April 11, 2016

JoAnne Deneron
Chair
Mackenzie Valley Environmental Impact Review Board
200 Scotia Centre
5102 50th Avenue,
Yellowknife, NT
X1A 2N7

Dear Ms. Deneron

**RE: Environmental Assessment EA1415-001, Prairie Creek Mine Reasons for Decision on DAR Adequacy – Inadequate Items**

We refer to the Reasons for Decision (RfD) document from the Review Board on the above noted subject dated December 21, 2015.

Canadian Zinc Corporation (CZN) is pleased to report on the three remaining items considered inadequate that CZN is responsible to report on. These are:

1. Effects assessment and description for the Sundog Creek re-alignment
3. Frequency of landslides and avalanches
4. Description of terrain from km 160-184

Each item is discussed below.

**Sundog Creek Re-alignment**

From Km 33 to 38, portions of an active creek channel are to be occupied by the road. In some places, the active channel will be moved over in equal part to the road encroachment. From Km 35.5 to 36.9, the road will occupy portion of the current main channel. We propose to deepen an adjacent channel, in use relatively recently, as necessary to recreate the original channel, and the adjacent channel will thus become the main or re-aligned channel. All channels in the area are relatively shallow (less than 40 cm), punctuated with occasional pools in proximity to rock abutments. In the absence of detailed site survey, which would be completed during the final design phase, it is difficult to estimate the quantity of material that would be excavated from the re-aligned channel and placed in the existing with any degree of accuracy. The excavated material would be incorporated into the road prism. If there is a material deficit, fill would be sourced from the borrow sources that have been defined, or the considerable number of reserve borrow sources.

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Tetra Tech EBA has evaluated the hydrology of the proposed creek re-alignment and other changes. Their report is attached, and addresses the environmental setting and preliminary design requirements defined in the RfD, including mitigation measures such as riprap armour.

Regarding environmental risks to project components, and risks to the road segment in the absence of channel re-alignment, Tetra Tech EBA's proposals are provided in their report. Without the creek re-alignment, creek flows would directly abut the road, and the road would be prone to erosion. Further, since the road would occupy a portion of the channel, hydraulic capacity would be diminished. By re-aligning the creek into a previously used channel, risks to the road can be substantially reduced and channel capacity maintained.

Once the channel has been re-aligned, there may be local thalweg shifting and channel infill. This is of no concern provided it does not lead to channel movement south to the original alignment. The potential for this occurrence is considered to be low, since partially vegetated islands exist between the two channels. There are a few low spots between islands that will need to be filled to ensure the re-aligned channel does not 'short-circuit' to the south. Channel location and bedload accumulation will be monitored. Bedload accumulation could force the channel to avulse in a direction not preferred. Therefore, if problematic bedload accumulation is noted, maintenance dredging may be considered. This would occur in the absence of channel flow in the late fall/early winter period, or later in winter if necessary. The re-aligned channel will not be allowed to move back to original location during the life of the road, and so the road prism and protection is not expected to change over the life of the project.

Allnorth have reviewed the preliminary road design for Km 33-38.1. Details are provided in their letter attached. The letter includes definition of the spatial footprint of the road on the floodplain and channels. The spatial footprint of the channel re-alignment, and the hydraulics of it, is described in the above noted Tetra Tech EBA report. That report also describes channel changes, other than the channel re-alignment, that will be required to maintain channel hydraulics and stability where the road bed will impinge on existing channels.

**Frequency of Landslides and Avalanches**

A letter from Tetratech EBA is attached addressing the magnitude and frequency of landslides. Tetratech EBA will be updating their terrain risk assessment to incorporate these results.

Regarding avalanches, an avalanche assessment of the permitted winter road alignment was completed in May 2012 by Avalanche Solutions. Avalanche maps were referred to by Tetratech EBA in their geotechnical report, and included as an appendix. The full report is attached. CZN will be following up on the recommendations in the report at the appropriate time in advance of winter road construction.

CZN did not include the avalanche report in the DAR because it was our understanding that avalanche assessment was only applicable to road sections where re-alignment was proposed (confirmed in the Board's January 22, 2016 Note to File regarding the content of a teleconference), and no re-alignments were proposed in the DAR in terrain where avalanche risk was identified is a concern. The exception is Km 25-28 where a re-alignment is planned to move the all season road to the south side of Sundog Creek, thus avoiding identified avalanche paths on the north side of the valley.

The Alpine Solutions report confirms that the scope of the avalanche assessment was the whole road. Alpine Solutions identified avalanche paths between Km 4-35, and provided frequency and magnitude projections.

**Description of Km 160-184**

Km 160-184 is the road section from the Liard River to the Liard Highway. From the river to Km 174, an old logging road built and used by the NDDB exists which CZN had planned to follow. At Km 174, the proposed road would tie into the existing Nahanni Butte all season road to the highway. Historic air photo interpretation and terrain mapping for Km 160-174 has been completed by Tetratech EBA and is attached.

If you have any questions, please contact us at 604 688 2001.

Yours truly,
CANADIAN ZINC CORPORATION

DPHarpley

David P. Harpley, P. Geo.
VP, Environment and Permitting Affairs

Attachments

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TETRA TECH EBA

March 17, 2016

ISSUED FOR USE
FILE: Y14103320-01
Via Email: david@canadianzinc.com

Canadian Zinc Corporation
Suite 1710, 650 West Georgia Street
Vancouver, BC V6B 4N9

**Attention:** David Harpley
VP Environmental & Permitting Affairs

**Subject:** Sundog Creek Realignment Reach, KP 35-38, Hydrotechnical Assessment
Proposed Prairie Creek All Season Road, NT

# 1.0 INTRODUCTION

As part of its review of Canadian Zinc's (CZN) Developer's Assessment Report (DAR) for the Prairie Creek All-Season Road Project, the Mackenzie Valley Review Board (MVRB) has requested additional information regarding an effects assessment and description for the proposed Sundog Creek realignment adjacent to road Kilometer Post (KP) markers 35 to 38. The details of the request are included in the MVRB's December 21, 2015 document titled "Reasons for Decision of the Adequacy of the Developer's Assessment Report."

This report presents the results of a hydrotechnical analysis that was performed to respond to the MVRB requests, together with a preliminary design for the proposed realignment. During the course of the analyses and preliminary design, the total length of proposed realignment has been reduced from the original proposal. The proposed realignment is now from KP 35.5 to 36.9. Minor alignment changes are being evaluated by others (Allnorth) on behalf of CZN to minimize encroachments into the presently-active channel where channel realignment is no longer being proposed. No realignment is proposed from KP 36.9 to 38.0 because a major northern tributary would render this reach unstable.

# 2.0 ENVIRONMENTAL SETTING

## 2.1 Channel Hydrology and Hydraulics

Assessment of the Sundog Creek reach of interest was performed using detailed LiDAR elevation data and orthophotos obtained in 2012 for the access road alignment. This was supplemented by 1:50,000 scale National Topographic System mapping and elevation data to determine basin areas, historic airphoto imagery from 1949 and 1994 to assess channel movement, and ground photos from prior fish habitat surveys to show bed material size.

Figures 1 and 2 show the study reach with the 2012 orthophoto images, and the LiDAR-derived colour-coded terrain surface, respectively. The figures are annotated to show Kilometer Post (KP) markers along the proposed road alignment, and the three major drainages that define this reach. There are the main stem and a major tributary at the upstream end of the reach, designated as "A" and "B", which enter from the south and west, respectively, join immediately upstream of road KP 35, and then flow to the northeast. Major tributary "C" enters from the north, joining the main Sundog Creek channel near road KP 37.



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Basin areas for tributaries A, B, and C are 61.2, 43.7, and 61.8 km$^2$, respectively. The presently-proposed channel realignment is limited to the upper portion of the study reach between road KP 35.5 and 36.9, for which the total basin area is approximately 105 km$^2$. The total basin area to the lower part of the study reach, downstream of KP 37, is approximately 171 km$^2$. The segment from KP 36.9 to 37.5 is a dynamic transitional reach corresponding to the confluence of the major tributary "C" with the main Sundog Creek channel.

Design flows for the upper and lower segments were determined from a regional analysis of recorded Water Survey of Canada peak flow data for Prairie Creek at Cadillac Mine (495 km$^2$), Flat River near the Mouth (8560 km$^2$), and South Nahanni River above Virginia Falls (14500 km$^2$). Flood quantiles for each station were determined with a Log Pearson 3 distribution, and best fit trend lines relating drainage area to flood quantiles were developed as follows:

$$Q_2 = 0.2114 * (\text{Area})^{0.9112}$$
$$Q_{10} = 0.6033 * (\text{Area})^{0.8391}$$
$$Q_{100} = 1.7883 * (\text{Area})^{0.7523}$$

Channel slopes and dimensions cited in the subsequent text were determined from the 2012 LiDAR elevation data. Figure 3 shows representative cross sections of the channel(s) and floodplain through the study reach. Note that the LiDAR data stops at the water surface and does not show the channel bathymetry. However, because the flow depths are believed to be generally shallow during non-flood periods, the LiDAR information was used "as-is" for the preliminary assessments of channel hydraulic characteristics.

For the upper study reach between road KP 35.5 and 36.9 where channel realignment is proposed, the 2-year and 100-year peak flows are approximately 14.7 and 59.3 m$^3$/s, respectively. The main channel through this segment has a typical width of 20 metres, depth of 1.5 metres, and a channel gradient of 1.6%. Assuming a Manning's "n" of 0.055, the 2-year flow depth would be 0.5 metres with a corresponding mean velocity of 1.4 m/s. The 100-year flow depth would be 1.2 m with a corresponding mean velocity of 2.3 m/s. Using a competent velocity figure from the Guide to Bridge Hydraulics[1], the 2-year flood would mobilize bed material with grain sizes up to about 25 mm diameter. The 100-year flood would mobilize bed material with grain sizes up to about 50 mm diameter. Larger size material would be expected to mobilize in areas of non-uniform flow such as in riffle sections and at the outside of meander bends.

In the lower study reach downstream of road KP 37, the 2-year and 100-year peak flows are approximately 22.9 and 85.6 m$^3$/s, respectively. The main channel through this segment has a typical width of 25 metres, depth of 1.5 metres, and a channel gradient of 1.2%. Assuming a Manning's "n" of 0.055, the 2-year flow depth would be 0.6 metres with a corresponding mean velocity of 1.4 m/s. The 100-year flow depth would be 1.4 m with a corresponding mean velocity of 2.3 m/s. Mobilization of bed material in the lower reach would be similar to that in the upper reach.

## 2.2 Channel Stability

Channel stability was assessed by reviewing the current (2012) channel position relative to historical positions shown by stereo orthophotos taken in August 1949 and June 1994. In addition, the channel position for 2008 was estimated from examination of oblique photographs. For each year, two sets of lines were developed as follows:

[1] Figure 4.13 in Guide to Bridge Hydraulics, Second Edition, Transportation Association of Canada, 2004.

- "Historic channel" lines were delineated on the basis of vegetation presence/absence and indicate where alluvial materials are exposed. Historic channel lines for 2008 (inferred from oblique photos) were the same as in 2012 and were not mapped.
- "Active channel" lines were delineated to show where water was visible in the airphotos. In the 1949 and 1994 photos, much of the study reach had no visible water, and lines were therefore not drawn because the position of the main channel could not be determined. Because the majority of the upper study reach from road KP 35 to 36.5 was completely dry in both the 1949 and 1994 photos, the analysis presented in this report relies on the more complete "historic channel" lines described above.

In the upper study reach between road KP 35.5 and 36.9, the Sundog Creek channel is quasi-stable, with channel positions and vegetated islands that tend to persist for as long as decades. From the terrain surface conditions shown on Figure 2, there appears to be a broad floodplain area about 180 m wide, with the scars of past channel positions over the full floodplain. Figure 1 shows that more than half of the floodplain area is presently vegetated, and that exposed alluvial material, indicating areas of more recent activity, is present over only about 80 metres. Figure 4 shows the historical edge of vegetation (e.g. exposed alluvium) from 1949 to date, from which persistent large islands are apparent within the area of historic braided channels. The development of large vegetated islands is consistent with a long term trend for vertical degradation (downward incision) but at a very slow rate that is inconsequential over the service life of the road.

Within the upper study reach, the main channel is located near the south edge of the floodplain. Starting at about road KP 35.5, there is a second flow path which breaks off from the main channel and flows through the central and northern portions of the floodplain. The second flow path is distinct for having exposed alluvial material (e.g., absence of vegetation) in all of the airphotos from 1949 through 2012.

In the lower study reach downstream of road KP 37, the channel is much more active and does not have the same persistent features identified in the upper segment. The higher activity is presumed to be the result of the major tributary which enters from the north, nearly perpendicular to the main channel. This tributary has braided channel characteristics and likely carries a considerable bed load at flood discharge which will interact with and locally disrupt the stability of the east-flowing main channel.

### 2.3 Bed Material

Figures 5a and 5b are photos taken during fish habitat surveys on Sundog Creek in the study area vicinity. The substrate consists of coarse gravels, cobbles and boulders, with cobbles dominating.

## 3.0 PROPOSED CHANNEL MODIFICATIONS

### 3.1 Design Concept

The proposed road alignment follows the southern edge of the Sundog Creek floodplain. This alignment, in places, encroaches into the Sundog Creek main channel. At these locations, the road embankment will require suitable armouring to resist erosion. In order to minimize the amount of armouring that is required along the road embankment, it is proposed that the creek be realigned, where feasible, to be away from the road. Where realignment is not feasible, the design concept is to protect the road with suitable armouring and to make local channel modifications to maintain channel hydraulic capacity and flow velocities.

The design concept initially presented to the MVRB was to use strategic channel realignment for all segments from KP 35 to 38 where the road alignment would encroach in to the existing active channel. Subsequent review of channel characteristics, described in Section 2 above, determined that channel realignment should be considered only in the reach from KP 35.5 to 36.9 where quasi-stable conditions exist. Channel realignment is not recommended for the reach from KP 37 to 38 downstream of the major tributary that enters from the north and produces very dynamic channel conditions that would be difficult to control.

In the reach from KP 35.5 to 36.9, a well-defined alternative flow path exists that does not impinge upon the proposed road alignment, and it is proposed that the stream be realigned to follow the alternative flow path. This will be accomplished by deepening (excavating) the alternative flow path to provide comparable hydraulic capacity to the existing channel, and diverting the flow into the new alignment. The existing channel would then be permanently abandoned and available for road construction, although the road bed is expected to occupy only a portion of the channel. The remainder of the abandoned channel would convey small volumes of water during periods of higher flows due to the high permeability of the alluvium, however flows in the abandoned channel will remain low and have minimal erosive force.

Where suitable alternative flow paths do not exist and it is necessary for the road footprint to encroach into the active channel, it is proposed that the road embankment be suitably armoured to withstand the anticipated flows. Impacts to channel hydraulic capacity would be mitigated by excavating the opposite bank so that the original channel dimensions (width, area, depth) are restored adjacent to the road.

## 3.2 Channel Realignment Preliminary Design

As described above, there is a well-defined alternative flow path that diverges from the main channel at about road KP 35.5 and flows through the central and northern portions of the floodplain. Hydraulic modelling was conducted to understand the hydraulic characteristics of the entire study area under existing conditions, with particular interest in the reach downstream of KP 35.5 that contains the alternative flow path.

A 2-D hydraulic model was developed to evaluate the existing channel hydraulics through the study reach. Channel geometry for the model was based on the 2012 LiDAR data. Simulated inundation extents and velocities for 2-year and 100-year peak flow scenarios are shown on Figures 6 and 7, respectively. Braided flow conditions occur in areas where exposed alluvium exists as a result of relatively recent large flow events; active braided flow conditions are most evident in the vicinity of KP 37 where the major tributary enters from the north. Quasi-stable conditions, with less braiding, occur in the reach downstream of KP 35.5 where the alternative flow path begins. Because the majority of flow in this reach below KP 35.5 is naturally contained within a single channel, it is considered feasible to realign the main channel to follow the alternative flow path that flows through the north side of the floodplain, away from the road.

The preliminary design of the proposed channel realignment for Sundog Creek from KP 35.5 to 36.9 includes two major parts: (1) deepening of the alternative flow path along the north side of the floodplain; and (2) construction of an armoured barrier berm to divert the watercourse from the existing channel into the alternate alignment. The historic flow path will be deepened by excavation to have a bottom width between 15 and 20 metres similar to the existing channel, and a bottom slope that is set so that end point bed elevations are matched to the existing channel. A minimum channel depth of 1.5 m will be provided, with berming if necessary, to match the geometry and hydraulic capacity of the existing channel. The outcome of this approach will be to retain the original channel velocities as near as possible. Excavated material will be used to partially fill the existing channel where the road bed will be.

A 2-D hydraulic model of the proposed channel realignment and diversion berm was developed. The realigned channel is approximately 1,600 m long with an average channel slope of 1.5%. Figures 8 and 9 present the results of the hydraulic model for 2-year and 100-year peak flow scenarios, respectively. The simulated 100-year flow inundation limits and velocities presented on Figure 9 show that the water is expected to be substantially contained within the realigned channel. Notwithstanding these results, ongoing inspections and monitoring will be required over the service life of the road to assess the stability of the realigned channel and to implement repairs as needed.

Figures 10a and 10b present oblique aerial views of the reach where the realignment is proposed.

## 3.3 Design Approach for Channel Encroachments

Upstream and downstream of the proposed channel realignment, some segments of the proposed road may encroach into the existing main channel. These segments will need to be armoured to resist embankment erosion. Where encroachments occur, it is recommended that the channel be excavated on its opposite bank so as to maintain its pre-construction geometry, hydraulic capacity, and water velocities adjacent to the road. This approach will be implemented on the road segment downstream from KP 37 where the channel is less stable due to the major tributary joining Sundog Creek from the north.

# 4.0 LIMITATIONS

This report and its contents are intended for the sole use of Canadian Zinc Corporation and their agents. Tetra Tech EBA Inc. (Tetra Tech EBA) 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 Canadian Zinc Corporation, 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 report is subject to the terms and conditions stated in Tetra Tech EBA's Services Agreement.

# 5.0 CLOSURE

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

Respectfully submitted,
Tetra Tech EBA Inc.

REGISTERED PROFESSIONAL ENGINEER
W.A. ROZEBOOM
LICENSEE
NT/NU

March 17, 2016

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/cee

Attachments: Figures (12)

**PERMIT TO PRACTICE**
**TETRA TECH EBA INC.**
Signature ______
Date March 17, 2016.
**PERMIT NUMBER: P 018**
NT/NU Association of Professional Engineers and Geoscientists

# FIGURES

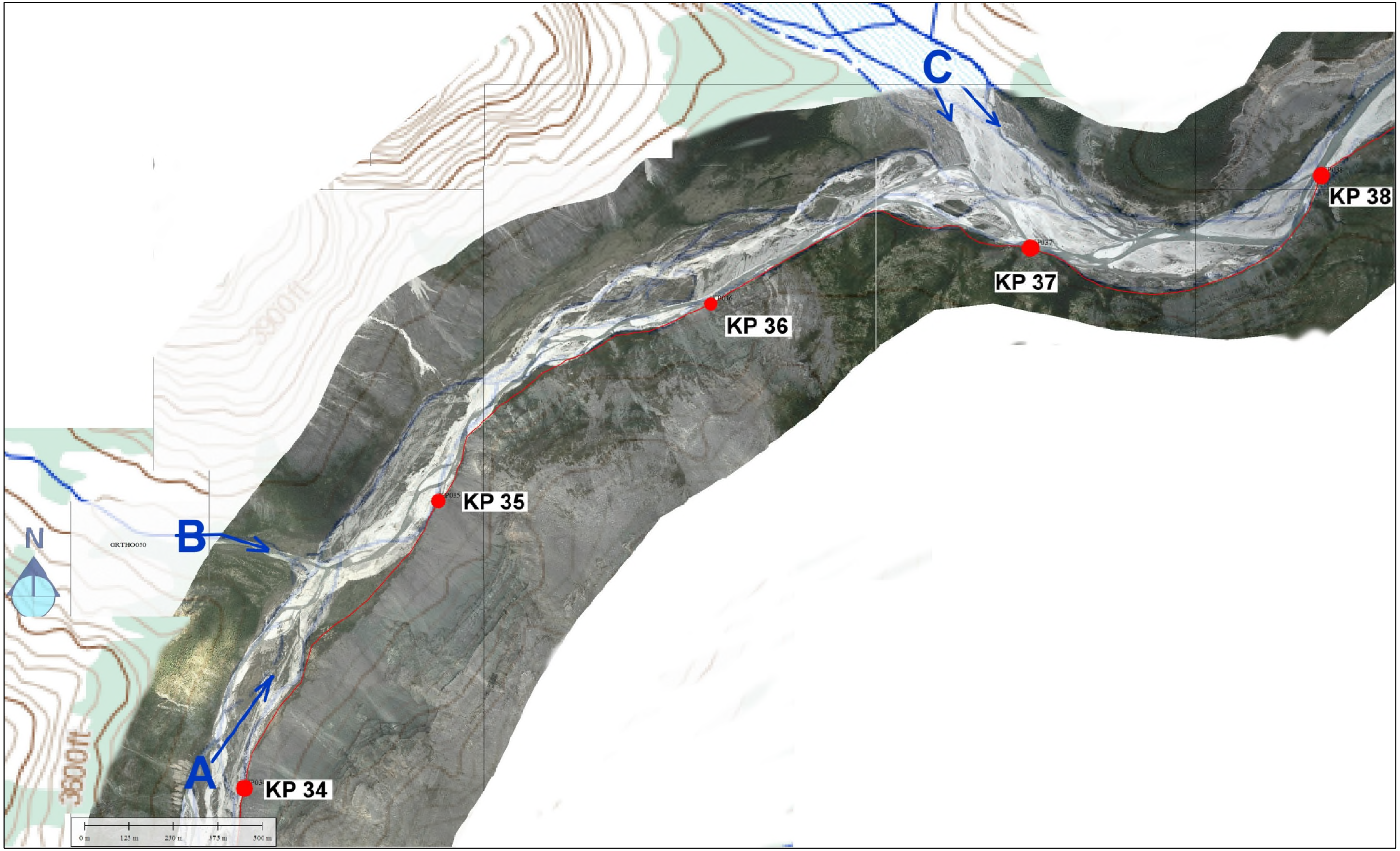


**Figure 1: Sundog Creek Study Reach with 2012 Orthophoto**

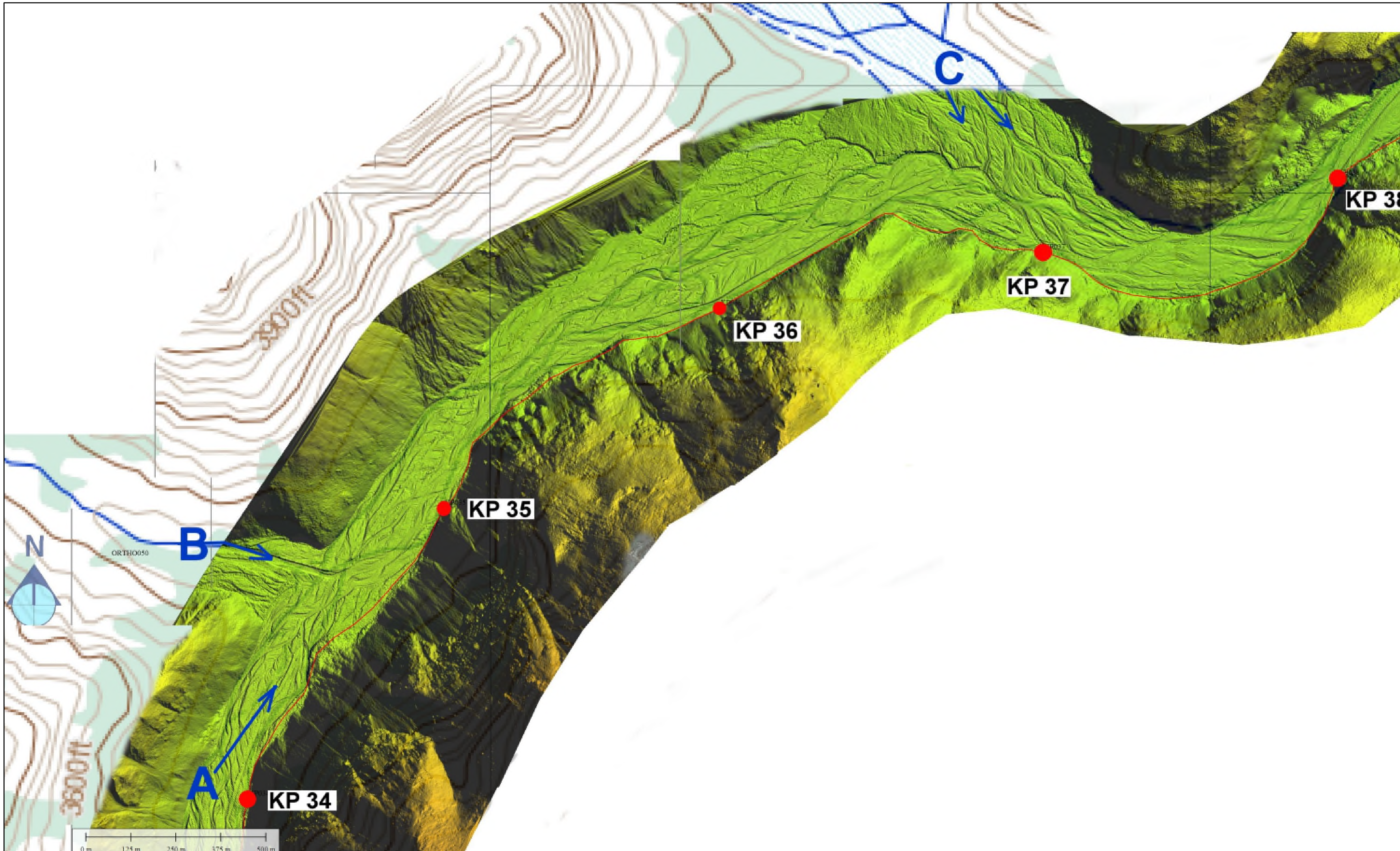


**Figure 2: Sundog Creek Study Reach with Terrain Surface Derived from 2012 LiDAR Elevation Data**

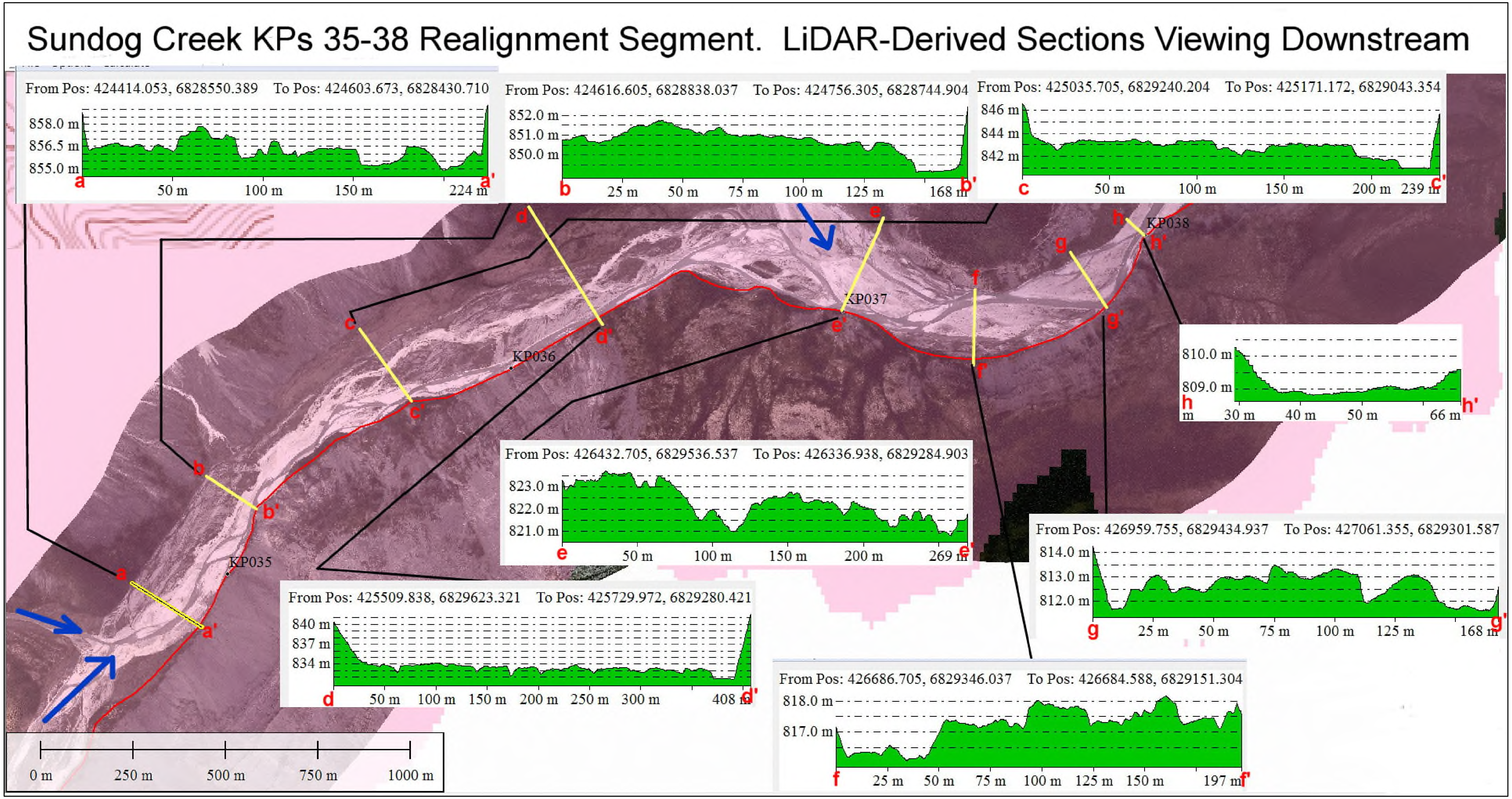


Figure 3: Sundog Creek Study Reach with 2012 LiDAR-Derived Cross Sections Viewing Downstream

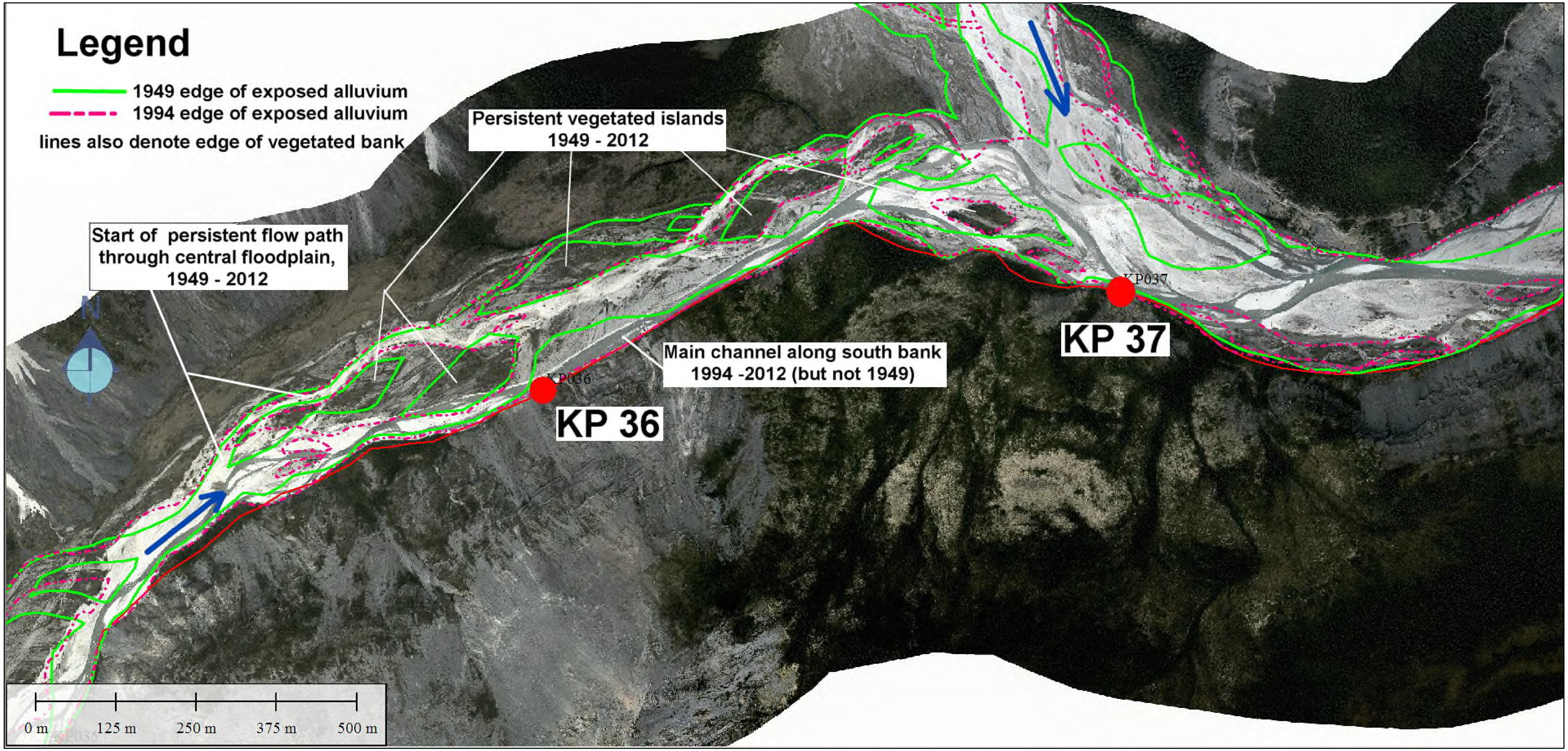


**Figure 4: Sundog Creek Historic Edge of Bank Shown on 2012 Orthophoto**

**Figure 5a: Sundog Creek View Downstream Near Road KP 37**

**Figure 5b: Sundog Creek Gravel Bar near Pool Downstream of Road KP 40, Not on Alignment**

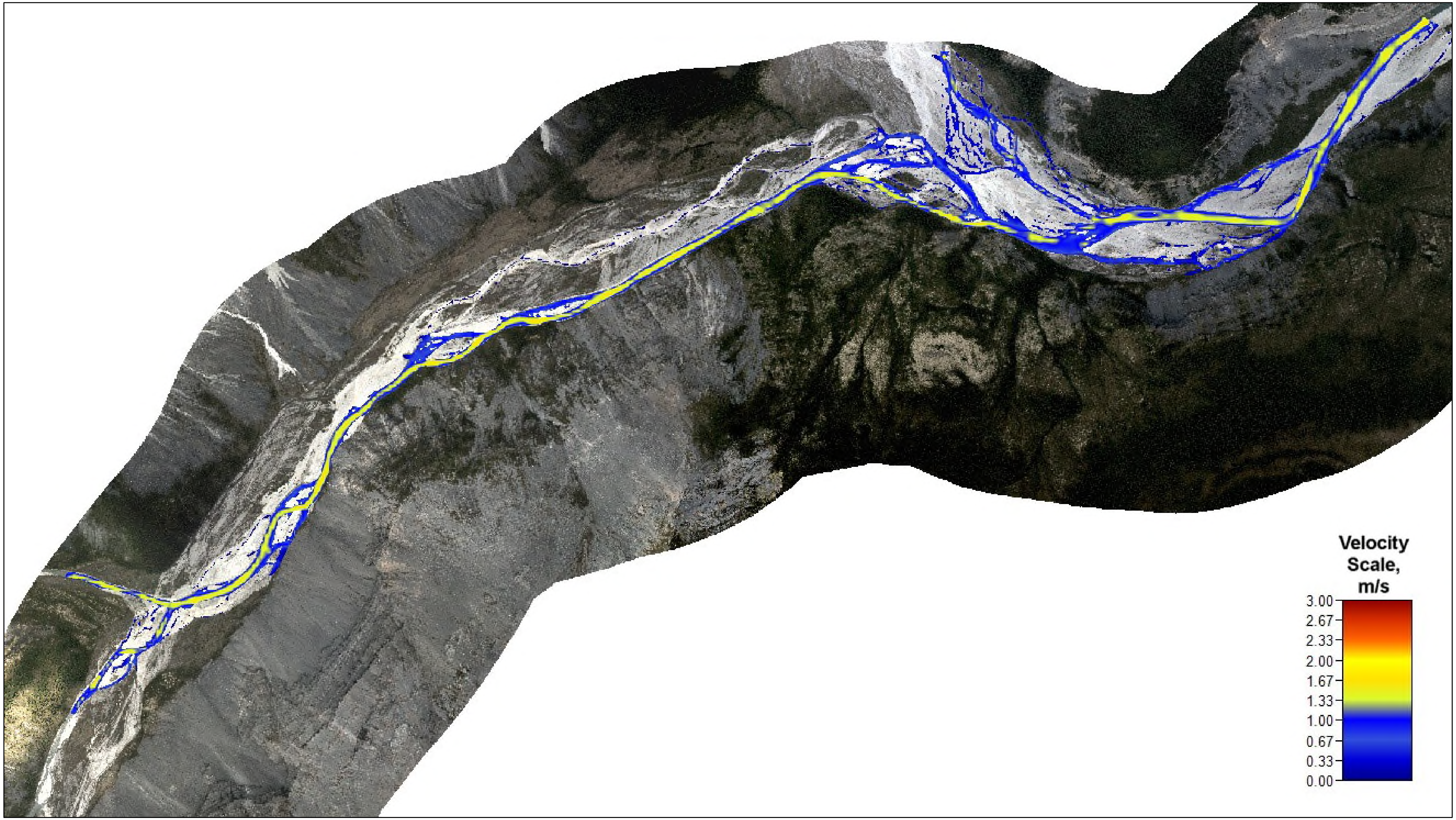


**Figure 6: Sundog Creek 2-year Peak Flow Inundation Limits and Flow Velocities**

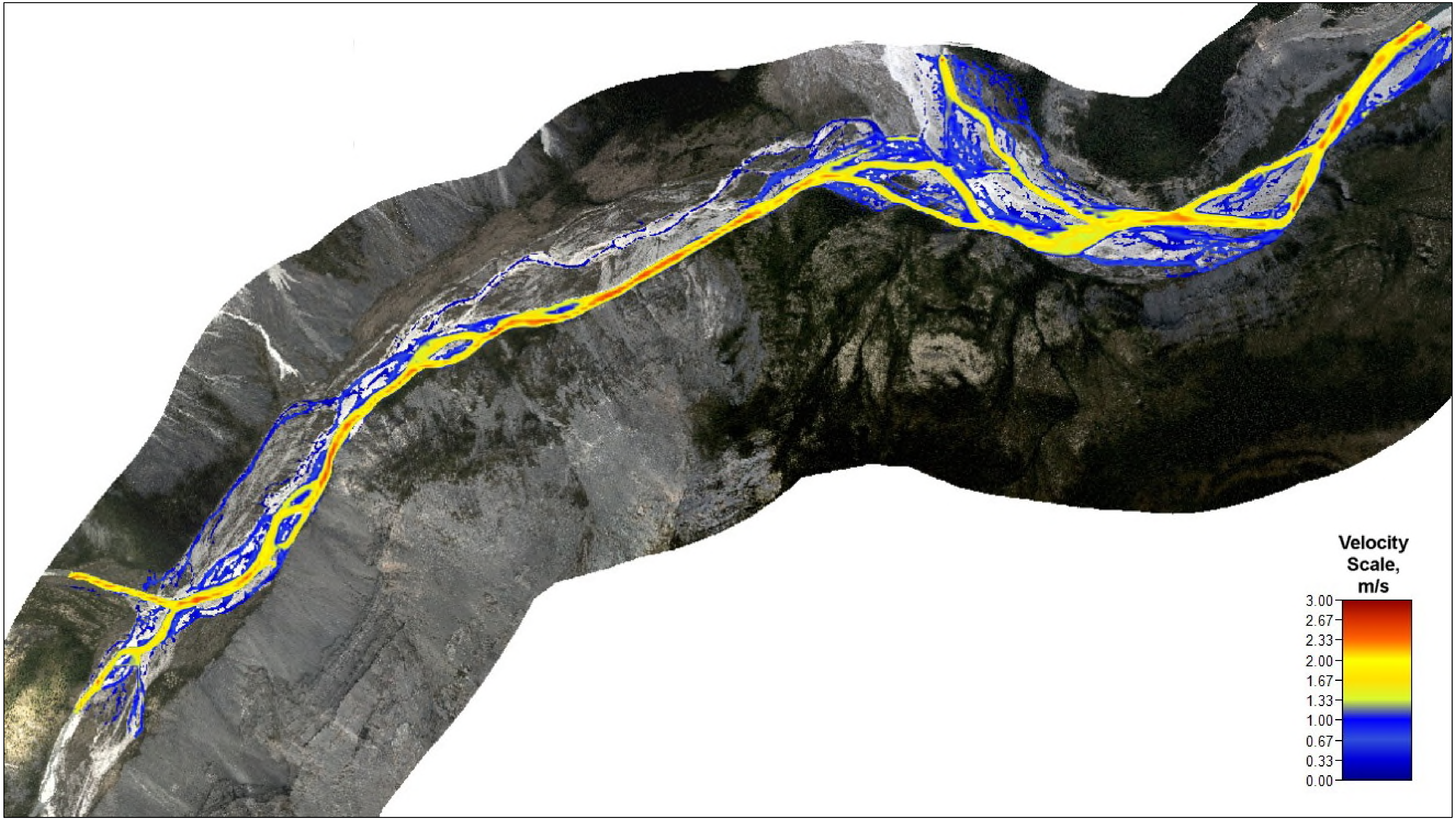


**Figure 7: Sundog Creek 100-year Peak Flow Inundation Limits and Flow Velocities**

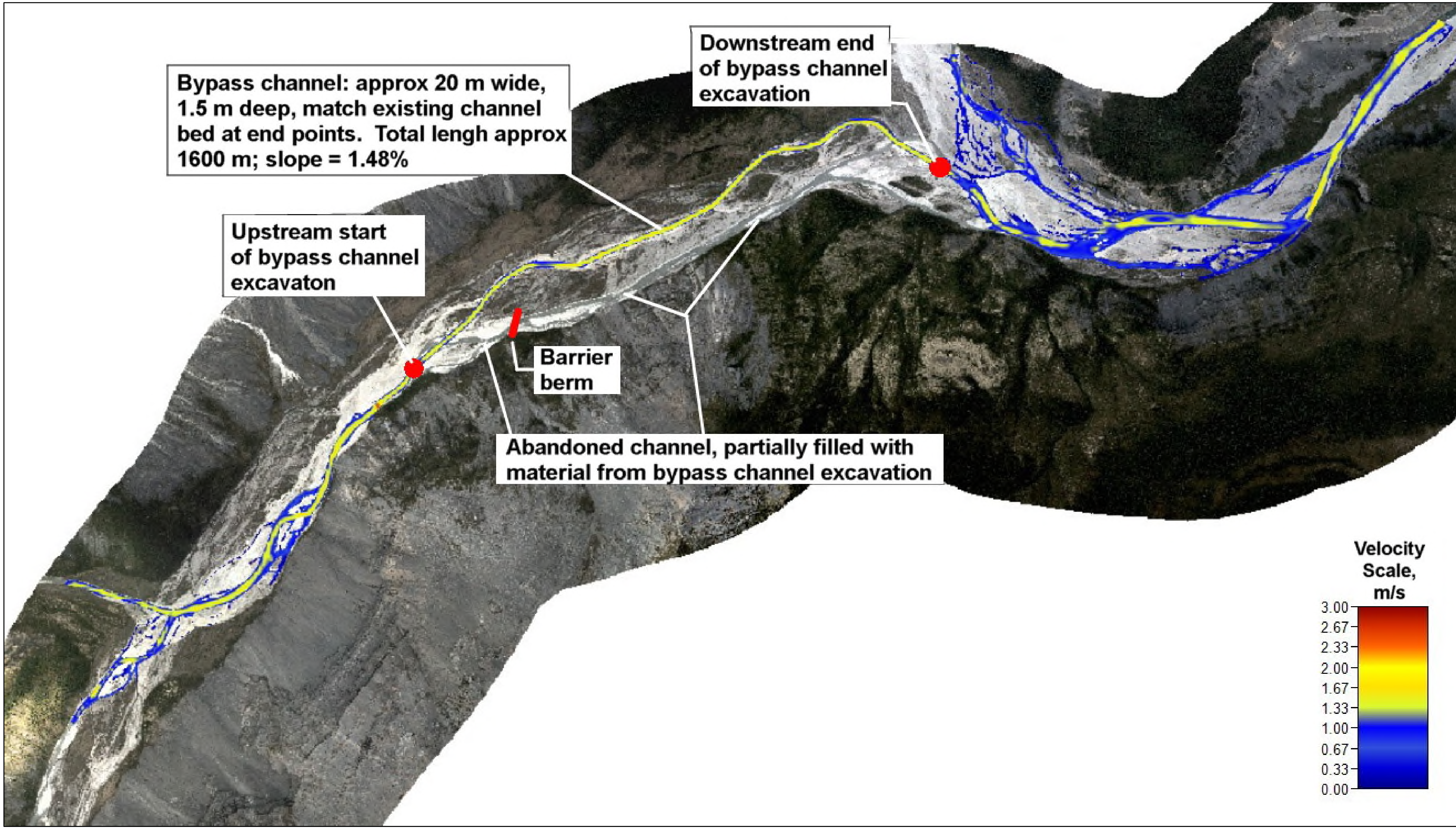


**Figure 8: Sundog Creek Proposed Re-alignment with 2-year Peak Flow Inundation Limits and Flow Velocities**

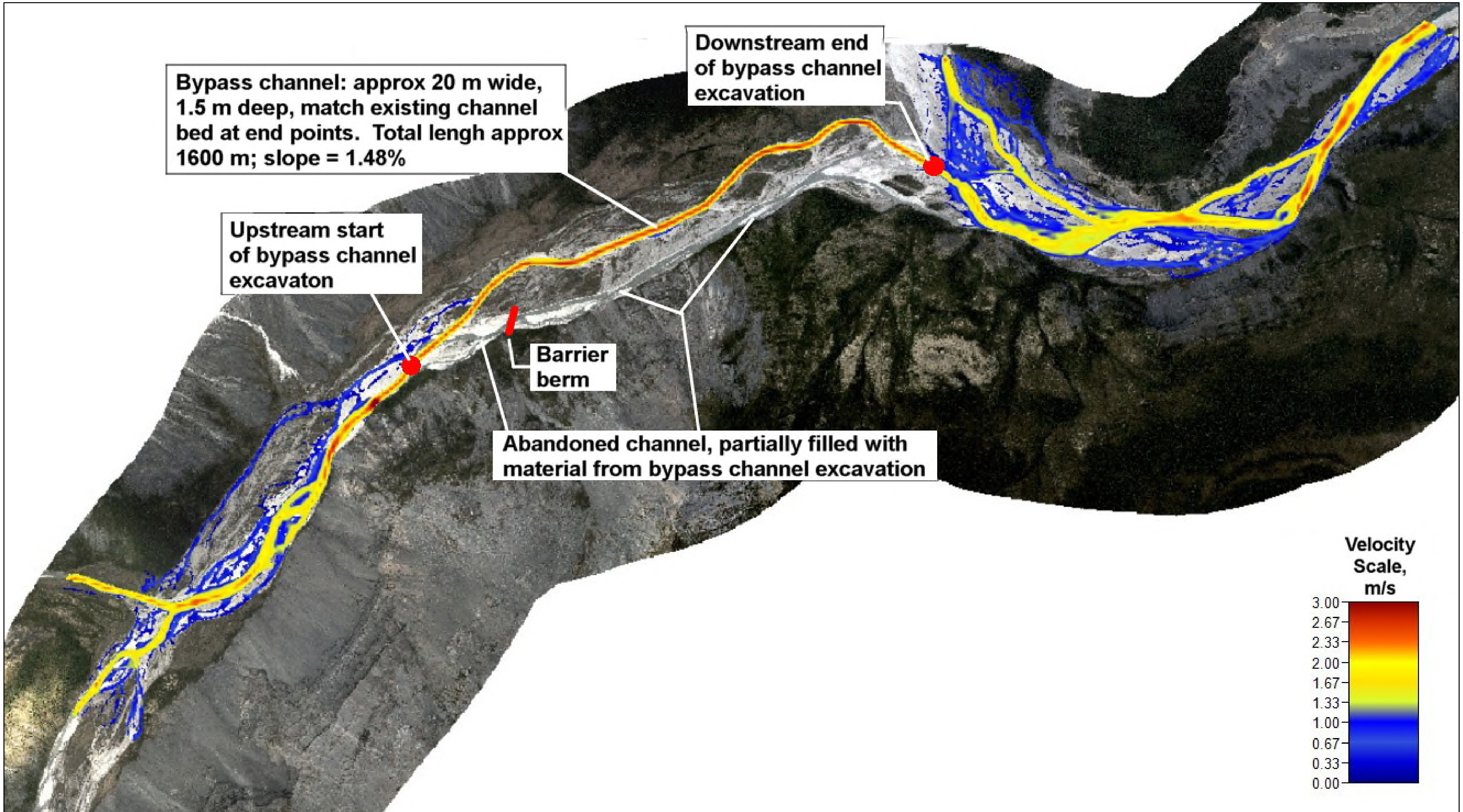


**Figure 9: Sundog Creek Proposed Re-alignment with 100-year Peak Flow Inundation Limits and Flow Velocities**

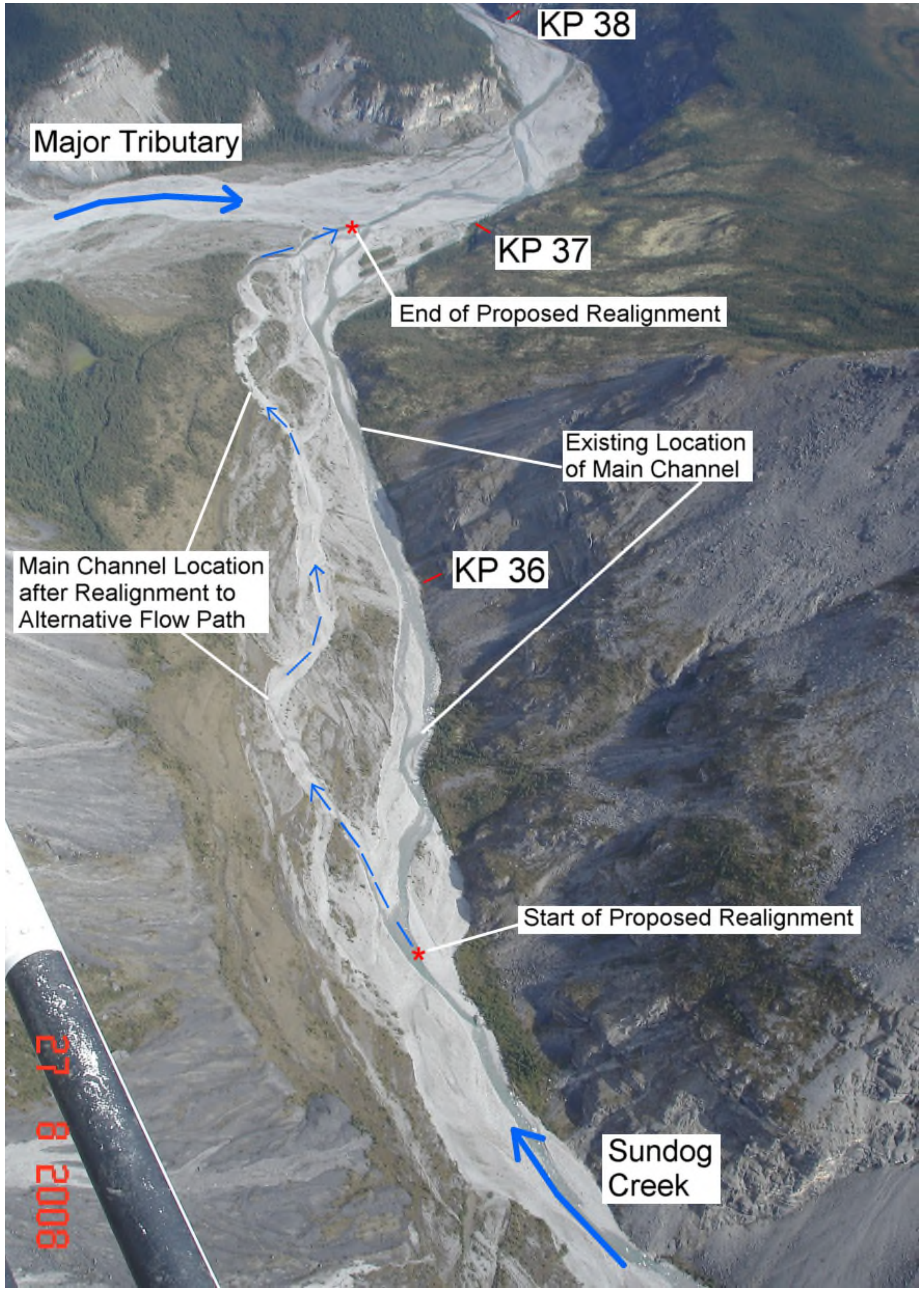


**Figure 10a: Sundog Creek Viewing Downstream at Realignment Reach**
**Photo date August 8, 2008**


**Figure 10b: Sundog Creek Viewing Upstream at Realignment Reach**
**Photo date September 15, 2009**

| Memorandum | | | |
|---|---|---|---|
| 2011 PG Pulpmill Road, PO Box 968, Prince George, BC V2L 4V1 Phone: 250-614-7291 | | | |
| Date: | March 18, 2016 | Project Number: | 16 GP 0041 (originally 14GP0128, 15GP0091) |
| Attention: | Dave Harpley | Project Description: | Prairie Creek Mine Access Road. |
| Company: | Canadian Zinc (CZN) | File Number: | |
| Phone: | 604 688 2001, Home 604 594 3855 | From: | Ernest Kragt |
| Fax: | | Email: | ekragt@allnorth.com |
| Email: | <david@canadianzinc.com> | | |
| Copy To: | Don Watt, Brad Major | | |

**RE:** **LOWER SUNDOG CREEK KP 33 TO 38.1**

**ROAD DESIGN, CONSTRUCTION APPROACH, AND ROAD PRISM FOOTPRINT**

# 1 BACKGROUND

Canadian Zinc (CZN) submitted a Developer's Assessment Report (DAR) application to the Mackenzie Valley Review Board (MVRB) on April 23, 2015 for a 184 km all season access road to its Prairie Creek Mine. The MVRB conducted an Adequacy Review and issued a document on May 22, 2015 requesting CZN to provide additional information. Allnorth supported CZN's submission of a Dar Addendum on September 13, 2015. The MVRB issued their Reasons for Decision on Adequacy (RFD) dated December 21, 2015. This identified five remaining items requiring further information, four from CZN.

CZN requested Allnorth to provide more detailed information related to one item, the portion of road from KP 33 to 38.5 located directly parallel to Sundog Creek, including the road prism footprint and how it impacts/occupies stream channels and the floodplain. This is in response to RFD Section 5.1, Sub-section titled "Environmental effects of the project components" – first bullet to reads "spatial footprint area of the road segment on the floodplain, active braided channel, and channel thalweg(s)".

# 2 FINDINGS

## 2.1 General Site Description

The proposed road section from KP 33 to 38.5 is located in a valley with steep slopes consisting of talus slopes and rock faces. Sundog Creek has a seasonally active channel and subsidiary channels that are prone to creep from year to year, and adopt different channels over 1-2 decades, within the confines of an historical floodplain. Photo 1 below is an example of the typical terrain within this section.

During most of the open water season, stream flows are low and are confined to one main channel with some small, braided secondary channels. All channels can be dry during low precipitation periods in the summer and fall. During spring thaw periods, levels rise and water can flow in multiple channels over the current active flood plain. The original winter road alignment, constructed in early 1980's, is distinguishable within most the valley bottom and largely "intact" despite active seasonal stream flows.

Only the most active stream sections have made the original road grade indistinguishable. The fact that the original road structure constructed over 30 years ago is largely intact suggests water energy during high flow periods has limited hydrological force, and/or most channel locations have not moved.

**Photo 1: A view of the Sundog valley floodplain looking north (downstream) near KP 33.**

As might be expected from viewing Photo 1 above, the natural materials within this confined valley are primarily clean gravels, cobbles, large fragmented, talus rock, and exposed bedrock. These natural, clean gravels (above the currently active floodplain) and rocks will provide ideal road building material and pose minimal risk related to sediment release during construction or road operations.

An alternative alignment was reviewed and discussed in Allnorth's "Supplement to Original Submission", included in the DAR Addendum, Appendix A, which would route the road out of the valley over the section in question. However, this alternative was rejected due to steep grade issues. Therefore, the only option is to locate the road in the confined valley bottom.

## 2.2 Road Alignment Approach and Footprint

The approach taken toward route selection integrates direction provided by the hydrology team at Tetra Tech EBA. For defining the road footprint occupying the active channel; the "*active floodplain*" is considered to be portions of the floodplain which experience surface water flows during some part of the year over successive years. The active floodplain is typically distinguishable in pictures as exposed, whitish gravels with no vegetation growth. An *"Active braided channel"* or secondary channel is a portion of the floodplain which experiences surface water flows only for a short period during the peak seasonal periods such as spring thaw or unusual summer storms. The active braided channel is typically distinguishable in pictures as fragmented, braided, narrow channels with noticeable vegetated portions. *"Old or historic floodplain"* would include portions of the floodplain which have not experienced surface water flow for some time, 20 years or more, and are considered quasi-stable. The historic floodplain is typically distinguishable in pictures darker in colour, noticeably vegetated. *"Channel thalweg"* is the portion of main channel that contains deeper water flows occurring over longer periods of the year.

The approach to determining the road alignment through this terrain was in the order of priority listed in Table 1 below:

**Table 1: Rating and approach applied for determining road alignment through lower Sundog Creek.**

| Rating | Approach |
|---|---|
| A | Whenever possible, locate the road prism/structure "outside" of the current active floodplain. This approach was possible over an estimated 2.8 km of the 5.1 total km, or 55% of the road. |
| B | Locate the road prism/structure as tight as possible to the confining talus/rock slopes to minimize road footprint within the active floodplain. Any road structure exposed to potential surface water scouring and erosion will be sufficiently armored to protect the road structure and stream integrity. |
| C | Locate the road prism/structure as tight as possible to the confining talus/rock slopes to minimize road footprint within the active braided or secondary channel portions of the floodplain. The road structure/base would be constructed of large fragmented rock, suitably armored and elevated 1 metre above the projected high water level. |
| D | Re-alignment of the main seasonally active Sundog Creek channel to maintain surface water flows away from the road prism/structure to eliminate or minimize long term impacts on the road structure and its operation and protect stream integrity. As the re-alignment of the stream will eliminate or minimize the potential of water scouring and erosion, generally the road structure would not be armored. |
| E | Where the terrain severely limits and constrains the location of the road, the road prism/structure is partially or fully (50 to 100%) occupying portions of the channel thalweg. In these cases, the hydrology does not support re-alignment/shifting of the channel thalweg. The road structure must be constructed to withstand the hydrological forces of the stream. The road structure/base would be constructed of large fragmented rock, heavily armored and elevated above the projected design high water level. |

Selected alignment locations also integrated safety considerations for rock fall/avalanche risks, as much as possible. Sufficient clearances were allowed for rock fall material along rock faces, where possible. Where not possible, rock fall protection will be considered during detailed design, as appropriate. Also, as stated in our original submission (DAR Appendix 1), an Avalanche/Rock Fall Management Plan should be developed prior to operations to manage avalanche/rock fall hazards along all susceptible sections of the proposed Prairie Creek Mine Access Road. Revised preliminary designs for road sections are attached.

## 2.3 Detailed Site Description and Approach

Table 1 below provides greater detail on the construction approach to be applied section by section.

**Table 1: Detailed site description and construction approach**.

| KP 33.0 to 34.8 |
|---|
| **Site Description and Construction Approach:** No preliminary design was completed for this section in the original submission. The alignment has been refined to follow tightly along the base of talus slopes. From KP 33.6 to 34.8, the main stream channel is located on the opposite (west) side of the floodplain. |
| **KP 33.0 to 33.6.** The road prism will be contained outside the active floodplain. |
| **KP 33.6 to 33.95. .** Follows tightly along a narrow vegetated band between the toe of the talus slope and the active braided channel floodplain. Estimate 25 to 50 % of the road prism may occupy the active braided floodplain. Toe of road prism will be sufficiently armored with defined coarse rock rip rap and/or gabion baskets. |
| **KP 33.95 to 34.05.** A 100 m road section will occupy 80 to 100% of a secondary channel to avoid a significant talus slope. Toe of road prism will be sufficiently armored with defined coarse rock rip rap and/or gabion baskets. |
| **KP 34.05 to 34.8**. Road prism will be located entirely outside the active floodplain. |
| Photos 4 and 5. |


**Photo 4: View at KP 33 looking north (downstream).**


**Photo 5: Aerial view of KP 34 to 34.8 looking from the west side of the valley to the east (downstream to left)**

## KP 34.8 to 36.45

**Site Description and Construction Approach:** A preliminary design was completed for this section in the original submission and was utilized to provide detailed breakdown. The alignment and design has been refined to follow tightly along the present active channel of Sundog Creek at the base of talus slope. A re-alignment of the main stream channel is proposed from KP 35.5 to 36.9, shifting the channel 75 to 150 m northeast of its present location. This re-alignment will prevent impacts on the road structure within this section.

**34+800 to 34+920**. Road prism is located outside active floodplain. Minor precautionary armouring may be required.

**34+920 to 35+010.** Follows tightly along a narrow vegetated band between the toe of the talus slope and the active floodplain. 25 to 50 % of the road prism may occupy the active floodplain. Toe of road prism will be sufficiently armored with defined coarse rock rip rap and/or gabion baskets.

**35+010 to 35+190.** Follows tightly along a narrow vegetated band between the toe of the talus slope and the active floodplain. 40 to 60 % of the road prism may occupy the active floodplain. Toe of road prism will be sufficiently armored with defined coarse rock rip rap and/or gabion baskets.

**35+190 to 35+300**. A series of steep talus and rock faces push the road prism 80 to 90 % into the active floodplain. The main road subgrade will be constructed with large, angular rock and located tightly along the steep rock faces. The structure will be heavily armored to resist impact from scour during high water flows.

**35+300 to 35+500**. Road prism is located outside the active floodplain.

**35+500 to 35+600.** A rock face pushes the road prism 80 to 100% into the present active floodplain. However, the re-alignment of the main channel starts here, and will prevent direct impacts of water flows on the road structure. The main road subgrade will be constructed with angular rock.

**35+600 to 35+800**. Road prism is located outside present active floodplain.

**35+800 to 36+120**. A significant portion of the road prism, 50 to 100%, is located in the "present" active floodplain. .

**36+120 to 36+3+360**. The road prism may occupy up to 50% of the present active floodplain.

**36+360 to 36+450.** A significant portion of the road prism, 50 to 100%, is located in the "present" active floodplain.

Photos 6 and 7.

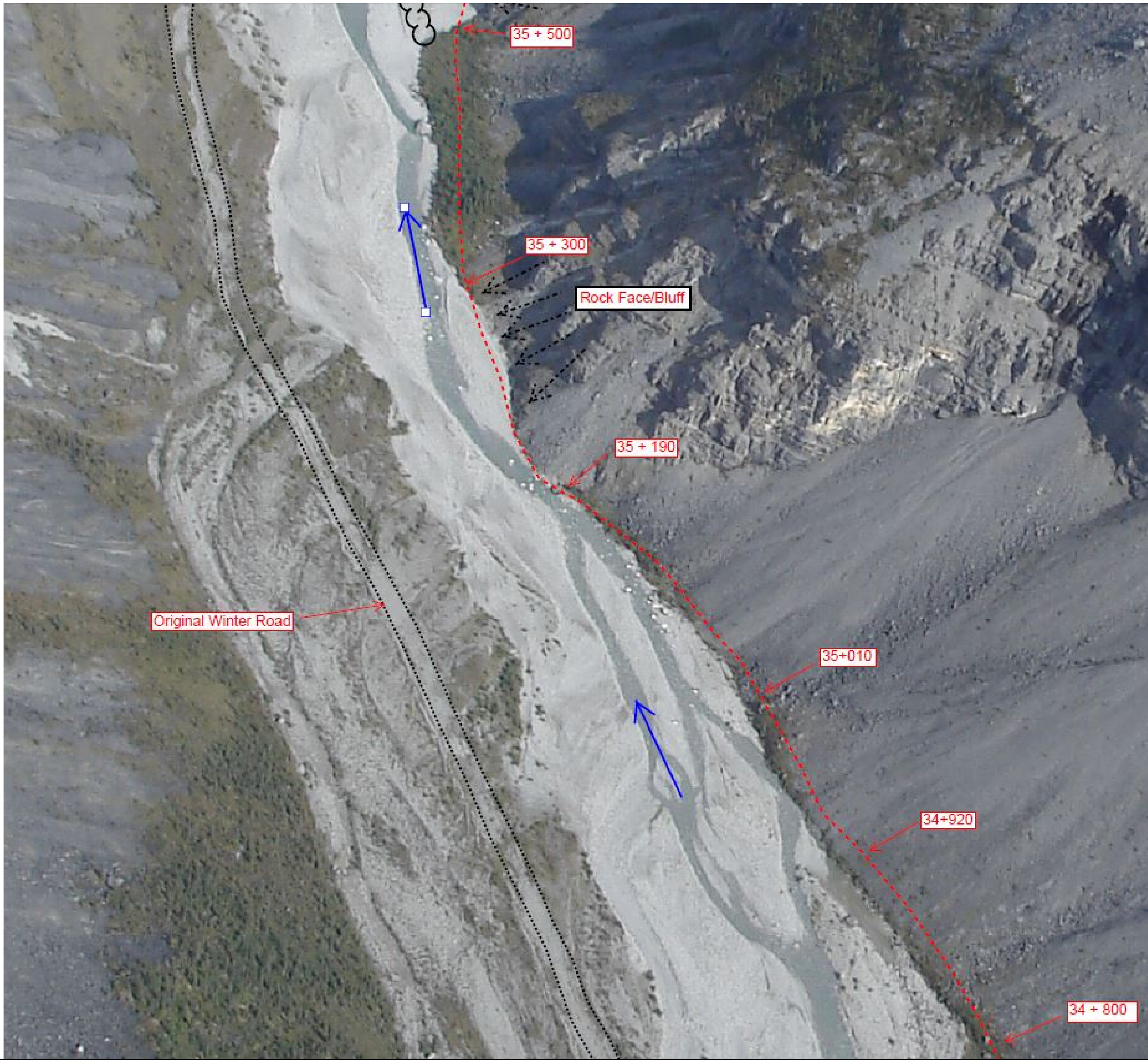


**Photo 6. Aerial view looking north from KP 34+800 to 35 +500.**


**Photo 7. Aerial view looking north from KP 35+500 to 36+450.**

# KP 36.45 to 37.5

**Site Description and Construction Approach:** A preliminary design was completed for this section in the original submission and was utilized to provide a detailed breakdown. The alignment and design has been refined to shift the majority of the road prism outside of the active floodplain. This shift in alignment increases the volume of blast rock which will be utilized in segments of the road.

**36+450 to 37+100**. The majority of final road prism is elevated 2 to 6 m above the active floodplain. It is expected this section will contain thin shallow soils, with a thin layer of rippable rock with bedrock underneath. This will increase the total blasting required but will provide a solid road base, particularly from 36+700 to 37+100. A short portion (50 m) of the road prism near 36+650 may occupy an old portion of floodplain.

**37+100 to 37+500**. Road prism is located outside the active floodplain.

Photos 8 and 9.

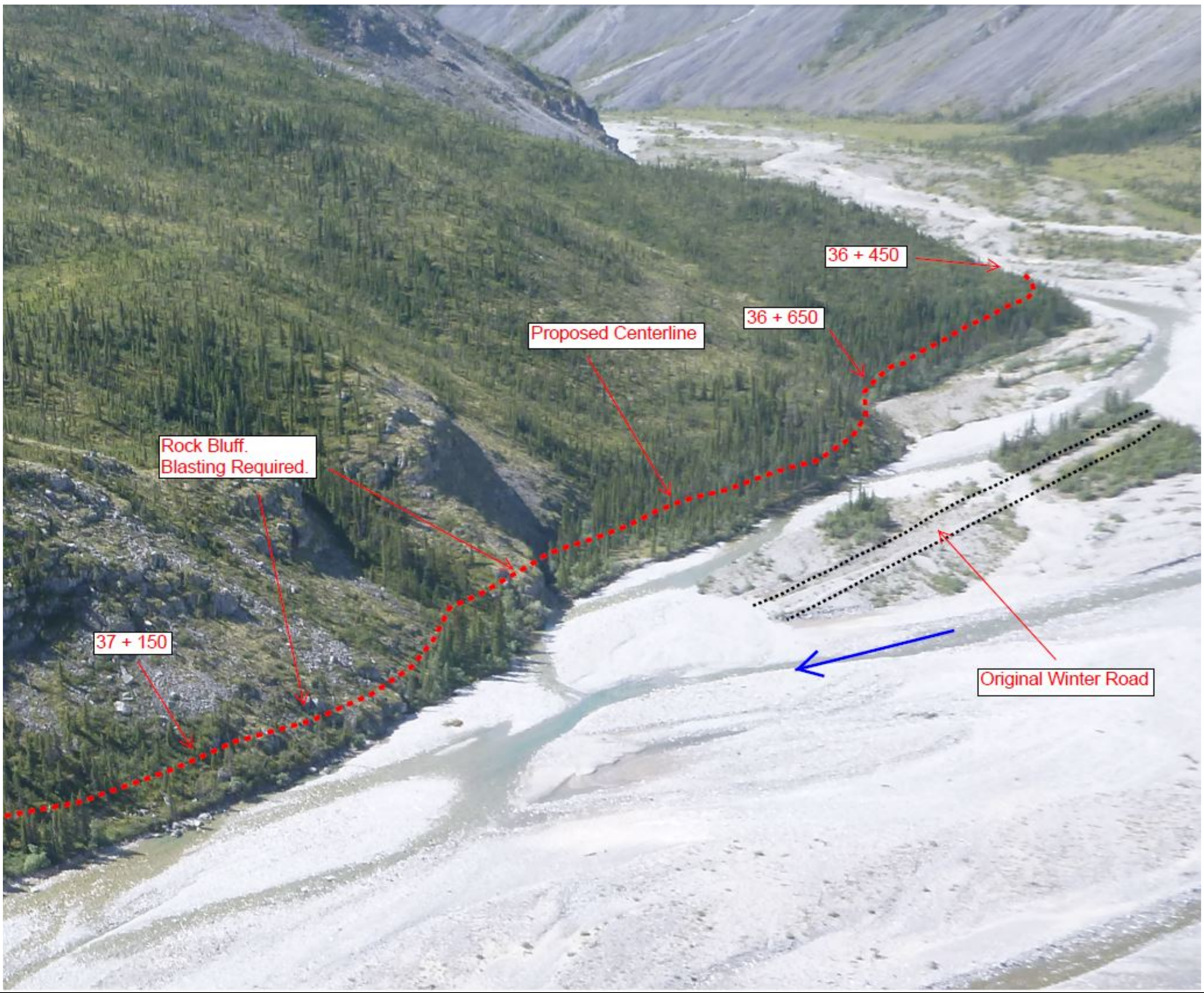


**Photo 8: Aerial view looking southwest from KP 36+450 to 37+500.**

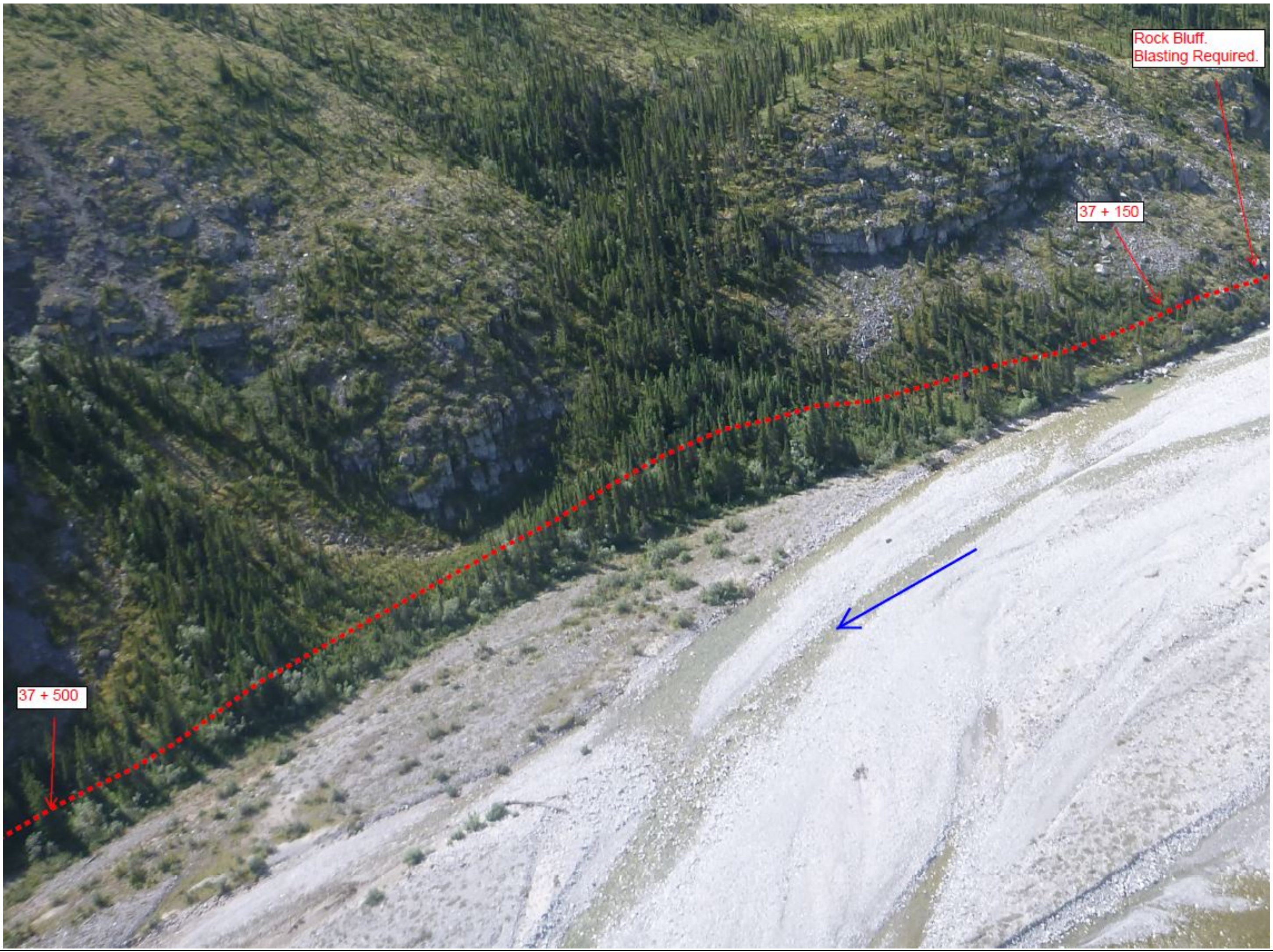


**Photo 9. View looking southwest from 37+150 to 37+500.**

## KP 37.5 to 38.1

**Site Description and Construction Approach:** A preliminary design was completed for this section in the original submission and was utilized to provide detailed breakdown. The hydrology does not support a re-alignment of the main channel (ref. Tetratech EBA). The major tributary from the north-west has significant hydrological influence on the main channel. The steep valley terrain, with rock cliffs near 37+800, force 50 to 100 % of the road prism into the active channel.

**37+500 to 37+750.** 50 to 100% of the road prism occupies a secondary/braided channel of the floodplain. The main road subgrade will be constructed with large, angular rock and located tightly anchored along the talus rock slope. The structure will be suitably armored to resist impact from scour during high water flows.

**37+750 to 38+100**. The road structure will be constructed and anchored along the rock face with 80 to 100 % of the road prism occupying the main active stream channel. The hydrological force is expected to be significant . The road structure will be constructed to a height 1 m greater than the defined high water level with large coarse rock and extensive armoring of the exposed slope. The channel thalweg will be relocated (shifted) to the west to accommodate the road prism (see photo 11 below).

Photos 10 and 11.

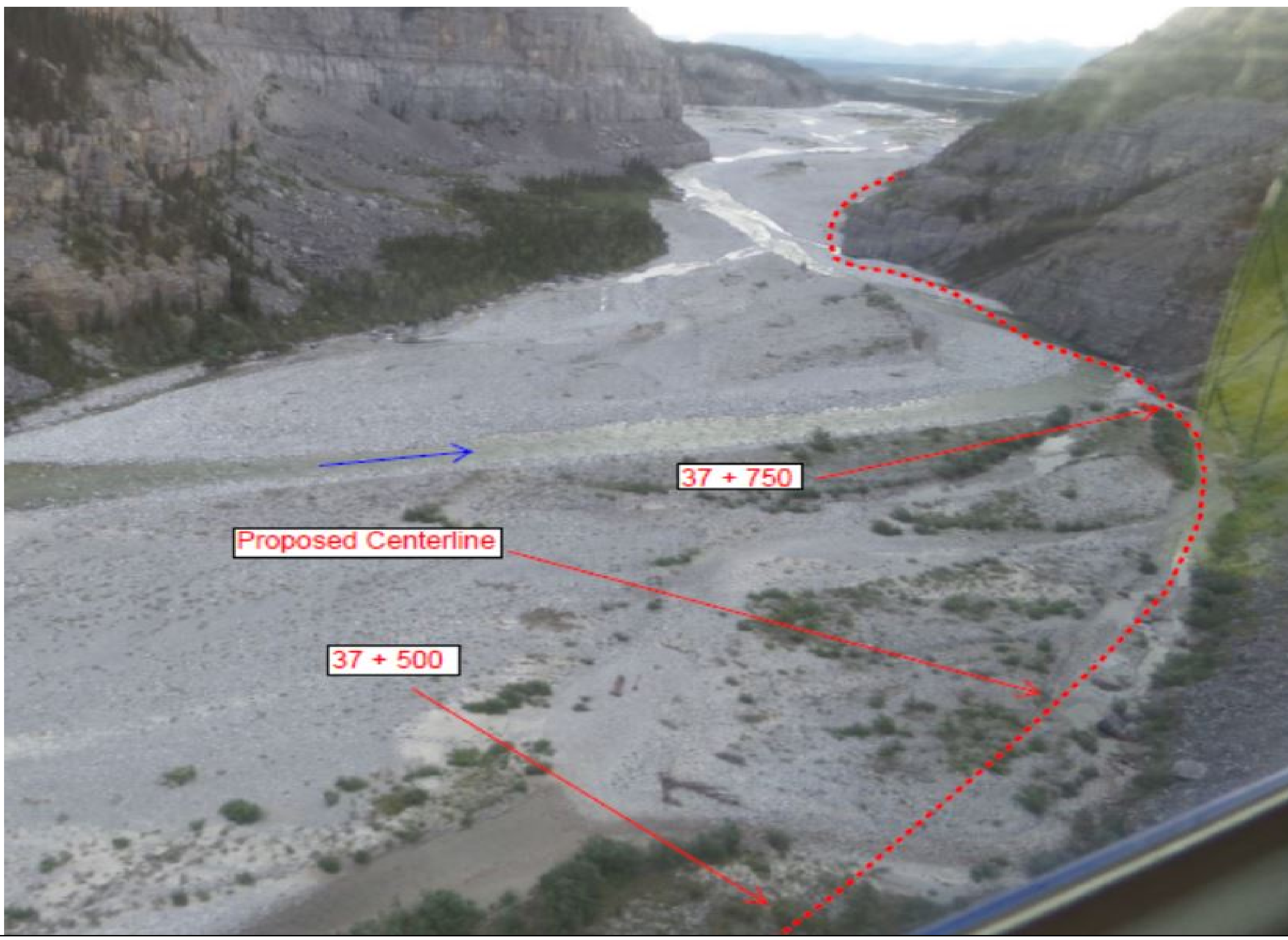


**Photo 10. View looking north-east (downstream) at KP 37.**


**Photo 11. Aerial view looking southeast from KP 37.5 to 38.1.**

### 2.3.1 Summary of Road Structure Footprint

Table 2 below summarizes the footprint of the road structure based on the approach listed in Section 2.2, Table1.

**Table 2: Breakdown summary of road prism footprint occupying Sundog Creek from Station KP 33.0 to 38.1 – 5.1 km total.**

| Rating | Road length (km) | Average width road prism occupying floodplain (m) | Estimated area occupying floodplain ($m^2$) | Comments |
|---|---|---|---|---|
| A | 2.92 | 0.0 | 0.0 | Outside active or braided/secondary floodplain |
| B | 0.38 | 6.6 | 2,500 | Within the active floodplain |
| C | 0.70 | 5.5 | 3,850 | Within the braided or secondary floodplain |
| D | 0.75 | 8.3 | 6,240 | Within "present" active floodplain. Re-alignment of main channel proposed |
| E | 0.35 | 10.0 | 3,500 | Within active "*thalweg*" channel / floodplain |
| **Total** | **5.1** | **3.15** | **16,090** | |

## 2.4 Construction Approach

The road base/subgrade will be constructed with local, readily available gravels, cobbles, and talus rock. Construction is scheduled for the late summer/fall of Year 2 and will be accomplished by working from both ends of the section to ensure the schedule is maintained. Construction activities will be directed continually by a prescribed Construction Supervisor, under the guidance of a Professional Engineer, and with environmental monitoring.

Site conditions will limit the numbers of large equipment working at each end. Equipment would probably consist of a large excavator loading rock trucks, two rock trucks hauling material, and an excavator placing material for road base/rip rap. At times a small dozer and packer will be used to spread, pack, and smooth road subgrade. This process may be repeated several times in layers until the defined road elevation is achieved. Initially, the priority would be to establish a base road connecting the two ends, and continuing to build up the road structure until the prescribed elevation is achieved.

It is expected that gabion baskets will be used extensively on cuts and fills in talus. The advantages of gabion baskets include:

- Minimize the footprint of the road structure
- Provide additional slope stability of the cut slopes
- Provides added armour protection along the bank exposed to a stream channel
- Provides more effective armour against flow events when compared to loose rock
- Reduce overall cut/fill volumes
- Economical to purchase and transport
- Utilizes local, native material

Photo 2 below shows a typical highway application for gabion baskets. Photo 3 shows a typical basket. Figure 1 is an example of a typical cross section with gabion baskets utilized. The detailed road design, based on final field evaluation and survey, will define where and how gabion baskets will be utilized.

Following the construction of the road, ongoing monitoring of the road structure will occur. Regular maintenance will be applied which will include rebuilding/adding additional armoring to those sections deemed insufficient, as required.

**Photo 12 is an example of the extreme capability of gabion baskets utilized on a highway structure (would not be necessary for the road standard prescribed for the Prairie Creek mine). Photo 13 is typical gabion basket**.

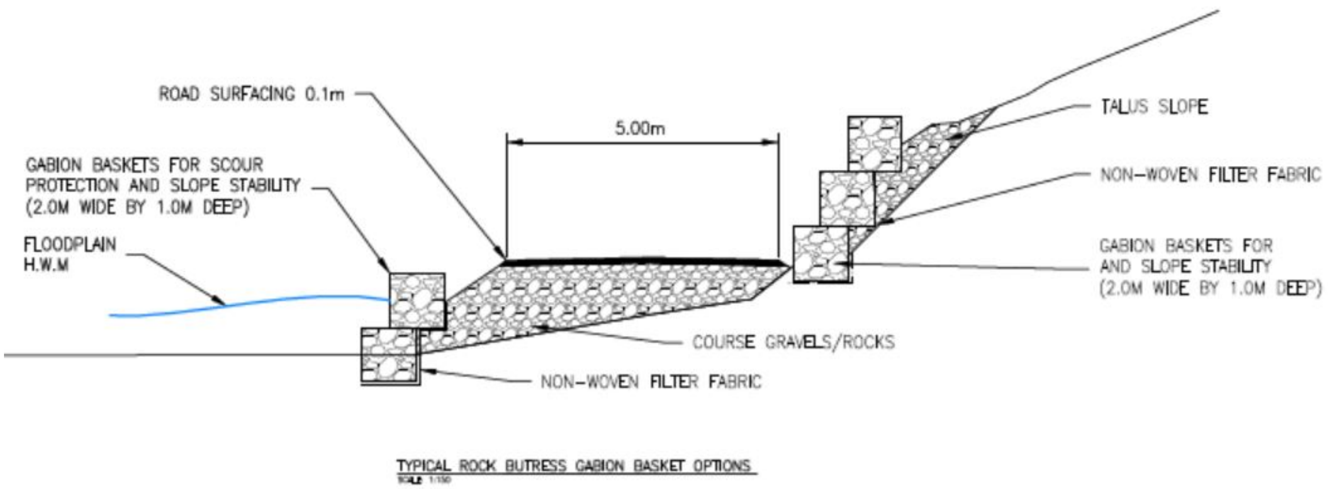


**Figure 1: Typical road cross section utilizing gabion baskets.**

# 3 CONCLUSIONS

This report clarifies the approach to be applied for the all season road construction adjacent to Sundog Creek from KP 33.0 to KP 38.1. The revised designs provided are considered preliminary. Detailed designs will be completed prior to construction.

Completed By: Ernest Kragt

Reviewed By: Brad Major

# TECHNICAL MEMO

ISSUED FOR USE

| | | | |
|---|---|---|---|
| **To:** | David Harpley | **Date:** | April 11, 2016 |
| **c:** | Nigel Goldup | **Memo No.:** | 01 |
| **From:** | Shirley McCuaig | **File:** | Y14103320-01 |
| **Subject:** | Magnitude/Frequency Analysis – Landslide Hazards<br>Proposed Prairie Creek All Season Road, NT | | |

## 1.0 INTRODUCTION

As part of its review of Canadian Zinc Corporation's (CZN) Developer's Assessment Report (DAR) for the Prairie Creek All-Season Road Project, the Mackenzie Valley Review Board (MVRB) has requested a desktop magnitude/frequency assessment for landslide and snow avalanche hazards along the proposed alignment. The details of the request are included in Section 5.3 of the December 21, 2015 document titled "Reasons for Decision of the Adequacy of the Developer's Assessment Report", provided by MVRB.

Tetra Tech EBA Inc. (Tetra Tech EBA) was retained by Canadian Zinc Corporation to complete a magnitude/frequency analysis for landslide hazards. Snow avalanche hazards are provided by other consultants.

Geohazards mapped for the proposed alignment include bedrock slumps; debris slides; debris flows; rockfalls; rockslides; earth slumps and flows; lateral spreads in surficial deposits; soil creep caused by permafrost presence; thaw flow slides and gully erosion (all defined in Howes and Kenk (1997)). These geohazards were mapped in detail and discussed as part of the DAR submission (Tetra Tech EBA 2015a) and subsequent submissions (Tetra Tech EBA 2015b, 2015c, 2016). The geohazard mapping formed a typical "Landslide Analysis" for the route (as per Wise et al. 2004). The work described herein is a "Hazard Analysis", which estimates the likelihood of occurrence of particular landslides that would be considered hazardous to the proposed road or its users (Wise et al. 2004). The purpose of this desktop study is to provide a preliminary assessment of the susceptibility of the proposed road to geohazards along the 184 km route alignment, including one alternate route alignment.

## 2.0 HAZARD RATINGS

### 2.1 Definitions

Definitions of the landslide magnitude and frequency ratings adopted for this study are provided in Tables 2.1 and 2.2 below. These definitions are based on the examples provided in Wise et al. (2004), with some modifications to suit the scope of this study and terrain conditions along the alignment.

Magnitude can be equated to the relative size or destructive potential of a particular hazard type. For landslide hazards, it is usually equated to the volume of material involved, the potential depth of erosion, or the amount of ground displacement. The latter two cannot be determined without detailed field studies, so the former is used as the best proxy for this analysis.

Frequency is a subjective estimate of the annual probability of occurrence (likelihood) of the landslide hazards.

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### Table 2.1: Magnitude (modified from Wise et al. (2004))

| Magnitude Rating | Area affected (ha) | Minimum volume involved ($m^3$)[1] |
|---|---|---|
| Very Large | > 2.5 | > 25,000 |
| Large | 0.5 to 2.5 | 5,000 – 25,000 |
| Medium | 0.05 to 0.5 | 500 – 5,000 |
| Small | < 0.05 | < 500 |

[1]Based on area affected and assuming landslide debris is on average 1 m thick

### Table 2.2: Frequency (modified from Wise et al. (2004))

| Likelihood Rating (Probability of occurrence) | Annual Probability of Occurrence | Probability of Occurrence over a 20-Year Design Life[1] | Qualitative Description |
|---|---|---|---|
| High | >1:50 | > 33% | Landslide is probable within the design life of the proposed road. |
| Moderate | 1:50 to 1:250 | 8% to 33% | Landslide is unlikely, but possible within the design life of the proposed road. |
| Low | <1:250 | < 8% | Landslide is a remote possibility within the design life of the proposed road. |

[1]Probability that at least one landslide event will occur within the assumed 20-year design life of the road

Note that the definitions of hazard and likelihood are different from that of risk:

- A hazard is a harmful or potentially harmful landslide expressed qualitatively (Wise et al. 2004);
- Likelihood (frequency) is the potential for the landslide to occur (Wise et al. 2004);
- Risk is the likelihood of a specific adverse consequence (loss of life, loss of infrastructure, damage to infrastructure) arising from a geohazard within a stated period and area. Mathematically, risk is defined as the product of landslide probability (likelihood of occurrence) ($P_H$), spatial probability ($P_{S:H}$ – the likelihood of a landslide reaching or affecting the proposed road or an individual), temporal probability ($P_{T:S}$ – the potential of the proposed road or an individual being present at the time of a slide), vulnerability (V – the probability of damage to the road or harm/loss of life to an individual), and the value or worth of the element (E) (number of people at risk or value of road) (Porter and Morgenstern 2013):
    - Risk = $P_H \times P_{S:H} \times P_{T:S} \times V \times E$

The magnitude/frequency analysis contained herein provides the $P_H$ and $P_{S:H}$ components in a qualitative manner.

## 2.2 Methods

Various geohazards have been mapped from air photos for three dates along the proposed alignment (generally 1949 and 1994 air photos and 2012 LiDAR images, but other photo years cover some parts of the route). The magnitude (volume) of landslide hazards were estimated based on the runout length and width of an event (e.g., the length and width of a rockfall or rock slide scar and its deposits), or by the mapped areal extent of larger slides. Runout lengths are shown by symbols and areal extents by mapped terrain stability polygons on the terrain stability map figures provided within the Mapping Summary Report (Tetra Tech EBA 2015c). The year of the air photo that a geohazard first appears on is shown by the colour of the feature in the same figures. Landslide frequency and magnitude were estimated using this data. A minimum landslide debris thickness of 1 m was used to estimate magnitude, as this cannot be determined via air photo interpretation alone. Frequency can only be approximated based on professional judgement and the activity levels observed on air photos and the LiDAR image.

# 3.0 HAZARD ASSESSMENT

## 3.1 General

Landslide hazards were analyzed along the 184 km of the proposed alignment and magnitude/frequency ratings were assigned to various portions of the route per the criteria given in Tables 2.1 and 2.2. The assessment was conducted at about a 1:10,000 scale and only those hazards having potential to affect the road were analyzed. Due to the scale of the mapping, the groupings of some portions of the route may contain localized areas of benign or potentially unstable terrain within the defined kilometre range, regardless of their magnitude and frequency ratings.

The assigned magnitude and frequency ratings are presented in Table 1, attached to this document, along with descriptions of each portion of the route, including hazard types present, and whether the hazard occurs upslope or downslope of the road. In some areas, more than one hazard is present. For the purposes of this study, magnitude and hazard ratings were only assigned for the dominant hazard process (the hazard most likely to affect the proposed road). Dominant hazards are identified by bold and italicized text in Table 1. Secondary hazards are listed and described; however, magnitude and likelihood ratings have not been assigned to these unless they were considered equally dominant (co-dominant) or subdominant but nearly co-dominant.

## 3.2 Assumptions and Interpretations

There are a number of assumptions and interpretations that are inherent to the desktop estimation of landslide magnitude and frequency:

- If a landslide occurred in the last 50 years, the available data will show it on the 1994 or 2012 images. We cannot know exactly when the slide occurred, only that it was sometime in the last 4 to 22 years if it appears on the 2012 LiDAR image and sometime in the last 22 - 67 years if it appears on the 1994 air photos but not on the 1949 air photos. If it first appears as a fresh-looking slide on the 1949 air photos, we assume it occurred in the last 50 to 250 years. Standard frequency classes (e.g., those discussed in Wise et al. 2004) are fairly broad and are universally recognized. Slides that occurred more than 250 years ago are more difficult to identify with the limited historical data available. These may be completely overgrown at lower elevations, but may not be at higher elevations. As a result, most of the slides visible on the 1949 air photos are given a frequency of moderate. For the most part, only very large slides with a recognizable footprint have been identified as having a low frequency. This means that very large slides may be over-represented in the low frequency grouping while smaller slides may be under-represented. This is in keeping with general slide activity however, as larger slides are much less frequent than smaller slides.
- Magnitude (volume) estimation is approximate and subjective. Rock slide scars in the KP0-30 area vary in length and width, with some being much larger than others. However, much of the runout path of a typical rock slide is exposed bedrock in many areas. We cannot know how much material the slide entrains as it moves down the slope, but if the deposit at the base of a slide is small, it can be assumed that a minimal amount of extra material was entrained (barring removal by river erosion). However, the same cannot be said of larger events. A large colluvial deposit may have formed over many years, with growth occurring in small amounts every time a slide occurs. We have addressed this issue based on the assumption that no material

is entrained over outcropping bedrock and that 1 m of material is entrained when the slide passes over surficial deposits (generally older colluvium), including the older colluvial cone or other depositional area (if erosion as well as deposition is apparent on the depositional area). The slide magnitude is thus a product of length and width of a slide scar in surficial deposits only and an assumed thickness of 1 m, which gives a volume, from which a magnitude rating is assigned as per Table 2.1.

- Large slide features, such as the one between KP88 and KP90, likely have a thickness of landslide debris greater than 1 m; however, this would not affect the assigned magnitude rating based on the areal extent of these slides, which places them into the very large magnitude category.
- Permafrost is a greater hazard on northwest, north, and northeast-facing slopes (see DAR). It is, however, a lesser hazard than rockfall, for example, so if both are present, the dominant hazard assigned in Table 1 is assigned to the rockfall hazard.
- If several slides are present within a described route section, the average magnitude or range of magnitudes is given in Table 1.The route between KP67 and KP76 was analyzed using 1994 hard copy air photos. As the slides are very similar to adjacent slides visible in the 1949 air photos, it is assumed that these features are also older than 1949. These slides appear to be slumps in surficial sediment, but Rutter and Boydell (1981) show the area to consist of bedrock. It is therefore possible that these are slumps in bedrock rather than in surficial sediments.

# 4.0 LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Canadian Zinc Corporation and their agents. Tetra Tech EBA 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 Canadian Zinc Corporation, 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 report is subject to the terms and conditions stated in Tetra Tech EBA's Services Agreement. Tetra Tech EBA's General Conditions are attached to this memo.

## 5.0 CLOSURE

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

Tetra Tech EBA Inc.

Prepared by:

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Apr. 11, 2016

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PERMIT TO PRACTICE
TETRA TECH EBA INC.
Signature
Date April 11, 2016
PERMIT NUMBER: P 018
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# REFERENCES

Howes, D.E. and Kenk, E. 1997. Terrain classification system for British Columbia; British Columbia Ministry of Environment, Lands and Parks, Victoria, Version 2.

Porter, M. and Morgenstern, N. 2013. Landslide Risk Evaluation: Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction. Geological Survey of Canada Open File 7312.

Rutter, N.W., Boydell, A.N. 1981. Surficial Geology and Geomorphology, Sibbeston Lake, District of Mackenzie. Geological Survey of Canada (GSC), Preliminary Map 10-1979, scale 1:125,000. GSC Library date 1981, compiled date 1975.

Tetra Tech EBA. 2015a. Geotechnical Evaluation and Developer's Assessment Report Sections for Proposed Prairie Creek All-Season Road, Near Nahanni Butte, Northwest Territories. Prepared for Canadian Zinc Corporation. March 2015. Tetra Tech EBA File: Y14103320.01-001.

Tetra Tech EBA. 2015b. Addendum and Progress Report to Address Adequacy Review of Developer's Assessment Report for Environmental Assessment, EA1415-01, Proposed Prairie Creek All-Season Road to Prairie Creek Mine, NT. Prepared for Canadian Zinc Corporation. September 2015. Tetra Tech EBA File: Y14103320.01-003.

Tetra Tech EBA. 2015c. Mapping Summary Report, Proposed Prairie Creek Mine All-Season Road, Northwest Territories. Prepared for Canadian Zinc Corporation. December 2015. Tetra Tech EBA File: Y14103320.01-003.

Tetra Tech EBA. 2016. Terrain Mapping, KP159 – 184, Proposed Prairie Creek All Season Road. Prepared for Canadian Zinc Corporation. March 2016. Tetra Tech EBA File: Y14103320.01-003.

Wise, M.P., Moore, G.D. and VanDine, D.F. (editors). 2004. Landslide risk case studies in forest development planning and operations, Land Management Handbook 56. British Columbia Ministry of Forests, Forest Science Program, Victoria, B.C.

Table 1: Magnitude and Frequency Ratings along the Proposed Prairie Creek All Season Road, NT

| Proposed Route Location | | | Geohazards (Geomorphic Processes)[1] | Upslope Hazard | Downslope Hazard | Magnitude Rating[2,3] | Likelihood Rating[2,3] | Comments |
|---|---|---|---|---|---|---|---|---|
| From KP (km) | To KP (km) | Distance (km) | | | | | | |
| 0.0 | 0.4 | 0.4 | ***Rockfall*** | ✓ | | Medium | High | Several older rockfalls, three small 2012 rockfalls |
| | | | Gully Erosion | ✓ | | | | Gullying of steep slope at KP0-0.3 |
| 0.4 | 1.0 | 0.6 | ***Rockfall*** | ✓ | | Medium | Moderate | Several older rockfalls |
| | | | Debris Slide | ✓ | | | | 1994 debris slide in older colluvium immediately above colluvial fan |
| 1.0 | 1.4 | 0.4 | ***Rockfall*** | ✓ | | Small | Moderate | |
| | | | Gully Erosion | ✓ | | | | |
| 1.9 | 2.1 | 0.2 | ***Debris Flow*** | ✓ | | Small | High | Debris flow on fan fed by rockslide and rockfall, some from 2012, with 1994 activity on the fan |
| 2.2 | 2.3 | 0.1 | ***Rockslide*** | ✓ | | Medium | Moderate | No evidence of recent activity |
| | | | Rockfall | ✓ | | | | |
| 2.7 | 3.4 | 0.7 | ***Debris Flow*** | ✓ | | Small | Moderate | No evidence of recent activity on fan despite recent rockfall at high elevations |
| | | | Rockfall | ✓ | | | | |
| | | | Gully Erosion | ✓ | | | | |
| 3.4 | 4.2 | 0.8 | ***Rockfall*** | ✓ | | Small | High | The most active rockfall is immediately adjacent to road |
| | | | Debris Flow | ✓ | | | | Debris flow fan is immediately adjacent to road, but no evidence of recent activity |
| 4.2 | 4.8 | 0.6 | ***Rockslide*** | | | Small to Medium | High | Recent activity on lower part of slope, but most material from these slides will be caught behind colluvial terrace and is unlikely to affect road |
| 5.8 | 6.1 | 0.3 | ***Rockfall*** | ✓ | | Small | High | Two 2012 scars |
| 6.6 | 7.1 | 0.5 | ***Gully Erosion*** | ✓ | | Small | Moderate | |
| 7.5 | 8.7 | 1.2 | ***Rockfall*** | ✓ | | Small | Moderate | Two 1994 scars at high elevation; do not reach road, 1949 ones reach or cross road |
| | | | Gully Erosion | ✓ | | | | |
| 8.7 | 9.7 | 1.0 | ***Rockfall*** | ✓ | | Small | Moderate | Rockfalls from 1949 photos present, a few almost reach the road alignment. |
| | | | Gully Erosion | ✓ | | | | |
| 10.7 | 11.2 | 0.5 | ***Rockfall*** | ✓ | | Small | Moderate | Rockfall in tributary valley could contribute to debris flow at this location but it does not appear to have ever done so in the past. |
| | | | Gully Erosion | ✓ | | | | |
| 11.7 | 12.6 | 0.9 | ***Rockslide*** | ✓ | | Medium | Moderate | 2012 rockslide at higher elevation, may have just reached the road, difficult to be certain |
| | | | Rockfall | ✓ | | | | |
| | | | Gully Erosion | ✓ | | | | |
| 13.3 | 13.4 | 0.1 | ***Debris Flow*** | ✓ | | Small | Low | Rockfalls and rockslides in tributary valleys above road could contribute to debris flows at this location but do not appear to have ever done so in the past |
| 13.8 | 14.7 | 0.9 | ***Rockfall*** | ✓ | ✓ | Small | High | 3 rockfalls cross road; a number of rockfalls from 1994 |
| 14.7 | 15.6 | 0.9 | ***Rockfall*** | ✓ | ✓ | Small | High | 3 rockfalls from 2012, 3 from 1994, 1 from 1982; 3 from 1949 that cross road |
| | | | Rockslide | ✓ | ✓ | | | 3 rockslides from 1949, 1 of these crosses road |
| | | | Gully Erosion | ✓ | ✓ | | | |
| 16.3 | 17.0 | 0.7 | ***Rockslide*** | ✓ | ✓ | Medium | High | 4 from 1949 and 1 from 1994, all of which cross the road; apparently little obvious effect on road as only occasional boulders seen in recent time (D. Harpley, pers. comm. Apr. 8, 2016) |
| | | | Rockfall | ✓ | ✓ | | | Evidence of rockfall activity in 1994 and 2012 |
| 17.0 | 19.0 | 2.0 | ***Rockslide*** | ✓ | | Small to Large | Moderate | Most almost reach road, a few older ones and one from 1994 cross it; small to moderate-sized slides more frequent than large ones |
| | | | Rockfall | ✓ | | | | |
| | | | Solifluction | ✓ | | | | |
| 19.0 | 20.5 | 1.5 | ***Rockslide*** | ✓ | | Large | High | Recent rockslide activity, but no slides meet road |
| | | | Rockfall | ✓ | | | | |
| | | | Gully Erosion | ✓ | | | | |
| 20.5 | 21.6 | 1.1 | ***Rockslide*** | ✓ | ✓ | Medium | Moderate | 1 rockslide from 1949 crosses road; more recent rockslides are located at higher elevations, although no historical evidence of upper elevation rockslides reaching the road |
| | | | Rockfall | ✓ | | | | |
| 21.6 | 22.5 | 0.9 | ***Rockslide*** | ✓ | ✓ | Medium to Large | Moderate | Rockslides adjacent to the road alignment; 5 rockslides intersect the road, with most recent of these visible on 1994 photos and the other 4 on 1949 photos |
| | | | Rockfall | ✓ | | | | Rockfall adjacent to road, from 1949 |
| | | | Gully Erosion | ✓ | | | | |
| 22.9 | 23.4 | 0.5 | ***Rockfall*** | | ✓ | Small | Moderate | Rockfall on the downslope side of the original alignment; new alignment has no visible hazards |
| 24.0 | 24.3 | | ***Debris Slide*** | ✓ | | Medium | Moderate | Recent and 1949 activity does not reach road, therefore given moderate rather than high frequency rating |
| 24.8 | 25.0 | 0.2 | ***Debris Slide*** | ✓ | ✓ | Small | Moderate | Road has been moved away from slope, but slides are small and unlikely to create significant hazards |
| | | | Gully Erosion | ✓ | | | | |
| 25.5 | 26.6 | 1.1 | ***Debris Slide*** | | ✓ | Small | Moderate | 2 at KP25.8 unlikely to affect road; 1 at KP25.6 could possibly affect road |
| | | | Gully Erosion | ✓ | ✓ | | | |
| 26.2 | 26.3 | 0.1 | ***Debris Flow*** | ✓ | ✓ | Medium | Moderate | Difficult to tell size of individual events as this is a fairly old feature, but there appears to be one upslope and one downslope; upslope ridge of uncertain origin |
| 27.2 | 27.4 | 0.2 | ***Rockslide*** | ✓ | | Medium | High | Recent activity, but does not reach road |
| | | | Debris Slide or Flow | ✓ | ✓ | Medium | High | Medium-sized debris slide or debris flow crossed alignment at gully in 1994; to be spanned with bridge |
| | | | Rockfall | | ✓ | | | |
| | | | Gully Erosion | ✓ | ✓ | | | To be spanned with bridge |
| 27.5 | 28.0 | 0.5 | ***Rockslide*** | | ✓ | Small | Moderate | Small slides from 1949 immediately below road |
| | | | Gully Erosion | ✓ | ✓ | | | |
| 28.3 | 28.7 | 0.4 | ***Rockslide*** | ✓ | | Medium | High | Evidence of recent activity, one slide crosses road in 2012 |
| | | | Gully Erosion | | ✓ | | | |
| 29.0 | 29.2 | 0.2 | ***Debris Flow*** | ✓ | | Medium | High | Recent debris flow activity on colluvial fan, reaches road at KP29.1; fan crosses road from 29.05 to 29.15 |
| | | | Rockslide | ✓ | | | | |
| 30.1 | 30.2 | 0.1 | ***Debris Flow*** | ✓ | | Medium | Moderate | Old rockslides appear to have developed into debris flows at lower elevations |
| 30.6 | 30.8 | 0.2 | ***Debris Flow*** | ✓ | | Medium | High | Evidence of recent activity on colluvial fan, does not reach road; 1949 debris flow crosses road and road is on fan |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 30.8 | 31.2 | 0.4 | ***Rockslide*** | ✓ | | Medium | High | Recent rockslide at KP31 reaches road, older slide crosses it |
| | | | Rockfall | ✓ | | | | Rockfalls from 1949 |
| 31.2 | 31.8 | 0.6 | ***Debris Flow*** | ✓ | | Large | High | 2 colluvial cones with recent activity reaching or crossing road |
| | | | Rockslide | ✓ | ✓ | | | |
| 32.2 | 32.5 | 0.3 | ***Debris Flow*** | ✓ | | Large | High | Debris flows from 1949 and 1994, do not reach road, but fan crosses road |
| 32.5 | 36.2 | 3.7 | ***Rockfall*** | ✓ | | Medium to Large | High | Majority are from 1949 photos, but plenty of evidence of recent activity |
| | | | Rockslide | ✓ | | | | |
| 36.7 | 37.2 | 0.5 | ***Gully Erosion*** | ✓ | | Medium | Moderate | Gullies at edge of polygon with soil creep at higher elevation, does not affect road |
| | | | Rockfall | ✓ | | | | |
| 37.2 | 37.8 | 0.6 | ***Rockfall*** | ✓ | | Small to Medium | High | Several rockfalls on 1994 photos |
| 37.8 | 38.7 | 0.9 | ***Rockfall*** | ✓ | | Large | Low | Rockfall from 1949 covered in vegetation at the toe |
| 40.2 | 41.4 | 1.2 | ***Lateral Spread in Surficial Material*** | ✓ | ✓ | Very Large | Low | Road crosses lateral spread with no evidence of movement since 1949 |
| | | | Gully Erosion | ✓ | ✓ | | | |
| 41.9 | 42.0 | 0.1 | ***Gully Erosion*** | ✓ | ✓ | Small | Moderate | |
| 42.9 | 43.3 | 0.4 | ***Lateral Spread in Surficial Material*** | | ✓ | Large | Low | Road is at crest of slide (lateral spread in glaciofluvial sediments) |
| | | | Gully Erosion | ✓ | ✓ | | | |
| 45.8 | 46.2 | 0.4 | ***Soil Creep in  Permafrost Terrain*** | ✓ | ✓ | Large | Low | Road crosses wet permafrost area that may experience slow soil creep |
| | | | Gully Erosion | ✓ | ✓ | | | |
| 46.8 | 48.4 | 1.6 | ***Slump in Surficial Material*** | ✓ | | Very Large | Low | Two large slumps in glaciofluvial material, likely very old, road skirts bottom of slides |
| | | | Gully Erosion | ✓ | | | | |
| 49.7 | 50.0 | 0.3 | ***Debris Slide*** | ✓ | ✓ | Large | Moderate | Re-route shifts road back from slides; road is already well back from slide areas that are being eroded by creek (the latter areas would have a high frequency) |
| | | | Gully Erosion | ✓ | ✓ | | | |
| 53.7 | 54.2 | 0.5 | ***Thaw Flow Slide*** | | ✓ | Medium | High | Thaw flow slide from 2012 nearby, but offset 56 m from road at closest point |
| 54.5 | 57.6 | 3.1 | ***Slump in Surficial Material*** | ✓ | | Very Large | Moderate | Alternate routes avoid most of these areas |
| | | | Debris Slide | ✓ | | | | Alternate routes avoid most of these areas |
| | | | Rockfall | ✓ | | | | |
| 59.7 | 60.4 | 0.7 | ***Debris Slide*** | ✓ | ✓ | Medium | Moderate | Route crosses a few older slides visible in 1949 photos |
| 61.4 | 61.5 | 0.1 | ***Gully Erosion*** | | ✓ | Medium | Moderate | Road traverses upper edge of this sizable gully |
| 67.9 | 72.0 | 4.1 | ***Slump in Surficial Material or Bedrock*** | | ✓ | Medium to Large | Moderate | Route passes between older slump features in surficial sediments (or possibly slumps in soft bedrock) |
| | | | Rockfall | ✓ | ✓ | | | Route crosses an older rockfall area and passes above others that are not likely to affect road |
| 72.9 | 75.2 | 2.3 | ***Slump in Surficial Material or Bedrock*** | | ✓ | Medium to Large | Moderate | Route passes between older slump features in surficial sediments (or possibly slumps in soft bedrock) |
| 76.0 | 81.4 | 5.4 | ***Slump in Surficial Material or Bedrock*** | | ✓ | Medium to Large | Moderate | Route passes between older slump features in surficial sediments (or possibly slumps in soft bedrock) |
| 83.5 | 85.5 | 2.0 | ***Debris Slide*** | | ✓ | Small to Medium | Moderate | Road is well back from older and younger debris slides and tension cracks |
| 85.5 | 87.3 | 1.8 | ***Lateral Spread in Surficial Material*** | | ✓ | Very Large | Low | Road avoids most of lateral spread |
| | | | Debris Slide | | ✓ | Large | Moderate | Road crosses toe of older debris slide |
| 88.0 | 89.5 | 1.5 | ***Lateral Spread in Surficial Material*** | ✓ | | Very Large | Low | Road skirts bottom of lateral spread that is likely quite old; it crosses a small portion at the edge with much less obvious evidence of activity (between KP88 and KP88.4) |
| | | | Gully Erosion | ✓ | | | | |
| 91.0 | 94.2 | 3.2 | ***Soil Creep in  Permafrost Terrain*** | ✓ | ✓ | Small to Medium | Moderate | Creep due to permafrost in wetland areas only; these make up about 30% of this section of route |
| | | | Gully Erosion | ✓ | | | | |
| 95.5 | 101.7 | 6.2 | ***Slump in Bedrock*** | ✓ | ✓ | Very Large | Low | Large rotational to translational slide that likely occurred quite some time ago |
| | | | Debris Slides | ✓ | ✓ | | | A few recent but small debris slides at upper elevations |
| | | | Gully Erosion | ✓ | ✓ | | | |
| 101.7 | 102.0 | 0.3 | ***Rockfall*** | ✓ | | Medium | Moderate | Rockfall on 1949 air photos |
| **Alternate Route** | | | | | | | | |
| 103.5 | 108.5 | 5.0 | ***Rockfall*** | ✓ | ✓ | Small to Medium | Moderate | Alternate route passes along base of rockfall area to avoid wet areas of recent soil creep in permafrost below; best location for both geohazards |
| | | | Soil creep in Permafrost Terrain | ✓ | ✓ | | | |
| 108.5 | 109.4 | 0.9 | ***Soil Creep in  Permafrost Terrain*** | ✓ | ✓ | Medium | High | Road crosses area with small amount of recent soil creep in permafrost, although soil creep polygon is Very Large, only the portion along the road will affect the road |
| 111.8 | 113.1 | 1.3 | ***Debris Flow*** | ✓ | ✓ | Large | Moderate | Road crosses debris flow area, but has been adjusted to lowest location on fans to avoid flows/slides that do not extend to edge of fan |
| | | | Debris Slide | ✓ | ✓ | | | |
| 113.1 | 116.2 | 3.1 | ***Rockslide*** | ✓ | ✓ | Medium | Moderate | Older rockslides reach or cross road in KP114 to 115.5 area, but road has been shifted to lowest possible elevation through slide area to avoid as many slides as possible |
| | | | Rockfall | ✓ | | | | Recent rockfall, but small and well above road |
| 119.9 | 120.3 | 0.4 | ***Rockfall*** | ✓ | ✓ | Small to Medium | Moderate | Alternate route passes along base of rockfall area to avoid river floodplain |
| **Original Route** | | | | | | | | |
| 109.0 | 109.2 | 0.2 | ***Gully Erosion*** | ✓ | ✓ | Small | Moderate | 2 gullies intersect he road |
| 109.9 | 110.2 | 0.3 | ***Rockfall*** | ✓ | | Small to Medium | Moderate | Re-route has shifted road back from rockfall area |
| 110.2 | 115.1 | 4.9 | ***Gully Erosion*** | ✓ | ✓ | Small to Medium | Moderate | Several gullies intersect road alignment |
| 115.5 | 115.7 | 0.2 | ***Rockfall*** | ✓ | | Medium | Moderate | Road crosses toe of older rockfall/rock slide area; scars visible on 1962 photos |
| 116.5 | 116.9 | 0.4 | ***Gully Erosion*** | ✓ | ✓ | Small | Low | In coarse-grained material; activity is older in 1949 photo; water flow in gullies likely rare |
| 120.7 | 120.8 | 0.1 | ***Debris Slide*** | ✓ | | Small | Moderate | Very small slide, short slope; likely to have have little effect on road |
| 129.0 | 129.1 | 0.1 | ***Gully Erosion*** | ✓ | ✓ | Small | Moderate | Gully erosion peters out at road, but still quite wet in 1949 photos |
| 135.9 | 136.0 | 0.1 | ***Gully Erosion*** | ✓ | ✓ | Small | Moderate | Inactive in 1971 photos, snow covered in 1949 and activity level uncertain due to poor quality 1949 photo |
| 136.4 | 137.3 | 0.9 | ***Debris Slide*** | ✓ | ✓ | Large | Low to Moderate | One feature at KP136.4 may be a debris flow, but feature is rather indistinct - may have a low frequency and/or may be intermixed with fluvial sediment |
| 139.0 | 139.1 | 0.1 | ***Gully Erosion*** | ✓ | ✓ | Small | Moderate | Inactive but wet in 1949 and 1982 |
| 139.7 | 139.8 | 0.1 | ***Debris Slide*** | | ✓ | Small | Moderate | Very small slide, short slope; unlikely to affect road |
| 140.6 | 140.9 | 0.3 | ***Debris Slide*** | ✓ | ✓ | Small | Moderate | Very small slides, short slopes; not large enough or close enough to affect road |
| 143.9 | 144.0 | 0.1 | ***Gully Erosion*** | ✓ | ✓ | Small | Moderate | Stream in  drains lake, expect ongoing but minimal erosion |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 146.3 | 146.4 | 0.1 | ***Gully Erosion*** | ✓ | ✓ | Small | Moderate | Road crosses drainage path in flattest part; gullying unlikely to affect road |
| 148.0 | 148.1 | 0.1 | ***Gully Erosion*** | ✓ | | Small | Moderate | Very small and inactive but wet in 1949 |
| 151.2 | 154.5 | 3.3 | ***Gully Erosion*** | ✓ | ✓ | Small | Moderate | Smaller gullies inactive in 1949, a few cross road; larger gullies active in 1949, with streams feeding fluvial fans, road crosses these at best possible locations |
| 154.5 | 155.3 | 0.8 | ***Earth Slump - Earth Flow*** | | ✓ | Very Large | Low | Assumed to be old as inactive in 1949, but could have moderate likelihood; road has been moved upslope to avoid this area |
| 155.9 | 159.3 | 3.4 | ***Earth Slump - Earth Flow*** | ✓ | ✓ | Very Large | Low | Assumed to be old as inactive in 1949, road has been moved upslope but is still immediately adjancent to upper portion of slide near KP 158 and tension cracks near KP157 |
| | | | Debris Flow | ✓ | ✓ | Medium | High | Debris flows visible on 2012 imagery cross route at 158.4 to 158.5; road must cross eastern portion of slump-flow in order to reach river crossing |
| | | | Gully Erosion | ✓ | ✓ | | | |

[1]Geohazards are described as per Howes and Kenk (1997); however, it is assumed that fluvial fans also contain some components of debris floods and water floods

[2]Ratings apply to the dominant / most probable hazard (indicated in ***bold italics***) along the proposed road alignment

[3]Definitions of magnitude and likelihood classes are provided in Tables 2.1 and 2.2 of the memo

**Notes/Limitations:**

-Magnitude/Frequency assessment applies only to road segments where geohazards are present
-A thickness of 1 m is assumed for landslide magnitude calculations; this should be considered a minimum estimate
-If several slides are present within a described route section, the average magnitude or range of magnitudes is given
-The groupings of some portions of the route may contain localized areas of benign or potentially unstable terrain within the defined kilometre range, regardless of its magnitude and frequency ratings, due to the scale of mapping
-Kilometre ranges are as per route alignment dated February 2015

# GENERAL CONDITIONS

## GEOTECHNICAL REPORT

This report incorporates and is subject to these "General Conditions".

### 1.0 USE OF REPORT AND OWNERSHIP

This geotechnical report pertains to a specific site, a specific development and a specific scope of work. It is not applicable to any other sites nor should it be relied upon for types of development other than that to which it refers. Any variation from the site or development would necessitate a supplementary geotechnical assessment.

This report and the recommendations contained in it are intended for the sole use of Tetra Tech EBA's Client. Tetra Tech EBA does not accept any responsibility for the accuracy of any of the data, the analyses or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than Tetra Tech EBA's Client unless otherwise authorized in writing by Tetra Tech EBA. Any unauthorized use of the report is at the sole risk of the user.

This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of Tetra Tech EBA. Additional copies of the report, if required, may be obtained upon request.

### 2.0 ALTERNATE REPORT FORMAT

Where Tetra Tech EBA submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed Tetra Tech EBA's instruments of professional service), only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Tetra Tech EBA shall be deemed to be the original for the Project.

Both electronic file and hard copy versions of Tetra Tech EBA's instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Tetra Tech EBA. Tetra Tech EBA's instruments of professional service will be used only and exactly as submitted by Tetra Tech EBA.

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

### 3.0 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, Tetra Tech EBA has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

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

Classification and identification of soils and rocks are based upon commonly accepted systems and methods 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 EBA 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.

### 5.0 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.

### 6.0 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of testholes and/or soil/rock exposures. Stratigraphy is known only at the locations of the testhole or exposure. Actual geology and stratigraphy between testholes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. Tetra Tech EBA 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 investigation and review may be necessary.

### 7.0 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.

### 8.0 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.

### 9.0 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and 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 are known.

### 10.0 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as 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.

### 11.0 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. 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.

### 12.0 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses 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 assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

### 13.0 SAMPLES

Tetra Tech EBA 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.

### 14.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of the report, Tetra Tech EBA may rely on information provided by persons other than the Client. While Tetra Tech EBA endeavours to verify the accuracy of such information when instructed to do so by the Client, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

# Prairie Creek Mine, NWT

*Preliminary Snow Avalanche Risk Assessment for Winter Road*

**DRAFT**

| | |
|---|---|
| *Report prepared for:* | *Canadian Zinc Corporation*<br>*Vancouver, BC* |
| *Report prepared by:* | *Alpine Solutions Avalanche Services*<br>*Squamish, BC* |
| *Project #:* | *1212-001* |
| *Date:* | *May 26, 2012* |

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May 26, 2012
Project No: 1212-001

Mr. David Harpley, VP Environmental & Permitting Affairs
Canadian Zinc Corporation
Suite 1710, 650 West Georgia Street
Vancouver, British Columbia
V6B 4N9

Dear Mr. Harpley,

**Re: Prairie Creek Access Road – Preliminary Snow Avalanche Risk Assessment for Winter Road – DRAFT**

Please find attached our draft report on snow avalanche risk for the Prairie Creek Mine Access Road. Thank you for the opportunity to complete this work.

Yours sincerely,

**Alpine Solutions Avalanche Services**
**per:**

Brian Gould, P. Eng., CAA-QAP

# Executive Summary

The Prairie Creek Mine is a zinc-silver-lead mine located in the South Mackenzie Mountains, approximately 550 km west of Yellowknife, NWT (Figure 2-1). The property has undergone various stages of development since the deposit was first discovered in 1928; however active mining has been discontinued since 1982. Canadian Zinc Corporation (CZC) is planning to resume mining operations, and is proposing a 170 km winter road in order to transport mine concentrate from the minesite to the Liard Highway, approximately 110 km southwest of Fort Simpson, NWT. Some of the proposed winter road utilizes a historic road used previously by the mine. At least 35 km of the winter road winds through steep mountainous terrain that is snow covered in winter.

CZC requested that Alpine Solutions undertake a preliminary avalanche hazard and risk assessment to determine the likelihood and potential consequences of avalanches reaching the proposed winter road. The hazard assessment included analysis of maps, aerial photographs, video segments, available climate data, and field reconnaissance by fixed wing aircraft. Twenty seven avalanche paths (or hazard areas) over an accumulated distance of approximately 17 km along the road were identified, and they are distributed from approximately 4 km to 35 km from the mine site (Drawings 1 through 6, Appendix A). Due to estimated shallow snowpack depths most winters, frequency of avalanches reaching the road is not high (annual or less frequent). Large avalanches (Size 3 and 4) would only be expected with frequency on the order of once every 3 years or less often, and would typically only be expected in the spring when the snowpack is near its maximum depth.

Potential consequences of avalanches reaching the winter road include traffic delays due to road blockage, potential vehicle damage, occupant injury or fatality, and mine concentrate spillage. In addition any fixed infrastructure (such as bridges) located in avalanche areas may be at risk if they are not designed to withstand the effects of avalanches. Associated consequences may include economic losses resulting from the above, and impact to company reputation.

A complete risk assessment for each individual scenario involving avalanches cannot be undertaken without further details regarding traffic frequency, and location of fixed infrastructure (bridges). However, considering the preliminary details which include:

- proposed active winter road use schedule, and
- extended length of road affected by avalanche paths,

the risk from avalanches to the winter road is estimated to vary between low and high, depending on annual snowpack and climate conditions.

If avalanche risk is determined to be unacceptable, options for mitigation should be considered. Mitigation measures for industrial roads typically includes an avalanche management plan which would specify weather and snowpack monitoring (to determine if avalanche threshold has been reached), safety measures for travelling the road, training for road users, and avalanche explosive control if

required. Mitigation measures may also include structural protection or diversion earthworks for high risk areas or for structures such as bridges.

Alpine Solutions recommends the following:

- Road layout on attached avalanche hazard maps should be reviewed and confirmed once the road alignment is finalized.
- A helicopter based reconnaissance should be completed in order to refine avalanche path locations and hazard areas. The helicopter based access would allow for ground based assessments in select areas. This reconnaissance could be completed during summer or winter season.
- If a more detailed risk assessment is required, a linear risk analysis should be undertaken. A typical method which can be used to compare with other industrial roads is the 'Avalanche Hazard Index' (Schaerer, 1984)
- An avalanche hazard management plan should be prepared for the Prairie Creek winter road. The plan should specify all measures employed to reduce risk to vehicles and occupants. In addition the plan should include an emergency response plan.
- If structures such as bridges are to be installed at creek and river crossings near avalanche paths along the mountain segment of the road, an assessment of potential avalanche impact should be undertaken.
- If mine activities are proposed to occur in valleys and slopes surrounding the immediate minesite area, an avalanche risk assessment should be prepared for those activities.

# Contents

# 1.0 Introduction

## 1.1 General

The Prairie Creek Mine is a zinc-silver-lead mine located in the South Mackenzie Mountains, approximately 550 km west of Yellowknife, NWT (Figure 2-1). The property has undergone various stages of development since the deposit was first discovered in 1928; however active mining has been discontinued since 1982. Canadian Zinc Corporation (CZC) is planning to resume mining operations, and is proposing a 170 km winter road in order to transport mine concentrate from the minesite to the Liard Highway, approximately 110 km southwest of Fort Simpson, NWT. Some of the proposed winter road utilizes a historic road used previously by the mine. At least 35 km of the winter road winds through steep mountainous terrain that is snow covered in winter.

CZC requested that Alpine Solutions undertake a preliminary avalanche risk assessment to determine the likelihood and potential consequences of avalanches reaching the winter road. If avalanche risk is determined to be unacceptable, options for mitigation may be considered. The results of this assessment will be used for mine and access road permitting, and operational planning for the winter road.


**Figure 2-1 Prairie Creek Mine Location**

## 1.2 Work Scope

CZC provided Alpine Solutions with the following maps and documentation:

- Three Drawings indicating road layout and topography completed by SNC Lavalin:
  - Prairie Creek Mine Proposed Access Road – Plan and Profile Sta. 0+000 to Sta. 72+000
  - Prairie Creek Mine Proposed Access Road – Plan and Profile Sta. 72+000 to Sta. 136+000
  - Prairie Creek Mine Proposed Access Road – Plan and Profile Sta. 136+000 to Sta. 180+000
- A selection of small scale aerial photos dated 1967 and 1994.
- A selection of photos of Sundog Creek area taken in 2008.
- A video segment of helicopter overview flight of the first 35 km of the road taken in 2007.
- 'Road Use Outline' – a document providing details regarding use of the winter road .
- A spreadsheet containing climate data at the mine site from May 2005 to July 2008.
- A spreadsheet containing climate data at the mine site from September, 2009 to September, 2010.

The scope of work included topographic map and aerial photo interpretation, combined with a study of available climate data to determine the potential for avalanches to affect the access road. Six drawings illustrating avalanche hazard mapping at 1:20,000 scale was completed for areas potentially affected by avalanches (Appendix A). An estimate of magnitude and frequency of avalanche's reaching the road is included, and potential consequences are determined. Avalanche mitigation options are presented.

# 2.0 Limitations

This report was prepared by Alpine Solutions Avalanche Services for the account of Candian Zinc Corporation. The material in it reflects Alpine Solutions' best judgment in light of the information available to Alpine Solutions at the time of preparation. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, is the responsibility of such third parties. Alpine Solutions accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions, based on this report.

This report provides an overview of snow[1] avalanche hazards which affect the proposed Prairie Creeek winter access road. Estimated magnitudes, frequencies, and areal extent of individual avalanche paths are based on climate analysis, map and imagery interpretation, and a fixed wing survey flight completed April 6, 2012. Boundaries of avalanche terrain indicated on the accompanying drawings are estimated and have not been confirmed with ground based survey or numerical analysis.

Although other geohazards exist in the region, the scope of this assessment is limited exclusively to avalanches. In addition, any significant artificial or natural alteration of the landscape or terrain due to

[1] The qualifier "snow" will not be included from here on. It was added here to make it clear that there is no mention of "rock avalanches" or "debris avalanches" in this report.

forest fire, landslides, may change the nature (magnitude/frequency/intensity/runout) of avalanche hazard, necessitating a re-assessment for the area affected.

As a mutual protection to our client, the public, and ourselves, all documents and drawings are submitted for the confidential information of our client for a specific project. Authorization for any use and/or publication of this document or any data, statements, conclusions or abstracts from or regarding our documents and drawings, through any form of print or electronic media, including without limitation, posting or reproduction of same on any website, is reserved pending Alpine Solutions written approval. If this document is issued in an electronic format, an original paper copy is on file at Alpine Solutions and that copy is the primary reference with precedence over any electronic copy of the document, or any extracts from our documents published by others.

## 3.0 Location and Terrain

The Prairie Creek mine site is located on the east side of Prairie Creek, approximately 43 km upstream from the confluence with the South Nahanni River. The winter road extends approximately 170 km from the mine to the Liard Highway. For the purpose of this report, the road is separated into 2 segments:

1. The 'mountain segment' which extends from the mine site to Cat Camp at km 40.
2. The 'non-mountainous segment' which extends from Cat Camp to the Liard Highway at km 170.

Avalanche hazard affecting the road was only identified along the first segment from the mine site to Cat Camp. Avalanche terrain was noted on the east side of the Grainger River at Grainger Gap (123 km from the mine site), but avalanches were not estimated to affect the current road alignment.

The mountain segment of the winter road extends north from the mine site (900 m elevation) along the east side of Prairie Creek for approximately 7 km before heading east along the Funeral Creek valley to treeline elevation (1300 m elevation) at approximately 13 km from the mine site. From here it extends over a pass at 1600 m between Funeral and Sundog Creeks Tributary valley. The road then extends 25 km down the Sundog Tributary and Sundog Creek drainages to Cat Camp (800 m elevation), approximately 40 km from the mine site. The remaining 130 km of the route mainly heads in a southeasterly direction in primarily non-mountainous terrain before reaching the Liard Highway.

## 4.0 Snow Climate Analysis

Snow climate refers to the general character of climate factors that contribute to snowpack and avalanche formation. Historical meteorological records often provide information on the frequency, timing, and sometimes magnitude of future avalanches.

The mountain segment of the Prairie Creek winter road is located in the southern region of the Taiga Cordillera, a cold continental climate zone just south of the Arctic. Winter conditions are expected to be generally cold and dry, and are interspersed with short periods of moderate temperatures and snowfall.

Climate data provided by CZC for the periods from May 2005 through July 2008, and from September 2009 through September 2010, was reviewed and analyzed. The area typically experiences monthly average temperatures below 0°C from October through April, with monthly averages near -20°C to -25°C during December through February. Precipitation data suggests that the area receives the majority of its annual snowfall during October and March. Wind is predominantly from the west. Normally the area experiences 3 to 5 precipitation events in the fall (October through early November), followed by a long stable period from November through February. Precipitation returns in March and April with typically another 8 – 10 precipitation events. Rain-on-snow events are expected in April when temperatures begin to reach daytime highs above freezing.

Average and maximum snowpack depths could not be determined from the provided data. During the site visit in April, the snowpack was approximately 70 cm deep at the minesite. The effect of wind and topography in the area is estimated to influence snowpack depth and distribution significantly. As a result, windward (typically westerly) slopes are likely to be heavily scoured, possibly to ground in some areas, while leeward (typically easterly) slopes will be loaded and is likely to form thick wind slab. Experience with this type of landscape and climate regime suggests leeward avalanche starting zones may have 3 to 5 times the valley bottom snowpack depth, depending on aspect and exposure to wind. Average snowpack depth is estimated to be greatest near the pass separating Funeral Creek and Sundog Tributary.

Considering the long periods of cold dry weather, the snowpack is expected to be shallow and weak, characterized by layers of depth hoar and facets throughout the entire snowpack. As a result avalanches which affect the road are usually full depth events, which normally would not occur more than once per year. Although large size avalanches (which run full path) would usually only be expected in late winter or spring, smaller early season avalanches which occur in October and November could still present hazard to personnel and vehicles transiting the winter road.

# 5.0 Winter Road Avalanche Hazard and Risk

## 5.1 Background on Snow Avalanches

Snow avalanches generally occur in areas where there are steep open slopes or gullies, and deep (>50 cm) mountain snowpacks. Risk associated with avalanches is normally due to exposure to the high forces that occur, as well as the effects of extended burial for any person caught in an avalanche. Impact forces vary significantly depending on avalanche size. Although the smallest avalanches can be insignificant to a human, larger avalanches may produce impact forces capable of destroying several hectares of mature forest.

**Characteristics of Snow Avalanches:**

Avalanches may initiate in either *dry* or *wet* snow. Although an avalanche may start in dry snow, it could become *moist* or *wet* during its descent. Terrain features including gullies deflect and often channel wet snow avalanches. Conversely, large, fast-flowing dry avalanches tend to flow in a straighter path, and may overrun terrain features.

Most large, dry avalanches consist of a dense component that flows primarily along the ground, and a less dense powder component that travels above and sometimes ahead of the flowing component. In some cases these components can separate and move independently. The dense-flowing component and powder component may reach speeds up to 60 m/s (200 km/h). Impact pressures from dense flow are much greater than the powder component due to the density of the snow.

*Avalanche terrain* is usually associated with steep open slopes in the mountains that allow an accumulation of snow before it releases in a destructive event. In addition to the steep slopes that the snow accumulates on, any area exposed to this release of snow is also considered avalanche terrain. Terrain is often subdivided into features that are connected, and generally contain or channel the volume of avalanche events into a common deposition area. These features are called *avalanche paths.*

**Avalanche Path:**

An avalanche path generally consists of a *starting zone*, a *track*, and a *runout zone*. Avalanches start and accelerate in the starting zone which typically has slope incline greater than 30°. Downslope of the starting zone, most large avalanche paths have a distinct track in which the slope angle is typically in the range of 15° to 30°. Large avalanches decelerate and stop in the runout zone where incline is usually less than 15°. Smaller avalanches may decelerate and even stop on steeper slopes (15° to 24°).

Within forested terrain, larger avalanche paths are often discernable as vertically oriented swaths of open forest terrain bordered by *trim lines* (mature forest on either side of the swath). Smaller avalanches however can occur in more subtle paths, and can occur on large cutbanks in a road cut.

Runout zones generally have vague trim lines, and analysis by an experienced avalanche specialist is required to determine estimates of maximum avalanche extent (often extends into mature forest). Some avalanche paths in terrain around cliffs can be much more subtle to observe, and can be confused with rockfall and or geotechnical events.

**Avalanche Frequency:**

Avalanche *frequency* is the reciprocal of avalanche *return period* and is typically referred to as an order of magnitude ranging from 1:1 (annual) up to 1:300 (1 in 300) years. Each winter, the probability of an avalanche with a specified return period is constant.

Avalanche frequency is dependent upon *snow supply* and *terrain.* Frequency decreases with distance downslope in the track and runout zone. Snow supply is determined by :

- Frequency of snowfalls and amount of snow; and
- Wind transport of snow into the starting zone.

Snow and weather conditions vary from year to year, and the frequency of avalanches is not uniform.

The primary terrain factors in avalanche formation are incline, slope orientation (aspect) with respect to wind and sun, slope configuration and size, and ground surface roughness. Slope configuration is important because features such as gullies will often have more frequent and larger avalanches than open slopes. Ground roughness determines the threshold snow depth for avalanches to occur. This is particularly important in light snow climates where snow may not exceed threshold depths some winters.

**Avalanche Magnitude:**

Avalanche *magnitude* relates to the destructive potential of an avalanche and is defined according to the Canadian avalanche size classification system. A general description of destructive potential, magnitude, and typical path length under this classification system is provided in Table 1.

Magnitude is often related to frequency. In general, large destructive avalanches occur less frequency, while smaller ones occur on a more regular basis. Magnitude and frequency of effect are also related to location in the overall path. For example a road location near the toe of an avalanche path will be affected by avalanches on a less frequent basis, but they will be larger avalanches. Both low frequency large avalanches and higher frequency small avalanches may affect a road crossing in the middle of an avalanche path.

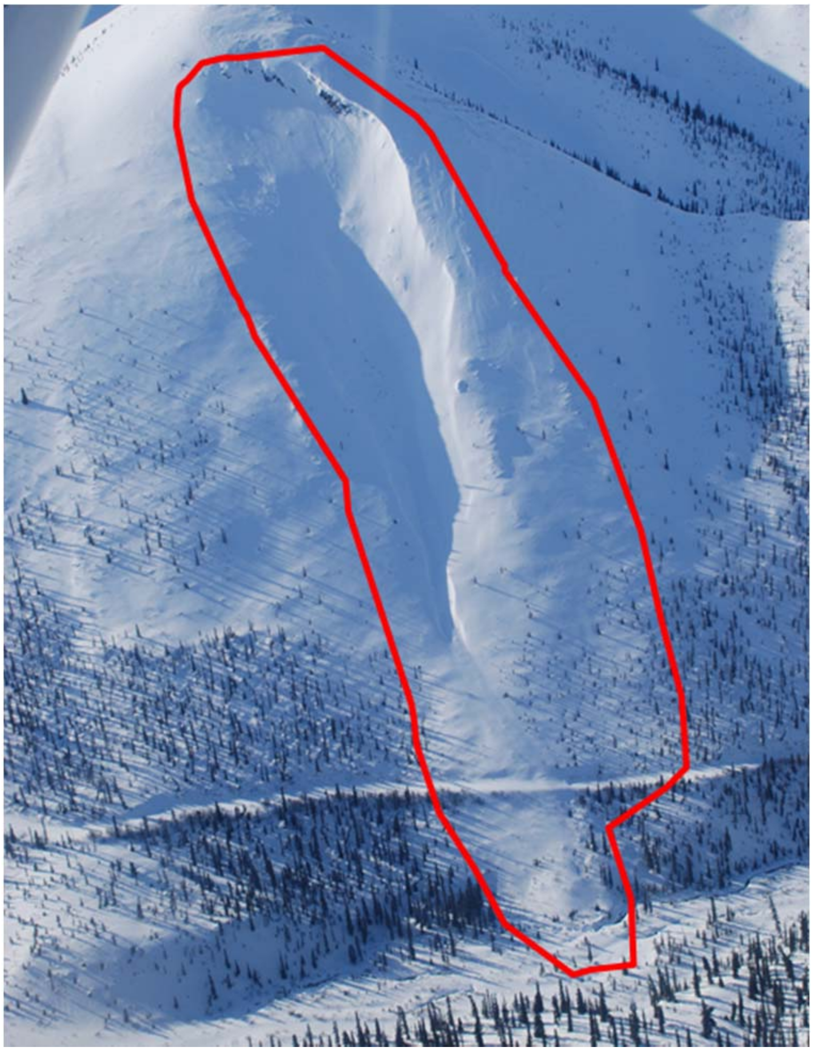
**Table 1 :** *Canadian classification system for avalanche size (McClung & Schaerer, 1993)*

| Size | Destructive Potential | Typical Mass | Typical Path Length | Typical Impact Pressures |
|---|---|---|---|---|
| 1 | Relatively harmless to people. | <10 tonnes | 10 m | 1 kPa |
| 2 | Could bury, injure or kill a person. | $10^2$ tonnes | 100 m | 10 kPa |
| 3 | Could bury a car, destroy a small building, or break a few trees. | $10^3$ tonnes | 1000 m | 100 kPa |
| 4 | Could destroy a large truck, several buildings, or a forest with an area up to 4 hectares. | $10^4$ tonnes | 2000 m | 500 kPa |
| 5 | Largest snow avalanches known. Could destroy a village or a 40 ha forest. | $10^5$ tonnes | 3000 m | 1000 kPa |

## 5.2 Winter Road Avalanche Hazard Analysis

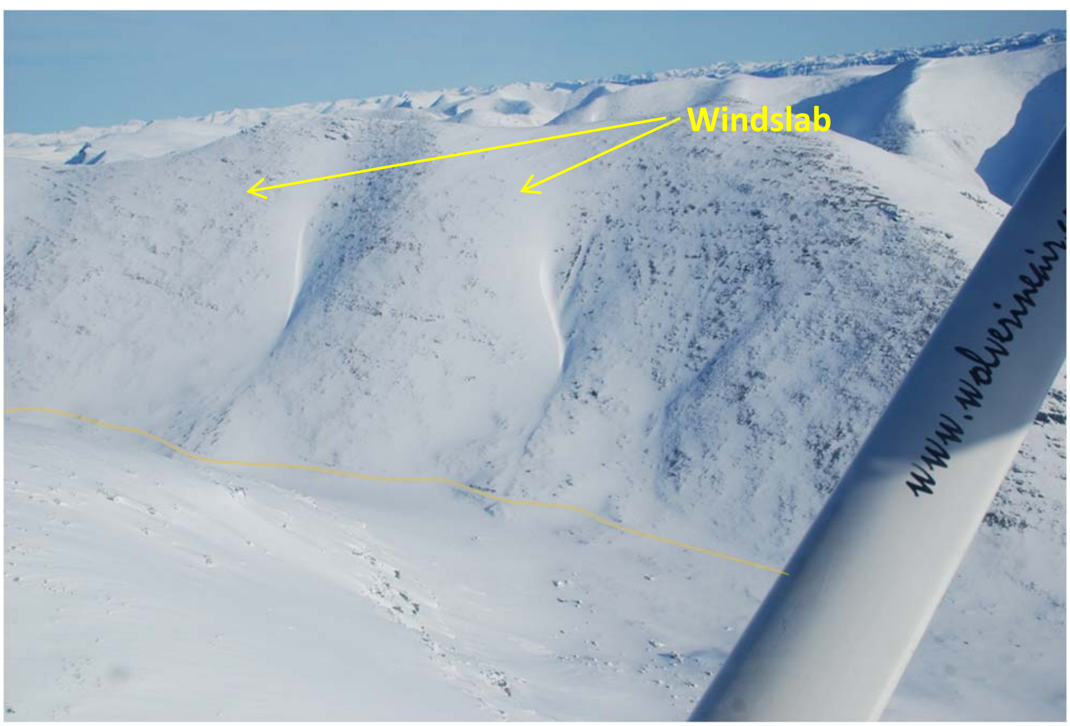
Avalanche paths and hazard areas that affect the winter road were identified by reviewing maps, photographs, and video segments. In addition, a field reconnaissance by fixed wing aircraft was completed on April 6, 2012. During this flight numerous photographs and video segments were collected and subsequently reviewed and analyzed.

During the overview flight, several avalanche paths were confirmed along the mountain segment of the road (example in Photograph 6-1). In addition, recent avalanche debris was noted in several places along the access road (example in Photograph 6-2). And numerous wind 'pillows' were observed indicating wind slab avalanche conditions (example in Photograph 6-3).



**Photograph 6-1 – Path 12 with cornices above start zone**

**Photograph 6-2 – Path 15 - Recent avalanche deposit (red) on road (yellow) from winter 2011/2012**




**Photograph 6-3 – Example of wind slab avalanche conditions above road (orange line)**

Avalanche paths and hazard areas are distributed from 4 km to 35 km along the winter road. Drawings 1 through 6 (Appendix A) illustrate location of avalanche terrain estimated to affect the road. Polygons on the drawings indicate the approximate extent of each avalanche path or hazard area. Table 5-1 summarizes location, estimated length of road affected, and magnitude/frequency estimates for each avalanche path. Twenty-seven avalanche paths or hazard areas are estimated to reach the winter road alignment, and three other potential avalanche areas may affect the road (dashed polygons, Drawings 3, 4, 5). Although polygons indicate areas directly affected by avalanches, other areas adjacent to creeks and rivers may be affected by flooding caused by temporary avalanche debris dams located upstream. Although this can pose a risk, avalanche debris dams tend to be short-lived and the associated outburst flood hazard tends to be significantly less than with landslide debris dams.

**Table 5-1 – Summary of Avalanche Paths affecting the winter road**

| PATH ID | APPROXIMATE LOCATION | ESTIMATED LENGTH OF ROAD AFFECTED | | MAGNITUDE/FREQUENCY ESTIMATE (Events:Years) | | |
|---|---|---|---|---|---|---|
| | | | ASPECT | Size 2 | Size 3 | Size 4 |
| 4 | Prairie Creek - 4 km along road | 600 | West | 1:1 | 1:10 | |
| 9 | Funeral Creek - 8 to 9 km along road | 1700 | South | | 1:10 | |
| 11 | Funeral Creek - 11 km along road | 250 | South | | 1:10 | |
| 12 | Funeral Creek - 12 km along road | 250 | North | 1:1 | 1:3 | |
| 12.5 | Funeral Creek - 12.5 km along road | 250 | East | | 1:10 | |
| 13 | Funeral Creek - 13 km along road | 200 | North | 1:3 | | |
| 15 | Funeral Creek - 15 km along road | 1200 | NW | 1:1 | 1:1 | |
| 16 | Funeral Creek - 16 km along road | 200 | South | | 1:10 | |
| 16.5 | Funeral Creek - 16.5 k along road | 50 | North | | 1:10 | |
| 17 | Sundog Tributary - just east of Pass | 700 | South | 1:1 | 1:3 | |
| 18 | Sundog Tributary - just east of Pass | 700 | South | 1:1 | 1:3 | |
| 20 | 4 km east of Funeral/Sundog Pass | 800 | NE | | 1:3 | |
| 22 | 6 km east of Funeral/Sundog Pass | 1000 | NE | 1:1 | 1:3 | |
| 25 | Sundog Trib - 15 km west of Cat Camp | 200 | SW | | 1:10 | |
| 25.5 | Sundog Trib - 14.5 km west of Cat Camp | 500 | SW | | 1:3 | |
| 26 | Sundog Trib - 14 km west of Cat Camp | 200 | SW | | 1:3 | 1:30 |
| 26.5 | Sundog Trib - 13.5 km west of Cat Camp | 800 | SW | 1:1 | 1:3 | 1:30 |
| 27 | Sundog Trib - 13 km west of Cat Camp | 400 | SW | 1:1 | 1:3 | |
| 28 | Sundog Trib - 12 km west of Cat Camp | 500 | SW | 1:1 | 1:3 | |
| 28.5 | Sundog Trib - 11.5 km west of Cat Camp | 200 | SW | 1:1 | 1:3 | |
| 29 | Sundog Trib - 11 km west of Cat Camp | 200 | SW | | 1:10 | |
| 30 | Sundog Trib - 10 km west of Cat Camp | 500 | SW | | 1:10 | |
| 31 | Sundog Creek - 9 km west of Cat Camp | 2000 | South | | 1:10 | |
| 33 | Sundog Creek - 7 km west of Cat Camp | 1400 | NW | 1:1 | 1:10 | |
| 34 | Sundog Creek - 6 km west of Cat Camp | 1200 | NW | 1:1 | 1:10 | |
| 35 | Sundog Creek - 5 km west of Cat Camp | 800 | NW | 1:1 | 1:10 | |

## 5.3 Winter Road Avalanche Risk Determination

Guidelines for determining avalanche risk to fixed facilities, worksites and industrial roads within Canada have been developed, and are outlined in the Guidelines for Snow Avalanche Risk Determination and Mapping in Canada (CAA, 2002). Risk determination is not only based on magnitude and frequency of avalanches, but also considers the differences in vulnerability and exposure time of the elements at risk. Avalanche risk planning for an industrial road typically involves the consideration of maximum size avalanches that generally have avalanche return periods of 100 years or more.

The Prairie Creek Road Use Plan suggests the winter road will typically begin to be used November 1 each year. Initially, thirteen tractor trailers will haul mine concentrate through the mountain segment of the road. After the annual road construction has been completed (estimate December 15), thirteen more tractor trailers will be added to the haul. , The haul is expected to end in April each year (date depends on ice conditions). In addition to the twenty six tractor trailers (thirteen initial and thirteen subsequent), it is expected that several utility and supply vehicles will travel the road during winter and spring. Traffic volume is estimated to exceed 5 vehicles per hour at peak times, and loaded vehicles may be reduced to slow speeds over the Funeral-Sundog pass.

The vulnerability of each element at risk depends on the size and the ability to sustain the effect of the avalanche. In general avalanches of Size 2 or greater are expected to pose a risk to a person, and avalanches of Size 3 and greater will pose a risk to medium to large size vehicles. This does not take into account the effect of terrain features which may augment the effect of an avalanche (eg. a vehicle being pushed into a river by a Size 2 avalanche). Occupants will be partially protected from avalanche impact if they are in a vehicle; however if the vehicle becomes stuck, and the occupants choose to go outside to shovel, their vulnerability increases substantially. Bridges or stationary vehicles and equipment may also be at risk, depending on their vulnerability.

Potential consequences of avalanches reaching the winter road alignment may include:

- damage to facilities (bridges), equipment and vehicles;
- worker injury or fatality;
- impact to the environment from any spills associated the avalanche; and
- delays due to road blockages.

Associated consequences may include economic losses resulting from the above, and impact to company reputation.

A complete risk assessment for each individual scenario involving avalanches cannot be undertaken without further details regarding traffic frequency, and location of fixed infrastructure (bridges). However, considering the preliminary details which include:

- proposed active winter road use schedule, and
- extended length of road affected by avalanche paths,

risk from avalanches to the winter road is estimated to vary between low and high, depending on annual snowpack and climate conditions.

## 6.0 Avalanche Mitigation

Avalanche mitigation for industrial roads generally involves the development of an avalanche management plan. The scope of this plan typically include details regarding avalanche monitoring, temporary closures, safety measures for traffic, and avalanche explosive control, if necessary. Typically an avalanche technician team would monitor conditions (either on site, or based on observations submitted by a trained observer), and determine daily safety measures or recommendations for closure and/or avalanche explosive control. Considering avalanches are not expected to be frequent during December through February, it is unlikely that an avalanche technician would be required to be on site for this period. However, during spring daily weather and snowpack analysis may be required to predict timing of avalanche events.

If any fixed facilities such as bridges are exposed and are not designed to accommodate potential effects of impact, fixed avalanche protection measures should be considered. These measures may include avalanche fencing, catchment ditches, diversion earthworks, or retarding mounds. These mitigation measures are designed to channel flows away from areas, or reduce the effects of avalanches.

# 7.0 Summary and Recommendations

The Prairie Creek winter road is located in steep mountains which are snow covered in winter and spring. Twenty seven avalanche paths (or hazard areas) over an accumulated distance of 17 km are estimated to affect the road between 4 km to 35 km from the mine site (Drawings 1 through 6, Appendix A). Due to estimated shallow snowpack depths most winters, frequency of avalanches reaching the road is not high (annual or less frequent). Large avalanches (Size 3 and 4) would only be expected with frequency on the order of once every 3 years or less often, and would typically only be expected in the spring when the snowpack is near its maximum depth.

Potential consequences of avalanches reaching the winter road include traffic delays due to road blockage, potential vehicle damage, occupant injury or fatality, and mine concentrate spillage. In addition any fixed infrastructure (such as bridges) located in avalanche areas may be at risk if they are not designed for avalanche impact. Associated consequences may include economic losses resulting from the above, and impact to company reputation.

A complete risk assessment for each individual scenario involving avalanches cannot be undertaken without further details regarding traffic frequency, and location of fixed infrastructure (bridges). However, considering the preliminary details which include:

- proposed active winter road use schedule, and
- extended length of road affected by avalanche paths,

the risk from avalanches to the winter road is estimated to vary between low and high, depending on annual snowpack and climate conditions. If avalanche risk is determined to be unacceptable, options for mitigation should be considered.

Alpine Solutions recommends the following:

- Road layout on attached avalanche hazard maps should be reviewed and confirmed once the road alignment is finalized.
- A helicopter based reconnaissance should be completed in order to refine avalanche path locations and hazard areas. The helicopter based access would allow for ground based assessments in select areas. This reconnaissance could be completed during summer or winter season.
- If a more detailed risk assessment is required, a linear risk analysis should be undertaken. A typical method which can be used to compare with other industrial roads is the ‘Avalanche Hazard Index’ (Schaerer, 1984)
- An avalanche hazard management plan should be prepared for the Prairie Creek winter road. The plan should specify all measures employed to reduce risk to vehicles and occupants. In addition the plan should include an emergency response plan.
- If structures such as bridges are to be installed at creek and river crossings near avalanche paths along the mountain segment of the road, an assessment of potential avalanche impact should be undertaken.

- If mine activities are proposed to occur in valleys and slopes surrounding the immediate minesite area, an avalanche risk assessment should be prepared for those activities.

Report Prepared by:

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Senior Avalanche Specialist

## References

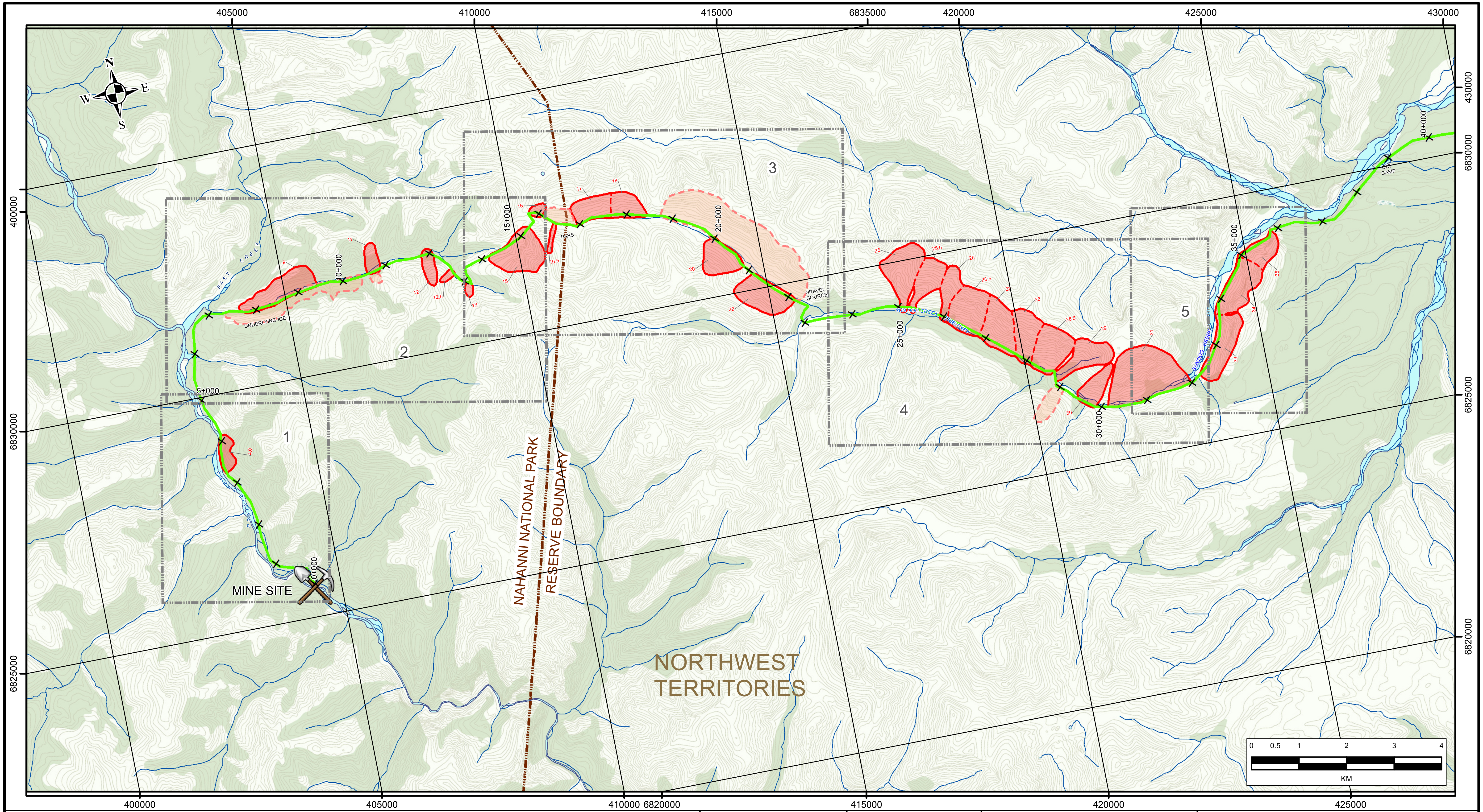

Canadian Avalanche Association (CAA). 2002. *Guidelines for Snow Avalanche Risk Determination and Mapping in Canada.* McClung, D.M., Stethem, P. A. Schaerer, and J.B. Jamieson (eds.), Canadian Avalanche Association, 23 pp.

McClung D.M., and P. Schaerer, 1993. *The Avalanche Handbook*. The Mountaineers.

Mears, A., 1992. *Snow-Avalanche Hazard Analysis for Land Use Planning and Engineering*. Colorado Geological Survey Bulletin 4Dept.ept of Natural Resources, Denver, Colorado

Schaerer, P. 1984. *The Avalanche-Hazard Index.* National Research Council Canada. Annals of Glaciology 13, 1989, p. 241-247.

# Appendix A




LEGEND

- AVALANCHE PATH
- POTENTIAL AVALANCHE PATH
- PROPOSED ACCESS ROAD
- 100 FOOT CONTOUR
- STREAM

NOTES:

1) DATUM: NAD 1983 ZONE 10U
PROJECTION: UNIVERSAL TRANSVERSE MERCATOR

2) THIS MAP SHOULD ONLY BE READ WITH THE ACCOMPANYING REPORT.

3) ACCESS ROAD LAYOUT DIGITIZED FROM: SNC LAVALIN DRAWING "PRAIRIE CREEK MINE PROPOSED ACCESS ROAD PLAN AND PROFILE" REV. PC - OCT 12, 2006.

4) SMALL AVALANCHE PATHS (SIZE ≤ 2) EXIST OUTSIDE OF THE AREAS DELINEATED BUT THOSE ARE TOO SMALL TO BE MAPPED AT THIS SCALE.

5) BASE MAPPING SOURCE: HTTP://ARCGISONLINE.COM

6) ONLY AVALANCHE PATHS WHICH ARE ESTIMATED TO AFFECT THE ACCESS ROAD AREA SHOWN. BOUNDARIES OF AVALANCHE PATHS OR AREAS REPRESENT A TRANSITION FROM HAZARD TO NO HAZARD. ANY FACILITIES PROPOSED ADJACENT TO MAPPED BOUNDARY LINES SHOULD BE EXAMINED WITH RESPECT TO AVALANCHE HAZARDS.

7) THIS MAP IS A SNAPSHOT IN TIME. CHANGES IN TOPOGRAPHY THROUGH FILL PLACEMENT, CUTSLOPES, GLACIAL RETREAT OR ADVANCE LANDSLIDING, AS WELL AS TREE REMOVAL MAY REQUIRE REDRAWING OF AVALANCHE ZONES IN THOSE AREAS.

8) THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:75,000 FOR 11" X 17" ("B" SIZE) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE

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| DATE: | MAY 18, 2012 |
| DESIGNED: | BG |
| DRAWN: | JN |
| CHECKED: | |
| APPROVED: | |

PROFESSIONAL SEAL:

CLIENT: CANADIAN ZINC CORPORATION

PREPARED BY: ALPINE SOLUTIONS AVALANCHE SERVICES

PROJECT: PRAIRIE CREEK MINE WINTER ACCESS ROAD

TITLE: AVALANCHE HAZARD INDEX MAP

| PROJECT NO: | DWG NO: | REV: |
|---|---|---|
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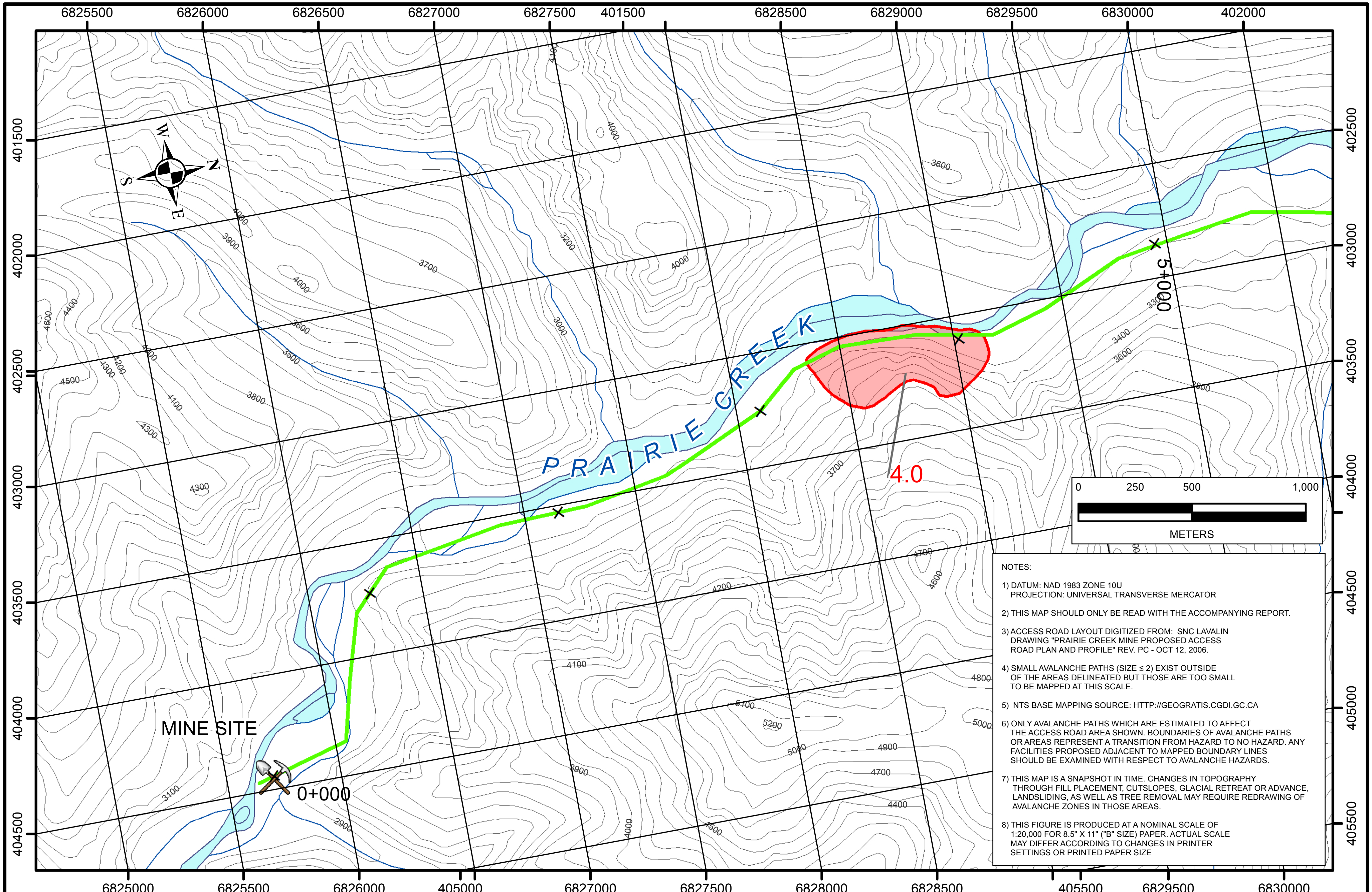


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5) NTS BASE MAPPING SOURCE: HTTP://GEOGRATIS.CGDI.GC.CA

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## LEGEND

- AVALANCHE PATH
- POTENTIAL AVALANCHE PATH
- PROPOSED ACCESS ROAD
- 100 FOOT CONTOUR
- STREAM

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| CHECKED: | |
| APPROVED: | |

PROFESSIONAL SEAL:

CLIENT: CANADIAN ZINC CORPORATION

PREPARED BY: ALPINE SOLUTIONS AVALANCHE SERVICES

PROJECT: PRAIRIE CREEK MINE WINTER ACCESS ROAD

TITLE: AVALANCHE HAZARD MAP

| PROJECT NO: | DWG NO: | REV: |
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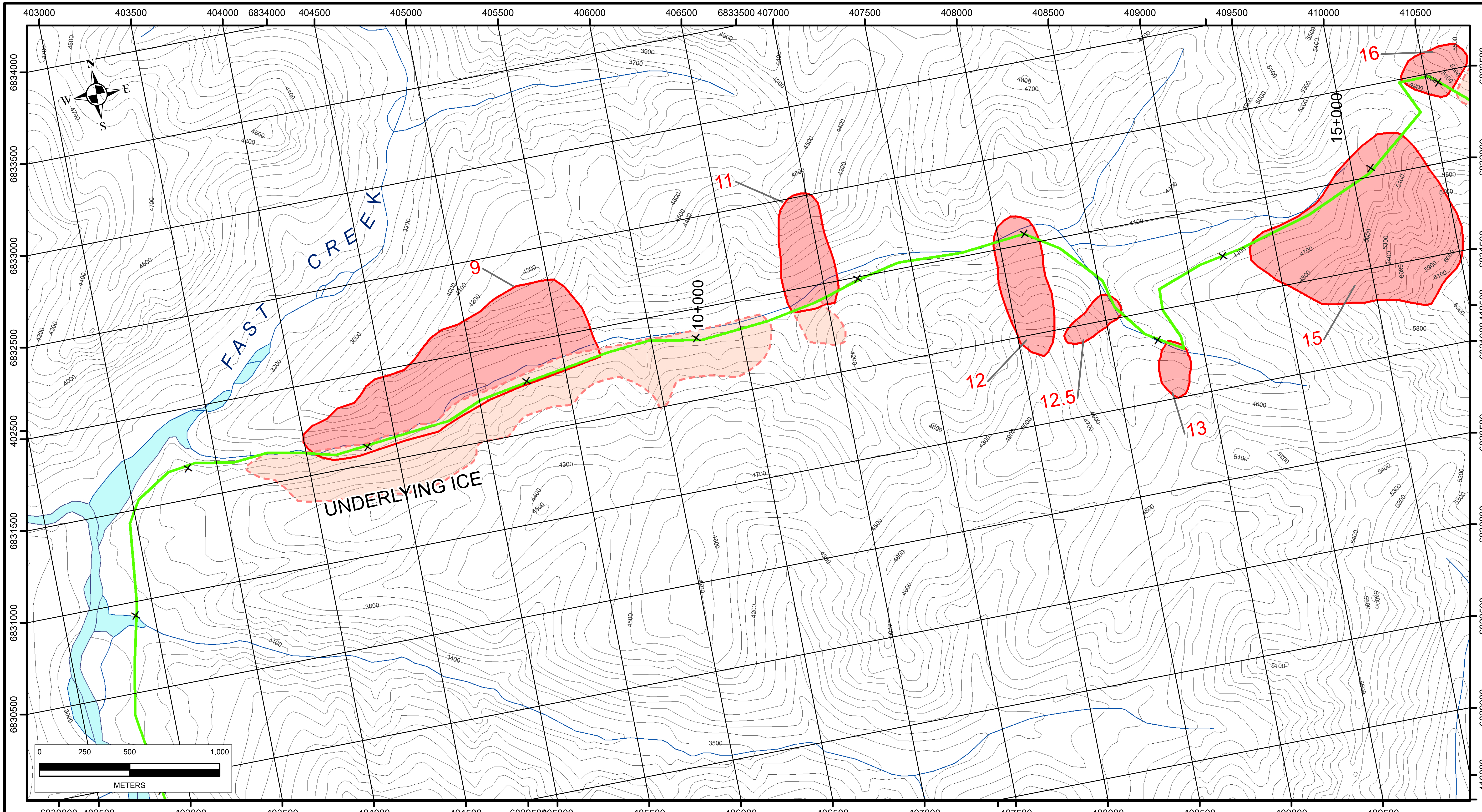
| | 2 | A |




## LEGEND

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| DATE: | MAY 21, 2012 |
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PROFESSIONAL SEAL:

CLIENT: CANADIAN ZINC CORPORATION

PREPARED BY: ALPINE SOLUTIONS AVALANCHE SERVICES

PROJECT: PRAIRIE CREEK MINE WINTER ACCESS ROAD

TITLE: AVALANCHE HAZARD MAP

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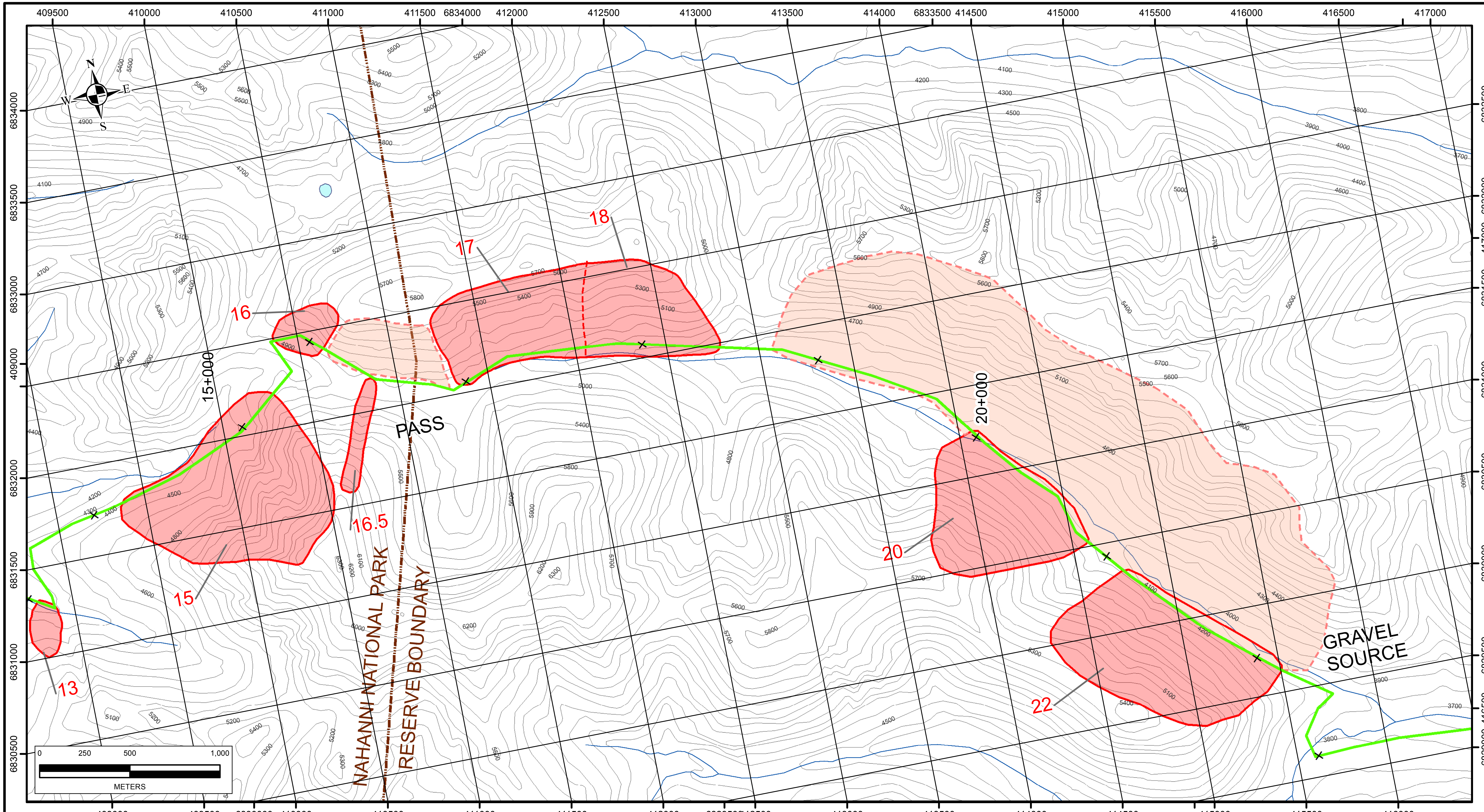



**LEGEND**

- AVALANCHE PATH
- POTENTIAL AVALANCHE PATH
- PROPOSED ACCESS ROAD
- 100 FOOT CONTOUR
- STREAM

NOTES:

1) DATUM: NAD 1983 ZONE 10U
PROJECTION: UNIVERSAL TRANSVERSE MERCATOR

2) THIS MAP SHOULD ONLY BE READ WITH THE ACCOMPANYING REPORT.

3) ACCESS ROAD LAYOUT DIGITIZED FROM: SNC LAVALIN DRAWING "PRAIRIE CREEK MINE PROPOSED ACCESS ROAD PLAN AND PROFILE" REV. PC - OCT 12, 2006.

4) SMALL AVALANCHE PATHS (SIZE ≤ 2) EXIST OUTSIDE OF THE AREAS DELINEATED BUT THOSE ARE TOO SMALL TO BE MAPPED AT THIS SCALE.

5) NTS BASE MAPPING SOURCE: HTTP://GEOGRATIS.CGDI.GC.CA

6) ONLY AVALANCHE PATHS WHICH ARE ESTIMATED TO AFFECT THE ACCESS ROAD AREA SHOWN. BOUNDARIES OF AVALANCHE PATHS OR AREAS REPRESENT A TRANSITION FROM HAZARD TO NO HAZARD. ANY FACILITIES PROPOSED ADJACENT TO MAPPED BOUNDARY LINES SHOULD BE EXAMINED WITH RESPECT TO AVALANCHE HAZARDS.

7) THIS MAP IS A SNAPSHOT IN TIME. CHANGES IN TOPOGRAPHY THROUGH FILL PLACEMENT, CUTSLOPES, GLACIAL RETREAT OR ADVANCE, LANDSLIDING, AS WELL AS TREE REMOVAL MAY REQUIRE REDRAWING OF AVALANCHE ZONES IN THOSE AREAS.

8) THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:20,000 FOR 11" X 17" ("B" SIZE) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE

| | |
|---|---|
| SCALE: | 1:20,000 |
| DATE: | MAY 21, 2012 |
| DESIGNED: | BG |
| DRAWN: | JN |
| CHECKED: | |
| APPROVED: | |

PROFESSIONAL SEAL:

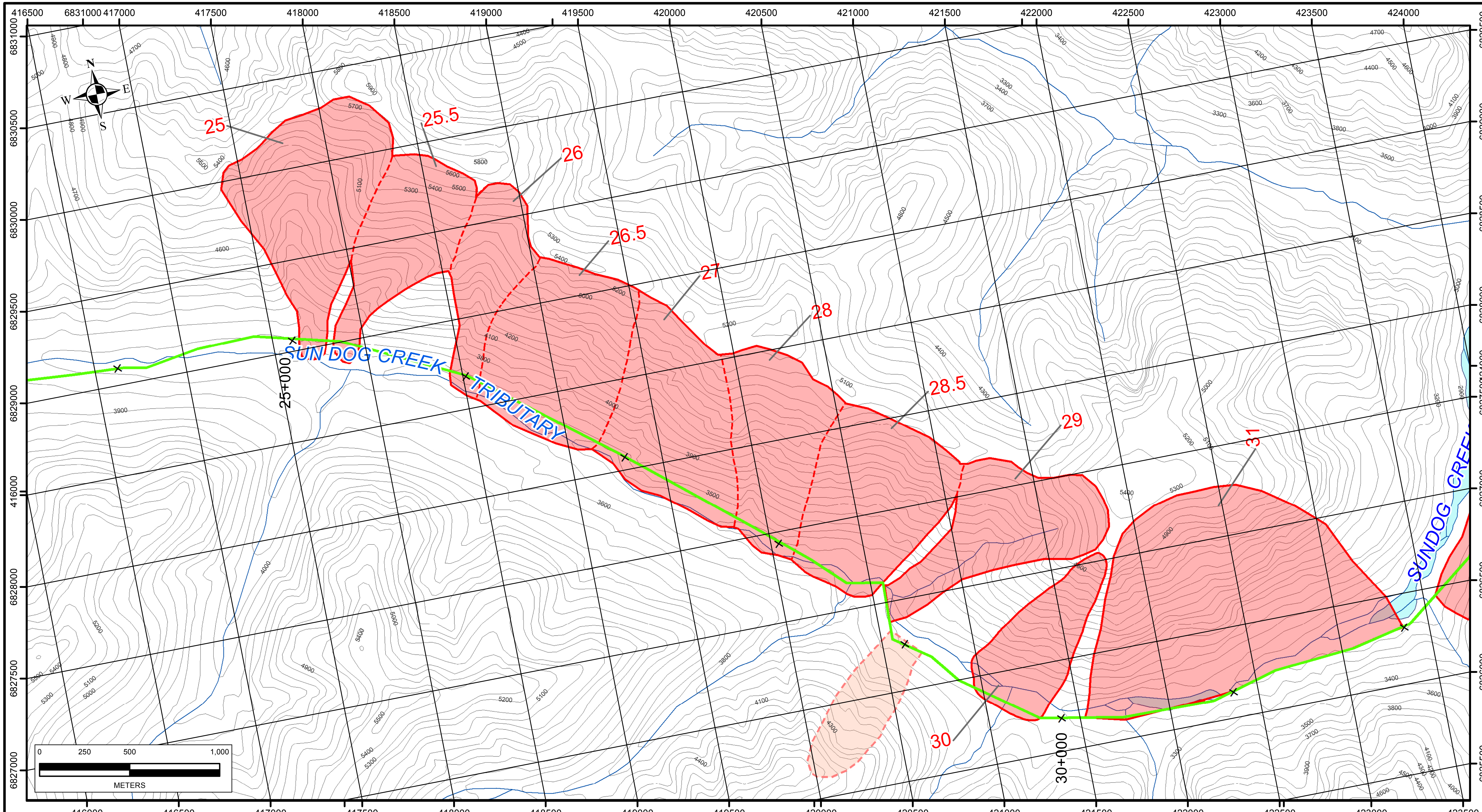
CLIENT: CANADIAN ZINC CORPORATION

PREPARED BY: ALPINE SOLUTIONS AVALANCHE SERVICES

PROJECT: PRAIRIE CREEK MINE WINTER ACCESS ROAD

TITLE: AVALANCHE HAZARD MAP

| PROJECT NO: | DWG NO: | REV: |
|---|---|---|
| | 4 | A |




## LEGEND

- AVALANCHE PATH
- POTENTIAL AVALANCHE PATH
- PROPOSED ACCESS ROAD
- 100 FOOT CONTOUR
- STREAM

NOTES:

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| SCALE: | 1:20,000 |
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PROFESSIONAL SEAL:

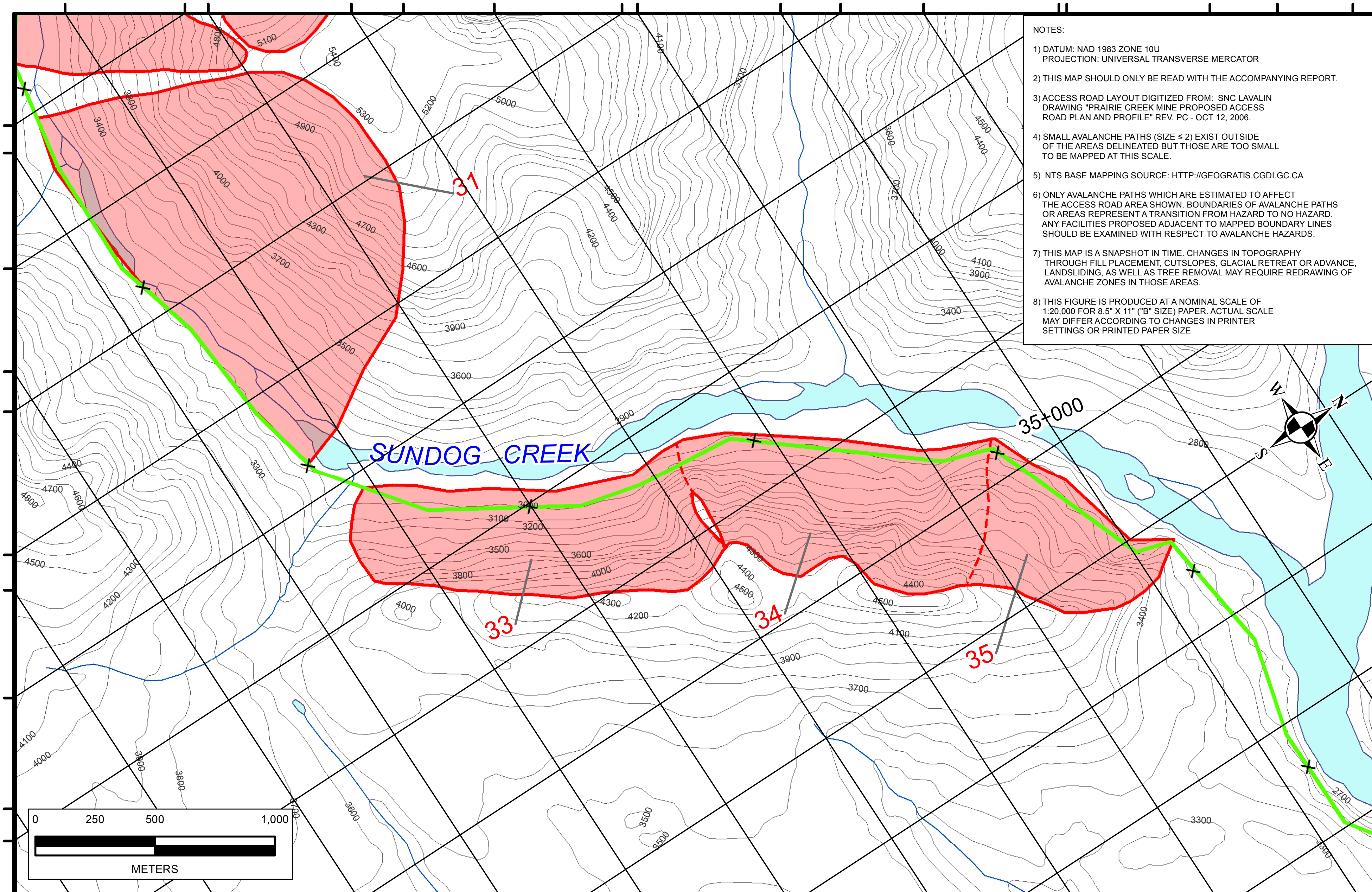
CLIENT: CANADIAN ZINC CORPORATION

PREPARED BY: ALPINE SOLUTIONS AVALANCHE SERVICES

PROJECT: PRAIRIE CREEK MINE WINTER ACCESS ROAD

TITLE: AVALANCHE HAZARD MAP

| PROJECT NO: | DWG NO: | REV: |
|---|---|---|
| | 5 | A |

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1) DATUM: NAD 1983 ZONE 10U
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8) THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:20,000 FOR 8.5" X 11" ("B" SIZE) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE

## LEGEND

- AVALANCHE PATH
- POTENTIAL AVALANCHE PATH
- PROPOSED ACCESS ROAD
- 100 FOOT CONTOUR
- STREAM

| | |
|---|---|
| SCALE: | 1:20,000 |
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PROJECT: PRAIRIE CREEK MINE WINTER ACCESS ROAD

TITLE: AVALANCHE HAZARD MAP

| PROJECT NO: | DWG NO: | REV: |
|---|---|---|
| | 6 | A |

TETRA TECH EBA

March 11, 2016

ISSUED FOR USE
FILE: Y14103320-01
Via Email: david@canadianzinc.com

Canadian Zinc Corporation
Suite 1710, 650 West Georgia Street
Vancouver, BC V6B 4N9

**Attention:** David Harpley
VP Environmental & Permitting Affairs

**Subject:** Terrain Mapping, KP159 - 184
Proposed Prairie Creek All Season Road

# 1.0 INTRODUCTION

As part of its review of Canadian Zinc's (CZN) Developer's Assessment Report (DAR) for the Prairie Creek All-Season Road Project, the Mackenzie Valley Review Board (MVRB) has requested additional information regarding mapping of the terminal portion of the proposed all-season road. The details of the request are included in the MVRB's December 21, 2015 document titled "Reasons for Decision of the Adequacy of the Developer's Assessment Report".

Tetra Tech EBA Inc. (Tetra Tech EBA) was retained by Canadian Zinc Corporation to map potential issues such as fluvial erosion, channel movement, and potential presence of areas underlain by permafrost.

The existing Nahanni Butte access road runs from KP174.2 – 184. It will form part of the Mine access route.

# 2.0 METHODS

Terrain stability between KP159 - 184 was evaluated and mapped accordingly, following the modified terrain stability mapping previously completed for much of the proposed road alignment. Stereo pair air photos from 1949 and LiDAR photographic and bare earth images from 2012 (viewed in 2D) were analyzed to assist with this evaluation.

The 1949 air photos were georeferenced for PurVIEW a second time, in order to obtain the most accurate spatial location for the photos (georeferenced air photos are compared to georeferenced ground controls and in this particular area, there are no mountains, lakes, or other fixed objects to tie the data to). A new georeferenced base image was used to achieve the improved accuracy. Increased accuracy was needed to determine the amount of movement of the Liard and Netla river channels over time.

# 3.0 RESULTS

## 3.1 Surficial Deposits

The mapped surficial deposits are in general agreement with the previous government mapping of the area (Rutter and Boydell 1981), but provide more detail (Figures 1 to 5 and Appendix B).

The Liard River portion of the proposed all-season road lies within the Liard River floodplain, which is essentially level, with a couple of slightly elevated, flat-surfaced terraces. The floodplain is subject to periodic flooding. The deposits consist of silt and sand (Rutter and Boydell 1981), which form low terraces at the edges of the Liard and



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Yellowknife, NT X1A 2P7 CANADA
Tel 867.920.2287 Fax 867.873.3324

Netla rivers. The terraces appear to be less than 1 m high, and are thus mapped as fluvial plain deposits (Fp) to distinguish them from the terraces that are slightly higher at KP163 and 171. Areas mapped as fluvial terraces (Ft) also contain terraces that appear to be less than 1 m in height.

Organic deposits are present from KP170 to 181. Many of these are fens that have formed within abandoned river and stream channels (e.g., “Bay Creek” at KP172, which does not appear to flow any longer). Larger wetlands are present between KP173 and 181. The one at KP181 is a bog.

Glaciolacustrine sediments (likely silt and clay) underlie the route from KP182 - 184.

## 3.2 Geohazards

Potential geohazards on the Liard River floodplain include periodic flooding and erosion by the Liard River. Erosion magnitude has been identified by mapping the Liard and Netla River shorelines in 1949 and 2012.

The erosion rates given below are approximate and are described as erosion rates in metres per year. This is an assumption that helps in decision making and it should be recognized as such. Episodic flood events are expected to occur, removing and adding larger amounts of material at one time, and then much smaller quantities in subsequent non-flood years.

The Liard River’s maximum erosion extent is in the vicinity of KP162 (Figures 1 and 2). Here, the river has eroded its floodplain by 257 m in a northeastward direction since 1949. At the same time, river flow has added a maximum of 80 m of material to the area near KP161, with accumulation occurring in a northwestward direction. This translates to approximately 4.1 m of erosion per year and 1.3 m of growth per year. At its closest point, the proposed road centerline is located 58 m from the eroding 2012 shoreline. At its most distant point, the road is 141 m from the aggrading[1] shoreline. Although erosion and aggradation occur episodically, an assumed rate of 4.1 m/yr of erosion and 1.3 m/yr of growth should put the shorelines at 41.6 and 146.2 m, respectively, in 2016. On this basis, the road has approximately 10 years before it will be affected by riverbank erosion. Consequently, the road alignment has been modified to move it further from the eroding river bank. The revised alignment is shown in Figures 1 and 2.

The realigned route between KP160 and 164 is now 1,200 m from the most rapidly eroding part of the floodplain. The proposed route now has more than 282 years before this part of the riverbank approaches it if the calculated erosion rate is assumed. At its nearest point to the eroding bank (KP164.7), the route would have been 190 m away from the shoreline in 2012. The rate of erosion here is 1.9 m/yr, so the 2016 distance from shoreline is estimated at 182.4 m. At this distance and erosion rate, the road should be unaffected by bank erosion for about 96 years.

At its closest point to the eroding bank, the route realignment between KP170 and 173 would have been 260 m from the bank in 2012. The erosion rate here is 1.4 m/yr, giving a distance of 254.4 m in 2016. The minimum road life is therefore approximately 182 years at this location.

Aggradation will not affect the road, but should be taken into account in detailed ramp design for the barge river crossing. Aggradation is likely to be in the order of 0.5 m/yr. The northern shore has receded 30 m between 1949 and 2012, giving an erosion rate of 0.5 m/yr, which should be similarly considered during the crossing detailed design phase.

[1] The building up of the Earth’s surface by deposition: in this case, the accumulation of material by fluvial processes.

Following the same logic, erosion rates of 1.2 to 2.7 m/yr are expected where the road nears the Liard River channel between KP170.7 - 171.5 (Figure 3). At its closest point, the proposed road was 190 m from the river channel in 2012, where the erosion rate is 1.2 m/yr. If the shoreline was 4.8 m closer to the road in 2015, this would give an approach time of more than 150 years. Where the erosion rate is highest, near KP170.7, an approach time of approximately 80 years is expected for the proposed road. Although the current alignment follows an old logging road in order to minimize environmental impact, to be conservative, the alignment has been moved slightly further away from the river bank (Figure 3).

Where the existing road is closest to the Netla River at KP176.4 (Figure 4), the floodplain is neither aggrading nor eroding. It appears that flow in the channel is waning over time because the LiDAR imagery shows vegetation growth along both sides of the active channel where none existed in 1949. However, as this area is an outer bank of the river, it is possible that this situation could change in the future if flow rates increase.

Other potential hazards include permafrost that likely underlies the wetlands. Organic (peat) deposits insulate the ground from summer heat, allowing potentially ice-rich permafrost to persist in these areas. The road embankment could therefore be subject to differential settlement associated with thermal degradation of ice-rich permafrost in the subgrade. Special geotechnical considerations for road design (adequate thermal protection through suitable embankment fill thickness), construction, and maintenance are important within these sections of the proposed road alignment.

The fine-grained glaciolacustrine sediments could potentially be ice-rich as well. However, the road is already built in this location (and across much of the fen and bog areas) and will likely only need whatever monitoring has already been designated for it in this area. Mitigation is assumed to be complete and monitoring ongoing for the existing road.

# 4.0 LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Canadian Zinc Corporation and their agents. Tetra Tech EBA Inc. (Tetra Tech EBA) 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 Canadian Zinc Corporation, 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 report is subject to the terms and conditions stated in Tetra Tech EBA's Services Agreement. Tetra Tech EBA's General Conditions are provided in Appendix A of this report.

## 5.0 CLOSURE

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

Tetra Tech EBA Inc.

Prepared by:

REGISTERED PROFESSIONAL GEOSCIENTIST
S.J. McCUAIG
LICENSEE
March 11, 2016
NT/NU

Shirley McCuaig, Ph.D., P.Geol.
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Reviewed by:

REGISTERED PROFESSIONAL GEOLOGIST
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March 11, 2016

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Senior Geologist/Geocryologist, Arctic Group
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MARCH 11, 2016
NWT/NU

Nigel Goldup, M.Sc., D.I.C., P.Eng.
Regional Manager, Arctic Region
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nigel.goldup@tetratech.com

**PERMIT TO PRACTICE**
**TETRA TECH EBA INC.**

Signature ____________

Date MARCH 11, 2016

**PERMIT NUMBER: P 018**

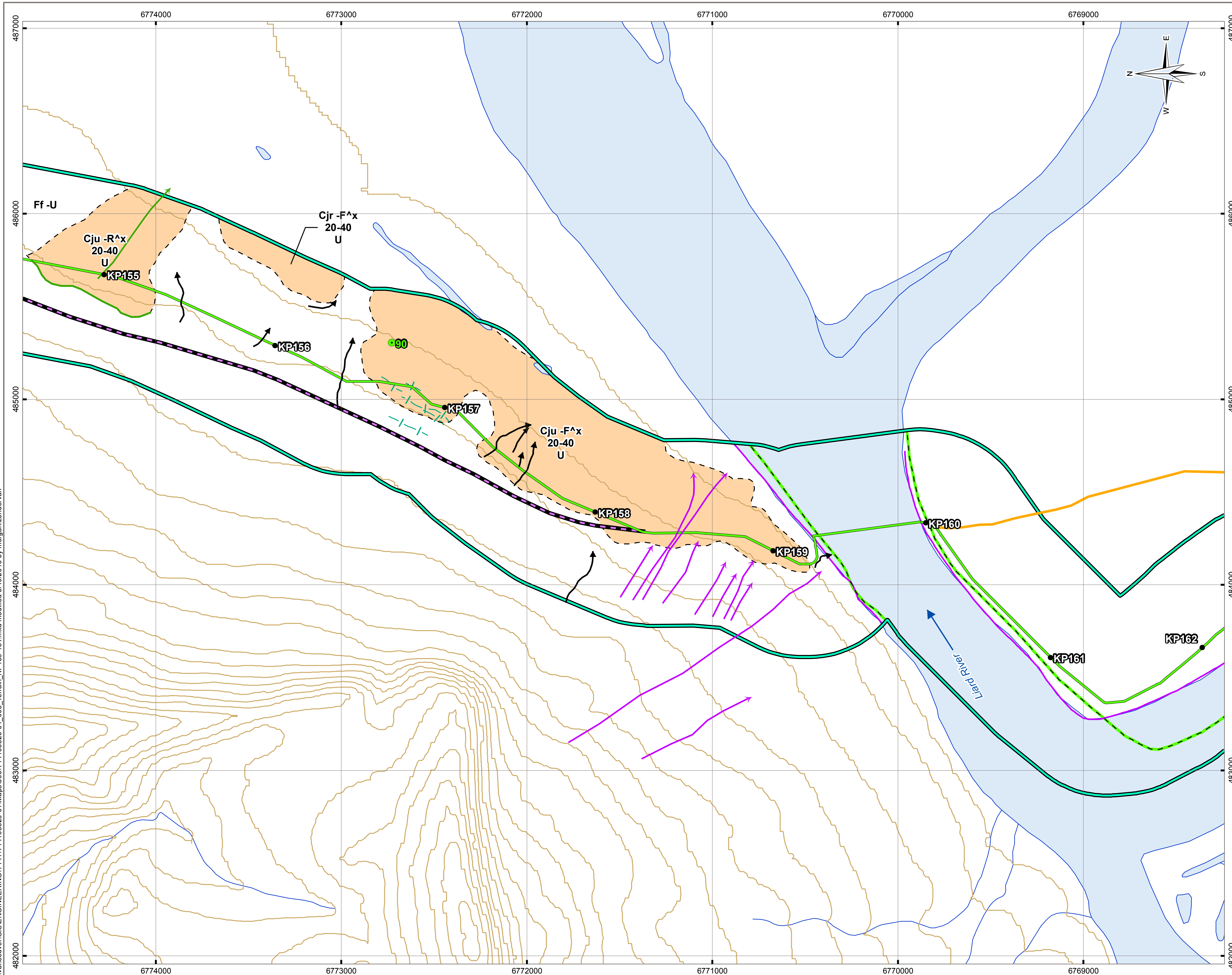
NT/NU Association of Professional Engineers and Geoscientists

/my

# REFERENCES

Rutter, N.W. and Boydell, A.N., 1981. Surficial Geology and Geomorphology, Sibbeston Lake, District of Mackenzie. Geological Survey of Canada (GSC), Preliminary Map 10-1979, scale 1:125,000. GSC Library date 1981, compiled date 1975.

# FIGURES




## LEGEND

1 km Buffer
Terrain Boundary

**Slope Stability Class**

P Potentially Unstable Terrain
U Unstable Terrain
Prairie Creek Access Road (Feb 24, 2015)
Prairie Creek Access Road Realignment (March 7, 2016)
Suggested Realignment

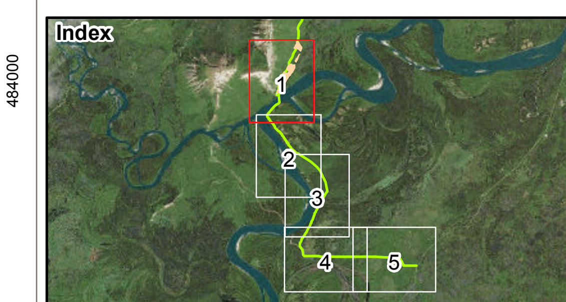
**Field Site**

Airborne Observation

**Geology**

Gully
Landslide Failure Scar Large (1949)
Landslide Failure Scar Large (2012)
Landslide Head Scarp Large (1949)
River or Stream Position (1949)
River or Stream Position (2012)
Tension Crack (1949)
Contour (40 m)
Watercourse
Waterbody

REGISTERED PROFESSIONAL GEOSCIENTIST
S.J. McCUAIG
LICENSEE
NT/NU
March 10, 2016




**NOTES**
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

**STATUS**
ISSUED FOR USE

# PRAIRIE CREEK ALL-SEASON ROAD

## Modified Terrain Stability Mapping

| PROJECTION | DATUM | CLIENT |
|---|---|---|
| UTM Zone 10 | NAD83 | CANADIAN ZINC CORPORATION |

Scale: 1:20,000
400 200 0 400
Metres

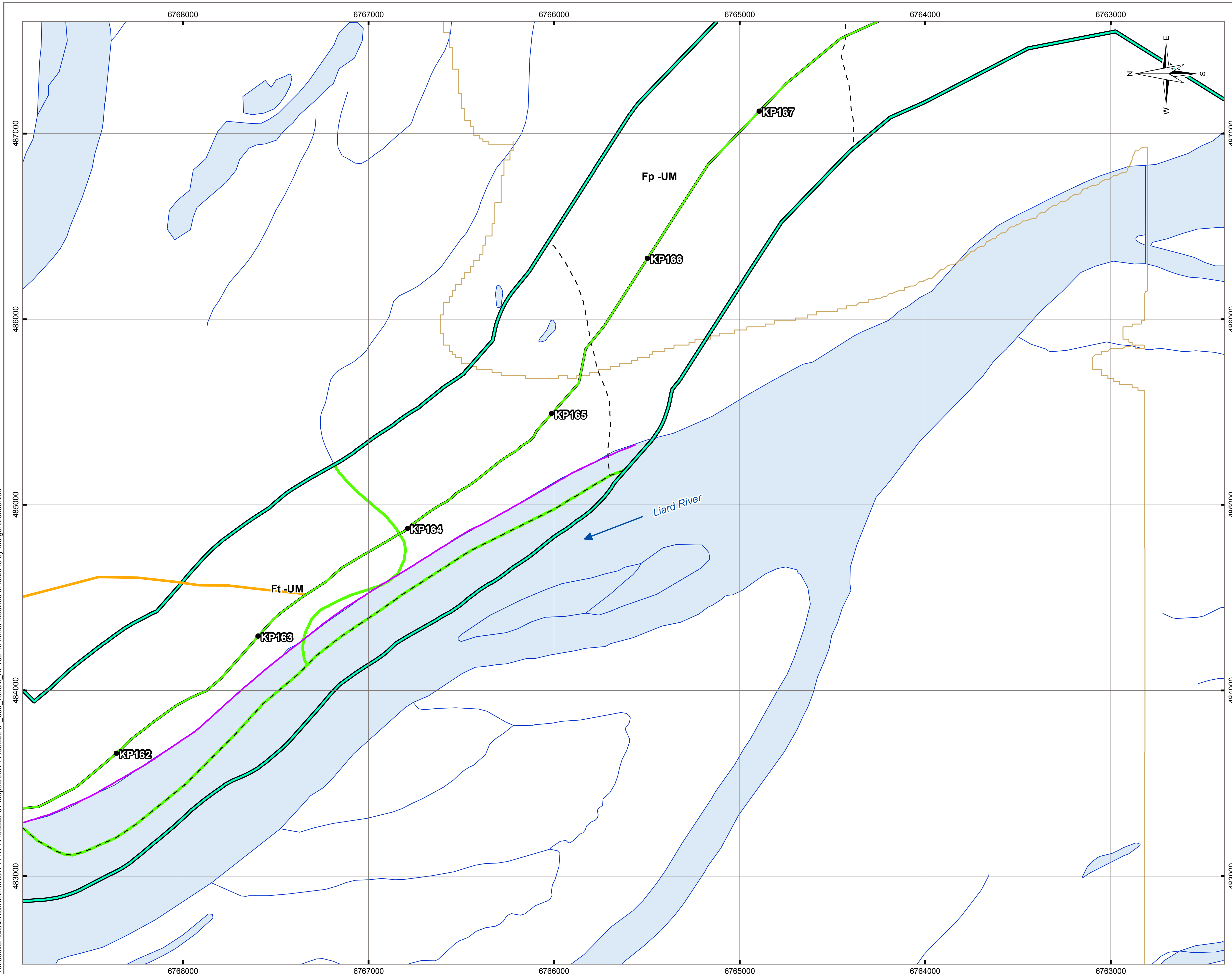
TETRA TECH EBA

**FILE NO.**
Y14103320-01_003_Terrain_KP159-184.mxd

| PROJECT NO. | DWN | CKD | APVD | REV |
|---|---|---|---|---|
| Y14103320-01.003 | MEZ | SL | SMC | 0 |

| OFFICE | DATE |
|---|---|
| Tt EBA-VANC | March 10, 2016 |

**Figure 1**




## LEGEND

- 1 km Buffer
- Terrain Boundary

**Slope Stability Class**

- P Potentially Unstable Terrain
- U Unstable Terrain
- Prairie Creek Access Road (Feb 24, 2015)
- Prairie Creek Access Road Realignment (March 7, 2016)
- River or Stream Position (1949)
- River or Stream Position (2012)
- Contour (40 m)
- Watercourse
- Waterbody

PROFESSIONAL GEOSCIENTIST
REGISTERED
S.J. McCUAIG
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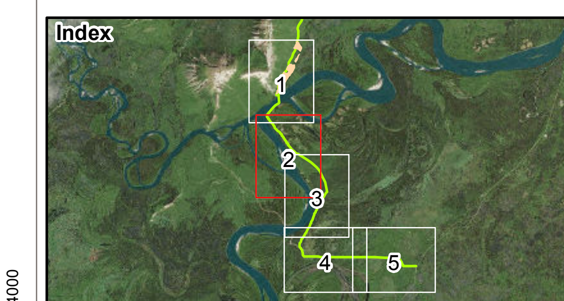


**NOTES**
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# PRAIRIE CREEK ALL-SEASON ROAD

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Scale: 1:20,000
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Metres

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| Y14103320-01.003 | MEZ | SL | SMC | 0 |

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|---|---|
| Tt EBA-VANC | March 10, 2016 |

**Figure 2**

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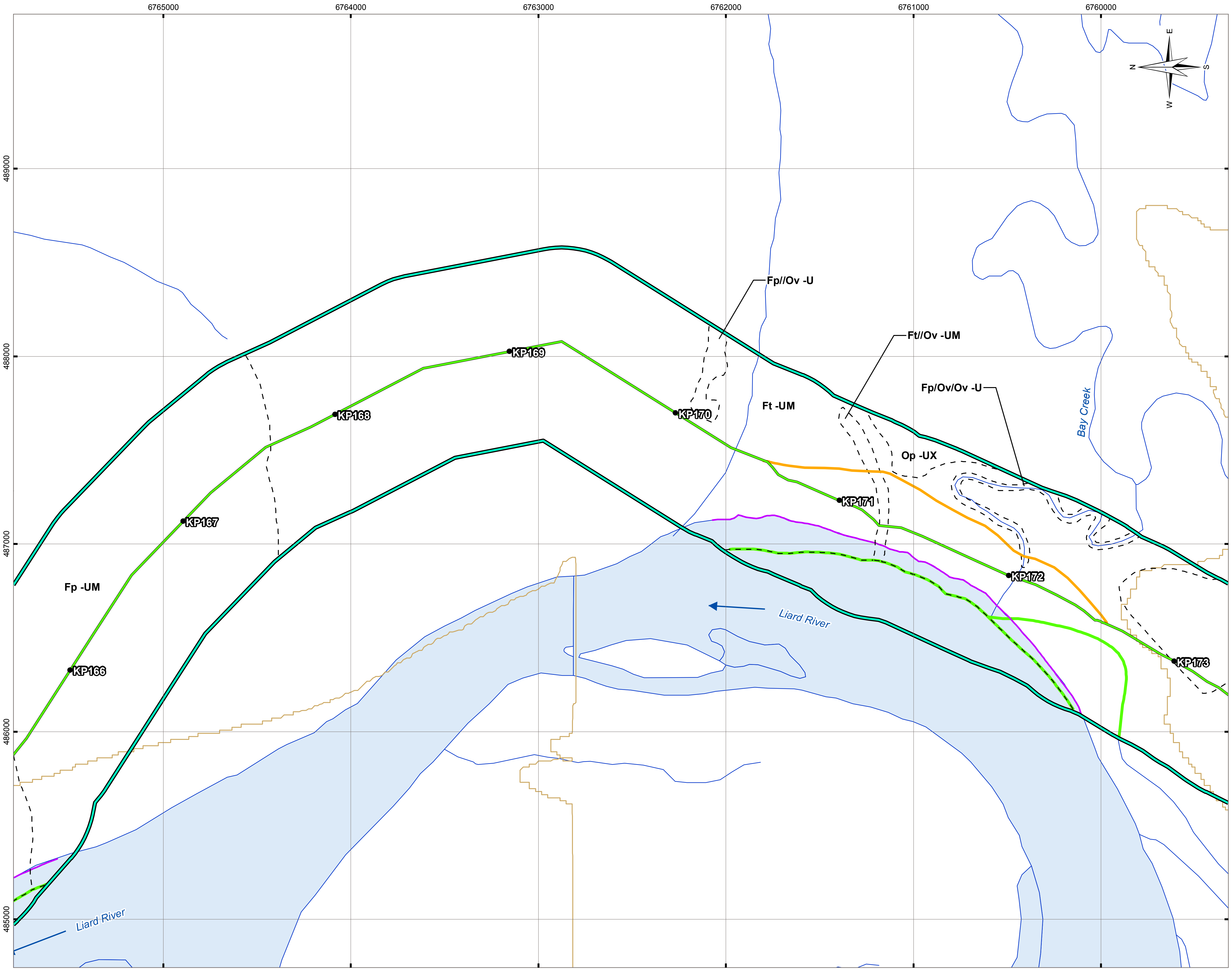




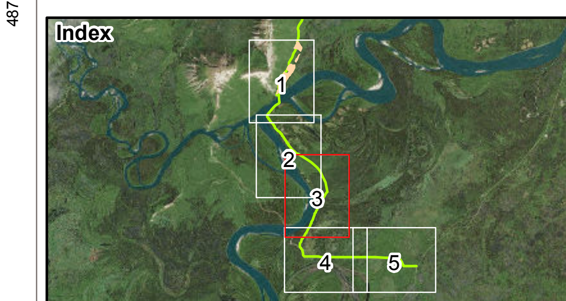

## LEGEND

1 km Buffer
Terrain Boundary

**Slope Stability Class**

P Potentially Unstable Terrain
U Unstable Terrain

Prairie Creek Access Road (Feb 24, 2015)
Prairie Creek Access Road Realignment (March 7, 2016)
River or Stream Position (1949)
River or Stream Position (2012)
Contour (40 m)
Watercourse
Waterbody


**NOTES**
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## PRAIRIE CREEK ALL-SEASON ROAD

## Modified Terrain Stability Mapping

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Scale: 1:20,000
400 200 0 400
Metres

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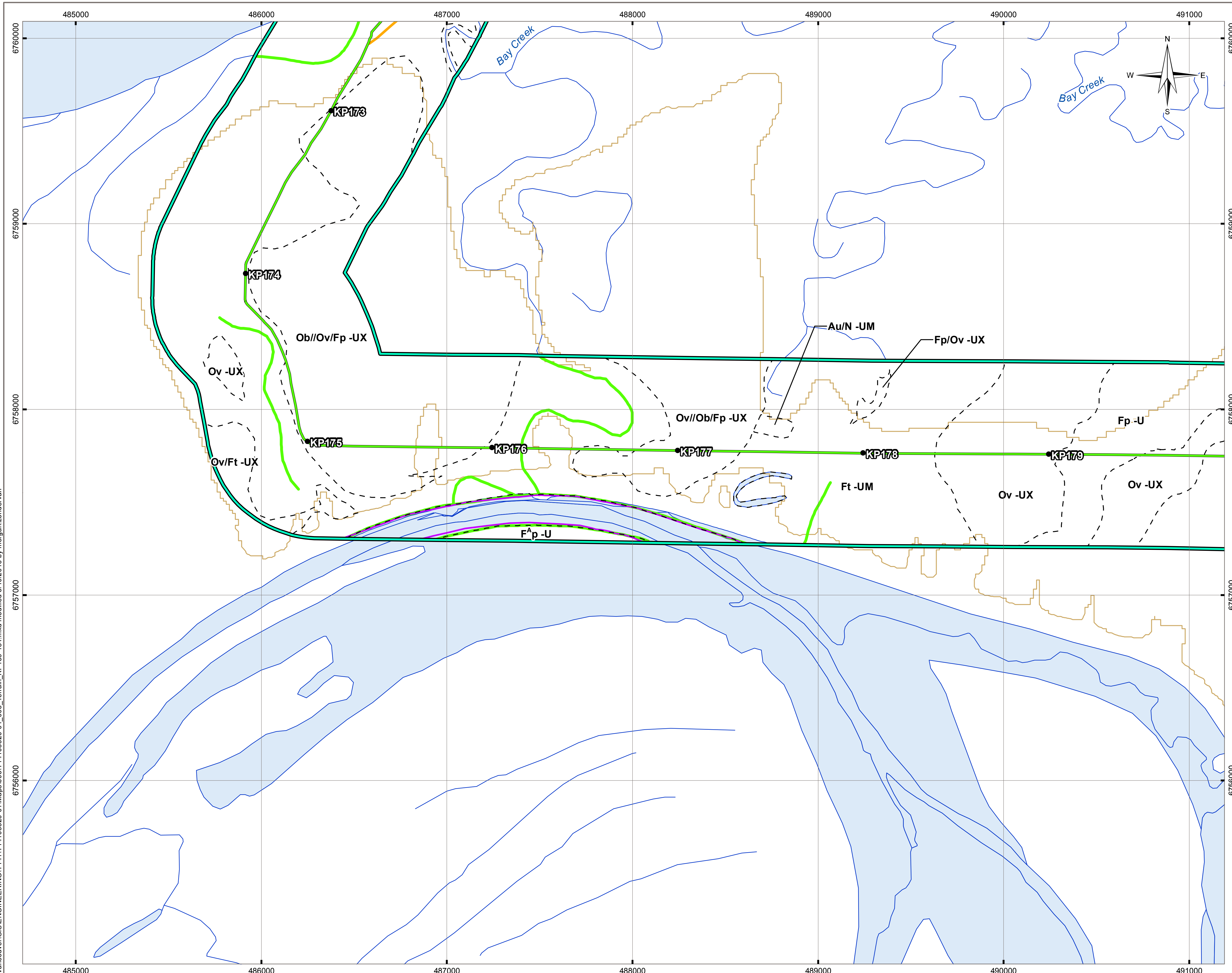
|---|---|---|---|---|
| Y14103320-01.003 | MEZ | SL | SMC | 0 |

| OFFICE | DATE |
|---|---|
| Tt EBA-VANC | March 10, 2016 |

**Figure 3**




## LEGEND

1 km Buffer
Terrain Boundary

**Slope Stability Class**

P Potentially Unstable Terrain
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Prairie Creek Access Road (Feb 24, 2015)
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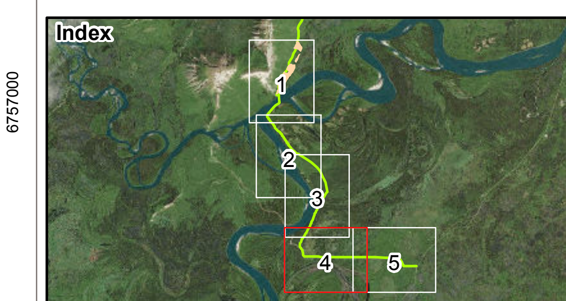


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Metres

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| Y14103320-01.003 | MEZ | SL | SMC | 0 |

| OFFICE | DATE |
|---|---|
| Tt EBA-VANC | March 10, 2016 |

**Figure 4**

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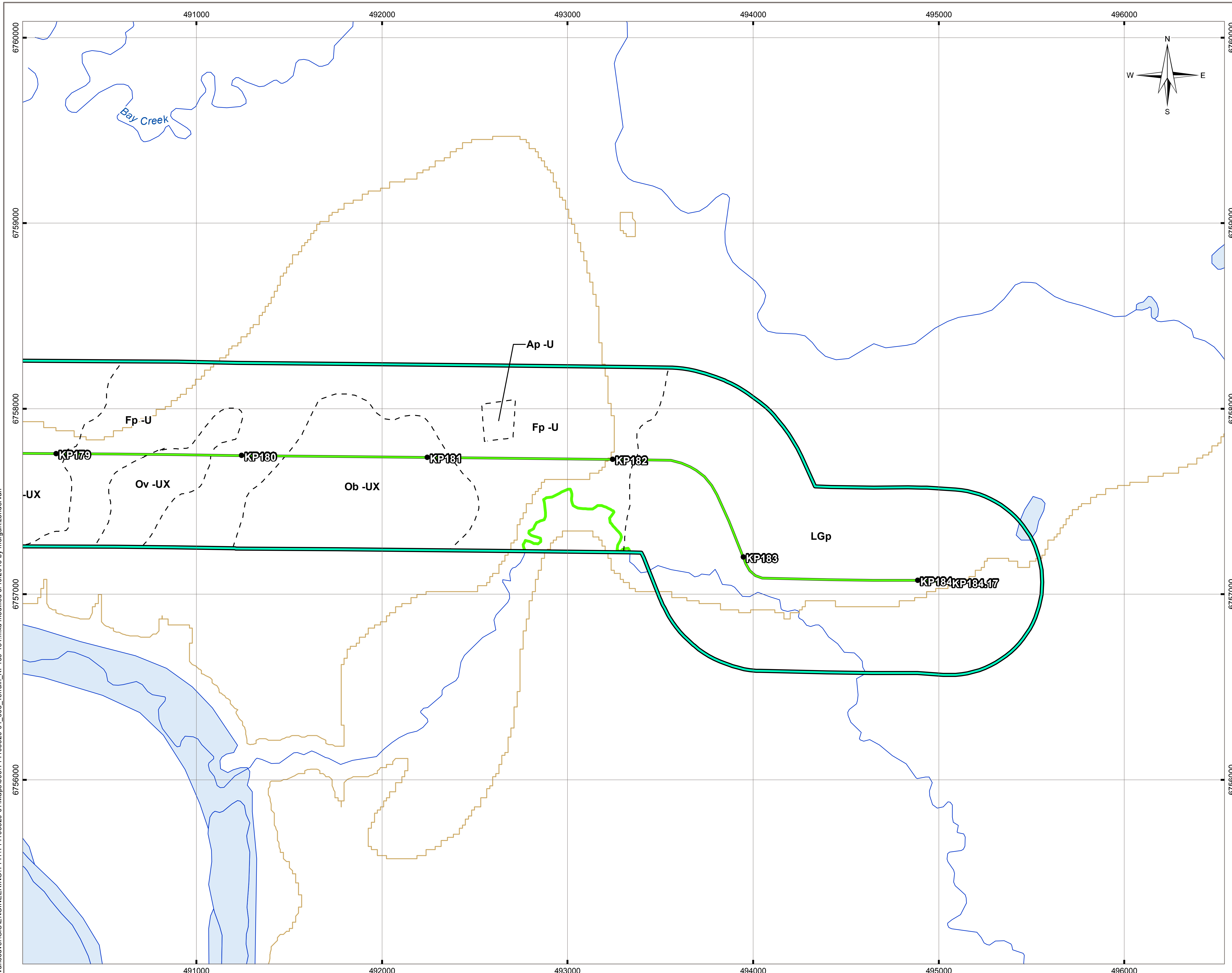


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**LEGEND**

- 1 km Buffer
- Terrain Boundary

**Slope Stability Class**

- P Potentially Unstable Terrain
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|---|---|---|---|---|
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| OFFICE | DATE |
|---|---|
| Tt EBA-VANC | March 10, 2016 |

**Figure 5**

# APPENDIX A
## TETRA TECH EBA'S GENERAL CONDITIONS

# GENERAL CONDITIONS

## GEOTECHNICAL REPORT

This report incorporates and is subject to these “General Conditions”.

### 1.0 USE OF REPORT AND OWNERSHIP

This geotechnical report pertains to a specific site, a specific development and a specific scope of work. It is not applicable to any other sites nor should it be relied upon for types of development other than that to which it refers. Any variation from the site or development would necessitate a supplementary geotechnical assessment.

This report and the recommendations contained in it are intended for the sole use of Tetra Tech EBA’s Client. Tetra Tech EBA does not accept any responsibility for the accuracy of any of the data, the analyses or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than Tetra Tech EBA’s Client unless otherwise authorized in writing by Tetra Tech EBA. Any unauthorized use of the report is at the sole risk of the user.

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### 2.0 ALTERNATE REPORT FORMAT

Where Tetra Tech EBA submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed Tetra Tech EBA’s instruments of professional service), only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Tetra Tech EBA shall be deemed to be the original for the Project.

Both electronic file and hard copy versions of Tetra Tech EBA’s instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Tetra Tech EBA. Tetra Tech EBA’s instruments of professional service will be used only and exactly as submitted by Tetra Tech EBA.

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

### 3.0 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, Tetra Tech EBA has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

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

Classification and identification of soils and rocks are based upon commonly accepted systems and methods 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 EBA 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.

### 5.0 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.

### 6.0 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of testholes and/or soil/rock exposures. Stratigraphy is known only at the locations of the testhole or exposure. Actual geology and stratigraphy between testholes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. Tetra Tech EBA 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 investigation and review may be necessary.

### 7.0 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.

### 8.0 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.

### 9.0 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and 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 are known.

### 10.0 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as 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.

### 11.0 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. 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.

### 12.0 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses 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 assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

### 13.0 SAMPLES

Tetra Tech EBA 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.

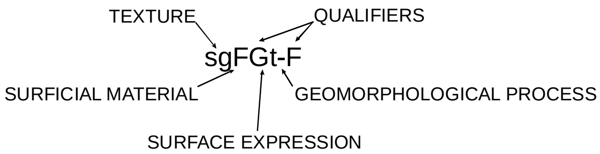
### 14.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of the report, Tetra Tech EBA may rely on information provided by persons other than the Client. While Tetra Tech EBA endeavours to verify the accuracy of such information when instructed to do so by the Client, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

# APPENDIX B
## LEGEND

# TERRAIN STABILITY LEGEND

## TERRAIN SYMBOL




Stratigraphic Units: When one or more surficial materials overlie a different material or bedrock. Materials are placed in order of occurrence and separated by a solid line.

| | | |
|---|---|---|
| e.g. | zEv<br>gFt | veneer of eolian silt overlying terraced fluvial gravels |
| | Mh<br>gFGp | hummocky morainal materials overlying glaciofluvial gravels |
| | /sEv<br>gFt | a moderately extensive, but discontiuous, eolian veneer on a river terrace |

Subclasses: Subdivisions of the general categories of the Geomorphological Processes classification.

| | | |
|---|---|---|
| e.g. | Fp-Mp | a meandering river with backchannels containing flowing orstanding water year-round |
| | Rs/Cv-VR^bd | gullied bedrock cliffs where rockfall (b) and debris flows (d) start (^) |
| | xrCk-Rb | talus slope receiving rockfall |

## DELIMITERS

| Map Symbol | Definition |
|---|---|
| . | Components on either side of the symbol are of approximately equal proportion |
| / | The component in front of the symbol is more extensive than the one that follows |
| // | The component in front of the symbol is considerably more extensive than the component that follows. |

## TEXTURE

| Symbol | Name | Description |
|---|---|---|
| **c** | clay | Particles less than 0.002 mm in size |
| **z** | silt | Particles between 0.002 and 0.0625 mm in size |
| **s** | sand | Particles between 0.0625 and 2 mm in size |
| **g** | gravel | Mix of boulders, cobbles and pebbles greater than 2 mm in size |
| **p** | pebbles | Rounded particles between 2 and 64 mm in size |
| **k** | cobbles | Rounded particles between 64 and 256 mm in size |
| **m** | mud | Mix of silt, clay, and some find sand |
| **x** | angular fragments | Angular blocks and rubble greater than 2 mm in size |
| **d** | mixed fragments | Mix of round and angular particles greater than 2 mm in size |

## QUALIFIERS

| Symbol | Name | Description |
|---|---|---|
| **A** | active | Used to qualify surficial material and geomorphological processes with regard to their current state of activity |
| **I** | inactive | |

## SURFICIAL MATERIALS

| Symbol | Name | Description |
|---|---|---|
| **A** | anthropogenic | Man-made disturbance |
| **C** | colluvial | Products of mass wastage |
| **D** | weathered bedrock | Physically or chemically weathered rock in place |
| **F** | fluvial | River deposits |
| **FG** | glaciofluvial | Fluvial materials deposited by meltwater streams |
| **LG** | glaciolacustrine | Lacustrine material deposited by ice-dammed lakes |
| **M** | morainal | Material deposited directly by glaciers |
| **N** | water | Lake or pond |
| **O** | organic | Accumulation/decay of vegetative matter |
| **R** | bedrock | Outcrops/rocks covered by less than 10 cm of surficial material |

## SURFACE EXPRESSION

| Symbol | Name | Description |
|---|---|---|
| **a** | moderate slope | Unidirectional surface; 27 to 49% |
| **b** | blanket | A mantle of unconsolidated materials; > 1m thick |
| **c** | cone | Cone-shaped landform; > 26% |
| **d** | depression | A steep-sided hollow |
| **f** | fan | Fan-shaped landform; up to 26% |
| **h** | hummocky | Hillocks and hollows, irregular plan; generally > 26% |
| **j** | gentle slope | Unidirectional surface; 6 to 26% |
| **k** | moderately steep | Unidirectional surface; 50 to 70% |
| **p** | plain | Unidirectional surface; 0 to 5% |
| **r** | ridged | Elongate hillocks; parallel in plan; generally > 26% |
| **s** | steep | Steep slopes; > 70% |
| **t** | terraced | Step-like topography |
| **u** | undulating | Hillocks and hollows; irregular in plan; generally < 26% |
| **v** | veneer | Unconsolidated material 0.1 to 1 m in thickness |
| **w** | mantle of variable thickness | discontinuous cover typically 0 to 3 m in thickness |
| **x** | thin veneer | unconsolidated material 2 to 20 cm in thickness |

# TERRAIN STABILITY LEGEND

## GEOMORPHOLOGICAL PROCESSES

| Symbol | Name | Description |
|---|---|---|
| **B** | braided channel | Many diverging/converging water channels separated by unvegetated bars |
| **E** | channeled | Channel formation by glacial meltwater |
| **F** | slow mass movement | Slow down-slope movement of masses of cohesive or non-cohesive material and/or bedrock |
| **H** | kettled | Depressions due to the melting of buried glacier ice |
| **I** | irregularly sinuous channel | Main water channel with irregular bends or backchannels |
| **K** | karst | Processes associated with the solution of carbonates |
| **L** | surface seepage | Abundant surface or seasonal seepage of moisture |
| **M** | meandering channel | Clearly defined water channel with regular repeating bends |
| **R** | rapid mass movement | Rapid downslope movement of dry, moist or saturated debris |
| **U** | inundation | Seasonally under water due to high watertable |
| **V** | gully erosion | Narrow ravine formed by running water, mass movement, or snow avalanching |
| **X** | permafrost processes | Presence, aggradation, or degradation of permafrost |

## SUBCLASSES FOR PERMAFROST PROCESSES

| Symbol | Name | Description |
|---|---|---|
| **f** | thaw flow slides | Slope failures from permafrost thawing |

## SUBCLASSES FOR MASS MOVEMENT PROCESSES

| Symbol | Name | Description |
|---|---|---|
| **^** | initiation zone | Source area for rockfall and debris flow |
| **b** | rockfall | Descent of bedrock masses |
| **c** | soil creep | Slow downward movement of soil |
| **d** | debris flow | Rapid flow of saturated debris |
| **e** | earth flow | Slow viscous flow of silt/clay material |
| **j** | lateral spread | Horizontal movement in surficial material |
| **k** | tension crack | Open fissures |
| **m** | slump in bedrock | Cohesive bedrock mass sliding along a concave upward or planar slip plane |
| **r** | rockslide | Sliding of large disintegrated bedrock masses |
| **s** | debris slide | Sliding of disintegrated surficial material masses |
| **t** | debris torrent | Water, earth, and vegetation rapid flow down a steep well-defined channel |
| **u** | slump in surficial material | Surficial material sliding along a concave upward or planar slip plane |
| **x** | slump earthflow | Combined slump (upper part) and earthflow (lower part) |