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TECHNICAL MEMO

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To:	David Harpley	**Date:**	May 4, 2016
c:	Alan Taylor, Nigel Goldup	**Memo No.:**	05
From:	Rita Kors-Olthof, Shirley McCuaig	**File:**	Y14103320-01.006
Subject:	Risk Analysis – Landslide Hazards Proposed Prairie Creek Mine 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 Mine All-Season Road Project, the Mackenzie Valley Review Board (MVRB) requested a desktop magnitude/frequency assessment for landslide 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. In response to that request, Tetra Tech EBA Inc. (Tetra Tech EBA) was retained by CZN to complete a desktop magnitude/frequency analysis for landslide hazards, which was provided in a technical memo (2016c).

The purpose of the magnitude/frequency analysis was 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. CZN subsequently requested that Tetra Tech EBA incorporate the findings of the magnitude/frequency analysis into an update of the risk analysis for the landslide-related hazards along the proposed route. The previous qualitative risk analysis for landslides and ground movement was presented as part of Table 7.2.2-1 in the geotechnical report for the route (Tetra Tech EBA 2015a). This memo presents the results of the updated analysis. The analysis is specific to potential risks to the road.

2.0 RISK-RELATED RATINGS

2.1 Definitions and Criteria

The definitions used in the updated risk analysis are consistent with those in the geotechnical report and the magnitude/frequency analysis (Tetra Tech EBA 2015a, 2016c), and are summarized here for convenience, along with some additional definitions that describe the risk analysis procedure as carried out for this memo. The criteria are based on those used in the magnitude/frequency analysis:

- A hazard [or geohazard] is a harmful or potentially harmful event expressed qualitatively; in this memo, landslides are the hazards analyzed (Wise et al. 2004). Hazards identified along the route were mapped and discussed as part of the geotechnical report (Tetra Tech EBA 2015a) and subsequent submissions (Tetra Tech EBA 2015b, 2015c, 2016b). The geohazard mapping provides the supporting data for "Landslide Analysis," "Hazard Analysis," and/or various levels of "Risk Analysis" for the route (as per Wise et al. 2004);

- Risk can be described qualitatively or quantitatively as:

  $$\text{Risk} = P_H \times P_{S:H} \times P_{T:S} \times V \times E$$

  (Porter and Morgenstern 2013; Wise et al. 2004)

Tetra Tech EBA Inc.
Box 2244, 201, 4916 - 49 Street
Yellowknife, NT X1A 2P7 CANADA
Tel 867.920.2287 Fax 867.873.3324

- Risk is the likelihood of a specific adverse consequence (loss of life/injury, 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 (P_H - likelihood of occurrence), 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). In the case of the present analysis, the risk being considered is that which results from the potential effect of a landslide on a road.

The component parameters of "Risk" are described in more detail as follows:

- Likelihood is the probability of occurrence of a specific hazardous landslide; that is, the potential for the landslide to occur, designated as P_H in the formula presented above. Elements at risk are considered only in general terms for P_H (Wise et al. 2004).
- The likelihood that a specific landslide will affect the route, also known as "encounter probability," is designated as P_H x $P_{S:H}$ in the equation. This value was determined in qualitative terms in the magnitude-frequency analysis. "Frequency," as defined in that analysis, is a subjective estimate of likelihood (probability), and is described in Table 2.1 below (Tetra Tech EBA 2016c; as per Wise et al. 2004, Porter and Morgenstern 2013). The qualitative risk analysis in the geotechnical report also used this concept to estimate the "likelihood of hazard affecting the element" (Tetra Tech EBA 2015a), similar to a typical evaluation presented in Porter and Morgenstern (2013).
- Magnitude (also a partial proxy for consequence) defines both the size and the spatial probability of a landslide reaching or affecting the proposed route, designated as $P_{S:H}$ in the formula above. Magnitude can be equated to the relative size or destructive potential of a particular hazard type, as shown in Table 2.2 below. 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 are difficult to determine, so the former is used as the best proxy for this analysis.
- Temporal probability, $P_{T:S}$, is the probability that the element at risk, in this case, the road, will be present at the affected site at the time the event occurs (based on Wise et al. 2004). Since the road is assumed to be present during the proposed service life, as well as during construction and decommissioning, $P_{T:S}$ would be numerically equal to 1 in a quantitative analysis, and thus does not affect risk analysis results related specifically to effects on the road itself. The temporal probability would account for the presence of people, understood to be during daytime only and very intermittently, therefore tending to significantly reduce risk. Vulnerability would likely be higher for people, however, which would conversely tend to increase risk. Risks to personnel are not shown in the tables or further discussed here.
- Vulnerability, V, takes into account how robust (or fragile) the element is, and its exposure to (or protection from) the landslide. Vulnerability forms part of the evaluation of consequence. Quantitatively, vulnerability can be considered as the estimated probability of total loss or damage, or the estimated proportion of loss or damage, with a range from 0 (no chance of loss or damage) to 1 (total loss or highest estimated proportion of loss). Since the entire road length is unlikely to be lost or damaged from any one event, an estimated proportion of loss or damage would be more appropriate. Qualitatively, the rating could be defined as *no loss or damage*, *low loss or damage*, *moderate loss or damage*, *high loss or damage*, and *total loss or damage* (Wise et al. 2004). Loss or damage could be considered in terms of the probability that some repairs would need to be made to the road as a result of a landslide, for example, soil or rock materials sloughing or falling onto the road that need to be cleaned up, or part of the road grade failing and needing to be replaced or repaired. Wise et al. (2004) also provide a useful description of what might constitute a "low loss or damage" rating compared to

"moderate" or "high" ratings, by presenting the loss in terms of the length of time the transportation corridor might be disrupted because of the event.

- Vulnerability is partly dependent on magnitude, since a larger event would be expected to have a larger impact on the requirements for cleanup or repair. This aspect relates to the road having a greater or lesser exposure, depending on the size of the landslide.
- Vulnerability is also dependent on the velocity of an event, with more rapid intense events such as rockfall, rockslides or debris flows potentially having a much greater impact than gradual soil creep, or a slowly slumping hillside. A velocity rating of "moderate" was used for anticipated intermediate velocities or for event velocities that can be more difficult to categorize, including earthflows and gully erosion. This aspect relates to the road having a greater or lesser resistance against an event, or how robust the road is against that event. For events that deposit material on the road, a rockfall event could have a higher momentum than a soil slide, causing more damage to the road surface due to rock impacts. For events that move rapidly across or alongside the road, quickly-moving materials would have higher erosive potential.
- The road would be expected to be less vulnerable to events where material falls on the road than for events that scour out the road. That is, if two events of the same size affect the road, a scouring event or a slope instability resulting in the loss of part of the embankment would likely cause more damage, resulting in higher vulnerability rating.

- Consequence is considered as $P_{S:H}$ x $P_{T:S}$ x V (Wise et al. 2004). $P_{S:H}$ is accounted for in the encounter ratings (likelihood of a hazard to affect the road, Table 2.1), and $P_{T:S}$ is invariable in the analysis of the road itself (equal to 1). The remaining contributor to consequence is therefore accounted for by V, as defined above. Consequence thus incorporates the effect on the road of a particular event type of a specified (probable) size or size range.
- The value or worth of the element, E, is sometimes added to a risk analysis, and could include direct costs such as the cost of rebuilding or repair or clearing debris, or indirect costs such as the economic loss resulting from the road being blocked or needing repair to make it usable again. This component is not included in the analysis described in this memo.

Table 2.1: Likelihood[1] of Hazard Affecting the Route (modified from Wise et al. (2004))

Likelihood Rating (Probability of occurrence)[3]	Annual Probability of Occurrence	Probability of Occurrence over a 20-Year Design Life[2]	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]Frequency as defined in Tetra Tech EBA (2016c).
[2]Probability that at least one landslide event will occur within the assumed 20-year design life of the road.
[3]Encounter probability, or likelihood that a specific hazardous landslide will affect the route, designated as P_H x $P_{S:H}$ in the equation above.

Definitions, criteria, and qualitative descriptions of the landslide frequency and magnitude ratings adopted for this study are provided in Table 2.1 above and Table 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. The ratings for the geohazards evaluated are shown in Table A1, attached at the back of this memo.

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

Magnitude Rating[2]	Area affected (ha)	Minimum volume involved (m^3)[1]	Magnitude Proxy for Contribution to Vulnerability Rating[3]
Very Large	> 2.5	> 25,000	High
Large	0.5 to 2.5	5,000 – 25,000	Moderate
Medium	0.05 to 0.5	500 – 5,000	Low
Small	< 0.05	< 500	Very Low

[1]Based on area affected and assuming landslide debris is on average 1 m thick.
[2]Magnitude as indicator of spatial probability or likelihood of a landslide reaching or affecting the proposed route, designated as $P_{S:H}$
[3]Magnitude used as a proxy for primary estimation of vulnerability of proposed road (see Table 2.3).

Tables 2.3 and 2.4 below show how the magnitude, velocity, and deposition vs. scouring proxies contribute to the vulnerability of the road and the probable consequence of an event impacting the road. Table 2.3 shows approximate ranges of velocities assigned to the velocity ratings, and the velocity rating assigned to each geohazard evaluated is shown in Table A1. It is noted that some variation may occur in the velocities observed for each type of geohazard, and the ratings assigned are approximations only. For example, a thaw flow slide could be rapid, resulting in a "high" velocity rating, but based on the observations of the conditions at the KP053.7 thaw flow slide, an overall velocity rating of "moderate" appears reasonable. Slumps in bedrock could in fact be rapid, depending on the trigger, for example, due to loss of toe support during deglaciation. Continued or intermittent movement could be slow to moderate, and a moderate velocity rating has been adopted to account for possible future slumping. Similarly, a lateral spread can refer to a slide or slump area and the velocity can vary from slow to moderate. Soil creep can be faster than suggested by the "low" rating if the soils are cut into, or if climate warming results in increasing plasticity of the ice in the soil. The analysis using the Table 2.3 criteria showed a vulnerability range from "extremely low" to "very high" resulting from the combination of magnitude and velocity proxies (Table A1).

Table 2.3: Vulnerability Estimate – Magnitude and Velocity Proxies

Vulnerability (Magnitude and Velocity Proxies)			Magnitude Proxy[1]			
			Very Low	**Low**	**Moderate**	**High**
Velocity Proxy[2]	< 1.5 m/year	**Low**	Extremely Low	Very Low	Low	Moderate
	1.5 m/year to 2 m/h	**Moderate**	Very Low	Low	Moderate	High
	> 2 m/h	**High**	Low	Moderate	High	Very High

[1]From Table 2.2, based on estimated range of magnitude.
[2]Velocity of event used as a secondary proxy for estimation of vulnerability, based on WP/WLI 1995 and Cruden and Varnes 1996 (see also Table 2.4 below).

When deposition vs. scouring proxies are accounted for in accordance with the criteria shown in Table 2.4 below, consequence ranges from "extremely low" to "very high," with no "extremely high" consequences noted in the analysis results (Table A1).

Table 2.4: Consequence Rating (Using Vulnerability Proxies)

Consequence Rating (Using Vulnerability Proxies)		Magnitude-Velocity Proxy[1]					
		Extremely Low	**Very Low**	**Low**	**Moderate**	**High**	**Very High**
Deposition vs. Scouring Proxy[2]	**Low**	Negligible	Extremely Low	Very Low	Low	Moderate	High
	Moderate	Extremely Low	Very Low	Low	Moderate	High	Very High
	High	Very Low	Low	Moderate	High	Very High	Extremely High

[1]From Table 2.3, based on magnitude and velocity proxies.

[2]Whether an event is likely to result in deposition (Low) or scour (High) is used as a tertiary proxy for estimation of vulnerability and consequence.

Table 2.5 below shows the risks resulting from the combination of the likelihood of a hazard affecting the route (from Table 2.1) and the consequence of the event if it occurs (from Table 2.4). No "extremely high" risk ratings were noted in the risk analysis (Table A1).

Table 2.5: Risk Rating

Risk Rating		Consequence Rating[1]					
		Extremely Low	**Very Low**	**Low**	**Moderate**	**High**	**Very High**
Likelihood Rating[2]	**Low**	Negligible	Extremely Low	Very Low	Low	Moderate	High
	Moderate	Extremely Low	Very Low	Low	Moderate	High	Very High
	High	Very Low	Low	Moderate	High	Very High	Extremely High

[1]From Table 2.4, based on magnitude, velocity, and deposition vs. scour proxies for vulnerability (V, part of consequence).

[2]From Table 2.1, based on hazard likelihood (P_H) and spatial probability (P_{S-H}).

It is noted that the ratings used in the magnitude/frequency analysis and this updated risk analysis have been refined somewhat from those used in the geotechnical report, reflecting the additional information available from the terrain mapping carried out since that time (Tetra Tech EBA 2015a, 2015c, 2016b, 2016c). As well, the route has been divided into smaller subsections than were used in the geotechnical report, allowing further refinement of the analysis. The findings are generally consistent with the previous findings, with some additional features and considerations flagged as a result of the intervening studies. Highlights of the risk analysis results are presented in Section 3.4 below.

2.2 Methods for Estimation of Landslide Frequency and Magnitude

Landslide frequency and magnitude were estimated in the desktop magnitude/frequency analysis (Tetra Tech EBA 2016c). The methods for that work are summarized below for convenience and the definitions are presented above in Tables 2.1 and 2.2.

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 a landslide hazard was 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 RISK ANALYSIS

3.1 General

The risk analysis was carried out in accordance with the definitions and criteria described in Section 2.1 above. The results of the analysis are presented in Table A1.

3.2 Magnitude and Hazard (Likelihood) Ratings

As previously described by Tetra Tech EBA (2016c), landslide hazards were analyzed along the 184 km of the proposed alignment and magnitude/frequency ratings were assigned to various portions of the route according to 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 (hazard likelihood or encounter) ratings are presented in Table A1, 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 likelihood 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 A1. Secondary hazards are listed and described; however, magnitude and likelihood ratings were not assigned to these unless they were considered equally dominant (co-dominant) or subdominant but nearly co-dominant.

3.3 Vulnerability Proxies and Consequence Ratings

As described in Section 2.1 above, three proxies for vulnerability were estimated to derive the consequence ratings. The proxies considered were the magnitude of an event; the anticipated relative velocity of typical types of events: rockfalls and rockslides, compared to debris flows and slides, compared to lateral spread and permafrost creep; and a deposition vs. scouring proxy. The criteria for these proxies are shown in Tables 2.3 and 2.4 above. The consequence ratings are presented in Table A1.

3.4 Risk Ratings

As described in Section 2.1 above, the risk ratings were estimated from the likelihood of hazard affecting the road (encounter ratings) and the consequence ratings, according to the criteria in Table 2.5. The results are presented in Table A1.

Road sections with “high” or “very high” risk ratings, and selected “moderate” risk ratings, are situated at the following locations:

- “High” or “Very High” risk rating:
    - KP026.2 to KP026.3 – Debris flow of moderate likelihood and high consequence. A sinuous ridge of debris above the road is of unknown origin. It appears to have directed water flow across the proposed road alignment in the past, scouring out the area below and forming a small depositional fan adjacent to the creek. Uncertain if debris flows have formed above road or not. Mapped as debris flow to be conservative. Culvert mitigation to be considered as described below for KP155.9 to KP159.3;

- KP027.2 to KP027.4 – Debris slide or flow with high likelihood and consequence, resulting in very high risk. This feature is to be spanned with a bridge. Regular monitoring is advisable in case additional mitigations are required in the future.

- KP028.2 to KP028.4 – Part of re-route to south side of valley: Minor rockfall activity in limited areas in 1994 and 2012 with high likelihood but moderate consequence; shaded in 1949, so unable to determine activity level at that time. Activity should be monitored and mitigation considered, if necessary.

- KP049.7 to KP050.0 – The realignment was adjusted after Terrain Stability Mapping to shift the road back from potentially retrogressive slides; the road is already well back from slide areas that are being eroded by the creek. The likelihood of ongoing movements is considered moderate and the consequence is very high (the latter areas would have a high frequency). Further shifting of the road upslope is not practical in this section due to steeper side-slopes and road grades, and another proposed stream crossing further upstream was determined to be less amenable to development due to slope stability issues. The current road location is therefore likely to receive fewer impacts from possible future slope movements than the adjacent routes that were considered. Should movement resume along existing slide paths in this section, it may be necessary to consider additional mitigations including possible erosion protection at the creek, retaining or buttressing parts of the slope, and/or implementing additional water drainage measures. Appropriate mitigations will be considered at the time of detailed design, and would include monitoring and/or specific measures. The latter would be determined in accordance with the likely contributors to, and types of, movement considered to be likely;

- KP053.7 to KP054.2 – A thaw flow slide visible on 2012 LiDAR image nearby, but offset 100 m from the road alignment at the closest point, and set back 125 m from road route upslope. Although the likelihood of continued climate change means that the thaw flow slide might continue to retrogress, the route is now located outside of the apparent near-surface permafrost area, and the increased setback compared to the originally proposed route has reduced the likelihood that possible future movements will affect the road. However, monitoring is required, to keep track of slope movements that might require future mitigation;

- KP059.7 to KP60.4 – Route crosses a few older slides visible in 1949 photos. Debris slide of moderate likelihood and high consequence because part of feature is below road and potentially could cut into road. Monitoring is warranted, in case slope mitigations are needed in the future;

- KP083.5 to KP085.5 – Debris slides on slope above river and below alignment have moderate likelihood but high consequence. Road is well back from older and younger debris slides and tension cracks. Regular monitoring of the slope below this road section is advisable, to keep track of slope movements that might require additional mitigation;

- KP095.5 to KP101.7 – Large rotational to translational slide or slump in bedrock that likely occurred quite some time ago. Although this location has a low hazard likelihood, due to its size and potentially low to high velocity, it has a very high consequence and therefore a “high” risk rating. Because of its very large size, mitigation requirements could be considerable if movement renews. In particular, the large amount of gullying indicates that there is abundant water movement on this slope. Drainage planning will be very important here to prevent lubrication of old slide planes during exceptional rain or rain-on-snow events. As noted in the geotechnical report (Tetra Tech EBA 2015a), the goal is to have sufficient drainage measures such that surface water does not flow in channels in locations where water would naturally flow as sheet flow. The design of appropriate drainage measures is especially important at switchback locations. Also on this slope are some newer soil debris slides that have occurred in the colluvial soils overlying the bedrock slide, as well as some larger debris slides/flows to the south and north of the alignment in similar terrain. While such slides/flows are likely to continue, the soil debris slides tend to be small, and appropriate drainage measures will also help to reduce the possibility of the road contributing to local debris slides or flows. While no significant changes have occurred affecting the former winter road, this is not necessarily a reliable predictor of future performance;

- KP136.4 to KP137.3 – Large debris slides in this section have been assigned a low likelihood and very high consequence. Potentially, a moderate likelihood exists but these features are difficult to discern on both sets of photos. One feature at KP136.4 may be a debris flow, but the feature is rather indistinct - may have a low frequency and/or may be intermixed with fluvial sediment. Monitoring is needed to track slope movements;

- KP0154.5 to KP155.3 – Earth slump/flow assumed to be old, as it was inactive in 1949, but could have up to moderate likelihood; road alignment has been moved upslope to avoid this area. In the analysis, this hazard was given a low likelihood of affecting the road, but it has a very high consequence due to being about 800 m long. If the slide moves again, it could be a very large event, entailing a lot of work to repair. The adjacent section of slope (KP155.9 to 159.3), with tension cracks above a similar slope failure in similar terrain, indicates that the possibility of renewed movement should not be disregarded in this section. Although the road has been moved upslope, it is not at low risk: the risk is simply reduced from what it would be if the road was immediately above the scarp. Regular monitoring of the slope below this road section is advisable, to keep track of slope movements that might require additional mitigation.

- KP155.9 to KP159.3 – Recently-developed debris flows, visible only on the 2012 LiDAR images, cross the route at KP158.4 to KP158.5. These flows are presently narrow (each about 25 m wide for the two that cross the road), but the source area for the debris is large. The debris flows have a high hazard likelihood rating and a high consequence rating, resulting in a very high risk rating. Culvert mitigation including larger culverts, strategic placement of back-up culverts, and channel armouring should be considered in the detailed design for this area. Culverts may still plug if debris flows occur, so culverts at staggered locations and elevations may be beneficial in case the lower culverts become plugged with debris. Additional mitigations may be needed if debris flow activity grows in magnitude due to increased water flow from thawing rock glaciers upslope, with possibilities including additional armouring, barriers, nets, and/or catch-basins. The road must cross the eastern portion of the same earth slump-flow that affects KP0154.5 to KP155.3 in order to reach the Liard River crossing. This part of the slide does not exhibit tension cracks and the slide frequency is low. However, if a slide occurs (or reactivates) in this road section, the consequence would be very high, due to the potentially very large earth volume that could move, resulting in a high risk rating. Below the alignment, seepage appears to be occurring; drainage planning will be important in this location. Regular monitoring of slopes and drainage provisions is advisable to keep track of events that might require additional mitigation in this section.

▪ "Moderate" risk rating:

  - KP030.8 to KP031.8 – Three colluvial cones with potential for rock slide and debris flow material originating upslope to cross road. These hazards have a high hazard likelihood rating and a low consequence rating, resulting in a moderate risk rating. Wide dispersion of rockslide debris evident on 1949 and 1994 photos shows that up to 90 m of road alignment on each fan was affected prior to 1949, possibly by single events. Recent debris flow activity (visible on 2012 LiDAR image) is much smaller and crosses about 50 m of road. Culverts will be used in mitigation, but may not capture all debris if new debris flows occur on other parts of fans. Armouring between culverts to be considered. Some possible culvert mitigations are as described above for KP155.9 to KP159.3;

  - KP111.8 to KP113.1 (Alternative route) – Road alignment crosses a debris flow area with recent activity, but it has been adjusted to the lowest possible location on the fans to avoid flows/slides that do not extend to the edge of the fan. The flows visible on the 2012 imagery are 20 to 40 m wide. Appropriate culvert locations and mitigations as described above will help protect the road in these locations; however, it is possible that new debris flows may occur elsewhere on the fans. Although this location has a “moderate” rating, considerable mitigation may be required if a substantial debris flow event occurs.

3.5 Assumptions and Interpretations

As described by Tetra Tech EBA (2016c) and repeated here for convenience, 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 consists of 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 2.2.
- 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 remarks in Tetra Tech EBA 2015a and 2016c). It is, however, a lesser hazard than rockfall, for example, so if both are present, the dominant hazard assigned in Table A1 is assigned to the rockfall hazard.
- 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.

One assumption pertains to the risk analysis only:

- If several slides are present within a described route section, the average magnitude or range of magnitudes was originally given (Tetra Tech EBA 2016c). For the purposes of the risk analysis, the areas where a range of magnitudes were given were re-assessed in PurVIEW and the average magnitude provided instead (Table A1).

4.0 LIMITATIONS OF REPORT

This memo 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 memo 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:
Rita Kors-Olthof, P.Eng., P.E.
Senior Geotechnical Engineer, Arctic Region
Direct Line: 403.763.9881 (cell)
Rita.Kors-Olthof@tetratech.com

Reviewed by:
Shirley McCuaig, Ph.D., P.Geol.
Senior Terrain Geologist, Geotechnical Engineering
Direct Line: 780.451.2130 x381
Shirley.McCuaig@tetratech.com

Reviewed by:

Jason Pellett, M.Eng., P.Eng./P.Geo
Senior Geotechnical Engineer
Direct Line: 778.945.5841
Jason.Pellett@tetratech.com

PERMIT TO PRACTICE
TETRA TECH EBA INC.
Signature
Date May 4, 2016
PERMIT NUMBER: P 018
NT/NU Association of Professional Engineers and Geoscientists

/kla

Attachments: Table A1
General Conditions

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Table A1: Hazard, Consequence and Risk Ratings along the Proposed Prairie Creek Mine All-Season Road, NT

Proposed Route Location			Geohazards (Geomorphic Processes)[1]	Upslope Hazard	Downslope Hazard	Magnitude Rating[2,3]	Hazard (Likelihood) Rating[2,3]	Magnitude Proxy Rating[4,5]	Velocity Proxy Rating[5]	Vulnerability Estimate (Magnitude & Velocity Proxies)[4,5]	Deposition vs. Scouring Proxy[5]	Consequence Rating (Vulnerability Proxies)[4,5]	Risk Rating[3,4,5,6,7]	Comments
From KP (km)	To KP (km)	Distance (km)												
0.0	0.4	0.4	***Rockfall***	✓		Medium	High	Low	High	Moderate	Low	Low	Moderate	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	Low	High	Moderate	Low	Low	Low	Several older rockfalls
			Debris Slide	✓										1994 debris slide in older colluvium immediately above colluvial fan
1.0	1.4	0.4	***Rockfall***	✓		Small	Moderate	Very Low	High	Low	Low	Very Low	Very Low	
			Gully Erosion	✓										
1.9	2.1	0.2	***Debris Flow***	✓		Small	High	Very Low	High	Low	Low	Very Low	Low	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	Low	High	Moderate	Low	Low	Low	No evidence of recent activity
			Rockfall	✓										
2.7	3.4	0.7	***Debris Flow***	✓		Small	Moderate	Very Low	High	Low	Low	Very Low	Very Low	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	Very Low	High	Low	Low	Very Low	Low	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	High	Very Low	High	Low	Low	Very Low	Low	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	Very Low	High	Low	Low	Very Low	Low	Two 2012 scars
6.6	7.1	0.5	***Gully Erosion***	✓		Small	Moderate	Very Low	Moderate	Very Low	Low	Extremely Low	Extremely Low	
7.5	8.7	1.2	***Rockfall***	✓		Small	Moderate	Very Low	High	Low	Low	Very Low	Very Low	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	Very Low	High	Low	Low	Very Low	Very Low	Rockfalls from 1949 photos present, a few almost reach the road alignment.
			Gully Erosion	✓										
10.7	11.2	0.5	***Rockfall***	✓		Small	Moderate	Very Low	High	Low	Low	Very Low	Very Low	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	Low	High	Moderate	Low	Low	Low	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	Very Low	High	Low	Low	Very Low	Extremely 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	Very Low	High	Low	Low	Very Low	Low	3 rockfalls cross road; a number of rockfalls from 1994
14.7	15.6	0.9	***Rockfall***	✓	✓	Small	High	Very Low	High	Low	Low	Very Low	Low	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	Low	High	Moderate	Low	Low	Moderate	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***	✓		Medium	Moderate	Low	High	Moderate	Low	Low	Low	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***	✓		Medium	Low	Low	High	Moderate	Low	Low	Very Low	Recent activity above road, but no slides meet road. Some slides from 1949 still active (or reactivated) in 1994. Road crosses older, gentler colluvial fans with no visible activity.
			Rockfall	✓										
			Gully Erosion	✓										
20.5	21.6	1.1	***Rockslide***	✓		Medium	Moderate	Low	High	Moderate	Low	Low	Low	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	Moderate	Low	High	Moderate	Low	Low	Low	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	***Debris Slide***		✓	Small	Moderate	Very Low	High	Low	Low	Very Low	Very Low	Debris slides on the downslope side of the original alignment; new alignment has no visible hazards
24.0	24.3	0.3	***Debris Slide***	✓		Medium	Moderate	Low	High	Moderate	Low	Low	Low	Recent and 1949 activity does not reach road, therefore given moderate rather than high frequency rating

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Proposed Route Location			Geohazards (Geomorphic Processes)[1]	Upslope Hazard	Downslope Hazard	Magnitude Rating[2,3]	Hazard (Likelihood) Rating[2,3]	Magnitude Proxy Rating[4,5]	Velocity Proxy Rating[5]	Vulnerability Estimate (Magnitude & Velocity Proxies)[4,5]	Deposition vs. Scouring Proxy[5]	Consequence Rating (Vulnerability Proxies)[4,5]	Risk Rating[3,4,5,6,7]	Comments
From KP (km)	To KP (km)	Distance (km)												
24.8	24.9	0.1	***Debris Slide***	✓	✓	Small	Moderate	Very Low	High	Low	Low	Very Low	Very Low	Road has been moved away from slope north of 24.9, but slides are small and unlikely to create significant hazards
			Gully Erosion	✓										
25.5	26.6	1.1	***Debris Slide***		✓	Small	Moderate	Very Low	High	Low	High	Moderate	Moderate	2 at KP25.8 unlikely to affect road; 1 at KP25.6 could possibly affect road, although latter may be a gully - hard to tell on photos
			Gully Erosion	✓	✓									
26.2	26.3	0.1	***Debris Flow***	✓	✓	Medium	Moderate	Low	High	Moderate	High	High	High	Debris flow of moderate likelihood and high consequence. A sinuous ridge of debris above road is of unknown origin. It appears to have directed water flow across the road in the past, scouring out the area below the road and a forming a small depositional fan adjacent to the river. Uncertain if debris flows have formed above road or not. Mapped as debris flow to be conservative. Difficult to tell size of individual events as this is a fairly old feature.
27.2	27.4	0.2	***Debris Slide or Flow***	✓	✓	Medium	High	Low	High	Moderate	High	High	Very High	Medium-sized debris slide or debris flow crossed alignment at gully in 1994; to be spanned with bridge
			Rockslide	✓		Medium	High	Low	High	Moderate	Low	Low	Moderate	Recent activity, but does not reach road
			Rockfall		✓									
			Gully Erosion	✓	✓									To be spanned with bridge
27.5	28.0	0.5	***Rockslide***		✓	Small	Moderate	Very Low	High	Low	Low	Very Low	Very Low	Small slides from 1949 immediately below road
			Gully Erosion	✓	✓									
28.1	28.4	0.3	***Rockfall***	✓		Small	High	Very Low	High	Low	High	Moderate	High	Re-route to south side of river: Minor activity in limited areas in 1994 and 2012; shaded in 1949 so unable to determine activity level at that time
29.0	29.2	0.2	***Debris Flow***	✓		Medium	High	Low	High	Moderate	Low	Low	Moderate	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	Low	High	Moderate	Low	Low	Low	Old rockslides appear to have developed into debris flows at lower elevations
30.6	30.8	0.2	***Debris Flow***	✓		Medium	High	Low	High	Moderate	Low	Low	Moderate	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	Low	High	Moderate	Low	Low	Moderate	Recent rockslide at KP31 reaches road, older slide crosses it
			Rockfall	✓										Rockfalls from 1949
31.2	31.8	0.6	***Debris Flow***	✓		Medium	High	Low	High	Moderate	Low	Low	Moderate	2 colluvial cones with recent activity reaching or crossing road, potential for major scour at ~KP031.2, rest of section is deposition. Recent debris flow activity crosses 50 m of road. Pre-1949 activity crosses about 80 m of road.
			Rockslide	✓	✓									
32.2	32.5	0.3	***Debris Flow***	✓		Medium	Low	Low	High	Moderate	Low	Low	Very Low	Debris flows from 1949 and 1994, do not reach road, but fan crosses road
32.5	36.2	3.7	***Rockfall***	✓		Medium	High	Low	High	Moderate	Low	Low	Moderate	Majority are from 1949 photos, but plenty of evidence of recent activity
			Rockslide	✓										
36.7	37.2	0.5	***Gully Erosion***	✓		Medium	Moderate	Low	Moderate	Low	Low	Very Low	Very Low	Gullies at edge of polygon with soil creep at higher elevation, does not affect road
			Rockfall	✓										
37.2	37.8	0.6	***Rockfall***	✓		Small	High	Very Low	High	Low	Low	Very Low	Low	Several rockfalls on 1994 photos
37.8	38.7	0.9	***Rockfall***	✓		Large	Low	Moderate	High	High	Low	Moderate	Low	Rockfall from 1949 covered in vegetation at the toe
40.2	41.4	1.2	***Lateral Spread in Surficial Material***	✓	✓	Very Large	Low	High	Moderate	High	Low	Moderate	Low	Road crosses lateral spread with no evidence of movement since 1949
			Gully Erosion	✓	✓									
41.9	42.0	0.1	***Gully Erosion***	✓	✓	Small	Moderate	Very Low	Moderate	Very Low	Low	Extremely Low	Extremely Low	
42.9	43.3	0.4	***Lateral Spread in Surficial Material***		✓	Large	Low	Moderate	Moderate	Moderate	High	High	Moderate	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	Moderate	Low	Low	Low	Very Low	Extremely 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	Moderate	High	Moderate	High	Low	Moderate	Moderate	Two large slumps in glaciofluvial material, likely very old, road skirts bottom of slides. Possible undermining along creek below road in a few short sections.
			Gully Erosion	✓										
49.7	50.0	0.3	***Debris Slide***	✓	✓	Large	Moderate	Moderate	High	High	High	Very High	Very High	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	Low	Moderate	Low	High	Moderate	High	Thaw flow slide from 2012 nearby, but offset 100 m from road at closest point; 125 m from road if retrogression is uphill only

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From KP (km)	To KP (km)	Distance (km)												
54.5	57.6	3.1	***Slump in Surficial Material***	✓		Very Large	Moderate	High	Moderate	High	Low	Moderate	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	Low	High	Moderate	High	High	High	Route crosses a few older slides visible in 1949 photos
61.4	61.5	0.1	***Gully Erosion***		✓	Medium	Moderate	Low	Moderate	Low	High	Moderate	Moderate	Road traverses upper edge of this sizable gully
67.9	72.0	4.1	***Slump in Surficial Material or Bedrock***		✓	Large	Moderate	Moderate	Low	Low	Low	Very Low	Very Low	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***		✓	Large	Moderate	Moderate	Low	Low	Low	Very Low	Very Low	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***		✓	Large	Moderate	Moderate	Low	Low	Low	Very Low	Very Low	Route passes between older slump features in surficial sediments (or possibly slumps in soft bedrock)
83.5	85.5	2.0	***Debris Slide***		✓	Medium	Moderate	Low	High	Moderate	High	High	High	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	High	Moderate	High	Low	Moderate	Low	Road avoids most of lateral spread
			Debris Slide		✓	Large	Moderate	Moderate	High	High	Low	Moderate	Moderate	Road crosses toe of older debris slide
88.0	89.5	1.5	***Lateral Spread in Surficial Material***	✓		Very Large	Low	High	Moderate	High	Low	Moderate	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***	✓	✓	Medium	Moderate	Low	Low	Very Low	Low	Extremely Low	Extremely Low	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	High	Moderate	High	High	Very High	High	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	✓	✓									Abundant gullies
101.7	102.0	0.3	***Rockfall***	✓		Medium	Moderate	Low	High	Moderate	Low	Low	Low	Rockfall on 1949 air photos
Alternative Route														
103.5	108.5	5.0	***Rockfall***	✓	✓	Medium	Moderate	Low	High	Moderate	Low	Low	Low	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	Low	Low	Very Low	Low	Extremely Low	Very Low	Road crosses area with small amount of recent soil creep in permafrost, although soil creep polygon is very large,likely only the portion along the road would affect the road
111.8	113.1	1.3	***Debris Flow***	✓	✓	Large	Moderate	Moderate	High	High	Low	Moderate	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	Low	High	Moderate	Low	Low	Low	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	Moderate	Very Low	High	Low	Low	Very Low	Very Low	Alternate route passes along base of rockfall area to avoid river floodplain
Original Route														
109.0	109.2	0.2	***Gully Erosion***	✓	✓	Small	Moderate	Very Low	Moderate	Very Low	High	Low	Low	2 gullies intersect the road
109.9	110.2	0.3	***Rockfall***	✓		Medium	Moderate	Low	High	Moderate	Low	Low	Low	Re-route has shifted road back from rockfall area
110.2	115.1	4.9	***Gully Erosion***	✓	✓	Medium	Moderate	Low	Moderate	Low	High	Moderate	Moderate	Several gullies intersect road alignment
115.5	115.7	0.2	***Rockfall***	✓		Medium	Moderate	Low	High	Moderate	Low	Low	Low	Road crosses toe of older rockfall/rock slide area; scars visible on 1962 photos
116.5	116.9	0.4	***Gully Erosion***	✓	✓	Small	Low	Very Low	Moderate	Very Low	Low	Extremely Low	Negligible	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 Low	High	Low	Low	Very Low	Very Low	Very small slide, short slope; likely to have have little effect on road
129.0	129.1	0.1	***Gully Erosion***	✓	✓	Small	Moderate	Very Low	Moderate	Very Low	Low	Extremely Low	Extremely Low	Gully erosion peters out at road, but still quite wet in 1949 photos
135.9	136.0	0.1	***Gully Erosion***	✓	✓	Small	Moderate	Very Low	Moderate	Very Low	Low	Extremely Low	Extremely Low	Inactive in 1971 photos, snow covered in 1949 and activity level uncertain due to poor quality 1949 photo

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Proposed Route Location			Geohazards (Geomorphic Processes)[1]	Upslope Hazard	Downslope Hazard	Magnitude Rating[2,3]	Hazard (Likelihood) Rating[2,3]	Magnitude Proxy Rating[4,5]	Velocity Proxy Rating[5]	Vulnerability Estimate (Magnitude & Velocity Proxies)[4,5]	Deposition vs. Scouring Proxy[5]	Consequence Rating (Vulnerability Proxies)[4,5]	Risk Rating[3,4,5,6,7]	Comments
From KP (km)	To KP (km)	Distance (km)												
136.4	137.3	0.9	***Debris Slide***	✓	✓	Large	Low	Moderate	High	High	High	Very High	High	Large debris slides in this section. 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. Features assigned a "low" frequency, but potentially could have a "moderate" frequency, due to the difficulty in distinguishing features on both sets of photos.
139.0	139.1	0.1	***Gully Erosion***	✓	✓	Small	Moderate	Very Low	Moderate	Very Low	Low	Extremely Low	Extremely Low	Inactive but wet in 1949 and 1982
139.7	139.8	0.1	***Debris Slide***		✓	Small	Moderate	Very Low	High	Low	Low	Very Low	Very Low	Very small slide, short slope; unlikely to affect road
140.6	140.9	0.3	***Debris Slide***	✓	✓	Small	Moderate	Very Low	High	Low	Low	Very Low	Very Low	Very small slides, short slopes; not large enough or close enough to affect road
143.9	144.0	0.1	***Gully Erosion***	✓	✓	Small	Moderate	Very Low	Moderate	Very Low	Low	Extremely Low	Extremely Low	Stream in drains lake, expect ongoing but minimal erosion
146.3	146.4	0.1	***Gully Erosion***	✓	✓	Small	Moderate	Very Low	Moderate	Very Low	Low	Extremely Low	Extremely Low	Road crosses drainage path in flattest part; gullying unlikely to affect road
148.0	148.1	0.1	***Gully Erosion***	✓		Small	Moderate	Very Low	Moderate	Very Low	Low	Extremely Low	Extremely Low	Very small and inactive but wet in 1949
151.2	154.5	3.3	***Gully Erosion***	✓	✓	Small	Moderate	Very Low	Moderate	Very Low	High	Low	Low	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	High	Moderate	High	High	Very High	High	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	High	Moderate	High	High	Very High	High	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	Low	High	Moderate	High	High	Very 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 hazard likelihood (encounter probability) classes are provided in Tables 2.1 and 2.2 of the memo
[4]Applied as partial proxy for consequence (vulnerability), as shown in Tables 2.2, 2.3, and 2.4 of the memo.
[5]Discussion and definitions of consequence and vulnerability classes are provided in Tables 2.3 and 2.4 of the memo. Resulting risk classes are shown in Table 2.5.
[6]Risk is the product of hazard likelihood and consequence. Definitions of hazard (likelihood) and consequence (vulnerability) classes are provided in Tables 2.1 and 2.4 of the memo. Resulting risk classes are shown in Table 2.5.
[7]Risk tolerance is not addressed in the risk matrix, but should be recognized as a necessary component in making land management decisions.

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.