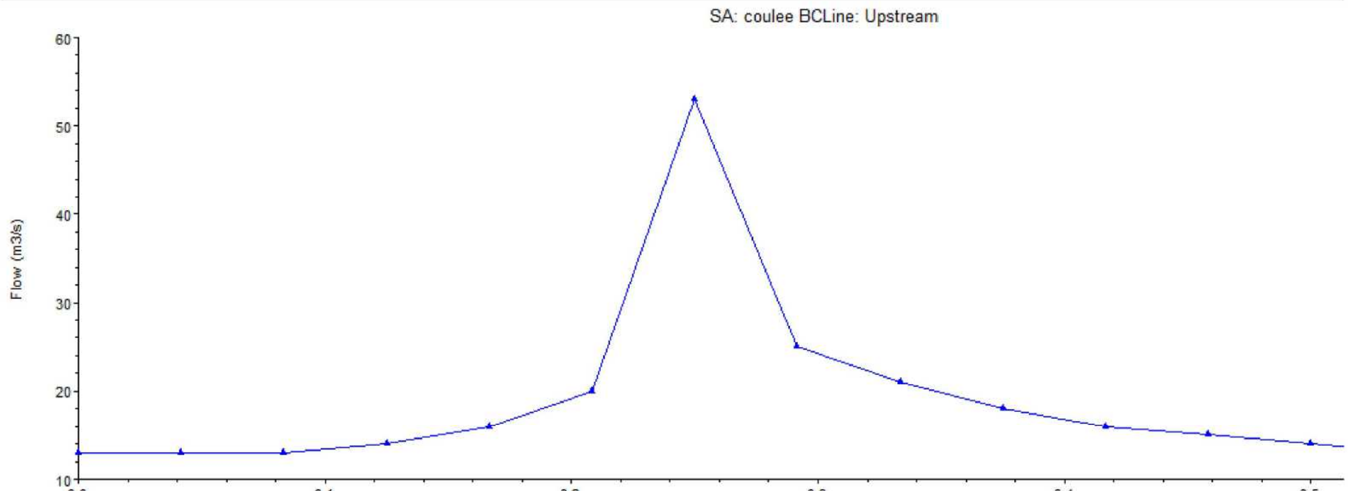


**Figure 4c. Hydraulic model inflow due to SCS Type II 12-hr Storm Event (1-in-200 year return period) flow response, with routing directly into Creek, and estimated baseflow**

The inflow was introduced into the model at the upstream boundary condition of the creek, which was set at the major stormwater system discharge point into the creek south of the Alaska Highway and east of 86$^{th}$ Street in Fort St. John. The downstream boundary condition for the creek was set to be the existing discharge point of the creek into the Peace River. Manning's roughness coefficient for the channel was set at 0.05. Simulations were run for the full 12-hour storm duration, plus a 2-hour buffer at the end of the event to capture any residual effects.

Debris bulking is a significant factor that can cause flooding of erosion-susceptible streams. This occurs when sediment, vegetation, and other debris collect in the stream due to erosion and sloughing along the path of the channel, thus bulking the volume of the flow in the stream. In this model, a debris-bulking factor of 2.0 was used, representing the conservative end of an "average debris flow" (Brunkal, 2017). In physical terms, this represents a 100% increase in the volume of flow entering the creek, or in other words, 200% of the volume of clearwater (no sediment) flow. The model was run at first with the assumption of clearwater only to be entering the creek, then again with the volume of inflow bulked by sediment. Figure 5 in the next section displays the predicted flooding extents for both the clearwater, and sediment-bulked scenarios.

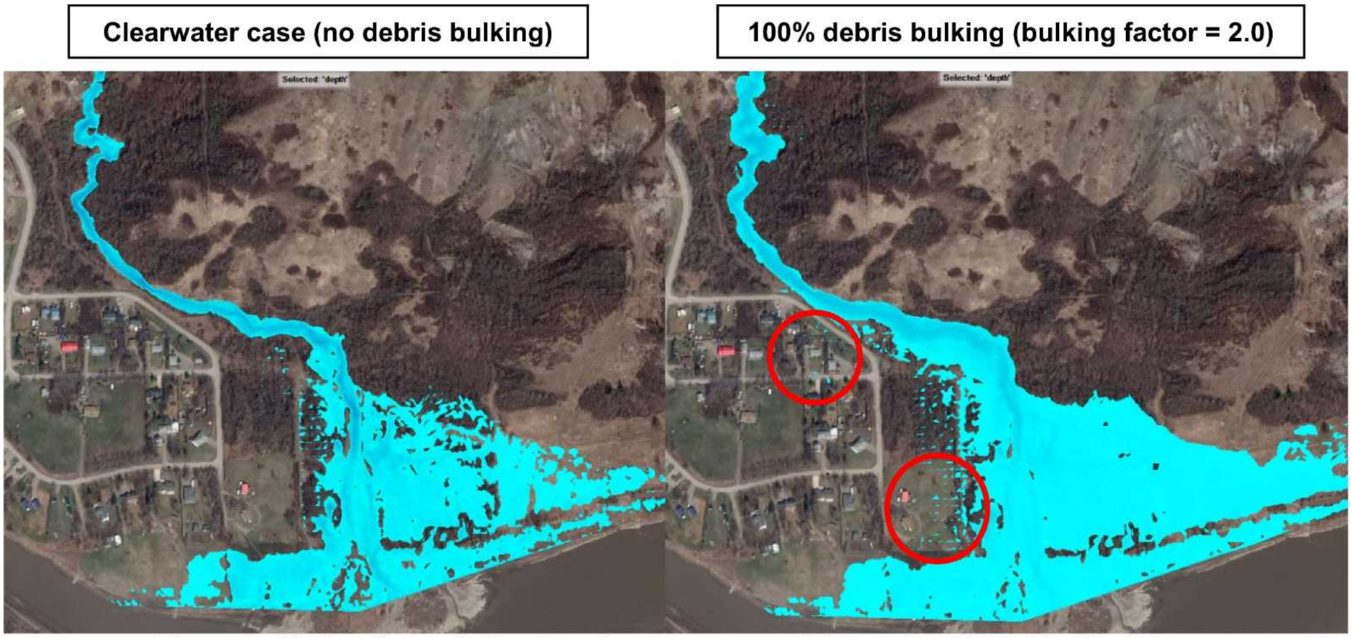


**Figure 5. Hydraulic modelling for clearwater case (left), and sediment-bulked case using bulking factor of 2.0 (right)**

## 5.0 RESULTS AND RECOMMENDATIONS

Using the SCS Type II 12-hr 1-in-200-year storm event, it was found that no significant flooding occurs in the Old Fort Area for a clearwater case (Figure 5, left). In this case, the water level is predicted to be approximately 1.7m below the crest of the existing dike. However, by including the effect of debris bulking on the creek inflow, it was found that flooding is predicted to appear south of the banks of the creek in the Old Fort Area. (Figure 5, right)

Tetra Tech observed ongoing erosion and sloughing along the banks of the creek while on site in June/July 2020, including shifting of the gabion baskets and concrete lock blocks. If no action is taken, the ongoing erosion in Buffioux Creek will make a debris-bulked flooding scenario more likely in the future and may worsen over time as Fort St. John continues to develop and urbanize the upstream land, coinciding with the stormwater system upgrades to increase discharge into the creek.

More holistically, it is important to note again that the flow case for this model reflects perfect conveyance of all storm runoff from Fort St. John down into Bouffioux Creek, so is currently conservative. At present, the storm system in Fort St. John is a limiting factor in the rate and amount of runoff that reaches the creek. Over time, if and when the City of Fort St. John upgrades its stormwater infrastructure (e.g., increasing the size of trunk mains), could increase peak flows in Bouffioux Creek. PRRD should ask the City of Fort St. John to be notified if/when stormwater upgrades are planned/constructed, so that the municipality and district can coordinate/plan flood protection of the Old Fort Area.

## 6.0 LIMITATIONS OF MEMO

This report and its contents are intended for the sole use of the Peace River Regional District and their agents. Tetra Tech Canada Inc. does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than the Peace River Regional District, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on the Use of this Document attached in the Appendix or Contractual Terms and Conditions executed by both parties.

# 7.0 CLOSURE

We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

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Prepared by:
Marc Lau, E.I.T.
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ENGINEER

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Reviewed by:
Dan Hajdukovic, P.Eng., Ph.D.
Senior Water Resources Engineer
Water Resources and Infrastructure

/ML/sy

Attachments: Limitations on the Use of this Document

# REFERENCES

Brunkal, H., & Santi, P. (2017). Consideration of the Validity of Debris-flow Bulking Factors. Environmental and Engineering Geoscience, 23(4), 291-298.

Urban Systems Ltd. (2013). City of Fort St. John Stormwater Masterplan Phase 1.

Urban Systems Ltd. (2004). Drainage Report for the Ministry of Transportation for the Alaska Highway No. 97 Fort St. John Corridor Improvements.

# APPENDIX I

## TETRA TECH'S LIMITATIONS ON THE USE OF THIS DOCUMENT

# LIMITATIONS ON USE OF THIS DOCUMENT

## GEOTECHNICAL

### 1.1 USE OF DOCUMENT AND OWNERSHIP

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The Professional Document is intended for the sole use of TETRA TECH's Client (the "Client") as specifically identified in the TETRA TECH Services Agreement or other Contractual Agreement entered into with the Client (either of which is termed the "Contract" herein). TETRA TECH does not accept any responsibility for the accuracy of any of the data, analyses, recommendations or other contents of the Professional Document when it is used or relied upon by any party other than the Client, unless authorized in writing by TETRA TECH.

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Where TETRA TECH submits electronic file and/or hard copy versions of the Professional Document or any drawings or other project-related documents and deliverables (collectively termed TETRA TECH's "Instruments of Professional Service"), only the signed and/or sealed versions shall be considered final. The original signed and/or sealed electronic file and/or hard copy version archived by TETRA TECH shall be deemed to be the original. TETRA TECH will archive a protected digital copy of the original signed and/or sealed version for a period of 10 years.

Both electronic file and/or hard copy versions of TETRA TECH's Instruments of Professional Service shall not, under any circumstances, be altered by any party except TETRA TECH. TETRA TECH's Instruments of Professional Service will be used only and exactly as submitted by TETRA TECH.

Electronic files submitted by TETRA TECH have been prepared and submitted using specific software and hardware systems. TETRA TECH makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

### 1.3 STANDARD OF CARE

Services performed by TETRA TECH for the Professional Document have been conducted in accordance with the Contract, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Professional Document. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Professional Document.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of TETRA TECH.

### 1.4 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

### 1.5 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Professional Document, TETRA TECH may have relied on information provided by third parties other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

### 1.6 GENERAL LIMITATIONS OF DOCUMENT

This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this document, at or on the development proposed as of the date of the Professional Document requires a supplementary exploration, investigation, and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

### 1.7 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, TETRA TECH has not been retained to explore, address or consider and has not explored, addressed or considered any environmental or regulatory issues associated with development on the subject site.

### 1.8 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems, methods and standards employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. TETRA TECH does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

### 1.9 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

### 1.10 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historical environment. TETRA TECH does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional exploration and review may be necessary.

### 1.11 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

### 1.12 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

### 1.13 INFLUENCE OF CONSTRUCTION ACTIVITY

Construction activity can impact structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques, and construction sequence are known.

### 1.14 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, and the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

### 1.15 DRAINAGE SYSTEMS

Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function. Where temporary or permanent drainage systems are installed within or around a structure, these systems must protect the structure from loss of ground due to mechanisms such as internal erosion and must be designed so as to assure continued satisfactory performance of the drains. Specific design details regarding the geotechnical aspects of such systems (e.g. bedding material, surrounding soil, soil cover, geotextile type) should be reviewed by the geotechnical engineer to confirm the performance of the system is consistent with the conditions used in the geotechnical design.

### 1.16 DESIGN PARAMETERS

Bearing capacities for Limit States or Allowable Stress Design, strength/stiffness properties and similar geotechnical design parameters quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition used in this report. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions considered in this report in fact exist at the site.

### 1.17 SAMPLES

TETRA TECH will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

### 1.18 APPLICABLE CODES, STANDARDS, GUIDELINES & BEST PRACTICE

This document has been prepared based on the applicable codes, standards, guidelines or best practice as identified in the report. Some mandated codes, standards and guidelines (such as ASTM, AASHTO Bridge Design/Construction Codes, Canadian Highway Bridge Design Code, National/Provincial Building Codes) are routinely updated and corrections made. TETRA TECH cannot predict nor be held liable for any such future changes, amendments, errors or omissions in these documents that may have a bearing on the assessment, design or analyses included in this report.