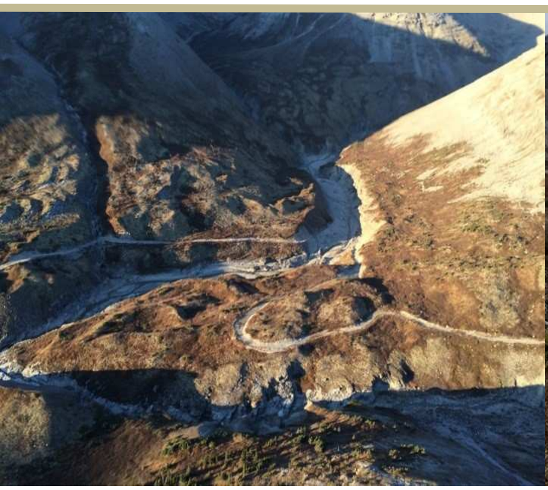
TETRA TECH EBA

Mapping Summary Report
Proposed Prairie Creek Mine All-Season Road
Northwest Territories



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

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EXECUTIVE SUMMARY

Tetra Tech EBA Inc. (Tetra Tech EBA) completed a geotechnical evaluation report in March 2015 in support of an engineering design and environmental assessment process for a proposed all-season road from Northwest Territories Highway 7 near Nahanni Butte to the Prairie Creek Mine (Tetra Tech EBA 2015a). Our geotechnical report was part of Canadian Zinc Corporation's (CZN's) Developer's Assessment Report (DAR), submitted to the Mackenzie Valley Environmental Impact Review Board (MVEIRB). Following an adequacy review of the DAR, CZN authorized terrain stability mapping (TSM) and air photo interpretation of the route. A description of the route, TSM findings and routing decisions made are provided in this report.

The mapping program has allowed the project team to confirm and/or refine the previous observations along the proposed road route. Numerous relatively minor realignments have been recommended to avoid or reduce contact with specific terrain features which might impact the road, or which could be sensitive to the effects of the road. Many of these realignments take advantage of better terrain nearby to reduce terrain-related risks and/or maintenance efforts. Mitigations are also proposed in some road sections in addition to the realignments. A few realignments are more significant where additional terrain hazards were identified. In some cases, realignments were not possible due to issues related to terrain obstacles or road grades, and in these cases, other mitigations have been proposed. In one case, there is more than one realignment option, and the selected option should be based on further investigation during the detailed design process. There are also cases where site-specific slope stability evaluations will be needed to fine-tune the requirements for the proposed mitigations. The intent of the realignments and mitigations is to allow the road to be built and maintained with an acceptable level of risk to users, the environment, and the road itself.

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DEFINITIONS

Active layer	The upper layer of soil that thaws and freezes every year. Does not always extend to the permafrost table in discontinuous permafrost. Active layer thickness depends on average air temperature, type of soil (coarse- or fine-grained), thickness of peat at ground surface, slope aspect, vegetation, etc.
Detachment slide	A type of slope failure that happens when the active layer detaches from the permafrost and slides downslope. Such slides can result from high air temperatures, rainfall events, rapid snowmelt, or surface disturbances.
Discontinuous permafrost	Permafrost that has unfrozen zones around or in it.
Frost-stable	Soils that do not settle or heave when subjected to thawing or freezing. Granular soils like sand or gravel are frost-stable if they have less than 10% silt and clay.
Frost-susceptible	Soils that will settle or heave when subjected to thawing or freezing. Silts are highly frost-susceptible, clays are also frost-susceptible but less so than silts. Sands and gravels can be frost-susceptible if they have more than 10% silt and clay.
Head Scarp	The exposed soil face at the upper edge of a slope failure, often near-vertical.
Ice-rich	Permafrost that is more than 100% saturated and/or has visible ice will lose its strength and settle or flow if it thaws. Fine-grained soils are usually more likely to be ice-rich. Ice-rich soils, even if they stay frozen, can creep and deform under very small loads. See also thaw-sensitive.
Karst	Karst topography is landscape formed from the dissolution of soluble rocks, primarily limestone and dolomite in this region. Features include sinkholes, caves, towers, arches, canyons, pavements, corridors, springs and sinking streams.
Patterned ground	Geometric patterns at ground surface, including circles, polygons, and stripes that show the sorting of fine-grained or coarse-grained soils and/or the presence of ice wedges in the soil.
Permafrost	Ground (soil or rock and including ice or organic material) that remains at or below 0°C for at least two consecutive years.
Permafrost table	Top of the permafrost.
Polje	A karst terrain feature with a flat bottom and steep walls, and no obvious outflowing surface stream, sometimes water-filled forming a lake, and sometimes drained. Polje is another name for a major sinkhole. Poljes can have smaller sinkholes on the bottom that are visible when the water is low.
Retrogressive thaw slump/flow	A type of slope instability triggered by permafrost thaw. Compared to slides, slumps and especially flows tend to happen when the moisture contents are higher in the failed soil. If the headscarp keeps failing and advancing upslope, making the failure larger, then it is a retrogressive failure.
Sinkhole (also known as Doline)	Sinkholes are common in karst terrain. They can result from suffosion (see below), collapsed caves (collapse sinkholes), or when the underlying carbonate bedrock dissolves unevenly and creates dish-shaped depressions (solution sinkholes). Sinkholes can be shaped like bowls, funnels, or cylinders; or they can be irregularly-shaped, depending on the cause. Sinkholes can range in size from 1 m to over 1000 m in diameter or length. Sinkholes often occur in lines or groups, and can be water-filled.
Suffosion	The process by which most sinkholes form. In suffosion, water seepage or flow causes underground leaching, piping, and erosion of soils or rocks, where the eroded material is washed into fissures and joints in the limestone or dolomite bedrock into caves below. The resulting material loss material can cause settlement at ground surface and create conical depressions and sinkholes in the landscape. Suffosion sinkholes can be only 1-5 m across, but suffosion can also enlarge other sinkhole types.
Talik	Layer of unfrozen soil, sometimes between the active layer and the permafrost, and sometimes under or beside a water body (river or lake). Taliks can include other unfrozen zones between patches or zones of permafrost in discontinuous permafrost.
Thaw-sensitive	Soil, often fine-grained, permafrost that has an ice content high enough that it will lose its strength and settle significantly or even flow if it thaws. Seasonally-frozen materials can also be thaw-sensitive if they have a high enough moisture content. See also ice-rich.

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 D of this report.

1.0 INTRODUCTION

Tetra Tech EBA Inc. (Tetra Tech EBA) completed a geotechnical evaluation report in March 2015 in support of an engineering design and environmental assessment process for a proposed all-season road from Northwest Territories Highway 7 near Nahanni Butte to the Prairie Creek Mine (Tetra Tech EBA 2015a). Our geotechnical report was part of Canadian Zinc Corporation's (CZN's) Developer's Assessment Report (DAR), submitted to the Mackenzie Valley Environmental Impact Review Board (MVEIRB).

Following an adequacy review (AR) of the DAR dated May 22, 2015, CZN requested Tetra Tech EBA to provide supplementary terrain mapping and air photo review information, as well as enhance the presentation of existing data in graphical form. The latter was presented in September 2015 as an addendum and progress report (Tetra Tech EBA 2015b). Several sets of maps were completed for that report, including slope gradient and slope aspect for the route and surficial geology and geomorphology for the portion of the route where existing mapping was available. Terrain stability mapping progress and results at that time, including maps, were reported for the sections of the route identified as "high-risk" in Tetra Tech EBA's March 2015 report.

Terrain stability mapping (TSM) and air photo interpretation has now been completed as follows for:

- Sections of the route identified as "high-risk";
- The original route and a proposed alternative alignment between KP103 and KP124;
- The route from KP0 to KP064, as there was no previous mapping available for that section of the route;
- Areas of concern identified as "moderate-risk" in Tetra Tech EBA's March 2015 report (2015a), noting that these portions of the route were mapped previously at 1:50,000 scale (Rutter and Boydell 1981). These include portions of the route between KP084 and KP102, KP124 and KP126, KP133 and KP138, and KP150 and KP159.

A description of the route, TSM findings and routing decisions made are provided herein.

Section 2 of the report below summarizes the tasks undertaken for the 2015 mapping program. Sections 3, 4 and 5 outline the findings of the 2015 mapping program and, for the convenience of the reader, also summarize the proposed realignments and/or other mitigations for the applicable route sections along with the relevant description of that part of the route. These sections refer to the terrain stability maps included Appendix A of the report. Appendix B provides a legend for the mapping, and Appendix C shows the locations and dates of the air photos used in the work and referred to in the text. Section 6 is an overall summary of the recommendations and considerations. Section 6.2 summarizes the overall findings along with the typical mitigations for specific types of findings. Finally, a table summarizing those mitigations, including realignments if/where applicable is presented in Section 6.3.

2.0 TERRAIN STABILITY MAPPING, HISTORICAL AIR PHOTO REVIEW

2.1 General Mapping Description and Tasks

As requested in the AR, Tetra Tech EBA has reviewed the availability of additional air photos for the route to assess the possibility of historical review in addition to the 1994 through 2014 data that had been used previously. Most of the pre-1994 coverage is very high-level coverage, at scales of 1:40,000 to 1:60,000. Coverage at 1:20,000 is available in some areas of the route and, rarely, coverage at 1:7,000 to 1:15,000 scale is available in very limited areas. Tetra Tech EBA is using a technology-intensive mapping method in order to efficiently use the higher-level coverage and to create scalable models of the air photo data for analysis.

In permafrost regions, TSM is a synthesis of the slope gradient, slope aspect, surficial geology, geomorphology, drainage pattern and permafrost information that can be gleaned from air photo analysis. It provides additional insight into the terrain types and conditions that may be encountered along the route and the potential for terrain instabilities to occur in particular areas. The terrain stability maps produced for this report are presented in Appendix A.

2.2 Methods

Air photos were acquired from the National Air Photo Library (NAPL) of Canada in Ottawa. The photo and roll number of air photos acquired are given in Appendix B.

Upon receipt of the high-resolution digital air photo images from NAPL, the photos were sent to a contractor for georeferencing and aerial triangulation. Available hard copy air photos from CZN were scanned at 15 micron resolution and similarly georeferenced and triangulated. The photo images and georeferencing files (models) were then loaded into PurVIEW. PurVIEW is an add-on software to ArcGIS that allows the mapper to not only view the photos in 3D on a computer screen, but also to zoom in and out to delineate otherwise difficult-to-identify features with greater accuracy than would be possible with a standard stereoscope and hard copy air photos. LiDAR data provided by CZN (acquired in 2012) was rendered as a bare-earth image and was referenced as well. The slope gradient and aspect maps, presented in Appendices A and B of the September 2015 report (Tetra Tech EBA 2015b), were used to guide the TSM in the mapping areas.

Mapping was carried out by Shirley McCuaig, Ph.D., P.Geo., in accordance with the guidelines set out by Howes and Kenk (1997), Resources Inventory Committee (RIC 1996) and British Columbia Ministry of Forests, Lands and Natural Resource Operations (BCMF 1999). TSM was completed at 1:20,000 scale, with helicopter reconnaissance and ground spot checks, resulting in a Terrain Survey Intensity Level (TSIL) of D (BCMF 1999). For TSIL D, stable areas are not required to be mapped. However, the surficial geology of these areas has been mapped as per the requirements outlined in the AR. If there is no P or U indicating Potentially Unstable or Unstable within a polygon, then the polygon is interpreted to be stable. A numerical range of the dominant slope gradients within a polygon is listed for all polygons labelled P or U.

The AR requested that photos from different years be examined to determine activity levels of certain geohazards, and also requested that channel meanders and avulsions be mapped. These are not a requirement for standard TSM according to Howes and Kenk (1997), but are considered a useful mapping addition in BCMF (1999). As snow avalanche studies have already been done by others (ASAS 2012), avalanche tracks are not mapped for this study.

The post-1994 stream positions were mapped where/as needed from the bare-earth LiDAR image. There are limitations to this method of mapping because one cannot tell exactly where a stream is within its floodplain from LiDAR data, which just shows a flat area where it could be. Also, in some places, the LiDAR data is insufficient to map from. In these areas, the river positions are discontinuous as only the areas where the data is appropriate for interpretation purposes were mapped.

The AR also requested that the mapping review the history of slide areas along the existing road. This can be done insofar as the features mapped from the air photos can be compared against present-day features. In some cases, new features have appeared since the most recent set of stereo air photo coverage, and are observed on the LiDAR and/or from the 2014/2015 field observations. In other cases, older features are obscured over time, sometimes due to vegetation regrowth and sometimes due to a different soil process occurring. On occasion, little or no change is observable. Applicable commentary is provided in the discussions in this report.

Field checking was completed by Shirley McCuaig on July 7 and 8, 2015 in accordance with the requirement for the mapper to complete fieldwork (RIC 1999). Additional information was incorporated to help confirm the mapping, including fieldwork completed by and field photos taken by Rita Kors-Olthof, P.Eng., P.E., and by Allnorth Consultants Ltd. (Allnorth) in 2014. These studies are considered Terrain Stability Field Assessments (TSFAs) and are part of the field-checking requirement for this report. This information, along with available testpit and borehole information, was added to ArcGIS for reference while mapping. The resulting number of field checks was sixty-five, giving a final amount of 8.7% of the 743 polygons mapped having been checked (TSIL D). Several checks in one polygon count as one check per polygon since only one polygon was confirmed, for example, where a field traverse on foot was carried out within a single polygon.

Mapping was checked against available field data. Field data included photographs and field data from the 2014 and July 7-8, 2015 site visits, Tetra Tech EBA borehole logs, testpits and laboratory test results, SNC-Lavalin borehole logs, Allnorth field photos and Allnorth sieve analyses.

2.3 Mapping Results

The results of the mapping are given in the maps provided in Appendix A. Different coloured symbols are used to represent features that are visible in different years. The colour represents the flight year of the photographs in which the feature was first visible. Gullies are an exception to this rule. They are visible in 1949 and 1994 but are given a black colour to allow differentiation from landslides.

The extent of landslide features is shown by mapped polygons outlining the colluvial area. Runout zone lengths are indicated by the length of the landslide scar arrows. For areas previously mapped, only those features not identified on the 1:50,000 scale mapping (Rutter and Boydell 1981) are mapped as new units (for example, the KP128 to KP159 area), and only those that may affect terrain stability are mapped.

Areas considered unstable or potentially unstable are mapped with the label U or P (in line with the Howes and Kenk (1997) style of mapping), but they are also given colours to make them stand out from the areas considered to be stable.

3.0 ROAD SECTIONS DESIGNATED “HIGH-RISK”

3.1 General

TSM has been carried out for the areas identified as “high-risk” in the previous work, as noted above. These priority mapping areas are located along the Polje re-route and a short section along the east side of Silent Hills and include several different types of slope instabilities. Air photos produced in 1949, 1963, 1982, 1983 and 1994 were analyzed for these areas. The resulting terrain stability maps are provided in Appendix A.

The general features of the three high-risk areas plus additional findings based on the historical photo review are described in the following sections.

3.2 KP048.8 to KP051 (West End of Polje Re-Route)

The valley in this area is about 1 km wide, but tributary valleys are present on the northwestern side of the route (Figure A08 in Appendix A). A tributary of Polje Creek meanders across its entire floodplain, locally eroding the valley slope sediments at its outer bends.

3.2.1 Mass Movement

Colluvium forms stepped topography that is clearly visible on the air photos on both sides of the valley. The mapping was expanded to cover the entirety of these two areas. The stepped features are better developed on the slopes southeast of the road alignment and creek and a couple of small slides have developed within the larger failures there. On the northwestern slopes, the slide blocks appear more like small individual knolls. The slide blocks appear to be developed in glaciofluvial terrace material.

Movement appears to be mostly translational on the southeastern slopes. Similar failures with larger and more discontinuous slide blocks are evident in the tributary valleys to the northwest. Some of the slides in the northwestern tributary valleys may be rotational, as a number of slide blocks form arcuate ridges.

All of the rotational slides are generally failing toward the centre of the tributary valleys and thus do not affect the main valley at present. However, some of the failures on the higher, southeastern-facing slopes have formed steep head scarps from which debris slides appear to have formed in the past. A few of these have long runout zones (Figure A08). Debris slides entering the creeks could potentially lead to debris flows/floods in these two tributary valleys. One of the steep scarps northwest of KP050.4 is covered with slide material that forms a hummocky terrace 20 m above the tributary valley floor. Reactivation of this slide would likely result in rapid movement as there is no supporting slide block material below it. The slide would affect only the upper part of the tributary valley but could lead to debris flows/floods in the tributary creek. Although there is no obvious evidence of former debris flows/floods in this small valley, the creek in this location has built out a fluvial fan that is more than three times larger than its counterpart draining the tributary valley to the south. However, its greater size could be due simply to the larger size of its watershed.

The historical air photo review for this area includes air photos from 1949 and 1994. From these photos, it is evident that most of the slides in the area were already established in 1949. The large translational and rotational slides had not moved between 1949 and 1994, so it appears they are not slow-moving failures but rather that they represent rapid failures that occurred and reached equilibrium at some point in the past, most likely shortly after deglaciation. Individual slide blocks were mapped for both years to compare movement, but these are not shown as they cause congestion on the map (Figure A08). The slide blocks of the rotational slides northwest of the proposed alignment show no changes over the 45-year time span. The translational slide blocks of the slide southeast of the Polje Creek tributary similarly did not move, but several of the blocks visible in 1949 are obscured by slope material in the 1994 photos. The obscuring of the slide blocks is interpreted to be evidence of creep on this slope. It is a northwest- to north-facing slope with numerous northwest-facing aspects (see slope aspect map between KP048.6 and KP050.5); therefore, it likely contains permafrost, with soil creep occurring within the active layer (caused by downslope movement of suprapermafrost water[1]). Although creep may also be happening on the few north-facing slopes present northwest of the alignment, it is not obvious on the photos. However, these areas are mapped as being affected by permafrost (-X) because they are similarly north- to northwest-facing. Creep on wet northwest-facing slopes shows that the potential north aspects underlain by permafrost include the northwest aspect.

Northwest- to northeast-facing slopes displaying seepage and organic cover are assumed to contain permafrost for the rest of the mapping areas. These slopes are mapped as Potentially Unstable (P) and are given a –X geomorphic process for the polygon label.

Several small debris slides, including the active one south of TFSA Site 29, have formed by riverbank erosion near KP050. A few small debris slides are new features on the 1994 photos (Figure A08). Two of these are caused by river bank erosion. The slide at KP050.5 is fresh looking in both sets of air photos, but it had widened slightly by 1994. The small slide feature adjacent to the newer head scarp (south of KP050.7) is an old slide that is covered with vegetation in both the 1949 and the 1994 photos. The proposed road’s closest points to the debris slide head scarps are 9 m and 17 m from the scarp edges. Moving the proposed alignment further northwest as shown in Figure A08 will allow the road to avoid this area. Grades do not allow the road to avoid an old debris slide at KP049.8, so debris slide mitigation will be required across the slide area. A slope stability evaluation will be needed

[1] Water occurring in unfrozen zones above perennially frozen ground

to determine the most suitable mitigation methods for this location. Possible mitigations could include modified cut and fill designs, buttressing of cut slopes and/or fill slopes, and/or installation of additional cross-drainage measures.

A post-1994 slide south of KP49 visible on the 2012 LiDAR image was confirmed by fieldwork in 2014 (Figure A08). This slide was initiated by toe removal in two locations caused by creek flow. It is a translational slide in glaciofluvial sand and its toe extends across the former river location. Tension cracks visible above the slide indicate that it will continue to fail in the future, which is consistent with ongoing removal of the sandy toe deposits by the creek. The proposed road is not affected by this slide.

The fieldwork results show that seepage is common on the slopes covered with colluvium, at least on the northwestern side of the valley. No direct evidence of permafrost is visible on the air photos (e.g. patterned ground, solifluction lobes, etc.). The boreholes and test pits on the slopes in this area reach a maximum of 1.2 m, so permafrost potentially could be present at greater depths, which may provide a barrier to downward water infiltration. However, seepage could also be caused by drainage disruptions caused by the failures. As mentioned above, north aspect slopes are assumed to contain permafrost.

Permafrost is also likely present in valley bottoms within poorly-drained river floodplains and terraces where covered by moderately dense to sparse stunted black spruce stands with thick moss and poorly-decomposed organic material cover.

Where permafrost is present, climate change could have the potential to reactivate or accelerate the movement of the large slides. It is recommended that where northwest-, north-, and northeast-facing aspects are to be crossed, determination of the depth to permafrost be undertaken during the detailed design phase.

Gullies are developed locally in areas of water flow concentration. Only one of these affects the road. It is located at KP049.9, between two old debris slides. As it is not within a slide area, standard culvert options for steep slopes should be sufficient. There are no new gullies in the 1994 photos.

3.2.2 Channel Morphology and Stability

The Polje Creek tributary forms a generally single irregularly-sinuous channel adjacent to KP049 to KP051. Its position has changed little between 1949 and 2012[2] (the date of the LiDAR data). Outer bend positions moved outward or laterally 8 to 30 m in this time frame. Additional air photos from 1983 were obtained for this area so that the creek's relationship to the slides could be determined.

At the slide locations, the outer bends have eroded 8 to 26 m further into the banks. This has initiated the post-1994 slide south of KP49 and the slide at KP49.9, and has expanded the slide at KP50.5. The 1983 photos show that the expansion of the latter slide occurred sometime before 1983. The position of the creek in 1983 has been added at this location on Figure A08. Outer bank erosion is evidently the cause of the debris slide at this location. If the maximum erosion of 26 m over the time interval of 45 years is selected, then bank erosion is occurring at a rate of approximately 58 cm per year. This rate is not linear, but episodic, with expansion occurring mainly in flood years. This means that the amount of erosion could be much larger than 58 cm in flood years, with little or no erosion occurring in other years.

[2] Note that the CanVec topographic data position of the creek is inaccurate for all channel morphology mapping (dark blue line) and therefore should be ignored.

3.3 KP053.5 to KP059.9 (East End of Polje Re-Route)

3.3.1 Mass Movement

The mapping for this road section is shown on Figure A09. The older air photos for this area were also produced in 1949. These photos cover a larger area than the 1994 ones, which allows the map area to be completely mapped, and also allows the mapper to zoom out and get an overview of the glacial deposits as they relate to bedrock.

The terrain stability mapping shows that glaciofluvial terraces are present between KP053.7 and KP060.5. They have failed at the terrace margins, likely due to glacier ice melt upon deglaciation, but also due locally to riverbank erosion and karst effects. The depressions on the surface of the glaciofluvial terrace units are thus likely kettles and not karst features. Golder mapped the larger feature just northwest of KP059 as a sinkhole (Figure A09, and Golder 2010 Figure II-2), but there is the distinct possibility that it is a kettle. This feature should be monitored, as recommended by Golder, to track any changes, specifically enlargement.

Almost all of the slides identified were visible in 1949. Some areas, such as the steep colluvium within a meltwater channel northeast of KP057, show active slides both in 1949 and 1994. The only difference in slide activity between the two years is the presence of several fresh but thin debris slides south of KP58 to KP59. These appear to be related to a forest fire in this area.

From KP053.7 to KP054.2, permafrost processes are evident near the road alignment (Figure A09). A thaw slump/flow on a northwest-facing slope that was identified in the field is also evident on the LiDAR bare-earth image, but is not present on the 1994 air photos (Figure A09). Such slides generally retrogress (expand upslope) as freshly-exposed ice-rich permafrost thaws. However, the adjacent mapped polygon does not appear to have permafrost near the surface as tree growth is quite consistent there (and there is no seepage, which may be an indication of permafrost presence). If that is the case, then the slide could grow no more than about 50 m upslope and would not affect the proposed route alignment. However, this area should be probed for permafrost presence/depth to confirm.

At KP054.6 to KP054.9 and between KP055.6 and KP055.9, debris slides are present above the proposed alignment. One such slide crosses the route at KP054.7 to KP054.8. Slide mitigation measures (engineering and/or administrative controls) may be required in these locations. Administrative controls could include signage, personnel procedures and training, inspection and maintenance schedules, and notification and reporting protocols. If administrative controls are used, road repairs may be more likely to be required after possible slide events. Moving the alignment westward at the slide crossing location may be advisable as well (location suggested in Figure A09). An alignment shift is suggested for KP055.6 and KP055.9 (Figure A09); however, this puts the road on the fluvial fan, which is not ideal. Engineering or administrative controls may be preferred at this location. A large alluvial fan is present south of the alignment between approximately KP055 and KP056.5. A possible karst depression or sinkhole near KP056, containing a pond, could be a thermokarst depression, but as there is no other evidence of permafrost on this south-facing slope, it is more likely a karst feature (Allnorth Photos SAM_6375 and 6376, Tetra Tech EBA Photos IMG_2010, 2014, and 2016). In its lower reaches, the alluvial fan is affected by karst processes occurring in the bedrock beneath it. These karst depressions are located about 230 m southwest of KP055.3 and 275 m south of KP055.7.

The route crosses slide material of low slope angles between KP055.9 and KP056.3 and between KP056.9 and KP057.3. The former is a large hummocky deposit formed by slides in bedrock. The latter are minor movements of surficial material down the slope. A slope stability evaluation will be needed to determine the most suitable mitigation methods for this location. Possible mitigations could include modified cut and fill designs, buttressing of cut slopes and/or fill slopes, and/or installation of additional cross-drainage measures. Between these two locations (KP056.4 to KP056.9) is some hummocky topography that also comprises older slide material. The road crosses through the centre of this material. An alignment that crosses the alluvial fan is not preferred because the fan is more likely to have ongoing debris flow/flood issues, whereas the hummocky slide material appears to have reached equilibrium at some point in the past. That material was present in the 1949 photos, does not have the appearance of a recent slide in those photos (e.g. unvegetated or less-vegetated surfaces), and there is no evidence of further movement in the 1994 photos. Specific attention to slope drainage is recommended to reduce the likelihood of concentrated water drainage in areas that have not historically received it. Most of these slide areas can be avoided with the route change suggestion shown on Figure A09. Confirmation of this route from a construction perspective will be determined during the detailed design phase.

The area from KP057.3 to KP059.9 has some terrain issues. The two poljes have affected the surficial sediments south of the proposed alignment. The continuing solution of the underlying bedrock has caused failures in the bedrock and consequently in the surficial sediments above it. These slide areas approach the alignment in the KP058 to KP059 area (10 m away from KP058 and 20 m away from KP058.7 at the closest points). Moving the route further north (Figure A09) in these locations would be prudent as more karst activity could lead to enlargement of these slides.

In general, large translational earth slides in glaciofluvial terrace material flank the southern and western sides of the glaciofluvial terrace. Later debris slides have reactivated smaller areas on the surface of these deposits where slopes are present. With the exception of the potentially fire-related debris slides/slumps as described in the geotechnical report (Tetra Tech EBA 2015a), including the above-mentioned KP054 thaw slump/flow, all of these slides were initiated prior to 1949 and may currently be in a state of relative equilibrium. However, reactivation is always a possibility, and thaw flow slides such as the recent one near KP054 are possible in areas underlain by permafrost, especially under a climate warming scenario. New debris slides may also be triggered by forest fire, but these are generally much smaller in size than the large translational slumps.

3.3.2 Channel Morphology and Stability

Polje Creek, immediately to the west of the area designated “high-risk” has a single meandering channel morphology within a wide floodplain. A number of old meander scars and two oxbow lakes are shown by the CanVec topographic data. Although the meander scars are not located accurately on the CanVec data, a general indication of their location and shape is given. The proposed alignment crosses the stream at a straight stretch, where movement between 1949 and 2012 indicates approximately 6 m of bank erosion in a southwest direction. This represents an erosion rate of less than 10 cm/year. The relative contribution from seasonal high water levels and/or periodic flooding to bank erosion is not known, but overall the erosion rate appears to be moderate. Because the floodplain is so wide, overbank flows could result in floodwater extending beyond the main bridge crossing, however, erosive effects would be expected to be significantly less than in the main channel, as can also be surmised from the well-treed nature of the floodplain.

The bank erosion at the toe of the thaw flow slide has actually lessened over the years in this location. The creek appears to have moved about 9 m to the southwest between 1949 and 2012. Therefore, toe erosion does not appear to be an important factor in slide initiation. There is an eroding bank about 300 m to the south within a similar unit. The creek’s path has moved very little over the years, only changing the position of the erosive outer portion of the creek in an east/west direction. The creek location could easily move to a more (or a less) erosive position in the future, or keep eroding the bank at its present location. This could potentially lead to instability of the slope above this location, but the proposed road alignment is well away from this area.

3.4 KP115 to KP116.5 (East Side of Silent Hills)

This area was thought to have the potential to be affected by debris flows from a gully (KP115.8) uphill of the alignment (Figure A18). A fresh rock face is evident on the north slope of the gully in both the 1963 and the 1982 air photos. Rockfall activity is therefore ongoing at this location. Rockfall material and surficial debris entering the gully could potentially create a debris flow where the road crosses the creek that drains the gully. However, despite the presence of the gully adjacent to the rock face and another downslope (east) of this location, there is no evidence that debris flows have formed in this location. The gullies appear to be water-formed, and landslides affecting the hills to the west do not reach the head of the gully adjacent to the rock face. It is possible that the rockfall activity may be minimal or produces large-enough material that does not get carried very far downstream.

All of the debris slides in this map area were evident in the 1963 air photos and no new activity is visible in the 1982 photos. Rockfall activity is evident on a bedrock ridge about 700 m south of KP116; it does not affect the proposed alignment. Two of the larger mass movements between KP116 and KP117 are also rockfalls. The smaller slide and the slides without head scarps are debris slides. There was no recent activity in either the 1963 or 1982 air photos in this location, but reactivation is always a possibility and would affect the road if it were to occur. Relocating the alignment further east (Figure A18) within the meltwater channel is advisable as this area remains unaffected by the slides.

A rockfall near KP115.5 is not obvious on the 1963 air photos, but this is suspected to be due to the poor quality of the photos for this area. A rockfall is readily visible in the 1982 photos. These photos show no new activity and the slope is the same shape as it was in 1963. The feature is, therefore, interpreted to be an older slide, although it is shown as being mapped from the 1982 air photos (Figure A18). Again, potential reactivation of the slide could affect the proposed road. Moving the road eastward into the stable till area would address this issue (Figure A18).

4.0 ROAD SECTIONS PREVIOUSLY UNMAPPED OR DESIGNATED “MODERATE-RISK”

4.1 KP0 to KP040

Air photos from 1949 and 1994 were analyzed for this portion of the route. LiDAR imagery and bare-earth LiDAR from 2012 were used as well. The entire area was mapped with modified TSM as there is no Geological Survey of Canada mapping available for this area. Therefore, although portions of this part of the route were designated “low-risk”, the entire section from KP000 to KP040 is discussed in this section.

Slide areas outside the mapping boundary were mapped if material from those slides could have possibly contributed material to the valley in which the road is located. This represented a significant amount of additional mapping for the proposed route. It was observed that many of the head scarps of slide areas are located within glacial cirques in the tributary valleys.

It should be noted that although there is potential for material to be contributed to the valleys containing the proposed road, the majority of mass movement material in the tributary valleys remains in its valley of origin. Any contribution of material to the larger valleys takes the form of debris flows and therefore is found mainly in fluvial fans. This observation from the air photo interpretation appears to be corroborated by CZN’s observation that slide activity along the route itself is characterized by frequent but limited rockfall. CZN noted that no significant slope failures had occurred during their tenure (report commentary: D.Harpley, R.Kors-Olthof; November 27, 2015). Not all slide locations were mapped, but rather a representative number of them. Slide activity appears to be ongoing over most of the area. Although the vast majority of slides were present in the 1949 photos, many remain active and unvegetated in the 1994 photos. Any new slide scars visible in 1994 were mapped to show new activity.

The first 17 km of the proposed road is located within the valleys of Prairie Creek and its tributaries, including a short reach of Fast Creek, and then primarily Funeral Creek on the climb to the mountain pass. On the east side of the pass, the road is within the Sundog Creek drainage to Cat Camp at KP040, crossing several tributaries along the way. Relief is over 700 m from river bottom to mountain peaks. Rockfalls and rock slides are typical in this type of terrain, and this area is no exception. The friable nature of the bedrock allows it to weather easily and break off to form colluvium on the mountain slopes. Rockfall at high elevations picks up material as it moves downslope and progresses to rock slide generation. In tributary valleys, rockfall may lead to the formation of debris flows when the material enters small creeks that drain the valleys. Most of the large colluvial cones are formed from a combination of rockfall and rock slide activity. Rockfall alone produces either colluvial veneers (thin covering of mass movement material) or thicker deposits that may cover the foot of a slope, resulting in a less-steep slope section. Debris flows are much less common. These form colluvial fans/cones or fluvial fans at the mouths of several tributary valleys.

The proposed road is already largely located in the valley bottoms, the preferred location in such mountainous terrain. There are a few non-colluvial deposits in the valley bottoms apart from the river floodplains, and the road generally follows these. It is not possible to avoid areas where mass movement is present as it is ubiquitous; therefore the road crosses a number of colluvial and fluvial fans. Mitigation consisting of engineering and/or administrative controls to protect the road and/or traffic from mass movement will likely be required in a number of areas.

A few areas of particular interest are highlighted below.

At KP000, some of the mine infrastructure rests on a fluvial fan that experiences both flooding and debris flow activity. At least one debris flow levee is visible on the 1994 air photos. A diversion channel has been constructed to manage this geohazard.

From KP000 to KP006, the route skirts along several colluvial fans (Figure A01). The fan at KP002 shows recent fan activity on the 1949 photos and by 1994 it has grown in areal extent and height, despite possibly having been used as borrow for the airstrip. This fan appears to be relatively active, and it is immediately adjacent to the road and the airstrip. Some protection for the road and airstrip may be advisable. The airstrip itself is on a fluvial terrace and thus is subject to flooding, although CZN reports that this has not occurred since construction (report commentary: D.Harpley, R.Kors-Olthof; December 1, 2015). A dyke constructed along the edge of the airstrip provides erosion protection.

In the 1994 photos, recent activity seen on the fan located between KP004.2 and KP004.6 is caused by fluvial aggradation and is small in size, but it does cross the road. The fan is adjacent to a terrace that that does not appear to be colluvial. This may be a remnant glaciofluvial terrace or possibly a remnant of a much larger fluvial fan. The terrace forms a natural barrier between the road and rockfall activity behind it. It is noted that this terrace has been proposed as a backup borrow area (BP 4B). If used for borrow, complete removal of the terrace is discouraged, so that the natural barrier can be retained. Prior to material being borrowed from this site, further evaluation may be required to assess the effects of material removal, and what volume can reasonably be removed without significantly increasing the risk to the road. Reactivation of the lower portion of a larger rockfall upslope is visible in the 1994 photos and on the LiDAR image at KP004.2. The toe of slope at the road in this location is similarly proposed as a backup borrow area (BP 4A), in conjunction with road widening, again potentially increasing the risk level at the road. Administrative controls are recommended for the rockfall area adjacent to the road. A need for debris flow mitigation and/or ongoing road maintenance/reconstruction should be anticipated due to potential future debris flow events on the fan.

At KP006.2, the route crosses the gently-sloping fan of a small tributary stream, Casket Creek (Figure A02). This fan was smaller in 1949. The current size of the fan was mapped from the bare-earth LiDAR image, which shows extension of the toe of the deposit by 13 to 25 m (to the west) compared to its 1949 extent, as well as another 22 m of growth on its northern side. The southern side (downstream in terms of Prairie Creek flow direction) has lost 22 m of material. This expansion represents normal aggradation of stream material and does not pose a problem for the road, except for the necessity of taking into account the potential for changing channel positions of the braided stream (shown on Figure A02) and potential thickening of sediments in bridge/culvert design. However, an extreme flood event could introduce stream material onto the road. Mitigations could include additional backup culverts and culverts staggered at different elevations. Maintenance could include cleanup of materials from the road in the event of a large flood. It is understood that a dyke may also be used to maintain the existing main channel location. At KP006, the new route is on a colluvial slope. The route cannot be moved onto the Prairie Creek floodplain for environmental reasons, so mitigation for rockfall is recommended as appropriate.

At about KP06.8, the road bends to the northeast to follow Fast Creek upstream, and after KP07.4, the road heads east, traversing up the Funeral Creek valley (Figure A02). Here it passes from fluvial terraces to small colluvial fans. These are much smaller than elsewhere and the valley bottom is the only logical location for the road. A colluvial terrace whose source area is the southern slope is crossed at KP008.4 to 008.5. There is no other possible location for the road here, so other mitigations may need to be considered. Since the feature has not been active since prior to 1949, administrative controls such as cleanup of intermittent rockfall/rockslide debris will likely suffice, with additional measures implemented if/as needed.

After KP012, the road crosses a few older colluvial deposits before crossing a tributary creek valley and making a switchback (Figures A02 and A03). The switchback between KP013 and KP014 crosses similar older colluvial material for which administrative controls will likely suffice, and then crosses till and weathered bedrock which appear stable. From KP13.7 to KP014.8, the route crosses colluvial deposits with a few slides that were unvegetated in 1994. Some of the more recent slides in those photos are immediately below the existing road; drainage from the road may have contributed to their recent activity. Rockfall mitigation is recommended for those areas where rockfall tracks cross the road. Such mitigation could include engineering and/or administrative controls. Improved cross-drainage is recommended for areas where newer activity is present below the road, so that surface water is not concentrated in areas that would not naturally receive concentrated water flows.

A colluvial cone complex surrounds the route at KP015 (Figure A03). These were unvegetated above and below the road in 1994. However, there is no other reasonable location for the road, so rockfall protection should be considered for this area. The switchback at KP016 is on a hummocky till deposit, which appears to be stable. Engineering and/or administrative controls should be considered for KP016.1 to KP016.9 as the rockfalls appear recently active in the 1994 photos and the 2012 LiDAR image. Some changes have been made to widen the switchback and reduce the grade but, otherwise, there is little room to make route changes in this area.

From KP017.7 to KP021, the road crosses a number of large colluvial cones showing recent activity in both sets of photos (Figures A03 and A04). Engineering and/or administrative controls may be required along this section. At KP019, the route passes by a large colluvial area, but the active portion of the colluvial cones is above the road in both photo years. Older slide paths and older cones with shallower slopes cross the road. Engineering and/or administrative controls may not be necessary here unless these features become more active.

At KP022.3, a slide path that does not cross the road in 1949 crosses it in 1994. Here, slide paths from both years are mapped. In addition, the slide material from the road to the creek appears fresher in the 1994 air photos. It may have been affected by drainage from the road. Drainage should be improved in this location and engineering and/or administrative controls provided. Drainage should also be improved at KP022.5 to KP022.6, where there is again apparently recent slide material below the road in the 1994 photos.

At KP023, the route crosses essentially stable glaciofluvial deposits until KP024.5 to KP024.6, where it crosses glaciofluvial sediments overlying bedrock that may be subject to karst activity. A possible suffosion hole was identified within these deposits at about KP025.6. Monitoring ground elevations in these areas may be warranted. Moving the road to a different location is not advisable due to the presence of abundant colluvium. A minor route change to the south is suggested near KP023 to keep the road away from the terrace slopes which have experienced several small debris slides in the past (Figure A04, area is too small to distinguish as a map polygon at this scale). These are still only semi-vegetated in the 1994 air photos, which suggests some ongoing movement. A minor move to the south for similar reasons is suggested at KP025 as well, but the road must cross a few of these slides to access the stream crossing, so a move is not suggested for KP025.2 to 025.3. Viability of the suggested route moves will be assessed during the detailed design phase.

At KP024 to KP024.3, colluvial material overtops the glaciofluvial terrace in two places (Figure A04). Above the colluvial material, a small rock glacier is present. Melting of ice in the rock glacier due to climate warming would likely lead to increased water flow on the portion of the colluvial deposit that is above KP024.2 to KP024.3. Reactivation of the slide is likely at this location. If that happens (most likely forming a debris slide), colluvial material would likely cross the road. Typical mitigations would initially include administrative controls such as caution signs, as well as inspection and reporting protocols to enhance road safety. Other mitigations could be implemented if/as needed, for example, if seasonal or other movements are observed.

At about KP027.2, a couple of erosion gullies cut across the proposed alignment (Figure A05). These are developed in a larger colluvial deposit. The route skirts around one gully, but a culvert will be required at the other. The latter has some colluvial material at its base; it appears to experience debris slides and possibly rockfall. In the 1994 photos, a narrow, unvegetated area appears to be a recent small debris slide that crosses the road. A crossing design that considers the unstable substrate will be necessary at this location.

The route has crossed other small gullies up to this point (KP25.5, KP26.4), but a standard culvert approach would be reasonable for these two gullies, as well as two other gullies at about KP027.5 that are formed in glaciofluvial sediments (Figure A05).

At KP028.3, four coalescing colluvial cones consisting of rockfall and rockslide material are traversed. These cones were cut during the winter road construction. Although the cones appear mostly inactive in the 1994 air photos, there is some recent activity evident on the LiDAR image from 2012 (Figure A05). As future rockfall/rockslide material is likely to cross the road, mitigation for these types of mass movement in the form of engineering or administrative controls is recommended.

The southeasternmost of the four cones (at KP028.7) experienced a debris slide that blocked the stream sometime before 1949, likely triggered by the creek eroding and undercutting the toe of the colluvial cone. This may be a somewhat unstable area as the stream appeared to still be cutting through the toe of the slide in 1994 and 2012, and a few small debris slides look fresh in the 1994 air photos. A route change suggestion is made on Figure A05, shifting the route slightly to the west and completing the river crossing slightly to the north, but erosion protection at the toe of the debris slide and mitigation above and below the proposed road are options as well. Suitable mitigations could involve buttressing the slope above and below the road across the width of the mapped slide block to reduce the likelihood of future movement of the debris slide. A slope stability analysis could be done during the detailed design phase to optimize design solutions, including optimizing road location and evaluating potential mitigation options. Avoidance of the reactivated slide area would require the bridge crossing to be about 50 m further north (upstream).

The colluvial cone at KP029.1 had an active portion in both sets of photos and on the LiDAR image (reaching the road at KP029.2). The road must cross this area as the creek is adjacent to the slide. Since the creek is also eroding the toe of this feature, this area could fail in the future in the same fashion as at KP028.7. Erosion protection may be required at this location.

At KP029.6 to KP029.8 and KP030.6 to KP030.8, fluvial fans that experience debris flows have to be crossed (Figure A05). Mitigation for debris flows may be needed at the first location as the fan has a large catchment area with plenty of colluvial activity. The creek is wide and doesn’t have obvious debris flow levees, but the bedload in the creek terraces contains large boulders, suggesting that debris flow is a geohazard along the creek. The creek is already well incised into its fan, so debris flow activity would be restricted to the creek area itself and the area up to 80 m to the north-northwest. The second location has a smaller catchment area but shows new activity and distinct debris flow lobes on the 1994 photos and the 2012 LiDAR image. There is a fresh channel on the 1994 photos, but it peters out before reaching the road. There is also a series of lobes that are older, as they are starting to revegetate but have not yet developed tree cover. The 1949 slide symbol is in the location where these lobes crossed the road sometime between 1949 and 1994, but at a time closer to 1994 as shown by the shrubby vegetation. Debris flow mitigation is suggested here as well. Moving the road to the other side of the valley is not desirable at either location as there are a number of active colluvial cones there.

Three colluvial cones are crossed between KP031.0 and KP031.8. The one closest to KP031 is small and showed recent activity in 2012. The other two (KP031.4 and 31.6) had active channels showing erosion into the fan apexes and deposition at their termini in both sets of air photos. New debris flow activity is visible on two of the fans on the 2012 LiDAR image (Figure A05). Accumulation appears to take the form of both rockslide and rockfall. In addition, the cones all reached the creek edge in 1994, which suggests that toe removal due to erosion by the creek could cause debris slide type failures. Erosion control will thus be important for these colluvial cones, as will engineering and/or administrative controls for possible mass movements.

From KP032.2 to KP032.5, the route crosses a small fluvial fan with a well-defined stream. Debris flow and flooding are the dominant geohazards at this location. Some recent debris flow activity is visible on the 1949 and 1994 photos (Figure A05), but these events did not reach the road. However, the fan reaches the edge of the river floodplain and therefore may be subject to undercutting by the stream. Erosion control and engineering and/or administrative controls are suggested for potential flooding and debris flows on the fan.

The road traverses a long colluvial talus slope from KP032.4 to KP035.2 (mostly fresh and unvegetated in 1994) and then a few small colluvial cones up to KP036 (Figures A05 and A06). Another mainly unvegetated talus slope is crossed from KP038 to KP038.8. Rockfall mitigation in the form of engineering and/or administrative controls will be required in these areas.

4.2 KP040 to KP046

The north-northwest-facing slope between KP040.3 and KP041.4 appears to be a permafrost-affected feature. It is perhaps best described as a lateral spread in glaciofluvial terrace deposits. As permafrost is likely present, the glaciofluvial sediments are probably finer-grained than elsewhere, most likely consisting of sand. A few slide blocks were mapped on the 1949 photos for this slope and the adjacent north-northeast-facing slope. None of the blocks appear to have moved at all by 1994 or by 2012, although the LiDAR image covers only a portion of the slide. However, Sundog Creek widens at this point and was eroding the toe of the slide in 1994. The organic deposits that cover much of the slide and the numerous gullies show that the slide is likely quite wet in the summer months. If toe erosion reactivates the slide, summer would be the most likely time for movement. Relocating the road away from this area is suggested. Two route options to the south are suggested on Figure A07. The choice of route will depend on constructability, which will be determined in the detailed design phase. The southern route option traverses a small but steep valley containing older colluvial deposits, which makes it less than ideal, but still feasible with appropriate design and construction. The northern route option must cross a portion of the slide, but it is located near the edge of the slide where it may not be affected by movement of the rest of the slide, and is thus considered acceptable. Cut and fills within the slide periphery will require stabilization, but the rest of this route option is considered stable.

The route crosses a glaciofluvial terrace east of this point, traversing a portion of the slide's edge from KP042.7 to KP042.8. A short southward route realignment is suggested here as well, which allow it to avoid the slide entirely (Figure A07).

Another wet permafrost-affected slope is crossed at KP046. It appears to be a lateral spread unit in glaciofluvial terrace sediments, where the sediments tend to spread as a result of creep of the ice-rich permafrost. Slide blocks are not obvious and thus are not mapped. Some route adjustments to avoid this area are suggested (Figure A08), but the slide is not affected by toe removal or other triggering factors so monitoring of potential activity due to permafrost degradation may be sufficient if the route is left in place. The nearby creek does not appear to be actively eroding the slide slope.

4.3 KP046 to KP049

There are two slides north of KP047 and KP048 (Figure A08). These look like the types of failures typical of the glaciofluvial sediments that they are found in (perhaps due to a lack of permafrost).

Slide blocks and slumped areas are easy to identify on the LiDAR bare earth image from 2012, but are difficult to identify on either the 1949 or the 1994 air photos. A few are mapped from the 1949 photos on the slide north of KP048. When compared to the 2012 bare earth image, 7 to 10 m of downslope movement is evident between the two years. This amounts to an average movement of 16 cm/year over this time period. The small amount of organic material present on the slide deposit surfaces formed after the slide occurred. The glaciofluvial deposits above are dry and the slopes are south-facing, so wetness and permafrost can be ruled out as formative agents. Toe removal by bank erosion of the creek below is therefore the likely cause of these larger slump features. However, the only location where the slide is being eroded by the creek in the 1994 air photos and the 2012 LiDAR image is at KP047.5, where a small debris slide has occurred. At KP048.5, the stream is near the road, but is not currently eroding it and also was not doing so in 1994. Erosion protection of the small slide at KP047.5 is all that is required for these two slides. The small average yearly amount of displacement is an acceptable risk for a mine road with a limited life span. Erosion control could be required in the future if different parts of the creek begin to erode towards the slide. Occasional helicopter reconnaissance flights or the purchase of satellite imagery on a yearly basis would both suffice for monitoring purposes.

4.4 KP060 to KP064

The remainder of the route between KP060 and KP064 appears to have no significant geohazard issues, although one small route change has been suggested at KP061.3 to avoid a gully containing colluvium (Figure A09). Detailed road design will determine if this alignment is feasible.

4.5 KP083 to KP096

Air photos from 1949 and 1994 were analyzed for this area. The mapping for this area is overlain on the (Rutter and Boydell 1981) map for reference as only the areas of concern are mapped.

From KP083.6 to KP085.8, parts of the road cross an area of surface water seepage. Drainage control will be important in this area. Moving the route northward would put it too close to debris slides and moving it south would locate it to areas that are even wetter.

From KP086.5 to KP086.9, another area of lateral spread with a northeast aspect is encountered. Within this slide, a smaller debris slide oriented to the south-southeast is present. It was vegetated with shrubs and grasses in 1949 and with trees of variable height in 1994, which is interpreted to mean that the slide has not moved since sometime in the couple of decades before 1949. The debris slide crosses the road, but an adjustment of the alignment to the south is not viable as it would place the road on wet and possibly fine-grained soil, as well as introducing another stream crossing (Figure A13). Therefore, stabilization of the slope above the road may be required.

Between KP088 and 089.3, the route crosses or is adjacent to a large lateral spread slide or possible earthflow with a northeast to east aspect. Tension cracks at the top of the slide are quite obvious on the 1949 photos but were somewhat overgrown by the time the 1994 photos were flown. While tension cracks usually indicate the possibility of future movement, these ones seem to imply that this possibility is not imminent. The most discrete slide blocks visible in 1949 were mapped. These slide blocks are typically oriented northeast to north-northeast, with a few local variations. When compared to the 1994 air photos and the 2012 LiDAR bare-earth image, no movement is apparent. This slide appears to be in an equilibrium state.

The Tetcela River only undercuts a small portion of the toe of the slide between KP88 and KP88.2; its position in 1949, 1994 and 2012 are shown on Figure A13. At this location, the river primarily moved laterally to the north, rather than westward toward the slide between 1949 and 1994, but the 1994 position is 30 m closer to the road than the 1949 location, thus about 50 m from the road in 1994. The next nearest bend in the river to the slope toe is at about KP089.1, where the river has moved both north and south, widening the bend. Here too, it was somewhat closer to the slope toe at the south part of the river bend in 1994, with little or no change at the previous outside corner of the bend. Determination of the 2012 river position is limited to the portion of the river located within the LiDAR coverage. However, it shows that the river has moved slightly eastward away from the slide at KP088.2 compared to 1994, but slightly westward toward the slide at KP089.1.

Monitoring of changes in the river channel location is recommended, with erosion controls to be added if the river moves westward and starts eroding the slide in these locations. Although the slide appears to be stable at the moment, if it were to reactivate, perhaps in the event of climate warming, through permafrost thaw due to the northeast-facing slide blocks, it would either cover the road or potentially retrogress southwestward toward the tributary river. Debris from this large slide could block portions or all of the Tetcela River below the road, which in turn could cause damming and dam-burst flooding. Monitoring of permafrost conditions with thermistor cables and/or inclinometers on the slope is thus recommended.

Glaciolacustrine fine-grained sediments are encountered between KP091 and 094.2 (Figures A13 and A14). Shallow borehole data to the south suggests that these sediments are underlain by clay-rich till, which can also contain excess ice (10% by volume was noted at a depth of 1.1 m in one borehole). The glaciolacustrine units are associated with abundant organic deposits because they are poorly drained. They are likely perennially frozen as the slopes are northwest- to northeast-facing and because fine-grained sediments tend to be ice-rich. However, the glaciolacustrine hummocks that rise above the organic low-lying areas do not appear to have moved between 1949 and 2012. Some lateral spread appears to have occurred in the past, but these areas do not resemble slides. However, potential thaw of ice-rich permafrost at this location could trigger retrogressive thaw flow slides that could affect the road. The potential for this area to contain permafrost and possibly ice-rich soil means that permafrost should be monitored at selected locations, such as low-lying wet areas adjacent to the road and embankment toes. Monitoring will help provide earlier notice of potential road safety concerns and assist in decision-making and proactive planning for mitigative measures or road repairs.

4.6 KP096 to KP102 Silent Hills West Side, Now Designated “High-Risk”

Air photos from 1949 and 1994 were analyzed for this area (Figures A14 and A15). Although several escarpments were previously mapped in the area, as well as rock/rubble slumps north and south of the route, the earlier mapping did not identify the features in the immediate vicinity of the route (Rutter and Boydell 1981).

A large, complex slide area is present between KP096 and KP102. The bedrock here forms a sharp ridge with a steeper slope on its west side. The route makes two switchbacks on the steep side to ascend the slope.

The area beneath the proposed road consists of a large bedrock slide that probably dates from the time of deglaciation. The bedrock slide’s large, sharp-edged head scarp is evident in the bedrock near the top of the ridge and a sharp-crested slide block from this event is found west of the linear pond that is just outside the map area south of KP098 (Figure A15).

Two smaller slides within the larger one appear to be reactivations of the bedrock slide. The larger of the two encompasses most of the switchback area; the smaller is adjacent to it near KP099 and appears to be the most recent, as it crosscuts the larger one. It does not affect the switchback area. All of the slides are in the same position in 1949 and 1994, and apparently in 2012 as well. The slides appear to be somewhat more vegetated in the 1994 air photos, but this may be due to the poorer quality of the 1949 photos. At any rate, all of the slides had occurred prior to 1949, possibly long before then.

Some new debris slide activity is evident on the 1994 photos and the 2012 LiDAR image. However, most of these are quite small and none affect the proposed road alignment. It is noted that slope sections immediately north and south of this area appear to be more active with respect to debris slides and other mass movements than the slopes at the route location, so the route does seem to be in the most favourable location on this part of the Silent Hills. However, the considerable colluvial activity at this location means that this slope area has been mapped as "unstable," requiring particular attention in design and construction. A slope stability evaluation should therefore be carried out as part of detailed design, to reduce the likelihood and magnitude of potential negative effects that road construction could have on slope stability. Further evaluation of the slope would also help in identifying possible triggers for slide reactivation. Road design and construction would need to take such triggers into account. Important mitigations could include installing additional cross-drainage along the road to allow surface water drainage to continue downslope in existing natural channels and to reduce the likelihood of creating concentrated water flow in areas not accustomed to receiving it. Such mitigations are particularly valuable at switchbacks, which tend to concentrate water if not carefully managed.

4.7 KP124 to KP159 (East Side of Nahanni Range)

Air photos from 1949 cover this whole section, however, the 1994 photos only cover the northern part of the area. Photos from 1971 and 1983 were acquired to cover the remainder of the route with newer photo years than 1949 (Figures A20 to A25).

Where specific colluvial areas and slides are not shown on the surficial geology and geomorphology map due to issues of scale (Rutter and Boydell 1981), they were mapped for this portion of the route and are overlain on the older map. Other relevant features were added as necessary.

From KP124 to KP125.5, colluvial slopes associated with steep bedrock slopes are found. Rockfall activity causes unstable slopes in this area (Figure A20). The proposed road crosses one of these mountain slopes at KP124.6, but it bypasses most of the active rockfall areas. One small rockfall visible on the 1994 photos reaches the road; rockfall mitigation is advisable at this location (Figure A20). A small route adjustment to the northwest places the road on an older fluvial terrace rather than the active floodplain that was visible in the 1994 photos. The road will experience floods less frequently on the higher terrace (Figure A20).

Rock glaciers are present at higher elevations on the slope southwest of KP126, but these are slow-moving and do not present a hazard to the road. However, in a climate warming scenario, the interstitial ice could melt, leading to increased water flow toward the valley. Because several rock glaciers drain toward the tributary stream crossing at KP126.7, that stream may increase in size in the future and a larger crossing structure than is currently necessary may be required. The possibility of thawing interstitial ice should also be considered if the rocky debris areas in the vicinity of the rock glaciers are being contemplated for use as borrow (e.g. BP 126, noted by Allnorth as a backup borrow pit).

Between KP128 and KP132 (Figures A20 and A21) and between KP139 and KP143.3 (Figure A22), a number of glacial meltwater channels are mapped at 1:20,000 scale. Small debris slides in glaciofluvial sediments have occurred on the steep sides of several of these channels. The majority of these do not affect the road, but minor alignment changes are recommended for a few of these areas, especially KP142 to KP143 (Figure A22). Constructability of these will be determined during the detailed design phase.

A gully crosses the route at KP129. It will require standard culvert construction. Upslope of KP129.2, there are two debris flows forming distinct lobes originating from a rock glacier area (visible in both sets of photos). These may indicate that the rock glaciers are melting in this location. The area upslope of KP129 should be monitored for possible renewed debris flow activity.

A fluvial fan that may experience debris flows is present upslope of the road (to the west) at KP130 (Figure A20). It currently does not reach the road area, but it should be monitored for new activity.

At KP134, a rock glacier is located about 1.2 km upslope and west of the road. The creek and the road between about KP133.7 and KP134.7 lie within a polygon that is undergoing slope creep that appears to be caused by the presence of permafrost. A thermokarst pond at the edge of the map area suggests that permafrost is present and is thawing in this area (Figure A21). This area should be investigated for the presence of permafrost, as it is an east-facing slope where permafrost would not ordinarily be expected. If permafrost is not present, then thaw-related subsidence or retrogressive thaw flow slides would not be a concern, either at the creek or on the adjacent slopes. Simple slope creep would still be enhanced by the presence of extra water, however, so even if permafrost is not present, a slope stability evaluation would be of value in determining the most suitable mitigations in this area.

Between KP135 and KP136, a small, steep-sided gully is crossed by the road. A shift of the road to the east is suggested for this location, which is a continuation of the alignment change for the permafrost area just discussed. While decreasing the slope angles of the road, this change may increase the amount of wet area that must be crossed. Issues around construction of this route option will be determined in the detailed design phase.

At KP136.5 and KP137.2, possible debris flow features have been identified, with exposed ground (soils and/or bedrock) in the channels upstream. They are very difficult to see on the 1949 and 1971 air photos due to poor photo quality in this area, and the feature at KP136.5 is obscured by clouds on the 1983 air photos. However, slope gradients are less than about 7% above the road in the suspect area in the KP136.5 stream channel, and the stream channel otherwise looks well-vegetated, so debris flow events probably do not reach the road elevation very often. Slope gradients above the road at KP137.2 are slightly greater at 10%. Moving the road to the east may not protect it from future debris flow activity in these two locations, as apparent old slope movements ended below the road. Crossing structures that include debris flow mitigations may be useful here, to be determined during the detailed design phase. Further discussion of this area was provided in the geotechnical evaluation (Tetra Tech EBA 2015a).

At KP151.1, 152.2 and 154.4, fluvial fans are mapped more accurately for this scale of mapping. Gullies are associated with the fans but they do not appear to experience debris flow activity (Figure A24).

From about KP149.3 to KP152.7, the older mapping shows an escarpment (Figures A23 and A24). The escarpment marks the edge of a terrace apparently in bedrock (Rutter and Boydell 1981); however, it is not perfectly located for mapping at this scale. Although the route appears to cross the escarpment at KP149.7 on the older mapping, it actually skirts around the bottom of it so there is no steep slope crossing at this location.

A large debris slide developed in till surrounds KP155. Disturbance across the head scarp could potentially reactivate this slide, so a route adjustment to the west has been suggested (Figure A24).

Between KP155 and KP159, two earthflows are present (Figures A24 and A25). The route at KP156 is about 320 m away from the earthflow downslope, so it is not currently at risk, but this type of failure tends to retrogress (expand upslope), so it should be periodically monitored for new activity. Tension cracks present from KP156.5 to KP157 are barely visible in the 1949 photos. They are easier to see on the 1983 air photos; however, they show no change in shape or size by that year. The LiDAR image covers only part of this area and is not very informative in terms of the tension cracks. The lack of change between 1949 and 1983 suggests that the slide was not active in 1983. It is well vegetated in both sets of photos. Gullies at KP157.3 to KP157.5 indicate increased water flow, which could lower the stability of the slide. Route alignment adjustments to the northwest have been suggested for the areas from KP153.6 to KP158.2 to avoid loading the heads of these slides (Figures A24 and A25). The suggested route between KP154 and KP156 also moves the route off the fluvial fan and gives it a simple gully crossing instead. It is not possible to keep the route higher than the slide at KP158.2, because there are multiple fresh debris flows or slides visible on the LiDAR image in this area (Figure A25). The road location is therefore not modified, crossing a small portion of the slide. Mitigations including careful placement of cross-drainage are likely to be required for this area. It is noted that slope instabilities originating either upslope or downslope could potentially still affect the road despite possible mitigations. Additional evaluation of the slope is recommended during detailed design of this road section to determine the most suitable mitigations for each feature.

4.8 KP160 to KP184.5 Liard Floodplain

The Liard River floodplain underlies KP160 to KP184. The only “moderate-risk” geohazard for this area is flooding. As this designation is implicit with a large river such as the Liard, this area is not mapped for this study.

5.0 ALTERNATIVE ROUTES BETWEEN KP103 AND KP124

5.1 General

Two routes are being considered for the road alignment between KP103 and KP124. The “original” route is the route that was evaluated in the 2014 field program and discussed in Tetra Tech EBA’s geotechnical evaluation report (2015a). Three options for an alternative route between KP103.4 and KP124 were evaluated during the 2015 field program (Tetra Tech EBA 2015b). Once the “selected alternative route” was chosen from these possibilities, the oldest and newest air photos available were ordered for this route and for the adjacent portion of the original all-season route.

Photos from 1949 cover just the southern few kilometres of both routes, but photos flown in 1963 cover the entirety of the two routes. Recent air photos (1994) were obtained, but coverage for part of the southern portion of the original route is missing from these flight lines. Photos from 1982 were used to cover this area instead.

The area covered by the two routes had been mapped previously by Rutter and Boydell (1981) and Rutter et al. (1993). However, at the scale of mapping for this project (1:20,000), significant differences were noted between these maps and what is visible on the air photos that cover these routes: much of the area previously mapped as bedrock along the original route was observed to be till and organic material overlying till, and some large fluvial fan features are not shown on the Rutter and Boydell (1981) and Rutter et al. (1993) maps. Therefore, more detailed mapping of these areas was required. Modified TSM, including extra data on landslides and other geohazards, was completed for this area, rather than merely labelling the existing mapping as Potentially Unstable (P) or Unstable (U) as was originally proposed.

5.2 Permafrost

Areas of colluvium are present in the northern part of the two routes: colluvial material covers the eastern portion of the original route and the western portion of the selected alternative route in this location (Figures A15 and A16). Rockfall colluvium coats the steeper bedrock hills and knobs up to original route KP110 and selected alternative route KP109.3, and commonly forms gentler talus slopes at the base of the steeper slopes. However, on the eastern side of these hills (east of the talus slopes), some of the colluvial talus material appears to have undergone lateral spread after deposition, causing it to become even more gently sloping. The material in the lateral spread areas appears to be slowly moving downslope (eastward). It is possible that these slopes are undergoing creep as well as lateral spread (labelled as -Fjc for geomorphic process). Certainly seepage is occurring, as flow lines showing the direction of water movement within the active layer are clearly visible on the air photos and these areas are partially or completely covered with organic material.

As these are east-facing slopes for the most part, permafrost presence was not initially suspected. To check possible speed of movement, a number of undulating slide "blocks" were mapped for the years 1949 and 1994. (The LiDAR image does not extend to this area.) Most show little to no movement in this time period (Figures A15 and A16), so either the creep is occurring very slowly or it has reached equilibrium. Since these areas still have some slope to them, it is more likely that the creep is very slow, perhaps due to the low slope angles or low ground ice content if the material is perennially-frozen. Permafrost has not been confirmed in these areas, but our interpretation of the air photos suggests that there is a high probability that it is present (mapped as –X in Figures A15 and A16). Fieldwork to investigate the areas of concern is recommended from about KP103.6 to KP110 on the chosen route. If permafrost is present, then the implications of climate warming must be considered. If it is not, then the creep must be caused by the weight of the colluvial deposits themselves and a climate warming scenario is much less likely to affect the speed of movement.

Permafrost appears to be locally present in other parts of the two routes as well. In general, in areas of sporadic discontinuous permafrost, the presence of black spruce, stunted "drunken forest" stands with moss and lichen ground cover interspersed with bog peat (organic deposits more than 1 m thick, mapped as Ob or Ow) indicate that permafrost is present. Even small areas of stunted black spruce forest within a non-permafrost polygon may contain the occasional patch of perennially-frozen ground. If these form less than 10% of a polygon, they are not labelled, but if more than 10%, a –X geomorphic process label has been added (Figures A16 through A19). A forest comprising healthy white spruce has a much lower probability of being on frozen ground. Areas covered with deciduous forest (e.g. bedrock knobs covered with till veneer) are highly unlikely to contain frozen ground.

Permafrost is expected beneath bog peat (Ob, Ow) due to the thick insulating cover of organic material, which protects the ground below from radiative warmth in the summer. However, fen peat (Op) and slow-moving streams (F^Ap) are very wet areas which cause the opposite effect and thus are not underlain by permafrost. East of the laterally-spread colluvium, there is a large wetland flanking a slow-flowing wetland creek (selected alternative route, Figures A15 and A16). A few other wetland-dominated areas are present along the route, but these can be avoided or exposure to these areas minimized with minor readjustments of the route locations.

It is not possible for either route to avoid bog peat completely. Where it must be crossed, it will be important to consider potential differential settlement of embankment material, and possible development of thermokarst due to road construction, and to select suitable embankment design and construction techniques accordingly. Natural surface water drainage paths should be preserved where possible, and diverted if/where necessary to keep water from pooling along the toe of the road embankment. The primary objective in this effort is to preserve ice-rich permafrost, thereby maintaining embankment integrity and reducing the likelihood of environmental impacts associated with permafrost thaw. Drainage structures should be designed to reduce the likelihood of thermokarst development. Diversions should direct surface water toward and along existing natural drainage paths. Flatter fill slope gradients will also need to be considered in these areas to reduce the likelihood of snow drifting against the road embankment. Snowdrifts tend to reduce cooling of the ground in winter, thus gradually allowing the permafrost to warm and eventually thaw, starting at the toe of the embankment. Such thaw tends to result in undesirable ponding of water, contributing to further thermal erosion.

5.3 Surficial Deposits

Till and glaciofluvial deposits dominate the two proposed routes, with some organic deposits (Figures A16 to A19). Only three small areas were identified as consisting primarily of bedrock along the original route, but the Nahanni Range along the selected alternative route has bedrock outcrops in its upper elevations.

Organic deposits have developed locally over top of thick, gently-sloping deposits of till in the north and central portions of the original route. Thicker organic units commonly become thinner at the edges, so areas with less than 1 m of organic cover in places are commonly labelled as Obv, Ovb or Ow. Both routes avoid the large fluvial/wetland area in the central valley at this location.

Glaciofluvial sediments are present on both routes, but are more abundant on the original route. These deposits often have meltwater channels cut into them, which have formed steeply-terraced slopes in some areas. Where the terrace slopes are large enough, debris slides have occurred on their surfaces.

A number of fluvial fans (previously unmapped) are now shown on Figures A15 and A16 between KP106 and KP110 on the selected alternate route. Fluvial fans are subject to avulsion and flooding, so design and construction measures need to take these possibilities into account.

The tributary stream entering from the north in the Grainger Gap area is also prone to changing its position (Figure A19).The floodplains of the Grainger River and its northern tributary are evident at the southern end of both routes. Four years of photos are available for this area, but only three river positions are mapped to decrease congestion on the map (1949, 1963, and 1994, as 1971 provides only partial coverage). The LiDAR image covers only a portion of these areas (between selected alternative route KP120 and KP125). The river position in the LiDAR image is similar to that of the 1994 air photo positions, except that it appears to have eroded slightly further southeast and some of the northwestern terraces are revegetated. This position is not shown on the map, again to retain clarity for reading the map figures.

The tributary stream is braided, with many channels, so only the outermost channels are mapped, which shows the maximum width of the channels at each point in time. The main stem of the Grainger River flowed as a braided river from 1949 to 1971; after that it became more of an irregularly sinuous channel, with a much reduced number of channels. The tributary stream flowed along the northeast side of a bedrock knoll in the middle of the floodplain in 1949 and remained there until at least 1971, forming braided channels in that location (Figure A19). In 1963 and 1971, it was also flowing west of the knoll and forming a fluvial fan, but much of the fluvial sediment did not reach far down the fan. Flow was reduced to a single channel on the fan in 1963, but returned to a more braided form in 1971. One of the channels on the fan flowed closer to the bedrock knoll to enter the main channel near KP123 on the original route. By 1994, the northern channel had been abandoned and the stream was flowing onto the fan in a similar manner as in 1963. Changes in tributary channel position could happen again in future if the tributary becomes heavily sediment-laden during a large flood.

5.4 Original Route

The original route crosses till and organic deposits overlying till between KP103.4 and KP116, and is preferentially routed along the drier till areas. However, keeping the route on higher, drier ground also means skirting or crossing some gullies (Figures A15, A16, A18).

The original route crosses an old rockfall whose headscarp is above and east of the route shortly after KP110, but a minor shift of the alignment to the west can avoid this rockfall path (Figure A16). Another minor shift at KP111 would move the route away from a wet area and is therefore optional. Mitigations for wet areas would otherwise be recommended, including provisions for adequate cross drainage. A move to the west is also recommended between KP113.5 and KP114.1 to avoid another potentially unstable rockfall area, this time located just below the route. The deviation from the original route is to reduce the likelihood of crest retrogression in the rockfall area from affecting the road near KP114 (Figure A16 and A18).

The area between KP115 and KP117 is discussed in detail in Tetra Tech EBA (2015b). Here the glacial deposits transition to glaciofluvial sediments. A route shift between KP115 and KP115.7 moves the road away from a slide area and a gully. Another at KP116 to KP116.5 places the route more centrally within a flat-bottomed meltwater channel to keep it away from the slide area on the southwest side of the channel. Both of these route alterations are shown on Figure A18.

After KP117, the route crosses alternating till and glaciofluvial deposits. At KP117.7, it crosses a tight spot between a small wetland that is too small to be mapped and a small but steep gravel ridge marking the edge of a former meltwater channel. Ice melt south of the ridge during deglaciation formed a depression behind it, creating a ridge feature rather than a terrace edge. A minor adjustment to the northeast at this location would allow the route to avoid the tight spot (Figure A18).

After KP118, the alignment crosses a couple of short but steep terrace edges. The first terrace at KP118 is crossed at right angles, while the second (up to KP118.6) is crossed diagonally (sidehilled). Some slope stabilization may be needed in this area; however, no obvious slide scars (old or new) are visible on the slope surfaces, so they likely are not as unstable as other nearby slopes in glaciofluvial material (Figure A18).

The alignment then crosses a meltwater channel floor before climbing up a colluvial slope formed over till and glaciofluvial material. Old debris slide scars are evident here above and below the meltwater channel scarp. The till above the slope is wet and displays abundant seepage. Water addition from above has likely contributed to instability on the slopes below. The route would be best realigned around this problematic area by continuing within the low ground of the meltwater channel to the southwest before climbing a less steep slope between KP119 and KP120. This realignment would require an additional stream crossing and its construction viability will be determined during the design phase (Figure A18).

At KP120.9, the route crosses an expanse of glaciofluvial deposits, minor organic veneer and one wet fluvial deposit and stream at KP122.1 that will require a bridge (Figure A19). At KP123, the route reaches a bedrock slope that it descends until KP123.1, where it crosses Grainger River, avoiding the fan area that is still active. From here, it stays on older fluvial deposits of the northern tributary fan. Two minor northward shifts of the alignment are recommended to reduce the likelihood of erosion from the Grainger River. Exact configuration will be confirmed during detailed design.

5.5 Selected Alternative Route

As mentioned above, the “selected alternative route” was considered to be the most suitable of the several alternative routes considered during the 2015 field program (not shown) (Tetra Tech EBA 2015a). This route was further evaluated during the 2015 mapping program. The selected alternative route crosses till and organic material between KP103.4 and KP103.6 (Figure A15).

After KP103.4, the route crosses some areas of colluvium and laterally-spread colluvial deposits as described in Section 5.2. This route crosses a number of these lateral spread deposits between KP103.4 and KP109.4. Slide blocks on these features were mapped for 1949 and 1994 as mentioned in Section 5.2. There has been little movement between these years (a maximum of 11 m). The soil creep/lateral spread is therefore slow (averaging 24 cm/year) and thus may be considered an acceptable risk. However, the weight of road embankment material could possibly accelerate the movement. Geotechnical engineering investigation is suggested for this section of road, including the delineation of permafrost.

From KP104.6 to KP105.3, an undulating colluvial deposit is crossed. This area appears to be rockfall material that has also moved downslope after deposition. The runout areas of the rockfalls do not extend this far; however, it is possible that these are undulating talus deposits from the same rockfall area, and as such are possibly within the runout zone. Moving the route to the potential permafrost area to the east (Figure A15) may be warranted in this particular case in order to avoid the greater of the two types of hazard. The route crosses the runout zone of a few rockfall areas between KP105.9 and KP108.2. Again, moving the route eastward into the potential permafrost creep area may be advisable (Figures A15 and A16).

The selected alternate route crosses fluvial areas that may be wet and that will require at least one stream crossing each. Some of these were previously unmapped but are now shown on Figures A15 and A16. The fluvial areas are found at the locations KP105.3 to KP105.4, KP106.4 to KP107, KP109.4 to KP109.9, KP110.6 to KP110.8, and KP111.2 to KP111.7 (note that the creek locations shown by the CanVec topographic data are inaccurate). The creeks within most of these units are so small that they are difficult to identify at all, but the fan-shaped deposits show they have changed positions numerous times in the past. However, these changes are likely to have occurred prior to 1949. The presence of gullies leading up to the fluvial deposits suggests that water floods have occurred in these locations in the past, again prior to 1949.

Between KP109.9 and KP111.6, the route traverses a small upland of till and organic material, then fluvial deposits (described above), and then glaciofluvial and fluvial material. These areas are expected to be stable, with the exception of the wetland areas that may be underlain by permafrost, and fluvial deposits that indicate the possibility of future flood events (Figure A16).

After crossing a short wetland stretch, the route moves into a large area that is mapped as unstable, from KP111.8 to KP115.7 (Figures A16 and A17). The northern part of this area (to KP113.3) is characterized by rockfall at high elevations that travels down bedrock gullies and crosses a deposit of gullied till. Here, rockfall processes transition into debris flow activity. Three large debris flow deposits are the product. Two of these have formed a fan (KP112 to KP112.2) and a cone (KP112.6 to KP113.1) of debris at the end of the runout zone. The third forms a thick sloping deposit between KP112.2 and KP112.4. The remainder of the rockfall area experiences less severe rockfall activity due to lower elevation bedrock exposed above it. The rockfall material travels in a similar manner across exposed bedrock (in gullies), travels across the gullied till, and then deposits material as sloping deposits at the base of the slope. This material appears to comprise debris slide deposits. In 1994, colluvial fan and cone deposits between KP112 and KP113.1 were active (Figures A16 and A17). Realigning the route lower on the slope to skirt along the toes of the affected areas would reduce the risks and maintenance related to those hazards. It is not possible to place the road any lower as it would cross wetland areas potentially underlain by permafrost and fine-grained sediments. It is preferable to build on the higher, firmer, drier ground. Engineering and administrative controls for debris flow are therefore required along this stretch of road.

From KP115.7 to KP118, till and one colluvial area are crossed. As there are older slide runout zones in the colluvial section, moving the route south to the toe of the slides has been suggested for the KP117 to KP118 area (Figures A17 to A19). Similar engineering and administrative controls are necessary here.

Debris slides in till and glaciofluvial material are crossed between KP118 and KP119.2 (Figure A19). A minor route shift avoids these issues.

A crossing of the northern tributary of the Grainger River is located between about KP118 and KP118.4. A detailed geotechnical study is recommended for bridge design at this crossing to assess the stability of the slopes as there are debris slides on both sides.

Shortly after the crossing, two organic-rich areas are traversed. One cannot be avoided (KP118.4 to KP118.5), while the other (KP118.5 to KP118.6) can be avoided with a minor route realignment to the southwest which would place it on the glaciofluvial terrace at that location. The first area shows seepage and possible creep of frozen substrate and should be investigated for the presence of permafrost. Another re-route skirting around KP119 allows the road to avoid the glaciofluvial slope that displays debris slide scars (both shown on Figure A19). Constructability of these two route options will be determined in the detailed design phase.

After KP119.2, the route crosses an area of till that may contain a creek (too small to map) and continues above the river floodplain to about KP120.2 along the steeply-sloping bedrock slopes that are covered with till or colluvial veneer. There are a few old rockfall paths in this area so mitigation would be required in these areas.

The remainder of the route rests on the Grainger River floodplain. The 1963 position of the northern tributary comes close to the route in a few places and one channel scar crosses it. The channel scar, located between KP120.4 and KP120.5, is first visible in the 1994 air photos. It apparently formed sometime between 1971 and 1994. Moving the route closer to the mountain is feasible, but this would place it closer to the rockfall runout zones. Erosion protection in this area is perhaps a preferable choice, but is only necessary if the channel north of the bedrock knob becomes active again.

5.6 Cadillac Airstrip

The airstrip, constructed by Cadillac Explorations Ltd. in the early 1980's, is visible on the 1994 photos to the northeast of KP104 and runs across an organic area and a wet fluvial area (Figure A15). It is mapped as Ap. Although flat, this is a poor location for an all-season airstrip or other infrastructure because of the poorly-drained conditions.

6.0 RECOMMENDATIONS AND CONSIDERATIONS

6.1 General

The report sections above have outlined the findings of the 2015 mapping program and, for the convenience of the reader, have also summarized the proposed realignments and/or other mitigations for the applicable route sections along with the relevant description of that part of the route. Section 6.2 summarizes the overall findings along with the typical mitigations for specific types of findings. Finally, a table summarizing those mitigations, including realignments if/where applicable is presented in Section 6.3. The intent of the realignments and mitigations is to allow the road to be built and maintained with an acceptable level of risk to users, the environment, and the road itself.

6.2 Overview of Findings and Typical Mitigations

The 2015 mapping program has confirmed decisions made in previous realignments, and has identified some additional road sections that would benefit from realignment and/or other mitigations. For example, in the Polje reroute area, most of the route was found to be in the appropriate location, but a few sections were considered to benefit from realignment. Of those sections, most were possible to realign, for example, the section of the route from about KP056.3 to KP059.5 was relatively straightforward to realign in order to avoid some significant slope instabilities. However, the section of the route from about KP049.7 to about KP050.4 at the west end of the Polje reroute will need a combination of realignment and slope mitigations, since grade considerations prevent a realignment of the portion climbing out of the stream valley at KP049.7. In order to mitigate the crossing of a slide at KP049.8, other strategies will be needed, to be determined during a slope stability evaluation at the time of detailed design. Possible mitigations could include modified cut and fill designs, stabilization of cut slopes and/or fill slopes, and/or installation of additional cross-drainage measures.

Similarly, the mapping program has allowed the project team to confirm or refine its observations in areas previously designated as "moderate-risk." In many cases, a minor realignment, or sometimes a more significant one, allows the route to be placed in a lower risk area of the terrain, avoiding such features as slide paths, very wet areas, terrain subject to permafrost creep, and so on. For example, the possible slope failures in the vicinity of KP129.8 noted in the earlier work (and in Section 4.7 above) appear to be related to the presence of a meltwater channel downslope. The route was previously realigned to avoid those features, and the additional detail available from the mapping has allowed this road section to be refined further. Some additional potentially-unstable terrain was also identified between KP0133.7 and 134.7, and for about 100 m at KP135.6. In each case, a realignment is a practical way of reducing the risks to the road and terrain.

In other cases, the mapping has identified road sections where realignments would be desirable but are not physically possible due to tight routing around terrain obstacles, issues with attaining necessary road grades, or where realignments would still encounter problematic terrain features and provide no net benefit to the route. For example, the Silent Hills west approach (about KP96 to KP102) is now designated as “high-risk” due to some large slides in bedrock as well as nearby soil debris slides and debris flows in similar terrain. Since the proposed route appears already to be in the most favourable location on the slope as a result of the earlier route review, additional realignment would offer no further apparent benefit. Instead, other mitigations are likely to be required, and would be implemented in accordance with the findings of a detailed slope stability evaluation at the time of detailed design.

Some recommendations for the installation and monitoring of instrumentation have also been provided for specific sections of the route, for example, where slope instabilities or potentially ice-rich creeping permafrost appear to be present but are not readily avoided by the route. In some cases, the route does not cross these terrain types directly, but has the potential to be affected by them, for example, in the case of rock glaciers present above the road that could be affected by climate change and in turn could affect the terrain at the road when they begin to thaw. Similarly, reactivation of a slide or slump can affect the road, whether the slide is above, below, or at the road itself. The intent of the instrumentation is to provide advance warning of changes in the terrain, such as ground temperature or slope movements that could affect the route, and allow proactive planning for mitigations or repairs, as well as the opportunity to provide appropriate administrative controls when required.

6.3 Summary of Recommended Realignments and Mitigations

Table 6.3-1 below provides a summary of the realignments and associated mitigations described in Sections 3, 4 and 5 above.

Table 6.3-1: Summary of Realignments and Mitigations Where Realignments Not Feasible

Road Section Start KP (km)	Road Section End KP (km)	Distance (km)	Realignment and/or Other Mitigations
1.85	2.00	0.15	Protection should be considered to limit possible intrusion of fluvial fan at airstrip.
4.06	4.45	0.39	Rockfall mitigation should be considered at cutslopes. Use of backup borrow sites BP 4A and BP 4B may increase risk at road.
5.67	6.12	0.45	Realignment not possible due to fish habitat enhancement/protection. Implement rockfall mitigation instead. Casket Creek flood mitigations.
16.30	17.37	1.07	Further realignment not possible due to grades. Rockfall mitigation and/or administrative controls.
22.99	23.36	0.37	Slight realignment south to avoid downslope instabilities.
24.88	25.15	0.27	Slight realignment south to avoid downslope instabilities.
28.30	29.08	0.78	Mitigation options to be determined with slope stability evaluation: proposed as rockfall mitigation starting at KP028.3, buttressing and erosion protection at KP028.7, or realigning route and stream crossing location.
38.74	42.95	4.21	Consideration of first of two suitable realignments to the south to avoid slide area, decision at detailed design to be based on constructability.

Table 6.3-1: Summary of Realignments and Mitigations Where Realignments Not Feasible

Road Section Start KP (km)	Road Section End KP (km)	Distance (km)	Realignment and/or Other Mitigations
39.59	42.95	3.36	Consideration of second of two suitable realignments.
42.07	42.95	0.88	Realignment south to avoid slide area - shown as part of preceding realignments.
45.35	46.31	0.96	Realignment south to avoid permafrost/organic area.
49.90	50.40	0.50	Grade issues prevent realignment at west end. Mitigations at slide area to be determined based on slope stability evaluation. Realignment in east end of section.
54.44	55.25	0.81	Short realignment west to avoid rockfall area.
55.46	55.77	0.31	Short realignment southwest to avoid rockfall area.
56.18	59.33	3.15	Realignment downslope, then upslope on terrace, to avoid instabilities along crest of slope.
60.94	61.55	0.61	Short realignment to avoid gully with colluvium.
83.60	85.80	2.20	Realignment not suitable south or north, drainage control important.
86.55	86.80	0.25	Realignment south not suitable due to wet area and stream. Mitigation of slide above road may be needed; stabilization proposed.
96.00	102.00	6.00	Road in most suitable location, other mitigations may be needed, e.g. drainage. To be determined with slope stability evaluation.
109.84	110.17	0.33	Original Alignment – shift alignment west to avoid rockfall.
111.04	111.38	0.34	Original Alignment – shift alignment west to avoid wet area.
113.59	114.44	0.85	Original Alignment – shift alignment west to avoid rockfall.
114.95	115.67	0.72	Original Alignment – shift alignment northeast to avoid slide and gully.
116.00	116.49	0.49	Original Alignment – shift alignment northeast to avoid slide.
117.47	117.81	0.34	Original Alignment – small shift northeast out of tight spot at ridge and wetland.
118.37	119.41	1.04	Original Alignment – shift southwest to avoid unstable slope of meltwater channel.
105.09	105.96	0.87	Alternative Alignment – shift alignment east to avoid permafrost creep area.
106.42	107.13	0.71	Alternative Alignment – shift alignment east to avoid permafrost creep area.
107.64	109.27	1.63	Alternative Alignment – shift alignment east to avoid permafrost creep area.
111.90	115.65	3.75	Alternative Alignment – shift alignment west to skirt toe of unstable area, yet stay high enough to keep route on dry ground.
116.95	118.00	1.05	Alternative Alignment – shift alignment south to avoid colluvium.
118.30	118.70	0.40	Alternative Alignment – shift alignment southwest to avoid organic-rich area.
118.70	119.30	0.60	Alternative Alignment – shift alignment northeast to avoid debris slides and steep ground.
123.31	123.66	0.35	Minor shift of alignment to north to reduce erosion potential.
124.11	124.45	0.34	Minor shift of alignment to north to reduce erosion potential.
127.77	129.22	1.45	Shift alignment northeast to avoid series of meltwater channels.
133.15	136.22	3.07	Shift of route alignment northeast to avoid permafrost creep, steep-sided gully.
141.41	143.26	1.85	Minor shift of route east to avoid crest of meltwater channel.
153.62	158.27	4.65	Shift of alignment to west to avoid crests of large debris slide and earthflows.
158.27	159.32	1.05	Mitigations required beyond KP158.27 along descent to Liard River, where alignment cannot be moved due to instabilities upslope.

7.0 CLOSURE

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

Respectfully submitted,
Tetra Tech EBA Inc.

Prepared by:
Shirley McCuaig, Ph.D., P.Geo.
Senior Terrain Geologist
Engineering Practice
Direct Line:780.451.2130 x381
Shirley.McCuaig @tetratech.com

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

Reviewed by:
Vlad Roujanski, Ph.D., P.Geo.
Senior Project Geologist – Geocryologist
Engineering Practice
Direct Line: 780.451.2130 x289
Vlad.Roujanski @tetratech.com

Reviewed by:
Kevin Jones, P.Eng.
Vice President – Arctic Development
Engineering Practice
Direct Line: 780.451.2125
Kevin.Jones @tetratech.com

/KLA

PERMIT TO PRACTICE
TETRA TECH EBA INC.
Signature
Date Dec. 3/2015
PERMIT NUMBER: P 018
NT/NU Association of Professional Engineers and Geoscientists

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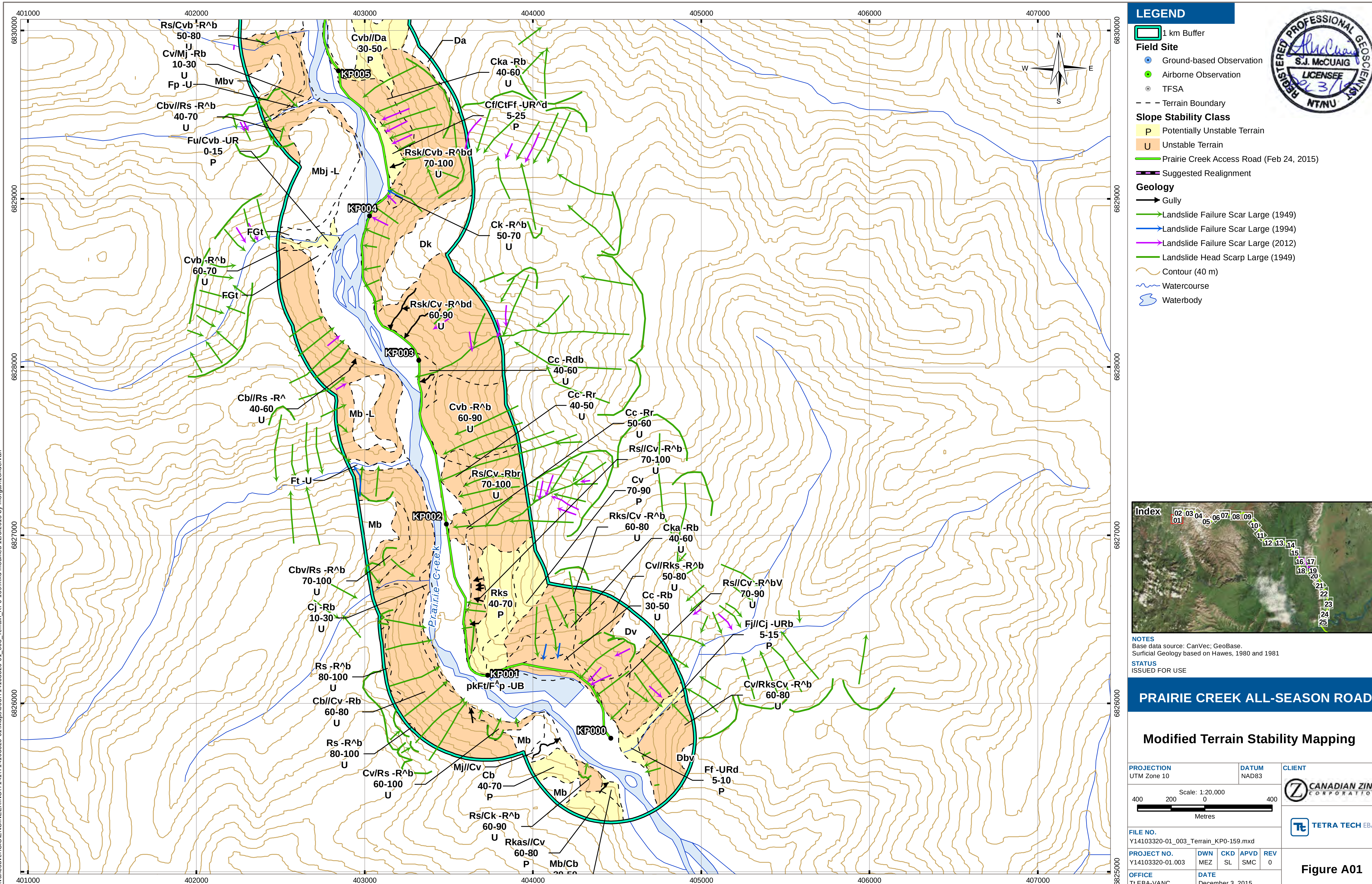
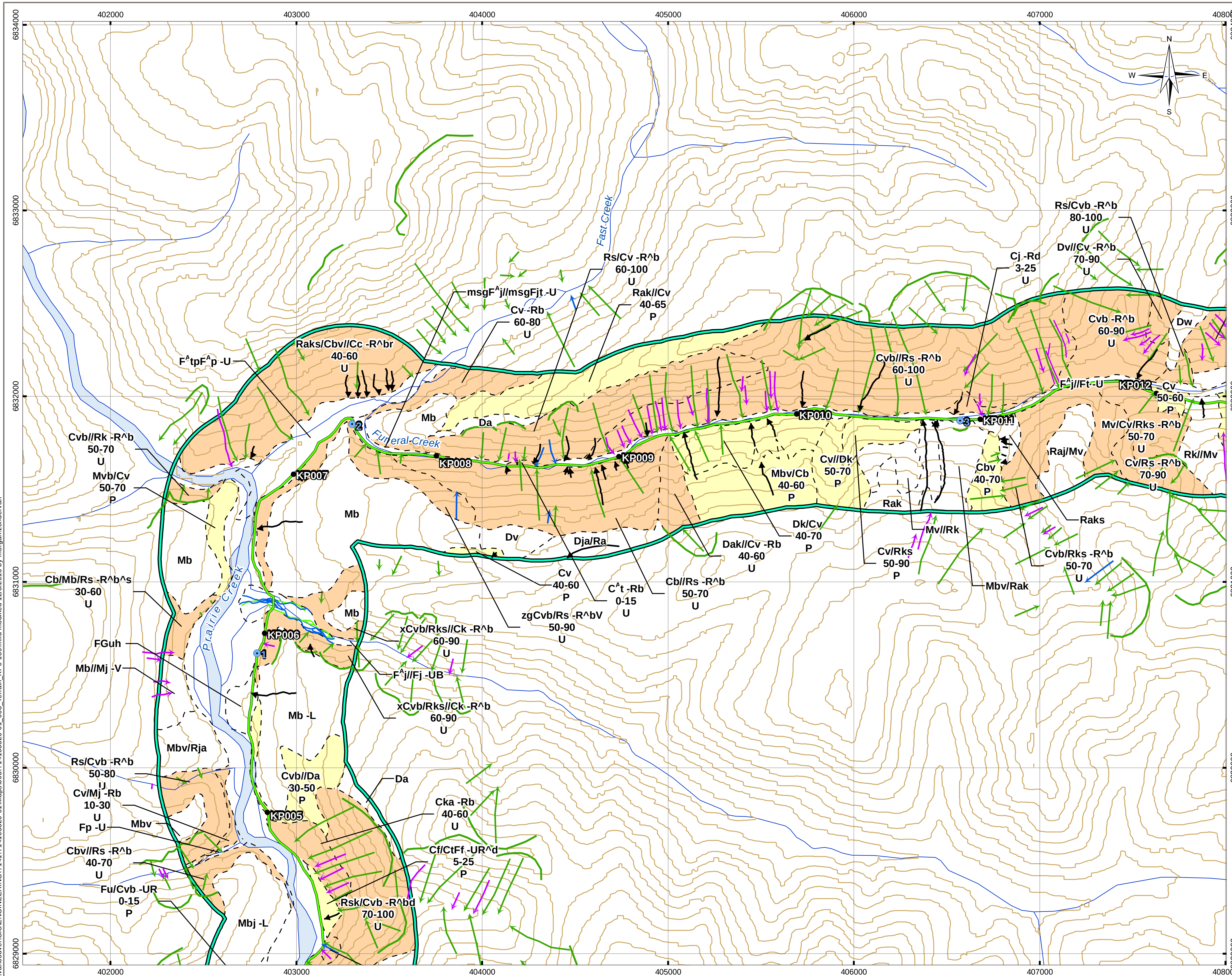
APPENDIX A
TERRAIN STABILITY MAPS


LEGEND
1 km Buffer
Field Site
Ground-based Observation
Airborne Observation
TFSA
Terrain Boundary
Slope Stability Class
P Potentially Unstable Terrain
U Unstable Terrain
Prairie Creek Access Road (Feb 24, 2015)
Suggested Realignment
Geology
Gully
Landslide Failure Scar Large (1949)
Landslide Failure Scar Large (1994)
Landslide Failure Scar Large (2012)
Landslide Head Scarp Large (1949)
Contour (40 m)
Watercourse
Waterbody
Index
KP000
KP001
KP002
KP003
KP004
KP005
Prairie Creek
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
UTM Zone 10
DATUM
NAD83
CLIENT
CANADIAN ZINC CORPORATION
Scale: 1:20,000
Metres
TETRA TECH EBA
FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd
PROJECT NO.
Y14103320-01.003
DWN
MEZ
CKD
SL
APVD
SMC
REV
0
OFFICE
Tt EBA-VANC
DATE
December 3, 2015
Figure A01



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LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

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

Geology

- Gully
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1994)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- River Position (1949)
- River Position (1994)
- River Position (Post-1994)
- Contour (40 m)
- Watercourse
- Waterbody

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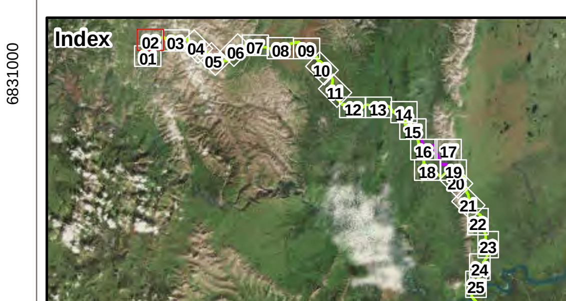


NOTES
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

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

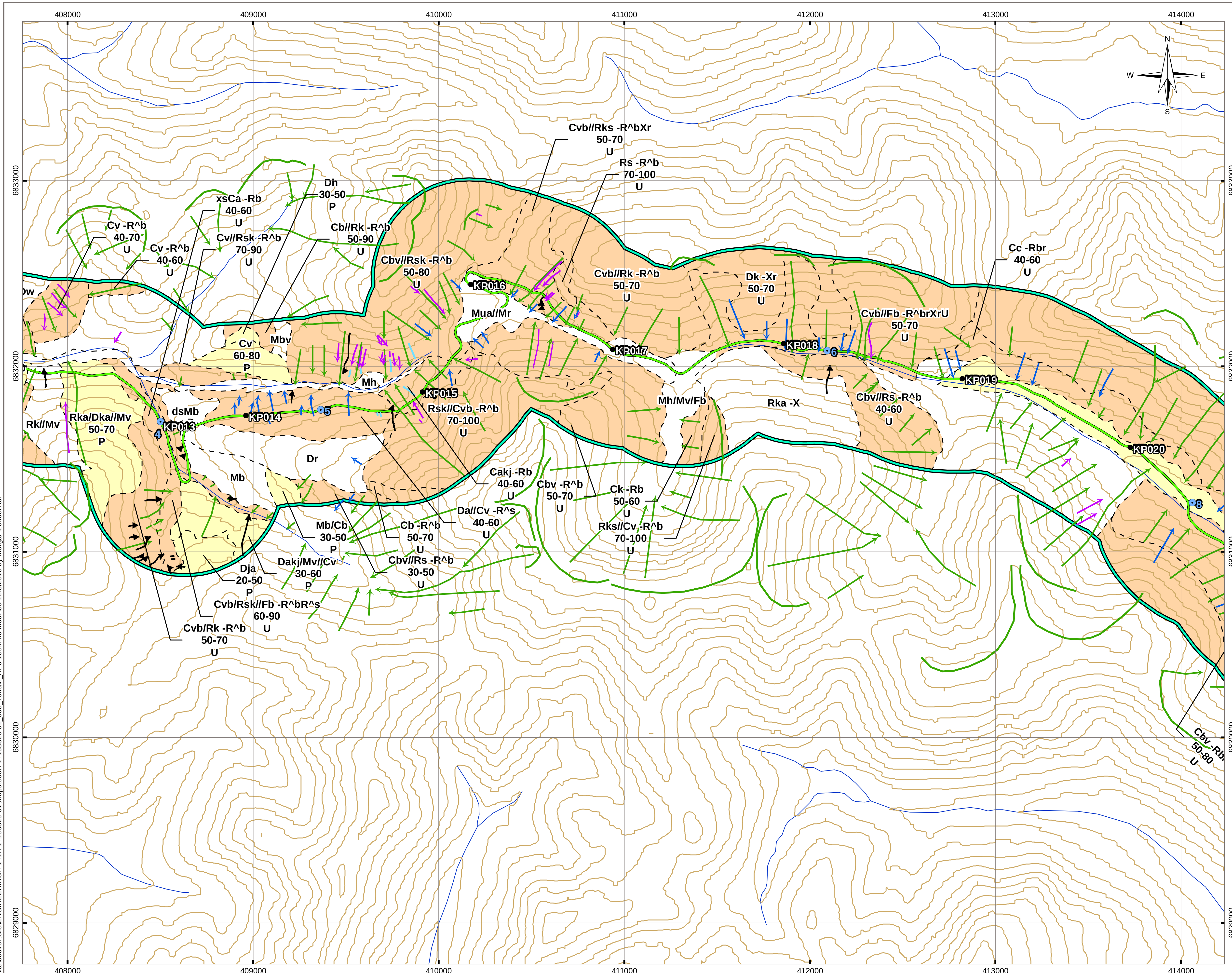
TETRA TECH EBA

FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A02



LEGEND

- 1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

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

Geology

- Gully
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1994)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- Landslide Head Scarp Large (1982)
- River Position (Post-1994)
- Contour (40 m)
- Watercourse
- Waterbody

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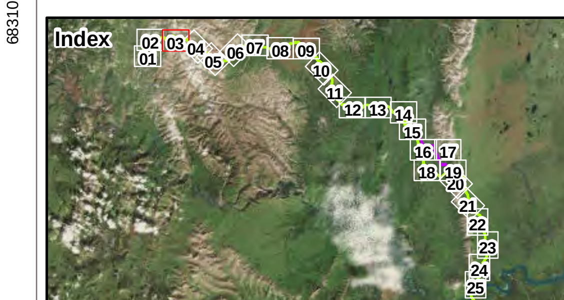

NOTES
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A03

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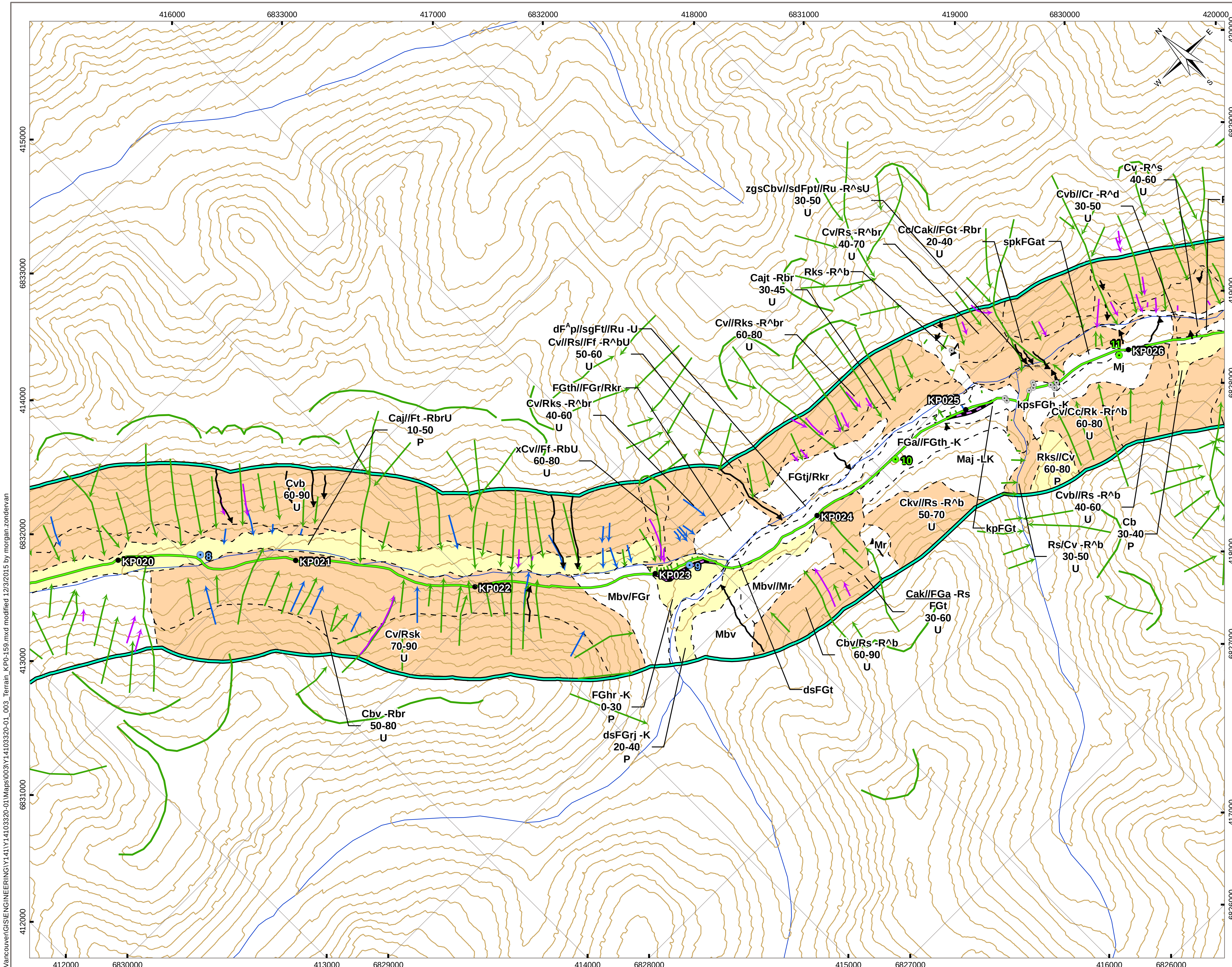

LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA

Terrain Boundary

Slope Stability Class

- P Potentially Unstable Terrain
- U Unstable Terrain

Prairie Creek Access Road (Feb 24, 2015)

Suggested Realignment

Geology

- Gully
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1994)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- Contour (40 m)
- Watercourse
- Waterbody

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S.J. McCUAIG
LICENSEE
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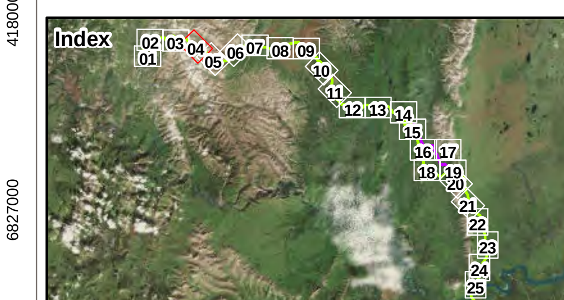

NOTES
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

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_KP0-159.mxd

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

OFFICE	DATE
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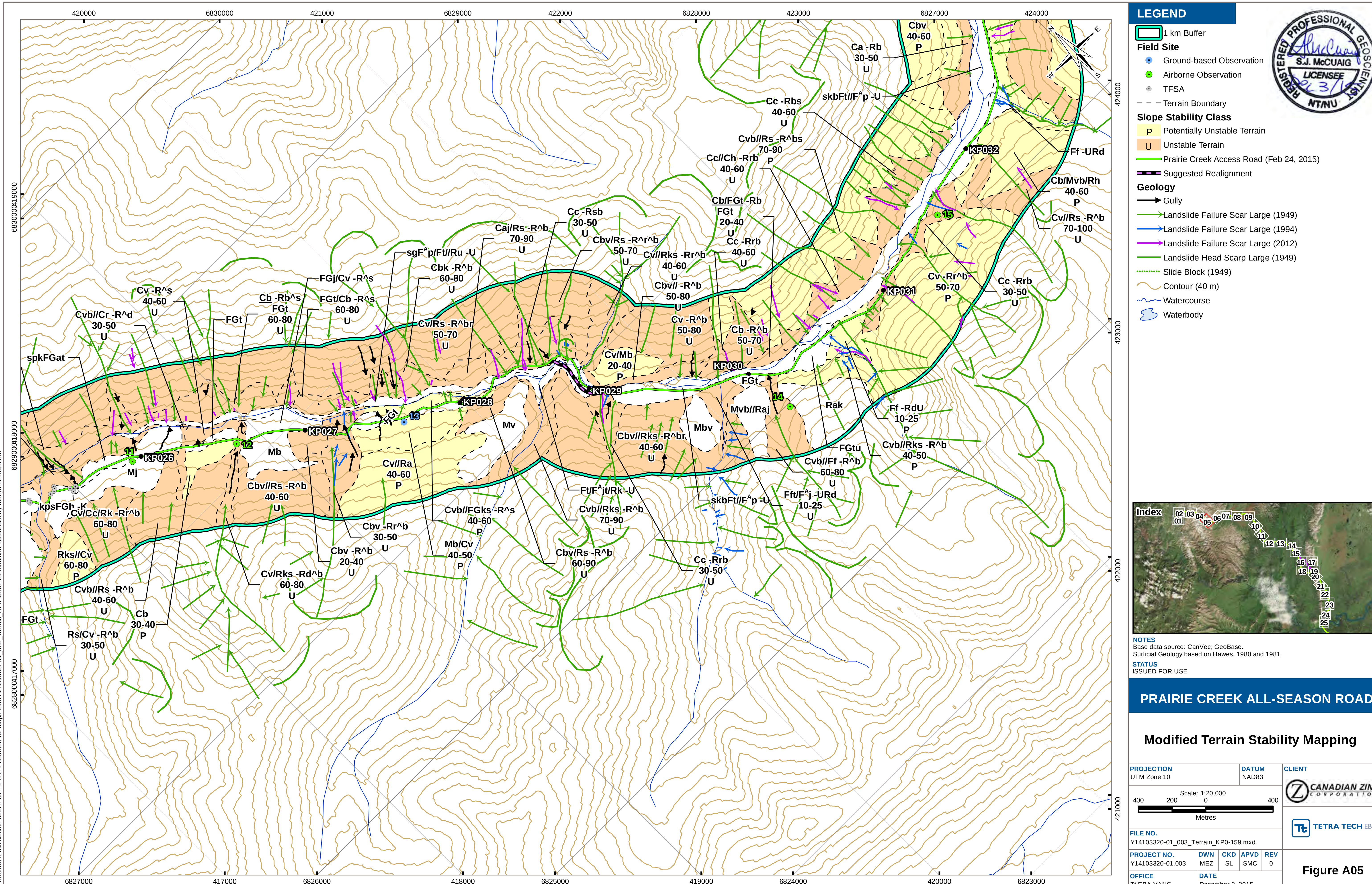
Figure A04



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_KP0-159.mxd

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

OFFICE	DATE
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Figure A05

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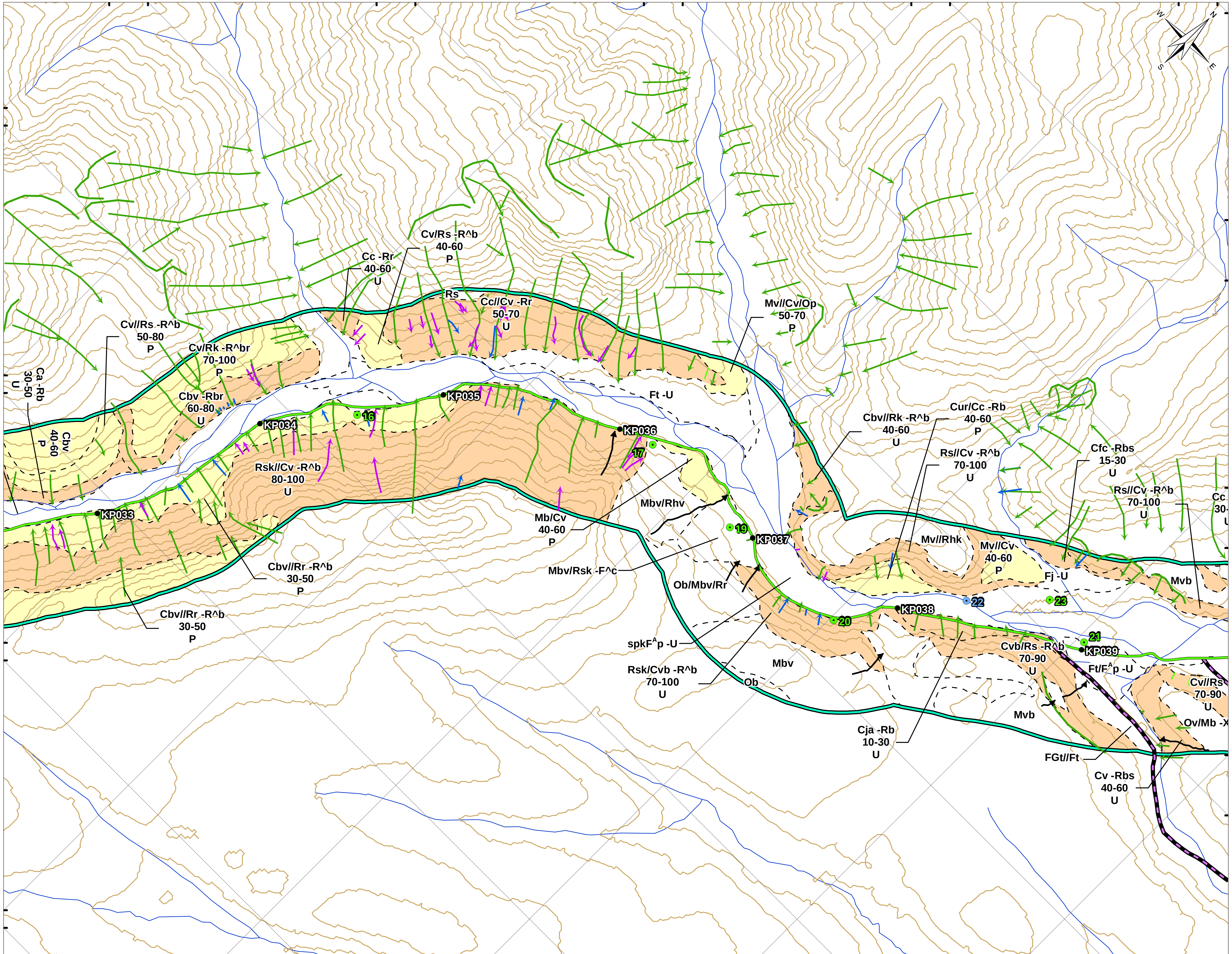

LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

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

Geology

- Gully
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1994)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- River Position (1949)
- Contour (40 m)
- Watercourse
- Waterbody

REGISTERED PROFESSIONAL GEOSCIENTIST
S.J. McCUAIG
LICENSEE
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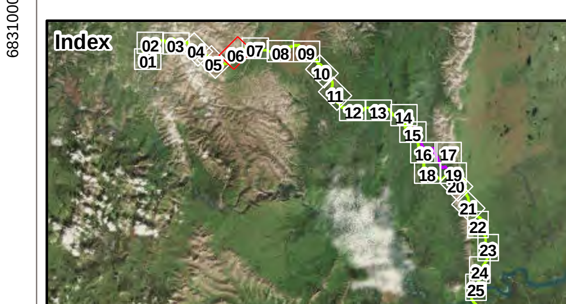

NOTES
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

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_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A06

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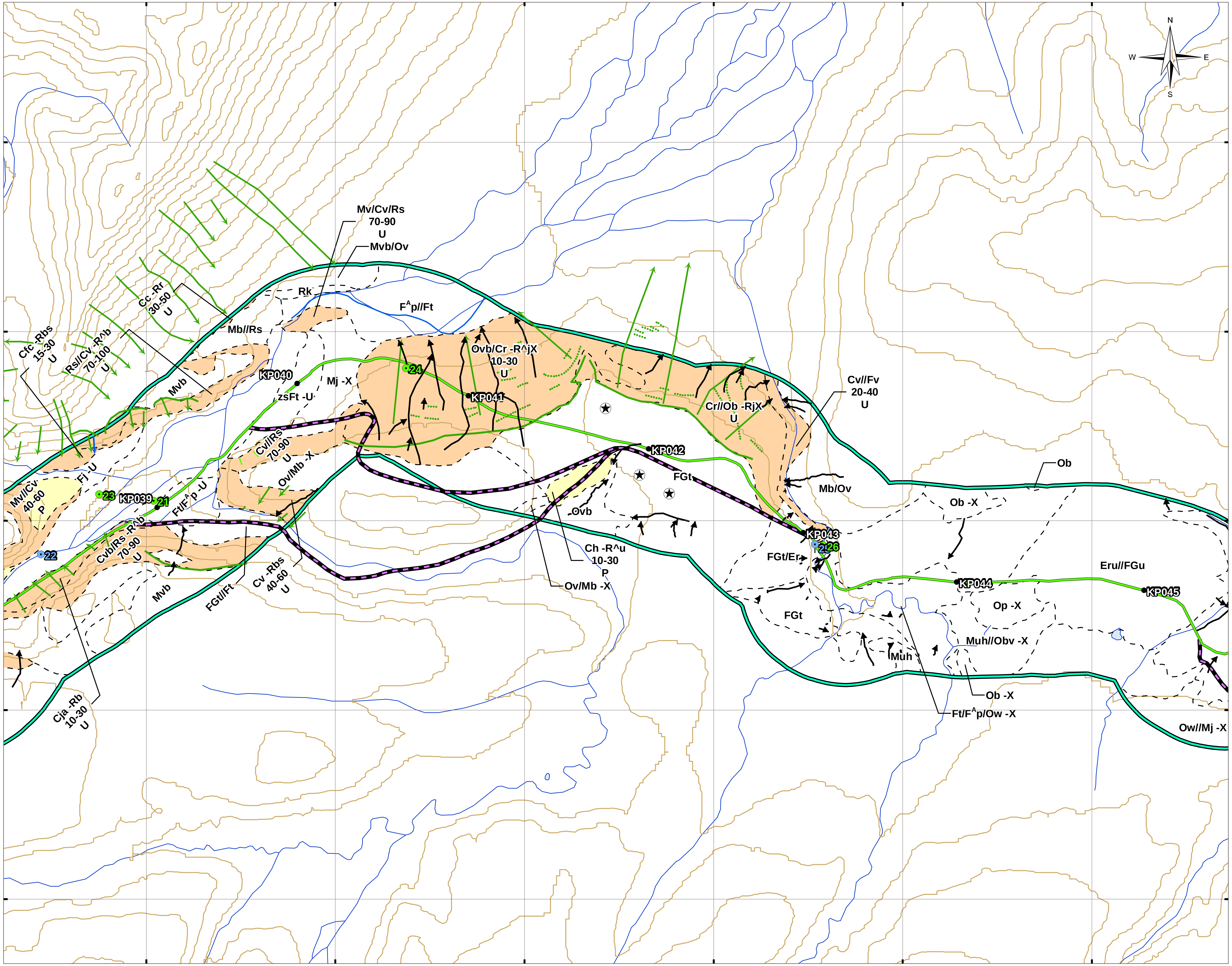

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LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

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

Geology

- Gully
- Possible Sinkhole or Kettle
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1994)
- Landslide Head Scarp Large (1949)
- Slide Block (1949)
- River Position (1949)
- River Position (1994)
- Contour (40 m)
- Watercourse
- Waterbody

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S.J. McCUAIG
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Index

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

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

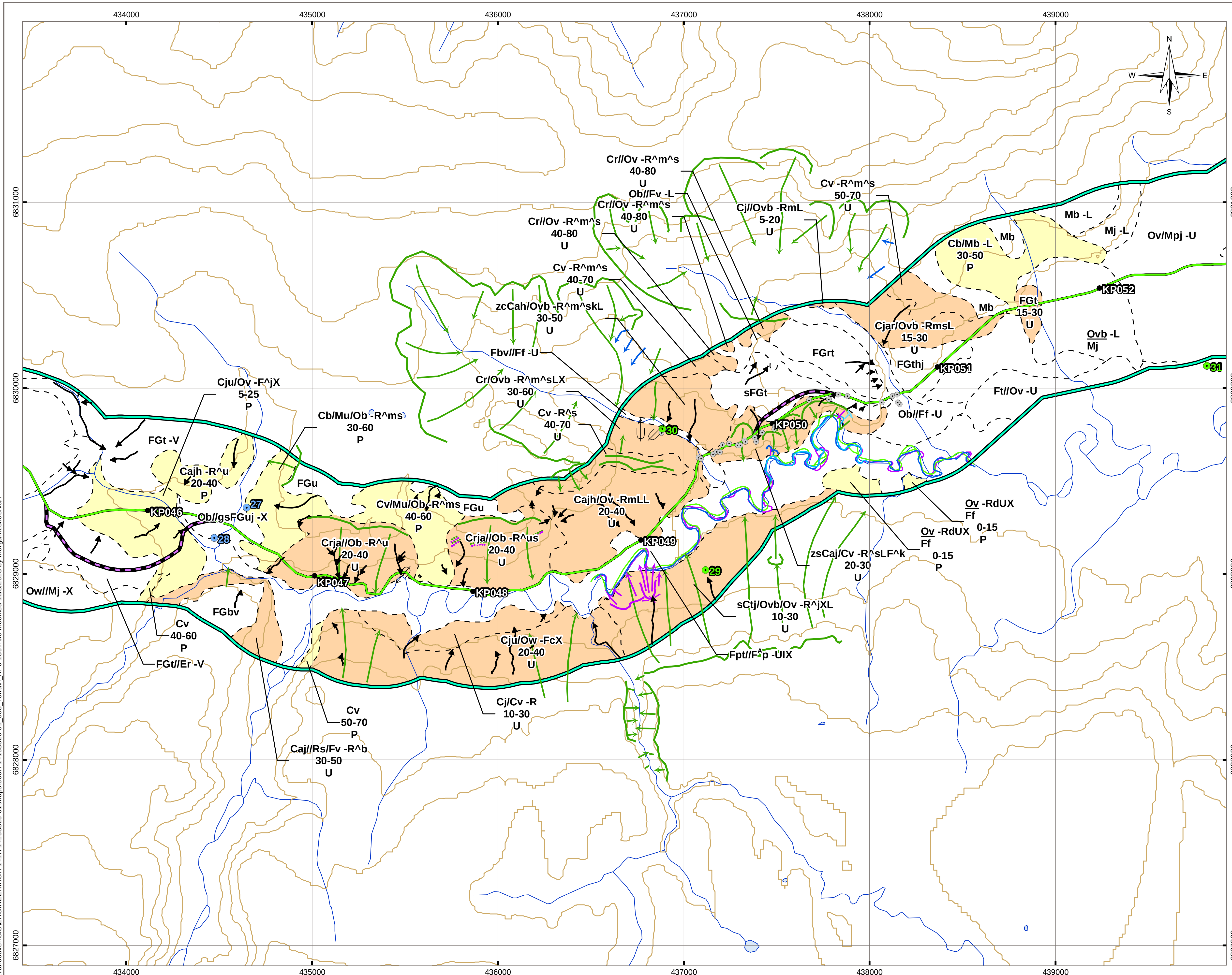
400 200 0 400

Metres

TETRA TECH EBA

FILE NO.				
Y14103320-01_003_Terrain_KP0-159.mxd				
PROJECT NO.	DWN	CKD	APVD	REV
Y14103320-01.003	MEZ	SL	SMC	0
OFFICE	DATE			
Tt EBA-VANC	December 3, 2015			

Figure A07



LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

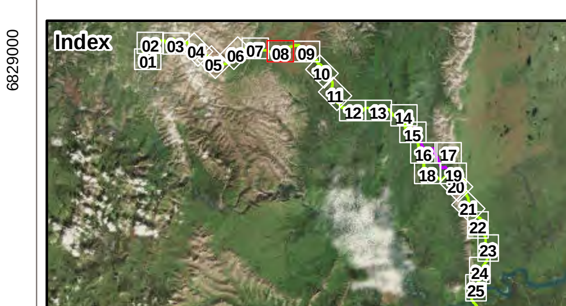
Slope Stability Class

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

Geology

- Gully
- Landslide and Active Layer Failure Scar (small)
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1982)
- Landslide Failure Scar Large (1994)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- Landslide Head Scarp Large (1982)
- Landslide Head Scarp Large (1994)
- Landslide Head Scarp Large (2012)
- Slide Block (1949)
- Slide Block (Post-1994)
- River Position (1949)
- River Position (1982)
- River Position (1994)
- River Position (Post-1994)
- Tension Crack (Post-1994)
- Contour (40 m)
- Watercourse
- Waterbody

Index



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

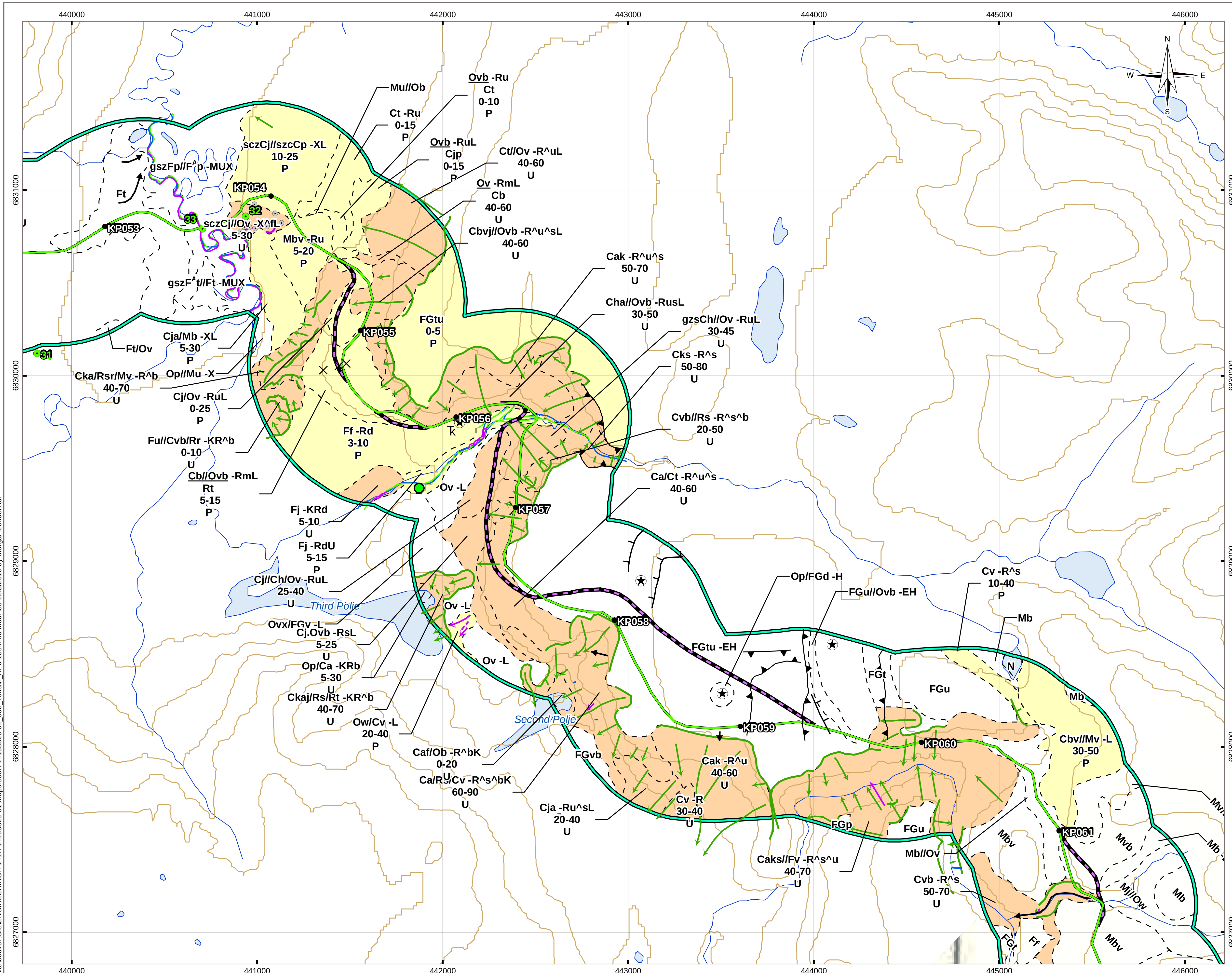
TETRA TECH EBA

FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A08



LEGEND

1 km Buffer

Field Site
- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class
- P Potentially Unstable Terrain
- U Unstable Terrain
- Prairie Creek Access Road (Feb 24, 2015)
- Suggested Realignment

Geology
- Escarpment
- Gully
- Meltwater channel (major)
- Bedrock Outcrop
- Karst Depression
- Possible Sinkhole or Kettle
- Thermokarst Terrain
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1994)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- Landslide Head Scarp Large (1994)
- Landslide Head Scarp Large (2012)
- River Position (1949)
- River Position (1994)
- River Position (Post-1994)
- Contour (40 m)
- Watercourse
- Waterbody

PROFESSIONAL GEOSCIENTIST REGISTERED S.J. McCUAIG LICENSEE Dec 3/15 NT/NU

Index
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A09

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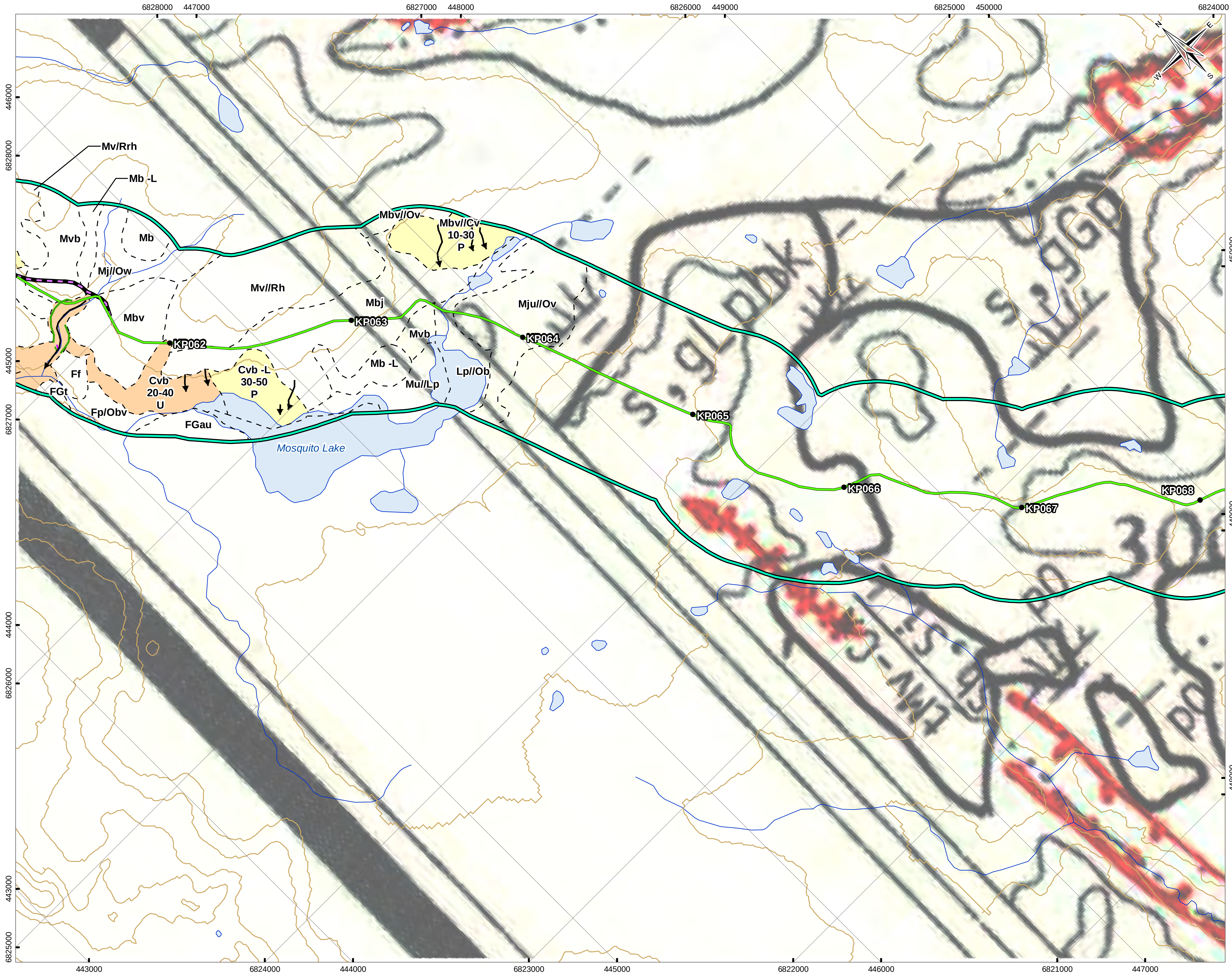

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LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

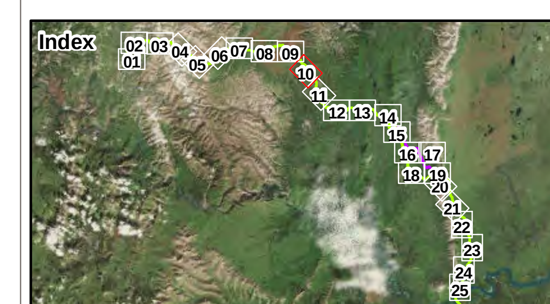
Slope Stability Class

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

Geology

- Gully
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- Contour (40 m)
- Watercourse
- Waterbody

REGISTERED PROFESSIONAL GEOSCIENTIST
S.J. McCUAIG
LICENSEE
Dec 3/15
NT/NU



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: UTM Zone 10
DATUM: NAD83
CLIENT: CANADIAN ZINC CORPORATION

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

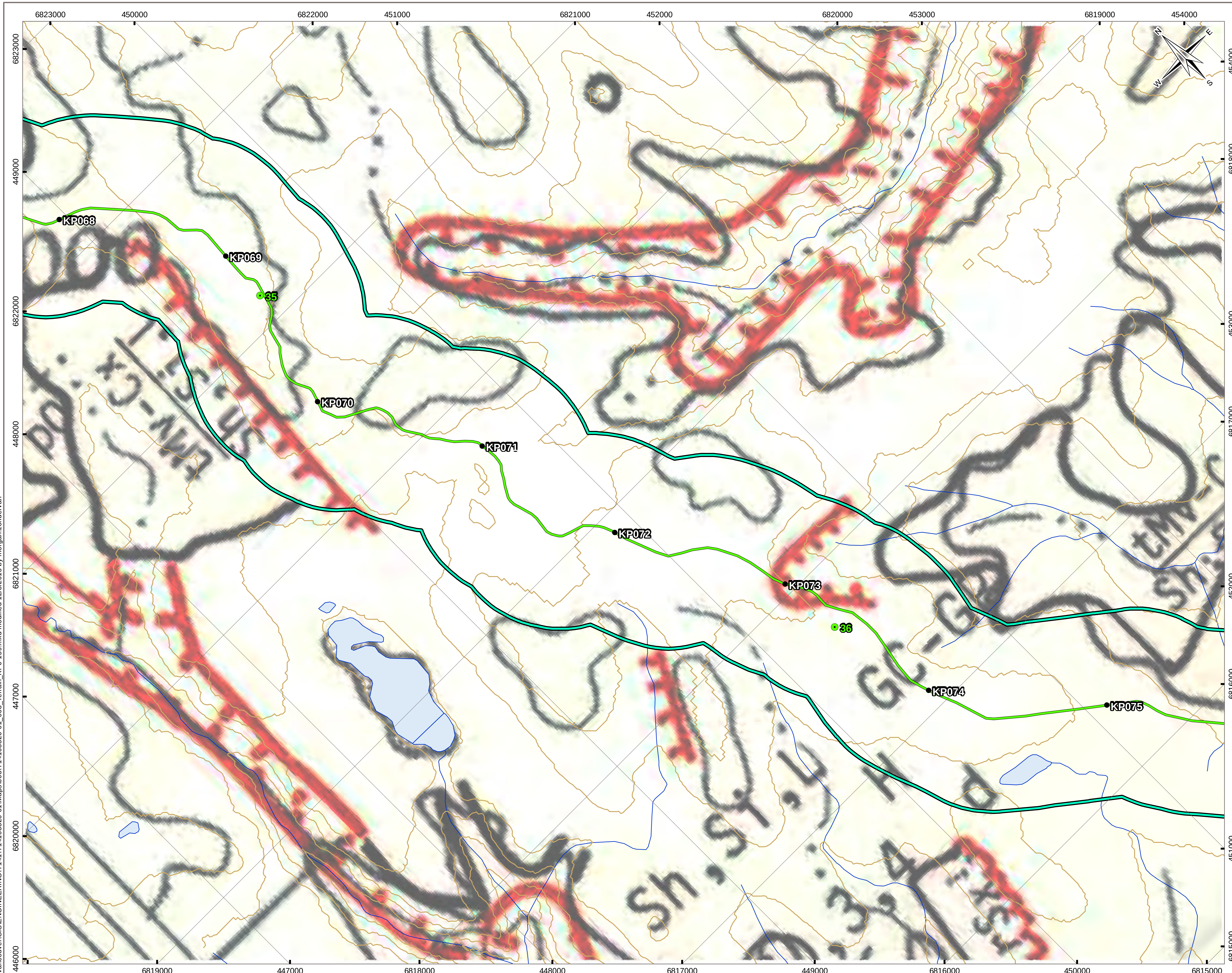
TETRA TECH EBA

FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd

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

OFFICE: Tt EBA-VANC
DATE: December 3, 2015

Figure A10



LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA

Terrain Boundary

Slope Stability Class

- P Potentially Unstable Terrain
- U Unstable Terrain

Prairie Creek Access Road (Feb 24, 2015)

Suggested Realignment

Contour (40 m)

Watercourse

Waterbody

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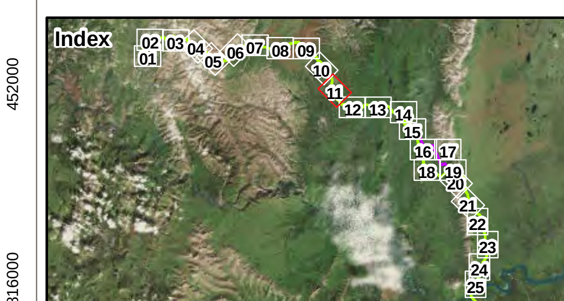


NOTES
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

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

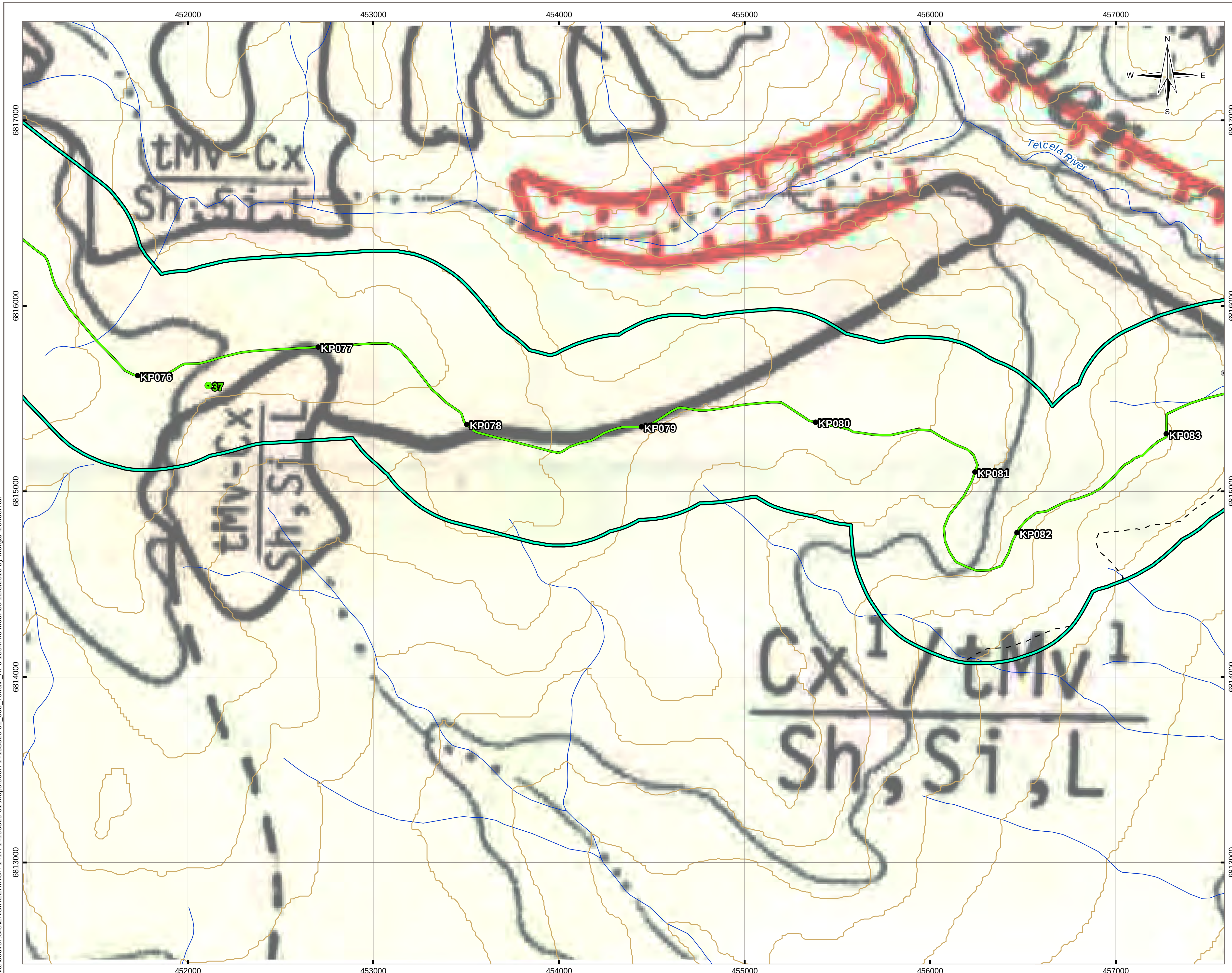
TETRA TECH EBA

FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A11



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LEGEND

- 1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

- P Potentially Unstable Terrain
- U Unstable Terrain
- Prairie Creek Access Road (Feb 24, 2015)
- Suggested Realignment
- Contour (40 m)
- Watercourse
- Waterbody

REGISTERED PROFESSIONAL GEOSCIENTIST
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LICENSEE
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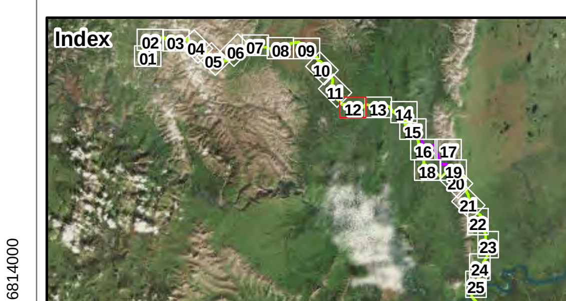
NT/NU



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

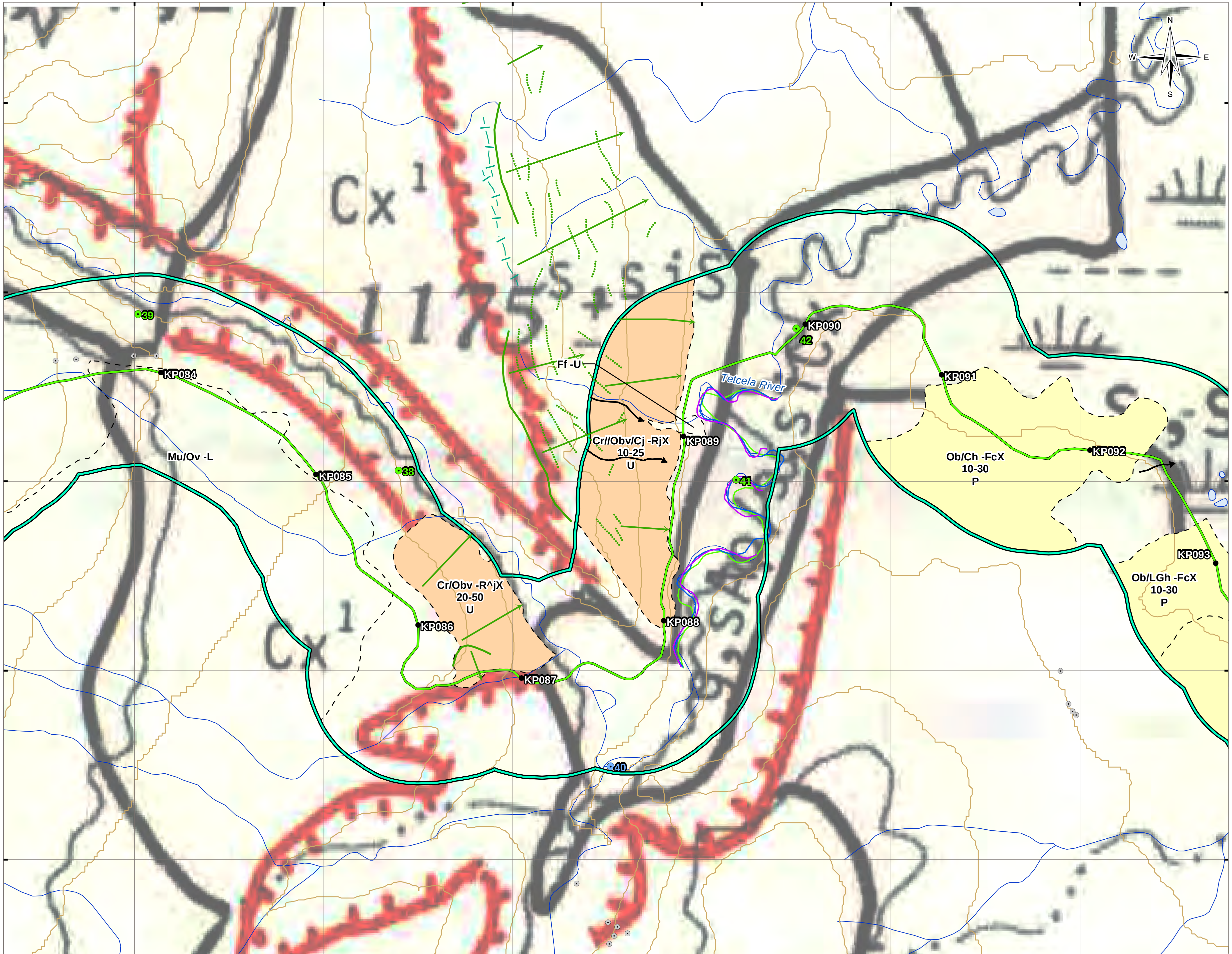
TETRA TECH EBA

FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A12



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LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

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

Geology

- Gully
- Landslide Failure Scar Large (1949)
- Landslide Head Scarp Large (1949)
- Slide Block (1949)
- River Position (1949)
- River Position (1994)
- River Position (Post-1994)
- Tension Crack (1949)
- Contour (40 m)
- Watercourse
- Waterbody

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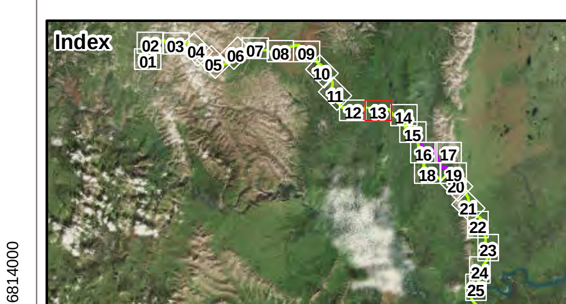
NT/NU



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

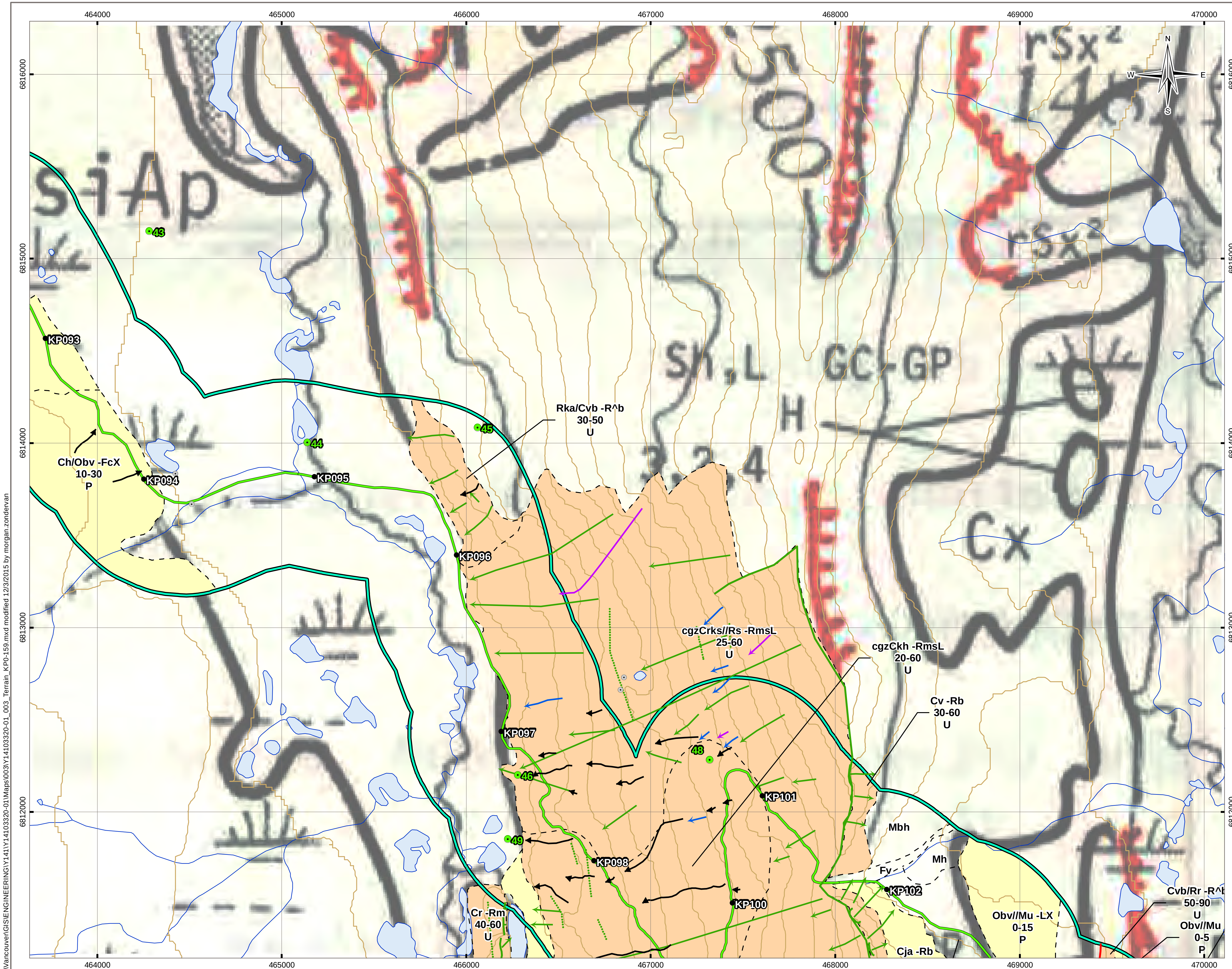
TETRA TECH EBA

FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A13



LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

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

Geology

- Gully
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1994)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- Landslide Head Scarp Large (1962)
- Slide Block (1949)
- Contour (40 m)
- Watercourse
- Waterbody

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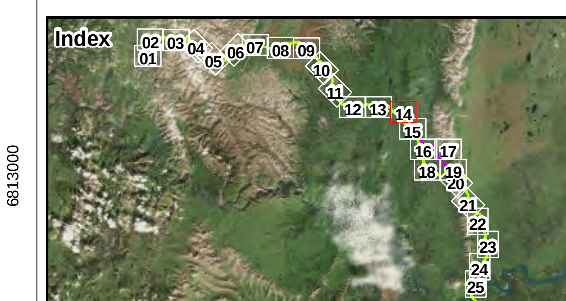


NOTES
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

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

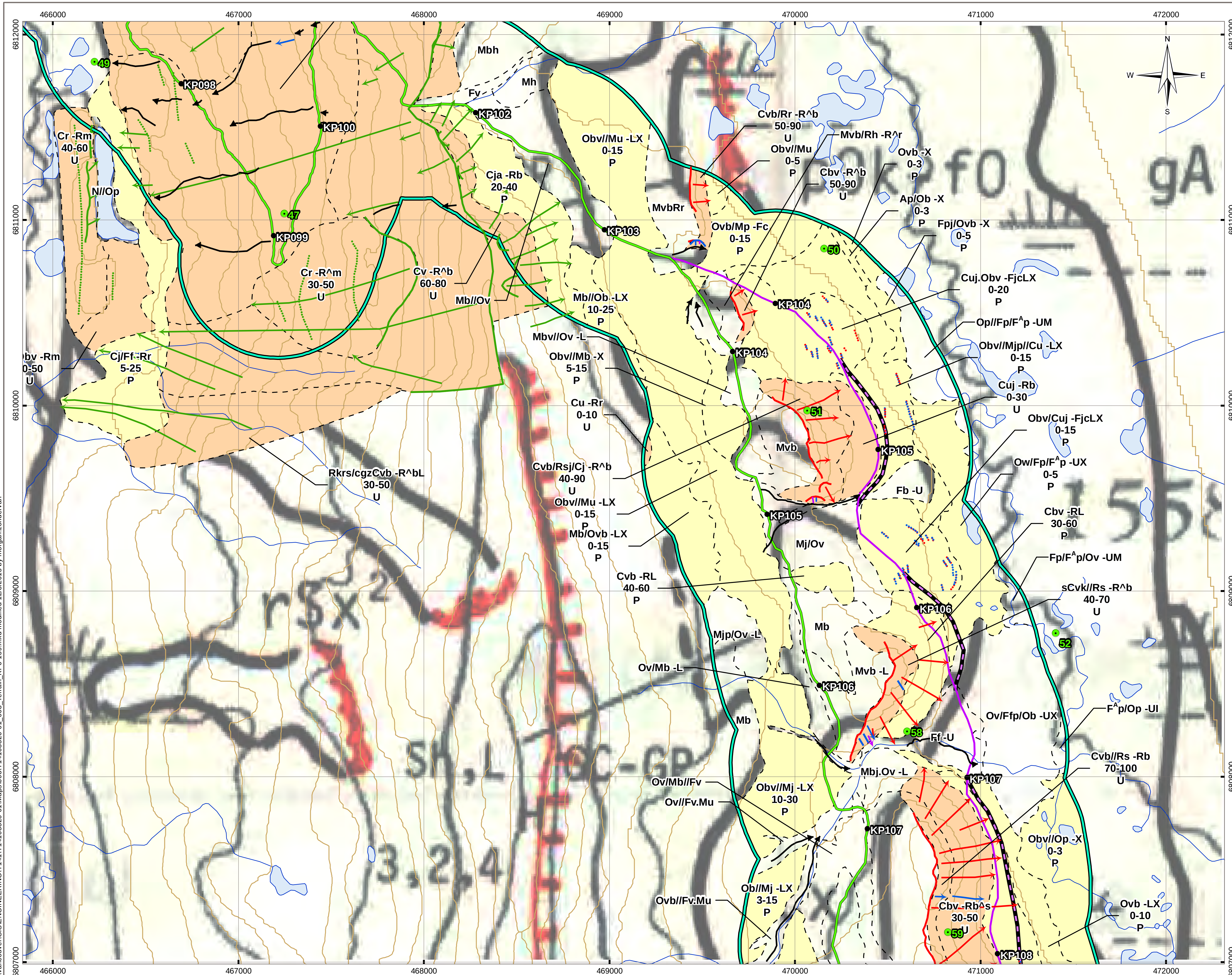
TETRA TECH EBA

FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A14



LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

- P Potentially Unstable Terrain
- U Unstable Terrain
- Prairie Creek Access Road (Feb 24, 2015)
- Alternative Alignment (July 30, 2015)
- Suggested Realignment

Geology

- Gully
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1962)
- Landslide Failure Scar Large (1994)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- Landslide Head Scarp Large (1962)
- Landslide Head Scarp Large (1994)
- Slide Block (1949)
- Slide Block (1962)
- Slide Block (1994)
- Contour (40 m)
- Watercourse
- Waterbody

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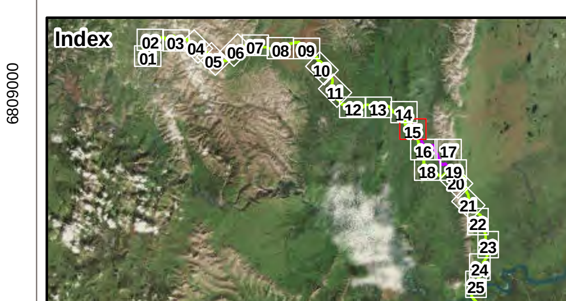
NT/NU



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_KP0-159.mxd				
PROJECT NO.	DWN	CKD	APVD	REV
Y14103320-01.003	MEZ	SL	SMC	0
OFFICE	DATE			
Tt EBA-VANC	December 3, 2015			

Figure A15a

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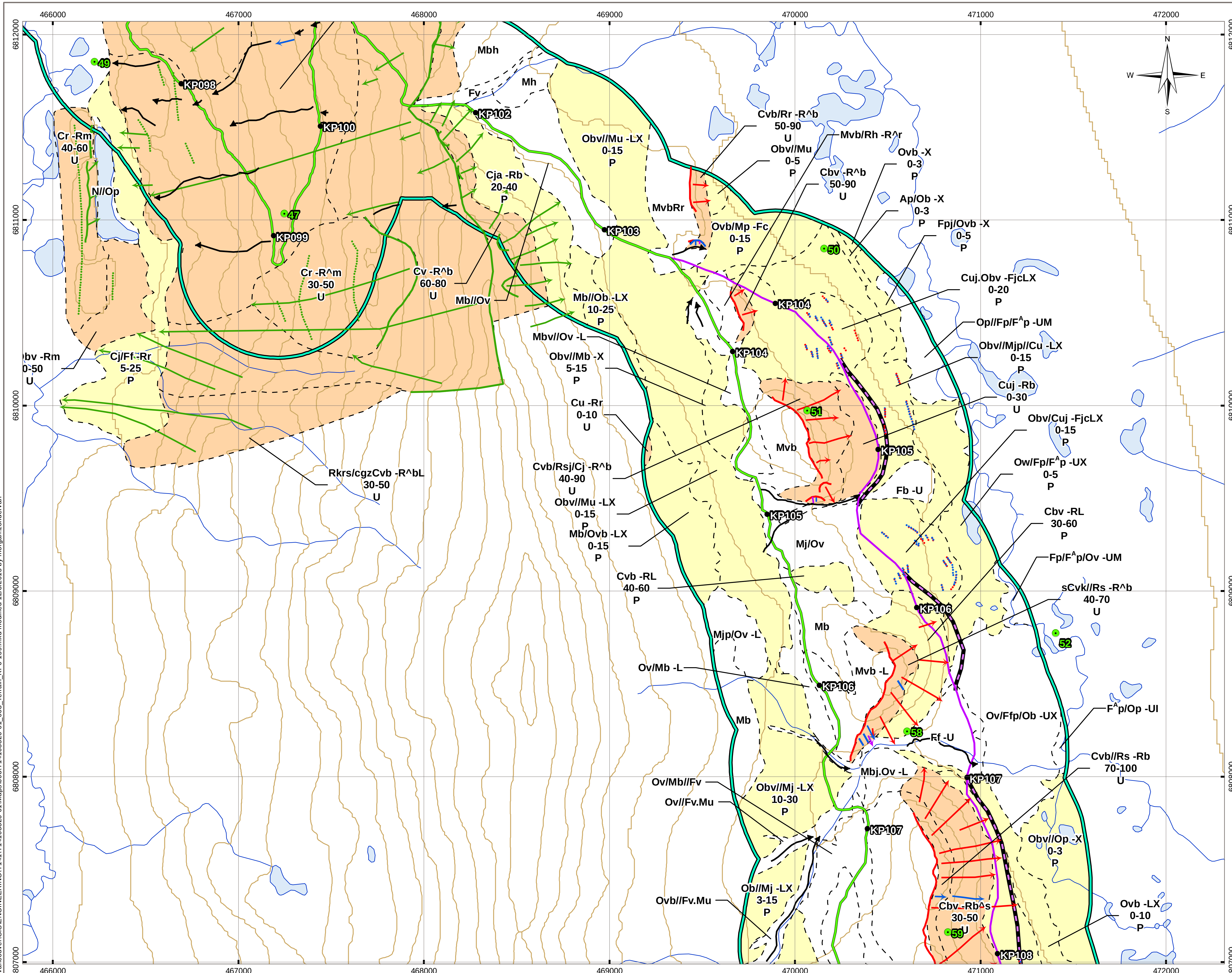

LEGEND

- 1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

- P Potentially Unstable Terrain
- U Unstable Terrain
- Prairie Creek Access Road (Feb 24, 2015)
- Alternative Alignment (July 30, 2015)
- Suggested Realignment

Geology

- Gully
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1962)
- Landslide Failure Scar Large (1994)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- Landslide Head Scarp Large (1962)
- Landslide Head Scarp Large (1994)
- Slide Block (1949)
- Slide Block (1962)
- Slide Block (1994)
- Contour (40 m)
- Watercourse
- Waterbody

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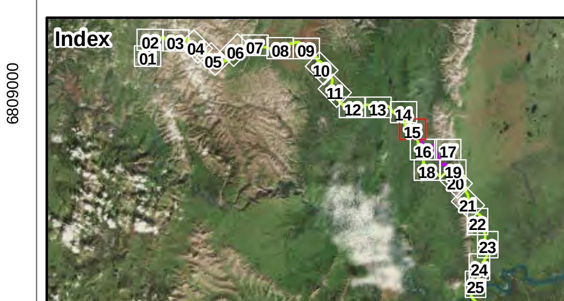

NOTES
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

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_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A15b

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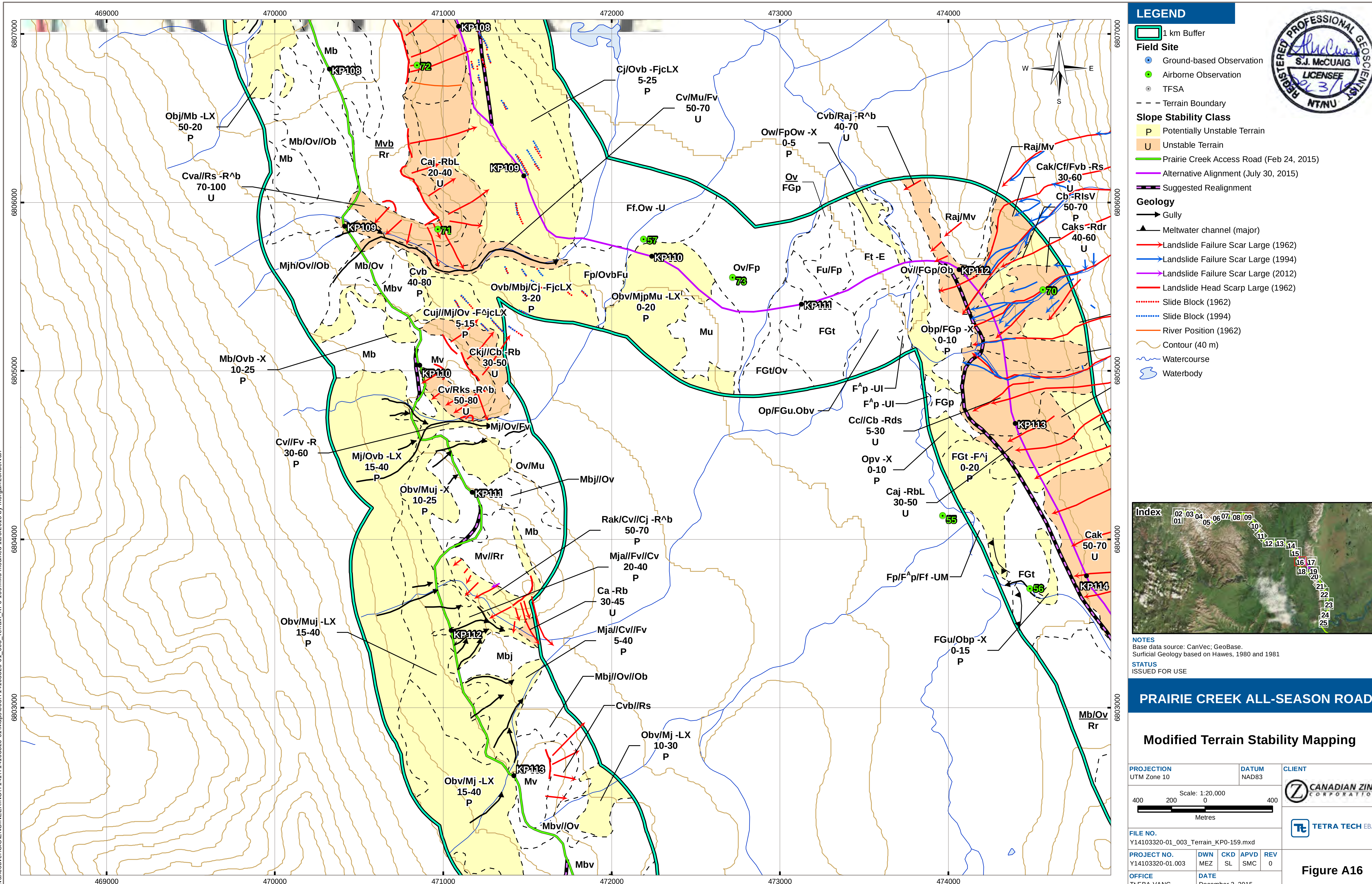

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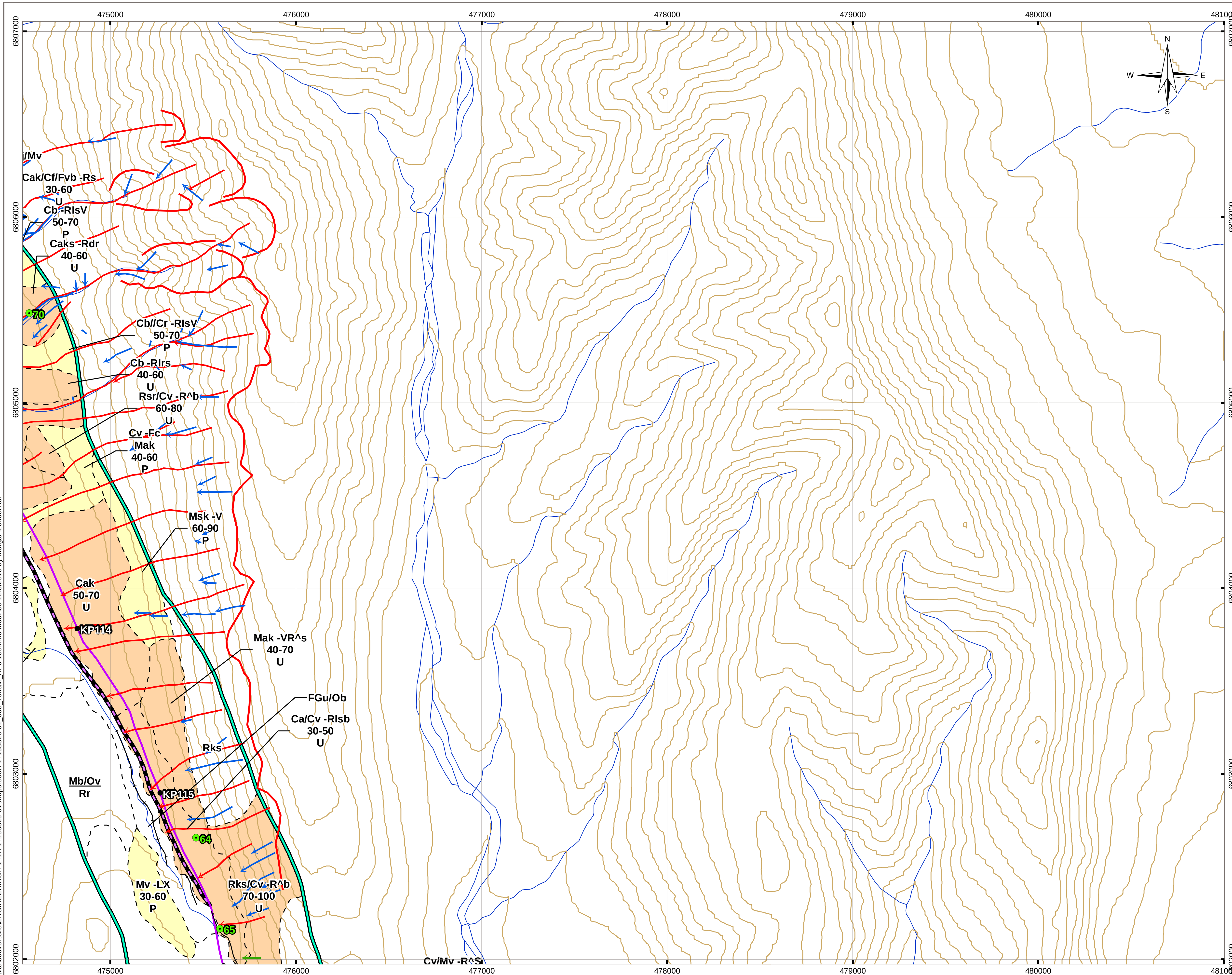

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LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

- P Potentially Unstable Terrain
- U Unstable Terrain
- Prairie Creek Access Road (Feb 24, 2015)
- Alternative Alignment (July 30, 2015)
- Suggested Realignment

Geology

- Meltwater channel (minor)
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1962)
- Landslide Failure Scar Large (1994)
- Landslide Head Scarp Large (1962)
- Contour (40 m)
- Watercourse
- Waterbody

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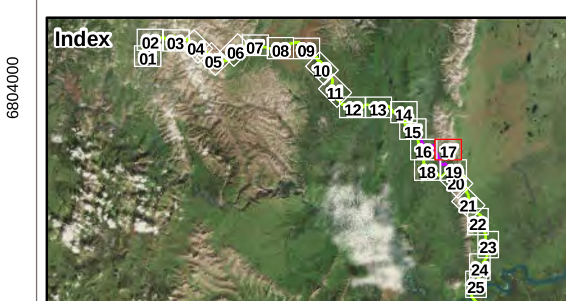
LICENSEE
Dec 3/15
NT/NU



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

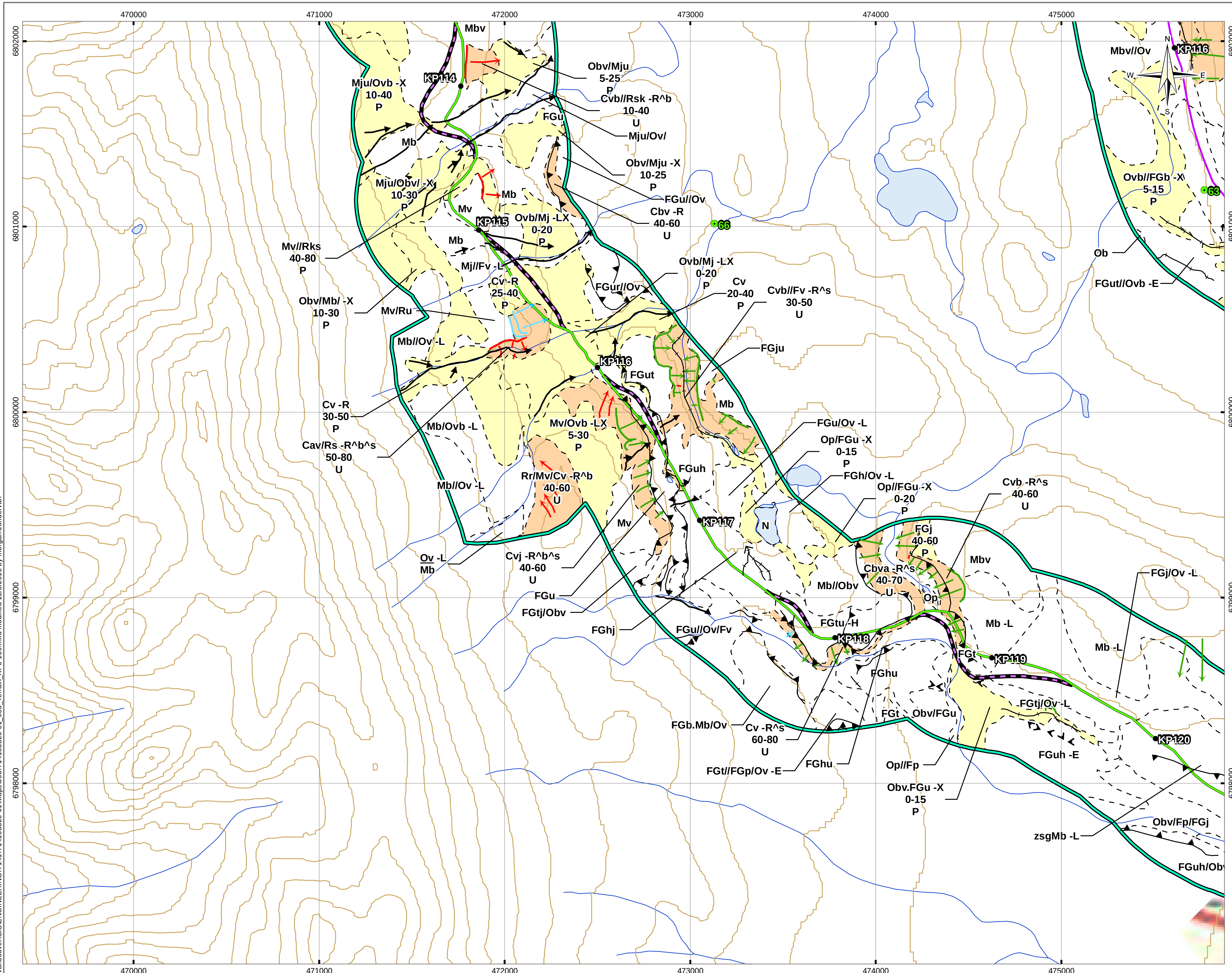
TETRA TECH EBA

FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A17



LEGEND

- 1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

- P Potentially Unstable Terrain
- U Unstable Terrain
- Prairie Creek Access Road (Feb 24, 2015)
- Alternative Alignment (July 30, 2015)
- Suggested Realignment

Geology

- Esker, direction of paleoflow unknown
- Gully
- Meltwater channel (major)
- Meltwater channel (minor)
- Meltwater channel (minor, flow indicated)
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1962)
- Landslide Failure Scar Large (1982)
- Landslide Head Scarp Large (1949)
- Landslide Head Scarp Large (1962)
- Landslide Head Scarp Large (1982)
- Contour (40 m)
- Watercourse
- Waterbody

REGISTERED PROFESSIONAL GEOSCIENTIST
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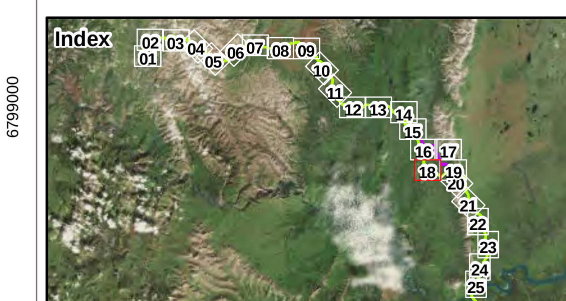

NOTES
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

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_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A18

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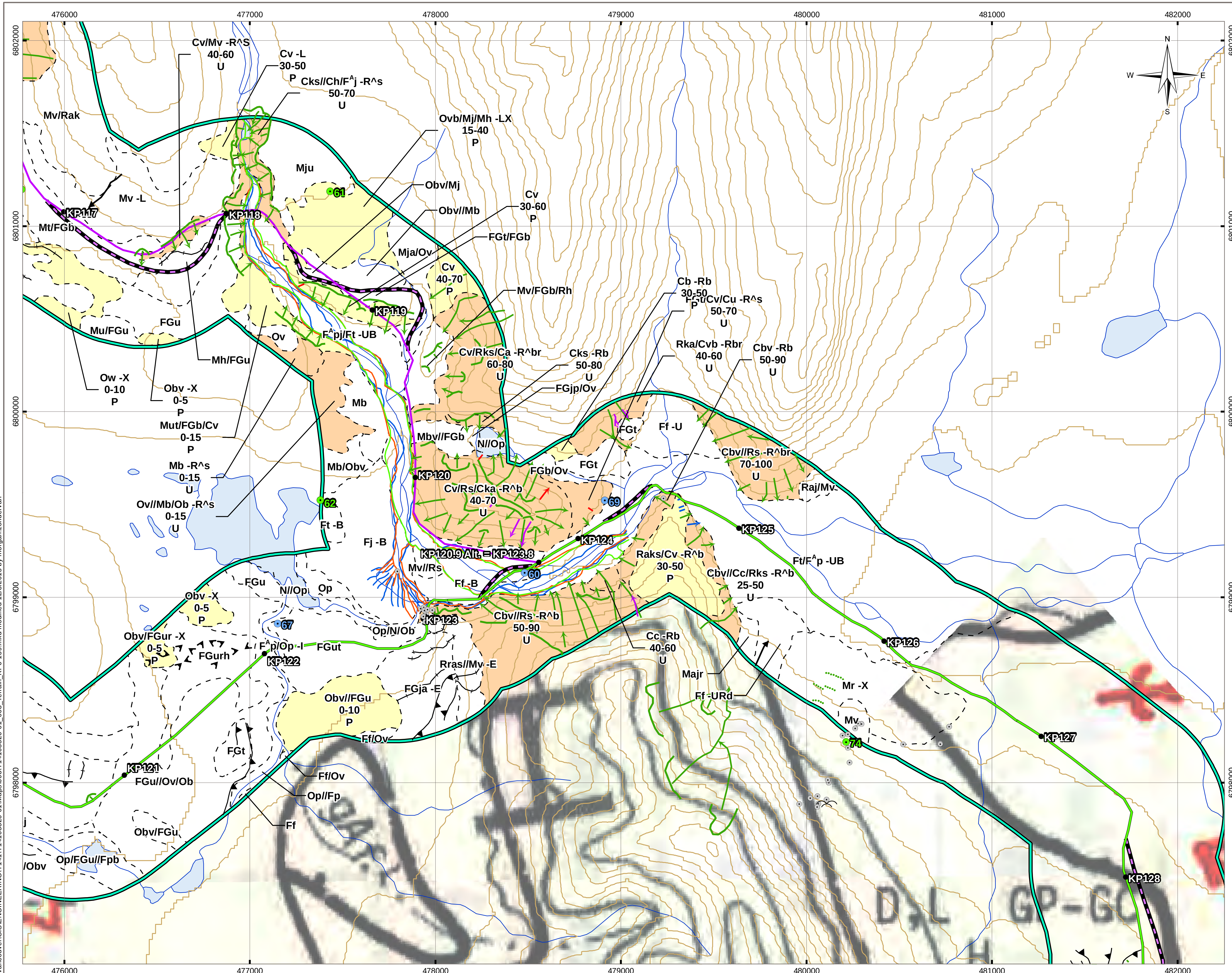

LEGEND

- 1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

- P Potentially Unstable Terrain
- U Unstable Terrain
- Prairie Creek Access Road (Feb 24, 2015)
- Alternative Alignment (July 30, 2015)
- Suggested Realignment

Geology

- Esker, direction of paleoflow unknown
- Gully
- Meltwater channel (major)
- Meltwater channel (minor)
- Relic Patterned Ground
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1962)
- Landslide Failure Scar Large (1994)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- Slide Block (1949)
- River Position (1949)
- River Position (1962)
- River Position (1994)
- Contour (40 m)
- Watercourse
- Waterbody

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LICENSEE
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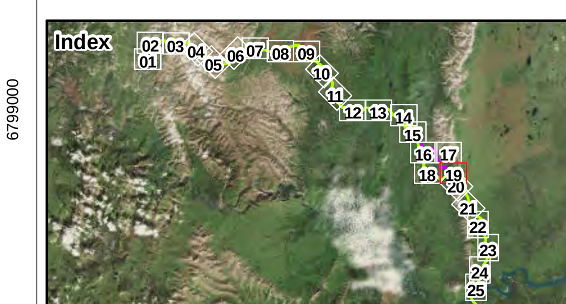

NOTES
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

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_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A19

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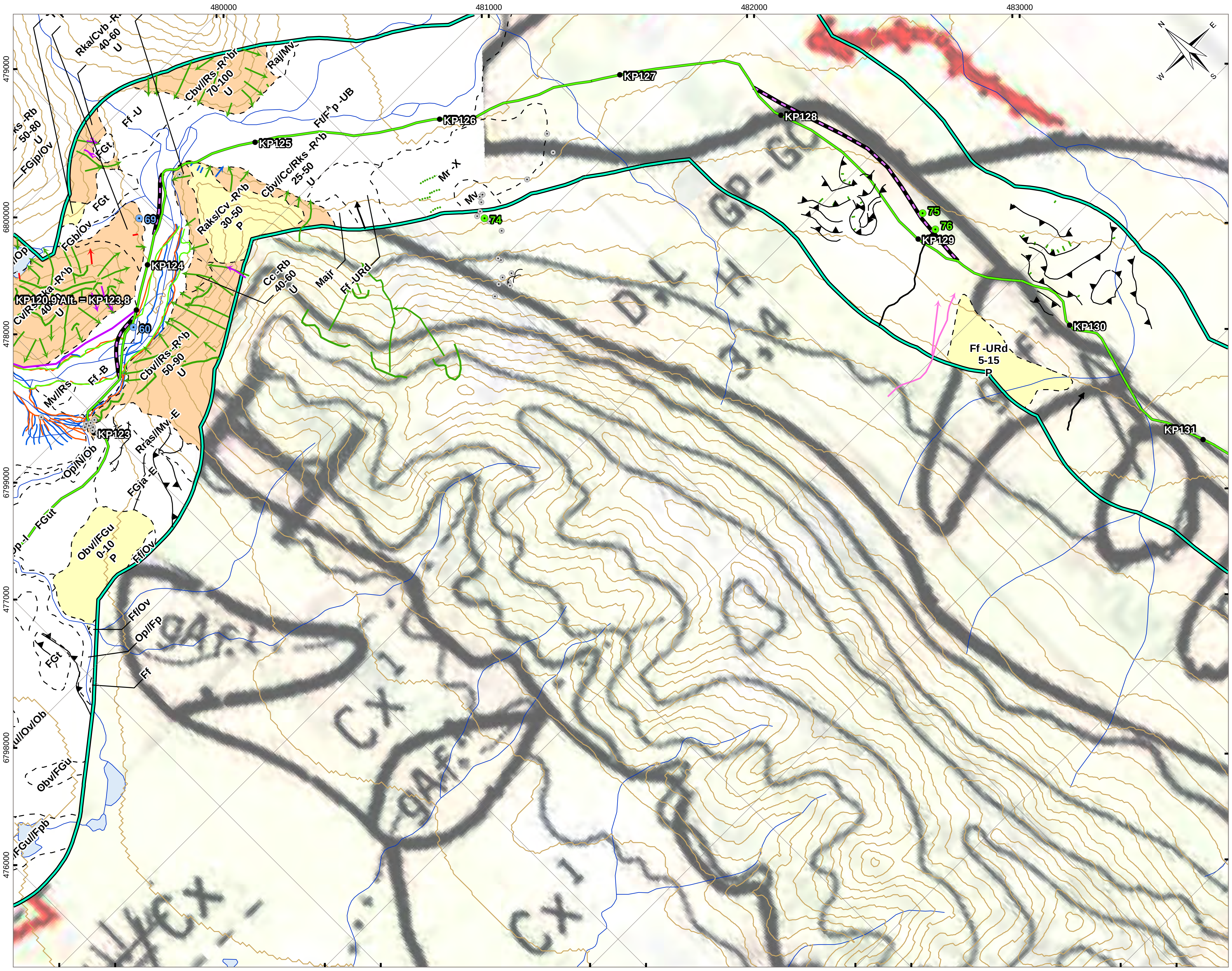

LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

- P Potentially Unstable Terrain
- U Unstable Terrain
- Prairie Creek Access Road (Feb 24, 2015)
- Alternative Alignment (July 30, 2015)
- Suggested Realignment

Geology

- Gully
- Meltwater channel (major)
- Meltwater channel (minor)
- Relic Patterned Ground
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (1962)
- Landslide Failure Scar Large (1971)
- Landslide Failure Scar Large (1994)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- Slide Block (1949)
- River Position (1949)
- River Position (1962)
- River Position (1994)
- Contour (40 m)
- Watercourse
- Waterbody

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Index

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

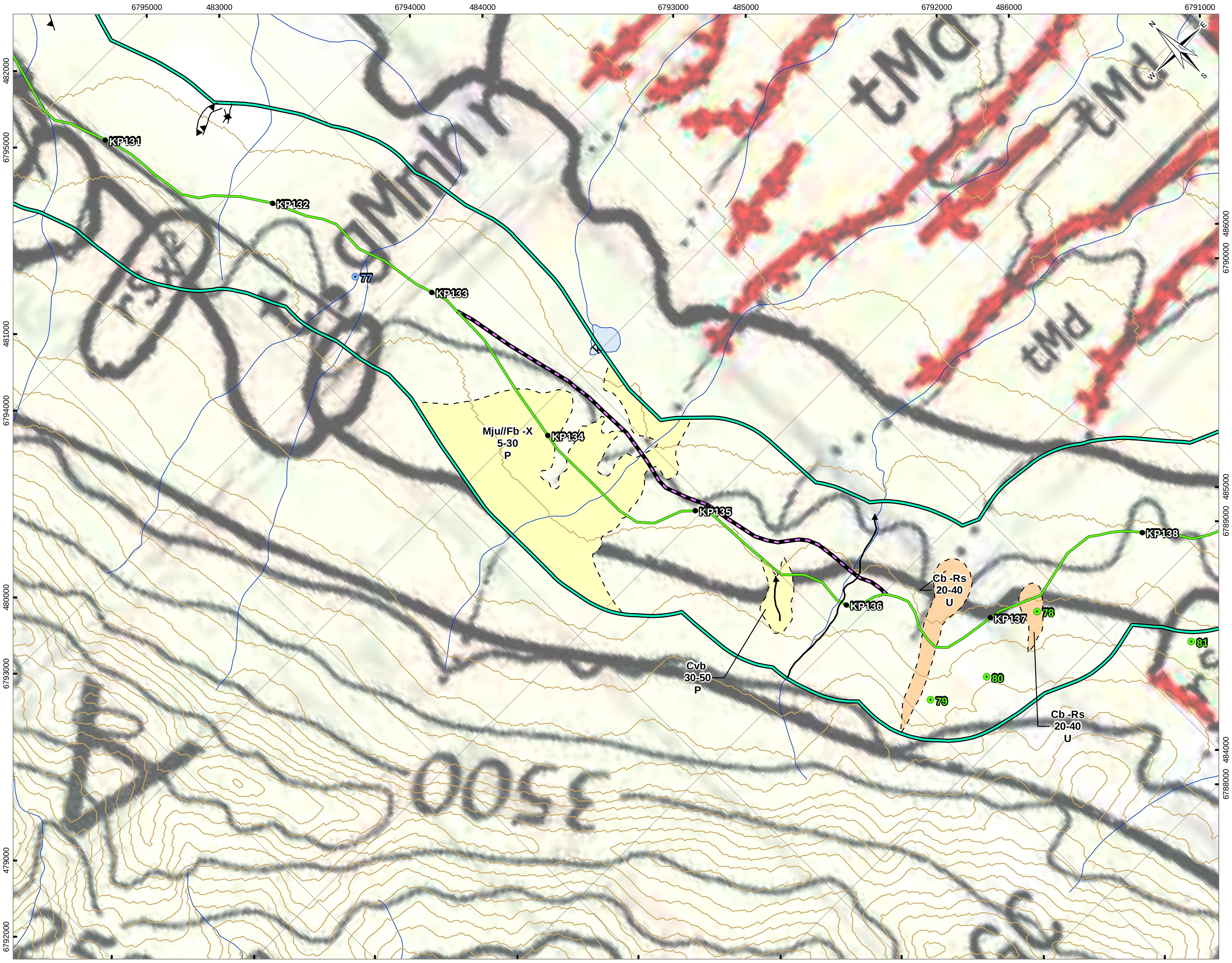
Scale: 1:20,000
400 200 0 400
Metres

TETRA TECH EBA

FILE NO.				
Y14103320-01_003_Terrain_KP0-159.mxd				
PROJECT NO.	DWN	CKD	APVD	REV
Y14103320-01.003	MEZ	SL	SMC	0
OFFICE	DATE			
Tt EBA-VANC	December 3, 2015			

Figure A20

Q:\Vancouver\GIS\ENGINEERING\Y141\Y14103320-01\Maps\003\Y14103320-01_003_Terrain_KP0-159.mxd modified 12/3/2015 by morgan.zondervan



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LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

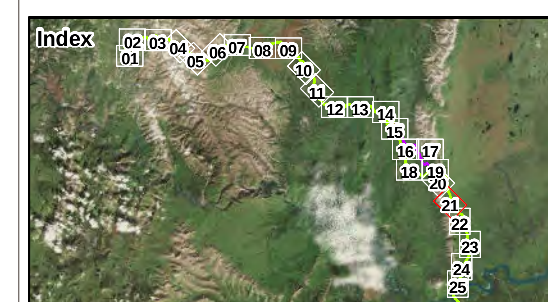
Slope Stability Class

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

Geology

- Gully
- Meltwater channel (major)
- Thermokarst Terrain
- Contour (40 m)
- Watercourse
- Waterbody

REGISTERED PROFESSIONAL GEOSCIENTIST
S.J. McCUAIG
LICENSEE
NT/NU



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

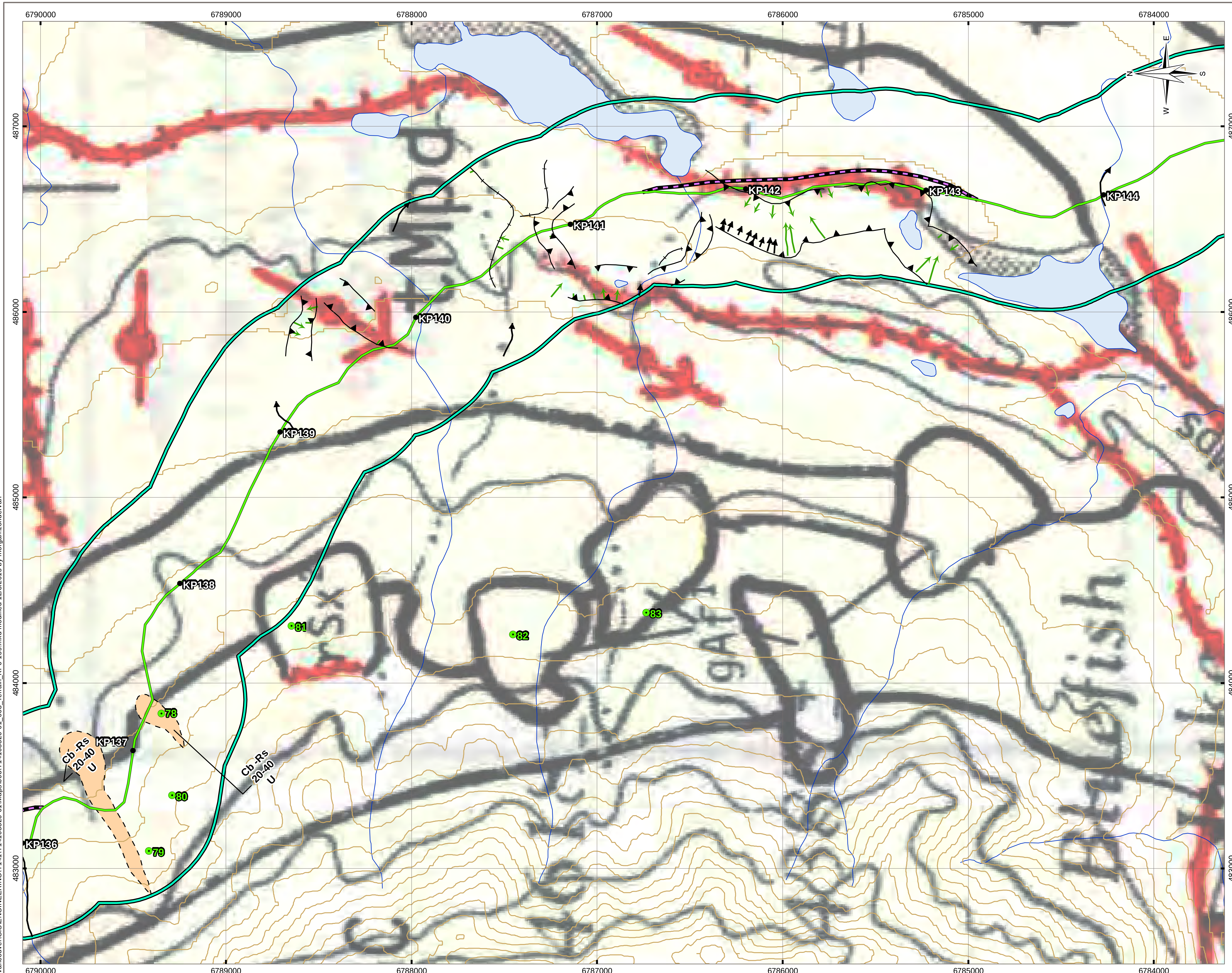
TETRA TECH EBA

FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A21



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LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

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

Geology

- Gully
- Meltwater channel (major)
- Meltwater channel (minor)
- Landslide Failure Scar Large (1949)
- Contour (40 m)
- Watercourse
- Waterbody

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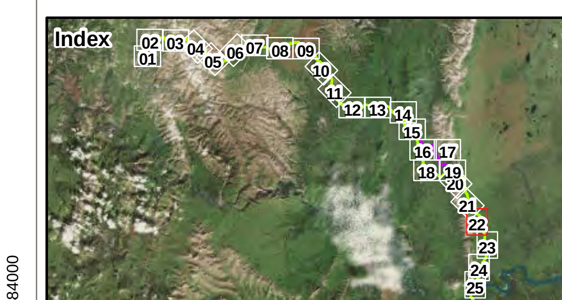


NOTES
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

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

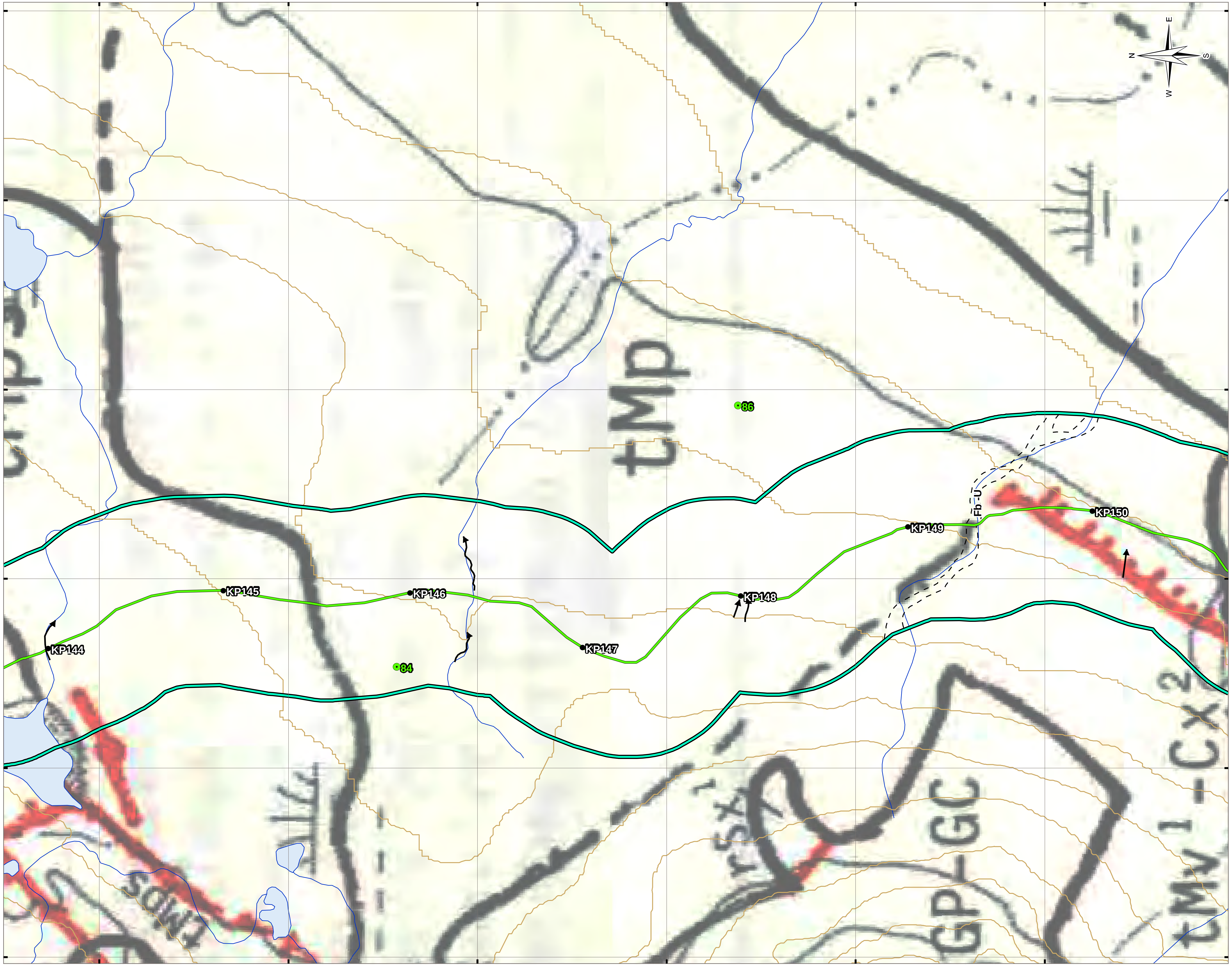
TETRA TECH EBA

FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A22



LEGEND

- 1 km Buffer
- **Field Site**
  - Ground-based Observation
  - Airborne Observation
  - TFSA
- Terrain Boundary
- **Slope Stability Class**
  - P Potentially Unstable Terrain
  - U Unstable Terrain
- Prairie Creek Access Road (Feb 24, 2015)
- Suggested Realignment
- **Geology**
  - Gully
  - Contour (40 m)
  - Watercourse
  - Waterbody

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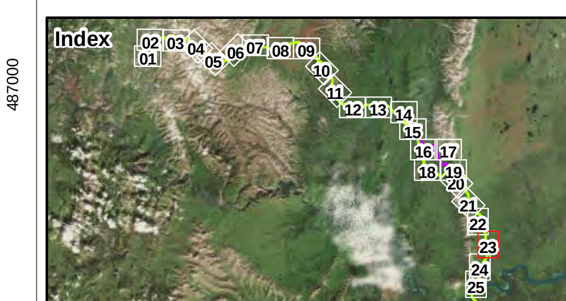


NOTES
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

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

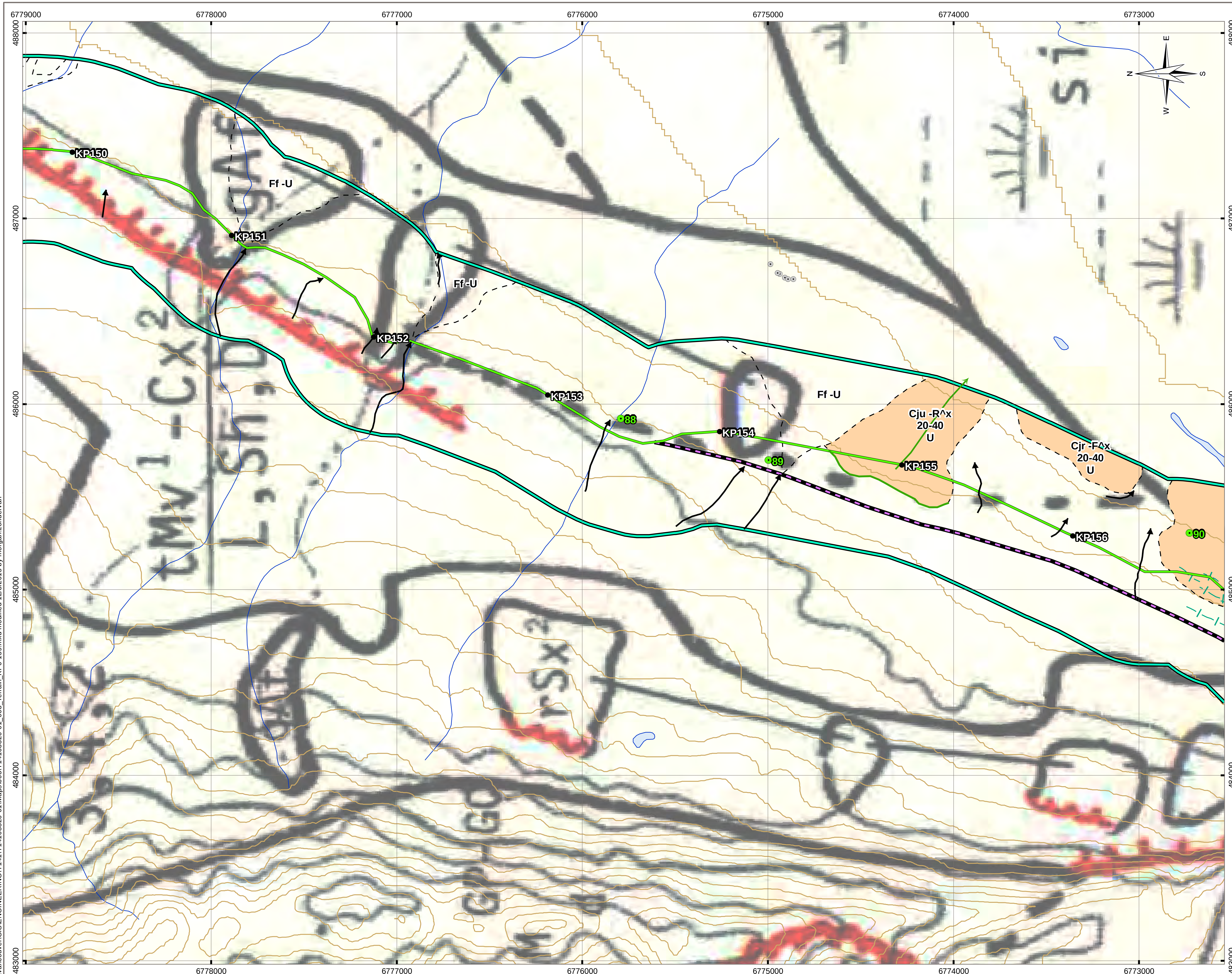
FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A23

Q:\Vancouver\GIS\ENGINEERING\Y141\Y14103320-01\Maps\003\Y14103320-01_003_Terrain_KP0-159.mxd modified 12/3/2015 by morgan.zondervan



LEGEND

1 km Buffer

Field Site
- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class
- P Potentially Unstable Terrain
- U Unstable Terrain
- Prairie Creek Access Road (Feb 24, 2015)
- Suggested Realignment

Geology
- Gully
- Landslide Failure Scar Large (1949)
- Landslide Head Scarp Large (1949)
- Tension Crack (1949)
- Contour (40 m)
- Watercourse
- Waterbody

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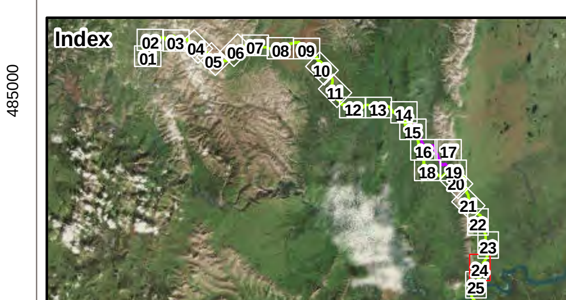


NOTES
Base data source: CanVec; GeoBase.
Surficial Geology based on Hawes, 1980 and 1981

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

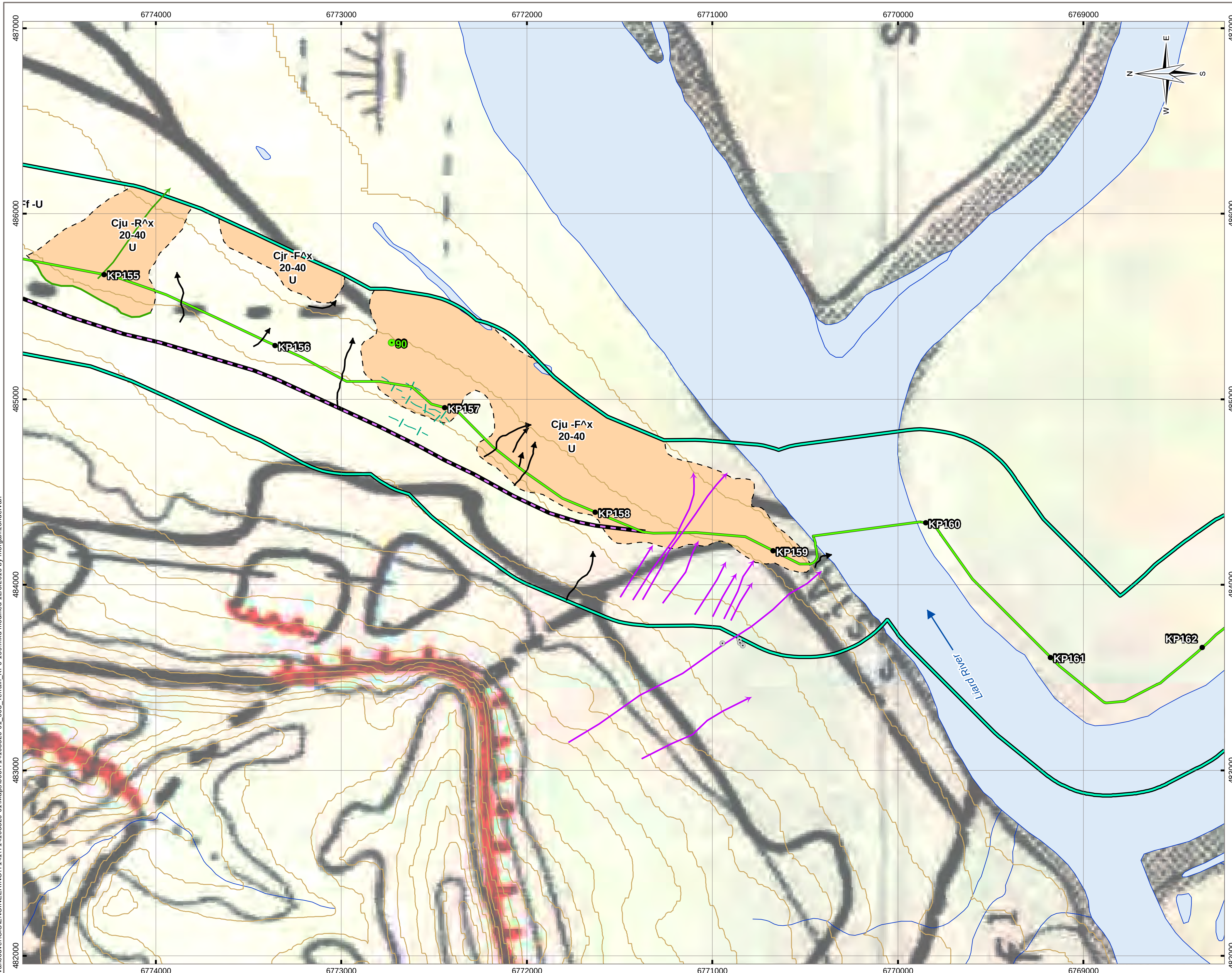
FILE NO.
Y14103320-01_003_Terrain_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A24

Q:\Vancouver\GIS\ENGINEERING\Y141\Y14103320-01\Maps\003\Y14103320-01_003_Terrain_KP0-159.mxd modified 12/3/2015 by morgan.zondervan



Q:\Vancouver\GIS\ENGINEERING\Y141\Y14103320-01\Maps\003\Y14103320-01_003_Terrain_KP0-159.mxd modified 12/3/2015 by morgan.zondervan

LEGEND

1 km Buffer

Field Site

- Ground-based Observation
- Airborne Observation
- TFSA
- Terrain Boundary

Slope Stability Class

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

Geology

- Gully
- Landslide Failure Scar Large (1949)
- Landslide Failure Scar Large (2012)
- Landslide Head Scarp Large (1949)
- Tension Crack (1949)
- Contour (40 m)
- Watercourse
- Waterbody

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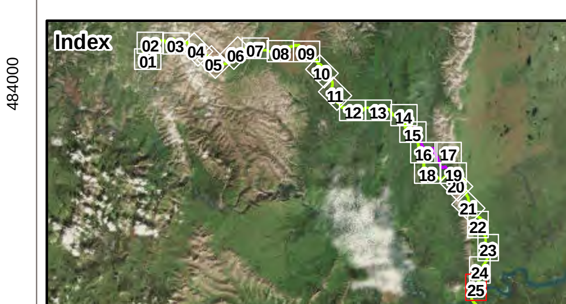
NT/NU



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_KP0-159.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure A25

APPENDIX B
LEGEND

TERRAIN STABILITY LEGEND

TERRAIN SYMBOL

TEXTURE QUALIFIERS

sgFGt-F

SURFICIAL MATERIAL GEOMORPHOLOGICAL PROCESS

SURFACE EXPRESSION

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 gFt	veneer of eolian silt overlying terraced fluvial gravels
	Mh gFGp	hummocky morainal materials overlying glaciofluvial gravels
	/sEv 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

TETRA TECH EBA

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)

RUTTER AND BOYDELL SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAP LEGEND

LEGEND

Note: Some map units and symbols shown in the legend may not appear on this map
Symbols are printed in red on the face of the map and may form geological boundaries

Rock outcrop... ×

Geological boundary (defined or approximate, assumed or transitional)..........

End or lateral moraine...

Crevasse fillings, moraine ridges...

Drumlinoid ridges, striae, flutings (direction of ice movement known, unknown)..........

Ice gouge...

Esker (direction of flow known, unknown).................................... <<<<<<< ><><><

Beach ridge (depositional, erosional)..

Meltwater channel (large, small)..

Landslide scar...

Escarpment..

Sinkhole...

Area of potential slumping...

Patterned ground...

Rock glacier...(R.G.)

MAP UNIT DESIGNATION

A combination of letters is used to designate each map unit or component of a compound map unit, e.g. gAf. The upper case letter indicates the broad genetic class; the lower case letter (s) that follows indicates morphology; the lower case letter (s) in front of the genetic classification describes texture. A number superscript is used to indicate class of slope, e.g. tMp' is used for ground moraine with slope 2^{o}-5^{o}

Textural Modifier (placed in front of genetic category)	Genetic Classification	Morphologic Modifier (placed after genetic category)	
r - rock and rubble	O - organic	p - plain	d - drumlinoid
t - till	A - alluvial	b - beach	c - channelled
g - gravel	C - colluvial	r - ridged	h - hummocky
s - sand	E - eolian	m - rolling	k - thermokarst
si - silt	L - lacustrine	t - terraced	e - eroded
c - clay	G - glaciofluvial	x - complex	f - fan
p - bog	M - morainal	s - striated (i.e., flutings)	v - veneer (<1.5m thick)
f - fen	S - slump		

Number Superscript

1 - gentle slope (2^{o}-5^{o}); 2 - steep slope (5^{o}-15^{o})
- slope is up to 20^{o} in Cx units

Complex Units

- a dash (-) means "with 16-49%" of the following unit (e.g., tMp-pO, pO constitutes 16-49% of the area)
- a slash (/) signifies that the following unit comprises 5-15% of the total area within the boundaries of that complex unit
- a plus (+) indicates the presence of an unknown percentage of a second unit; less than 5% of a second unit is ignored
- fractionated units indicate a veneer of one unit over a thicker zone of another unit: (e.g., $\frac{\text{s,siLpv}}{\text{tM}}$ - a flat-surfaced veneer of sandy, silty lacustrine material over till)
- brackets () separate groups of units (e.g., (pO-fO)-tMp means pO containing 16-49% fO, and 16-49% of the total area is tMp

N.B. - one textural modifier signifies the dominant material
- commas used between textural modifiers for distinct lithologies: e.g., g,s,siAp - floodplain consisting predominantly of gravel and sand with minor silt

LEGEND AND NOTES TO ACCOMPANY SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAPS, SIBBESTON LAKE, DISTRICT OF MACKENZIE, 1981.

RUTTER AND BOYDELL SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAP LEGEND

UNIFIED SOIL CLASSIFICATION

Major divisions			Group Symbol		Typical Names	Classification criteria for coarse grained soils		
Coarse grained soils (more than half of material is larger than No.200 sieve size)	Gravels (more than half of coarse fraction is larger than No.4 sieve size)	Gravels with fines (appreciable amount of fines)	GW		Well graded gravels, gravel-sand mixtures, little or no fines	Depending on percentages of fines (fraction smaller than No. 200 sieve size), coarse grained soils are classified as follows: Less than 5% - GW, GP, SW, SP; More than 12% - GM, GC, SM, SC; 5 to 12% - Borderline cases requiring dual symbols	$C_u = D_{60}/D_{10} > 4$ $C_r = 1 < D^2{}_{30}/D_{10} \times D_{60} < 3$	
			GP		Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Clean gravels (little or no fines)	GM	d u	Silty gravels, gravel-sand-silt mixtures		Atterberg limits below A line or $I_p < 4$	Above A line with $4 < I_p < 7$ are borderline cases requiring use of dual symbols
			GC		Clayey gravels, gravel-sand-silt mixtures		Atterberg limits above A line with $I_p > 7$	
	Sands (more than half of coarse fraction is smaller than No.4 sieve size)	Clean sands (little or no fines)	SW		Well graded sands, gravelly sands, little or no fines		$C_u = D_{60}/D_{10} > 6$ $C_r = 1 < D^2{}_{30}/D_{10} \times D_{60} < 3$	
			SP		Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (appreciable amount of fines)	SM	d u	Silty sands, sand-silt mixtures		Atterberg limits below A line or $I_p < 4$	Limits plotting in hatched zone with $4 < I_p < 7$ are borderline cases requiring use of dual symbols
			SC		Clayey sands, sand-clay mixtures		Atterberg limits above A line with $I_p > 7$	
Fine grained soils (more than half of material is smaller than No.200 sieve size)	Silts and clays (liquid limit < 50)		ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity			
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL		Organic silts and organic silty clays of low plasticity			
	Silts and clays (liquid limit > 50)		MH		Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH		Inorganic clays of high plasticity, fat clays			
			OH		Organic clays of medium to high plasticity, organic silts			

BEDROCK AND MOUNTAIN TERRAIN MAP SYMBOL DESIGNATION

TOPOGRAPHIC SYMBOL

M Mountain: local relief greater than 450 m
H High Hill: local relief 150-450 m
L Low Hill: local relief 30-150 m

BEDROCK

D	Dolomite
L	Limestone
S	Sandstone
Si	Siltstone
Mu	Mudstone
Sh	Shale
Ch	Chert
Cg	Conglomerate

SLOPE ANGLE

1	$< 5^o$
1	Plateau surface
2	$5\text{-}15^o$
3	$15\text{-}35^o$
4	$> 35^o$

MORPHOLOGIC MODIFIER

d dissected

EXAMPLE

(Bedrock) D, L — (Texture - surficial) GC-GP

M

3,4,2 (Slope angle in order of abundance) — d

This describes a dissected area of mountainous relief where the dolomite and limestone bedrock is covered by a discontinuous residual or colluvial veneer of clayey gravels, gravel-sand-silt mixtures, and poorly graded gravels, with slopes generally $15^o\text{-}35^o$, in places $> 35^o$, but locally $5^o\text{-}15^o$

LEGEND AND NOTES TO ACCOMPANY SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAPS, SIBBESTON LAKE, DISTRICT OF MACKENZIE, 1981.

RUTTER AND BOYDELL SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAP LEGEND

Description of Map Units For Unconsolidated Materials

MAP UNIT (NOTE 1)	NAME	SURFICIAL DEPOSIT		LANDFORM		GROUND ICE (NOTE 2)	UNIFIED SOIL CLASSIFICATION (NOTE 5)	SOILS (NOTES 2 and 3)							DOMINANT VEGETATION (NOTE 4)		COMMENTS
		MATERIAL	ESTIMATED THICKNESS	TOPOGRAPHY	DRAINAGE PATTERN			PREDOMINANT SOIL*	ZONE (deciles) 6S	6N	5	4	3	2	STABLE	AFTER FIRE	
fO	Organic (fen)	Dominantly moderately decomposed fen peat derived from sedge, tamarack, and mosses	2-3 m	Flat to very gently sloping, some with reticulate net-work of low (<1 m) ridges (patterned fen)	No organized drainage; water at surface throughout summer months	Unfrozen to at least 3 m	Pt	Typic Mesisol (P-VP)	10	10	10	10	10	-	Sedge-Bi or Sedge-Bi-tL in all zones	Same, probably would not burn	Poor drainage, plus high compressibility and low strength of the material make it unsuitable for any type of construction
pO	Organic (bog)	Dominantly moderately decomposed forest and/or undecomposed sphagnum peat derived from black spruce, cladonia, feather - mosses, ericaceous and/or sphagnum vegetation	1.5-7 m	Flat to gently sloping areas with scattered mounds (average relief 1 m, rarely to 6 m); numerous steep-sided depressions and trenches	Depressions intercon-nected by seepage channels	Frozen at 0.3-0.5 m. Segregated ice content commonly 60-80% in peat; typically 10-100 cm thick. Segregated ice in mineral soil below. Peat in wet depressions commonly thawed to at least 1 m. Ice-wedge polygons present in zone 3	Pt	Mesic Organic Cryosol (W-I) Fibric Organic Cryosol (W-I)	5	7	7	7	10	10	bS-Fm-Er in zones 6S and 6N; bS-lichen-Er in zones 4 and 5; lichen-bS-Er in zones 2 and 3	Sphagnum, Er	Alternation of permanently frozen peat mounds and thawed depressions and water bodies presents serious problems in construction of roads, pipelines, etc.; material highly compressible when thawed
								Typic Fibrisol (P) Typic Mesisol (P)	5	3	3	3	-	-	Sphagnum or sphagnum-bS in zones 4, 5, 6S, and 6N	Sphagnum, Er	
pOk	Organic (bog) thermokarst	Dominantly moderately decomposed forest and/or undecomposed sphagnum peat derived from black spruce, cladonia, feather - mosses, ericaceous and/or sphagnum vegetation	1.5-7 m	Flat to gently sloping areas with mounds (average relief 1 m, rarely to 6 m); numerous exposed peat scarps, depressions, and trenches	Depressions intercon-nected by seepage channels; drainage continually being modified	Frozen at 0.3-0.5 m. Segregated ice content commonly 60-80% in peat; typically 10-100 cm thick. Segregated ice in mineral soil below. Peat in wet depressions, and scarps commonly thawed to at least 1 m	Pt	Mesic Organic Cryosol (W-I) Fibric Organic Cryosol (W-I)	-	7	-	7	-	10	bS-Fm-Er in zones 6S and 6N; bS-lichen-Er in zones 2 and 3	Er, Fm, bS	Alternation of perman-ently frozen peat mounds, some actively degrading, and thawed depressions and water bodies presents serious problems in construc-tion of roads, pipelines, etc.; material highly compressible when thawed
								Typic Fibrisol (P) Typic Mesisol (P)	-	3	-	3	-	-	Sphagnum or sphagnum-bS in zones 4, 5, 6S, and 6N	Sphagnum	
g,s,siAp	Alluvial floodplain	Gravel, sand, and silt; textures vary with the dominant material indicated first	1-8 m	Floodplain and low bordering terraces; floodplains within mountains commonly scarred by braided channels; floodplains within plains region commonly with meander scars	In braided areas inter-mittent drainage through channels; in meander scar areas no integrated drainage system, impeded by meander scroll ridges	Ground ice in gravel, sand, and silt of low terraces in zone 2; Not observed elsewhere. Permafrost and segregated ice also present in areas where bog is more than 1.5 m thick	SM-GM	Cumulic Regosol (W)	4	-	4	4	-	-	wS-wB, bPo-wS-Eq, wS-bPo in zones 4, 5 and 6S	Wi, Al, bPo	Subject to periodic flooding; floodplains within the mountains are potential sources of aggregate; extraction of aggregate may cause deleterious changes in stream course and downstream changes in stream regimen
								Gleyed Cumulic Regosol (I)	3	-	3	3	-	-			
								Rego Gleysol (P)	3	-	-	-	-	-	Wi, Wi-Al, bPo-Al in zones 4, 5, and 6S	Wi, Al, bPo	
								Gleysolic Turbic Cryosol (P)		-	3	3	-	-			
g,s,siAt	Alluvial terrace	Gravel, sand, and silt; textures vary with the dominant material indicated first	1-30 m	Terraces with relief inter-mediate between terraces associated with Ap and Gp or Gt; level to slightly sloping surfaces; some interrupted by shallow channels and low terraces	Surface drainage with-out integrated drainage system	Frozen groundwater in gravel, sand, and silt of terraces, up to 30 m thick, in zone 2. Not observed elsewhere	SM-GM to ML	Eluviated Eutric Brunisol (W) Orthic Eutric Brunisol (W)	6	6	6	6	-	-	wS-wB, wS-bPo, tA-wB, bPo, tA in zones 4, 5, 6N, and 6S; wS-wB, bS-bPo, tA-bS in zone 2	wB, tA, bPo	Good construction sites and aggregate source where material is coarse
								Brunisolic Turbic Cryosol (W)	-	-	-	-	-	6			
								Gleyed Eutric Brunisol (I)	1	1	1	1	-	-	bPo-wS, wS-bPo, Wi, tA-wS in zones 4, 5, 6N, and 6S; bS-bPo, wS-bPo in zone 2	wB, Wi, tA, bPo	
								Brunisolic Turbic Cryosol (I)	-	-	-	-	-	1			
								Rego Gleysol (P)	3	-	-	-	-	-	bS-Fm, bS-Fm-Er, bS-sphagnum in zones 4, 5, 6N, and 6S; bs-Lichen-Er in zone 2	Wi	
								Gleysolic Turbic Cryosol (P)		3	3	3	-	3			
gAf	Alluvial fan	Mostly gravel, some sand	3-25 m	Gently to moderately sloping (1°-8°)fans and coalescent fans	One or more shifting streams commonly present; downslope seepage in poorly defined runs	None observed	Variable	Cumulic Regosol (W)	-	-	6	6	-	6	Mainly wB, tA, Wi, and Al in zones 2, 3, 4, 5, 6N, and 6S	Wi, Al, wB	Generally offer well drained building sites, but sudden channel shifting may cause damage; good source of aggregate
								Gleyed Cumulic Regosol (I)	-	-	2	2	-	2			
								Rego Gleysol (P)	-	-	2	2	-	2			
								Gleysolic Turbic Cryosol (P)	-	-	2	2	-	2			
Cx	Colluvial complex	Colluvium derived from entire range of surficial deposits	1-6 m	Gently to steeply sloping irregular surfaces; $Cx^1 <5^o$, Cx^2 5^o-20^o		Silty clayey colluvium contains disseminated ice crystals to seams 1 m thick in zones 2 and 6N	GC-GP to ML-CL	Orthic Regosol (W) Orthic Eutric Brunisol (W)	-	-	5	-	5	5	tA, wS, wB at low elevations and stunted Alpine fir or wS, Er, lichen at high elevations in zone 5; bS, wB at low elevations and Er, lichen at high elevations; cryoturbated sur-faces are unvege-tated in zones 2 and 3	tA, wB at low elevations	Irregularity of topography and slope instability present major problems for any type of construction; texture prefix included in map unit if known
		Colluvium over bedrock (see note 6 for lithology) is shown as a fraction-ated symbol, e.g., $\frac{Cx}{Si, Sh}$; dominant lithology indicated first	Variable					Gleyed Regosol (I) Gleyed Eutric Brunisol (W)	-	-	2	-	2	2			
								Rego Gleysol (P)	-	-	3	-	3	3	Sphagnum, bS-sphagnum-Er in zones 2, 3, and 5	Sphagnum, Er	
								Gleysolic Turbic Cryosol (P)									
sEr sEh	Aeolian deposits	Sand, mainly fine to mdeium grained	1-20 m	sEr, dune ridges, usually parallel to subparallel; sEh, irregularly shaped dunes, no apparent pattern	Mainly subsurface seepage	None observed, probably no ice present	SP-SW	Eluviated Eutric Brunisol (W)	5	-	5	-	-	-	P, tA-wB in zones 5 and 6S	P, tA	Subject to wind erosion when vegetation mat is removed
								Gleyed Eluviated Eutric Brunisol (I)	2	-	2	-	-	-	tA-bS-Wi in zones 5 and 6S	P, W	
								Rego Gleysol (P)	3	-	3	-	-	-	bS-Fm, bS-sphagnum-Er in zones 5 and 6S	Wi	
								Gleysolic Turbic Cryosol (P)		-		-	-	-			

LEGEND AND NOTES TO ACCOMPANY SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAPS, SIBBESTON LAKE, DISTRICT OF MACKENZIE, 1981.

RUTTER AND BOYDELL SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAP LEGEND

Description of Map Units For Unconsolidated Materials

si,sLp si,sLpv	Glaciolacustrine plain	Mainly silt and fine sand; locally includes gravel (g) and clay (c); dominant material indicated first	si,sLp 1.5-50 m si,sLpv 0.5-1.5 m	Flat to gently sloping	Surface seepage through organic-filled depressions and downslope seepage in shallow subparallel runs	Commonly 10-50% segregated ice as thin (1 mm - 2 cm) seams parallel with bedding, segregated ice in a reticulate network up to 60% by volume, and thick tabular bodies in zones 2 and 6N; discontinuous zones of segregated ice as seams, reticulated networks, and tabular bodies (up to 3 m thick) in northern part of zone 6S; no ice recorded in southern part of zone 6S except below pO	CL-ML to SM	Brunisolic Grey Luvisol (W)	3	-	3	-	-	-	wS, wS-tA in zones 5 and 6S; wS-tA, bS-wB-tA in zone 6N	tA	Failure common along scarps; generally unsuitable for location of structures because of poor bearing capacity and drainage characteristics
								Orthic Grey Luvisol (W)	-	2	-	-	-	-			
								Gleyed Grey Luvisol (I)	2	-	2	-	-	-	bS-wB-tA, bS-Wi-Al in zones 5, 6S, and 6N	Wi, Al, wB	
								Luvisolic Turbic Cryosol (I)	-	2	-	-	-	-			
								Rego Gleysol (P)	5	-	-	-	-	-	bS-Fm-Er, bS-tL-wB in zones 5, 6S, and 6N	Wi	
								Gleysolic Turbic Cryosol (P)		6	5	-	-	-			
si,sLh	Hummocky glaciolacustrine deposits	Mainly silt and fine sand	2-5 m	Low hummocks up to 2 m; individual hummocks up to 5 m relief; slopes to 20°	Deranged	None observed	CL-ML	Brunisolic Grey Luvisol (W)	3	-	3	-	-	-	wS, wS-tA in zones 5 and 6S; wS-tA, bS-wB-tA in zone 6N	tA	Failure common along scarps; generally unsuitable for location of structures because of poor bearing capacity and drainage characteristics
								Orthic Grey Luvisol (W)	-	2	-	-	-	-		tA, wB	
								Gleyed Grey Luvisol (I)	2	-	2	-	-	-	bS-wB-tA, bS-Wi-Al in zones 5, 6S, and 6N	Wi, Al, wB	
								Luvisolic Turbic Cryosol (I)	-	2	-	-	-	-			
								Rego Gleysol (P)	5	-	-	-	-	-	bS-Fm-Er,bS-tL-wB in zones 5, 6S,and 6N	Wi	
								Gleysolic Turbic Cryosol (P)		6	5	-	-	-			
g,sLpbx g,sLpbxv g,sLpbv	Glaciolacustrine beaches	Mainly gravel with minor sand; locally include silt(si); dominant material indicated first	g,sLpbx 1.5-2 m g,sLpbxv 0.5-1.5 m g,sLpbv 0.5-1.5 m	g,sLpbx and g,sLpbxv, parallel to subparallel beach ridges arranged in belts; up to 6° slopes; g,sLpbv, beach material without distinct ridges forming belts up to 6+ km wide	Drainage mainly subsurface	None observed	SP-GP	Eluviated Eutric Brunisol (W) Orthic Eutric Brunisol (W)	5	-	-	-	-	-	P, P-wB-tA	P, tA, wB	Good construction sites and aggregate source where material is coarse; beaches at 800-900 foot (240-275 m) elevations offer the best potential
								Gleyed Eutric Brunisol (I)	2	-	-	-	-	-	P-wB-Wi, bS-wB-Wi, tA-bS-Wi	P, tA, Wi, wB	
								Rego Gleysol (P)	3	-	-	-	-	-	bS-Fm-Er	Wi	
g,s,siGp g,s,siGpv g,s,siGt gGpc	Glaciofluvial plain Glaciofluvial terrace	Gravel, sand and silt; textures vary with the dominant material indicated first	g,s,siGp 1-30+ m g,s,siGpv 0.5-1.5 m g,s,siGt 1-30+ m	Flat to gently sloping	Drainage mainly subsurface	Frozen groundwater in gravel, sand, and silt in zone 2. Not observed elsewhere. Where overlying bog is more than 1.5 m thick permafrost may be present below	GP-GW to SP-SW	Eluviated Eutric Brunisol (W) Orthic Eutric Brunisol (W)	5	5	-	-	-	-	p-wB-tA, P in zones 6S and 6N	P, tA	Good construction sites and aggregate source where material is coarse
								Gleyed Eutric Brunisol (I)	2	2	-	-	-	-	bS-wB-Wi,P-wB-Wi,tA-bS-Wi in zones 6S and 6N	P, tA, Wi, wB	
								Rego Gleysol (P)	3	-	-	-	-	-	bS-Fm-Er in zones 6S and 6N	Wi	
								Gleysolic Turbic Cryosol (P)	-	3	-	-	-	-			
g,sGh g,sGr	Hummocky glaciofluvial deposits Ridged glaciofluvial deposits; includes eskers and esker complexes	Mainly gravel with sand	1-10 m 1-30 m	Hummocks with local relief up to 10 m Long, sinuous esker ridges, up to 30 m high	Drainage mainly subsurface	No segregated ice in well drained sites, but segregated ice may be present in association with silt layers beneath depressions in zones 2, 3, and 6N	GP-GW to SP-SW	Eluviated Eutric Brunisol (W) Orthic Eutric Brunisol (W)	-	-	-	5	-	-	tA-bS-wB, P, wS-tA-wB	P, tA, wB	Good construction sites and aggregate
								Gleyed Eutric Brunisol (I)	-	-	-	2	-	-	bS-tA-wB	tA, wB	
								Gleysolic Turbic Cryosol (P)	-	-	-	3	-	-	bS-Fm-Er, bS-lichen-Er	Wi	
tMp tMpc	Moraine plain	Moderately to strongly calcareous glacial till, typically clay, silt, and minor sand with 5% pebbles and boulders; prefixes g, s, si, or c, indicate lenses of gravel, sand, silt, or clay within the till. If till is thin (tMv), the nature of the underlying bedrock is shown by a fractionated symbol (Note 6 gives bedrock lithology); dominant lithology indicated first	tMp 1.5-50 m tMpc 1.5-50 m	Flat to uniformly sloping; tMp^1, tMv^1: slope 2°- 5° tMp^2, tMv^2: slope 5°-15°; map symbol may be suffixed by one or more r, m, s, d, or h (see below) indicating the mapped area in part consists of one or more of these landform units	Downslope seepage in subparallel runs Downslope seepage in shallow channels	Locally 5-40% segregated ice as thin (1 mm-2 cm) horizontal layers or in a reticulated network in zones 2, 3, and 6N; presence controlled by exposure, elevation, drainage, and/or organic cover	CL	Brunisolic Grey Luvisol (W)	4	-	3	-	-	-	wS-tA-wB, tA-P-wB in zones 4, 5, 6S, and 6N; wS-wB, bS-wB in zones 2 and 3	tA, P, wB	Failure common along scarps; poor source of aggregate; up to 10% unmapped pO and/or fO; because of drainage by numerous subparallel runs, roads, or berms normal to slope direction, numerous culverts required to avoid impoundment of surface water; slopes susceptible to soil creep and channelling
								Orthic Grey Luvisol (W)		3		3	-	-		wB, tA	
								Brunisolic Turbic Cryosol (W)	-		-	-	4	5			
								Gleyed Grey Luvisol (I)	2	-	3	2	-	-	wS-tA-wB, wS-tA-Wi in zones 4, 5, 6S, and 6N; bS-Wi-Al, bS-wB in zones 2 and 3	tA, wB, Wi,	
								Gleyed Brunisolic Grey Luvisol (I)		-		-	-	-		Al	
tMv			tMv <1.5 m		Downslope seepage in subparallel runs			Brunisolic Turbic Cryosol (I)	-	2	-	-	1	1			
								Rego Gleysol (P)	4	-	-	-	-	-	bS-Fm-Er in zone 6S; bS-Fm-lichen-Er in zones 4, 5, and 6N; bS-lichen-Er in zones 2 and 3	Wi, Al	
								Gleysolic Turbic Cryosol (P)		5	4	5	5	4			
tMd tMsd tMds tMs	Drumlins Flutings and drumlins Flutings	Moderately to strongly calcareous glacial till; prefixes g, s indicate lenses of gravel or sand within the till	2-30 m	Area consisting largely of parallel drumlins and/or flutings	Trellis pattern or deranged drainage in drumlin areas to parallel seepage or streams in fluted areas	Segregated ice may be present in some drumlins and flutings in zones 2, 3, and 6N, although none has been observed; intervening depressions in the same zones likely contain segregated ice; presence controlled by exposure, elevation, drainage, and/or organic cover	CL	Brunisolic Grey Luvisol (W)	4	-	4	-	-	-	P-tA, tA-P-wB, wS-tA-wB in zones 4, 5, and 6S; wS-wB, bS-wB-Wi in zones 2 and 3	tA, P, wB	Poor source of aggregate except where gravel is present; some drumlins and most flutings are bedrock cored; crests of drumlins and flutings typically well drained; intervening depressions poorly drained
								Orthic Grey Luvisol (W)		-		3	-	-		Wi, wB, tA	
								Brunisolic Turbic Cryosol (W)	-	-	-	-	4	4			
								Gleyed Grey Luvisol (I)	2	-	2	2	-	-	wS-tA-wB, wS-tA-wB in zones 4, 5, and 6S; bS-Wi-Al, bS-wB in zones 2 and 3	tA, wB, Wi, Al	
								Gleyed Brunic Grey Luvisol (I)		-		-	-	-			
								Brunisolic Turbic Cryosol (I)	-	-	-	-	2	2			
								Rego Gleysol (P)	4	-	-	-	-	-	bS-Fm-Er in zone 6S; bS-Fm-lichen-Er in zones 4 and 5; bS-lichen-Er in zones 2 and 3	Wi, Al	
								Gleysolic Turbic Cryosol (P)		-	4	5	4	4			

LEGEND AND NOTES TO ACCOMPANY SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAPS, SIBBESTON LAKE, DISTRICT OF MACKENZIE, 1981.

RUTTER AND BOYDELL SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAP LEGEND

Description of Map Units For Unconsolidated Materials

t,g,sMr	Crevasse fillings or ridge moraine	Moderately to strongly calcareous glacial till, gravel, and sand; textures vary with the dominant material indicated first	1-10 m	Individual, parallel to sub-parallel, straight to sinuous ridges within a moraine plain; 0.5-5 m relief; slopes 5°-30°	Integrated, weakly developed drainage controlled by ridge pattern	None observed, probably no ice present	CL	Brunisolic Grey Luvisol (W)	6	-	6	-	-	-	P-tA, tA-P-wB, wS-tA-wB in zones 4, 5, and 6S; wS-wB in zones 2 and 3	P, tA, wB	Crests of prominent ridges offer restricted but good construction sites
								Orthic Grey Luvisol (W)		-		6	-	-		wB, tA	
								Brunisolic Turbic Cryosol (W)	-	-	-	-	6	6			
							CL to GP-SP	Rego Gleysol (P)	4	-	-	-	-	-	bS-Fm-Er in zone 6S; bS-Fm-lichen-Er in zones 4 and 5; bS-lichen-Er in zones 2 and 3	Wi, Al	
								Gleysolic Turbic Cryosol (P)		-	4	4	4	4			
t,g,sMh	Hummocky moraine	Moderately to strongly calcareous glacial till, gravel, and sand; textures vary with the dominant material indicated first	1-20 m	Individual to coalescent hummocks; slopes to 20°	Deranged	Crests of prominent hummocks well drained and ice free; lower slopes and depressions commonly have 5-40% segregated ice as thin (1 mm-2 cm) horizontal layers or in a recticulated network in zones 2, 3, and 6N; presence controlled by exposure, elevation, drainage, and/or organic cover	CL	Brunisolic Grey Luvisol (W)	6	-	6	-	-	-	P-tA, tA-P-wB, wS-tA-wB in zones 4, 5, and 6S; wS-wB, bS-wB in zones 2 and 3	tA, P, wB	Crests of prominent hummocks offer restricted but good construction sites
								Orthic Grey Luvisol (W)		-		6	-	-			
								Brunisolic Turbic Cryosol (W)	-	-	-	-	6	6			
							CL to GP-SP	Rego Gleysol (P)	4	-	-	-	-	-	bS-Fm-Er in zone 6S; bS-Fm-lichen-Er in zones 4 and 5; bS-lichen-Er in zones 2 and 3	Wi, Al	
								Gleysolic Turbic Cryosol (P)		-	4	4	4	4			
tMm	Subdued hummocky and rolling moraine	Moderately to strongly calcareous glacial till	5-30 m	Subdued hummocks and rolling terrain; slopes 5°-30°	Deranged	Well drained sites ice free; lower slopes and depressions commonly have 5-40% segregated ice as thin (1 mm-2 cm) horizontal layers or in a reticulate network in zones 2, 3, and 6N; presence controlled by exposure, elevation, drainage, and/or organic cover	CL	Brunisolic Grey Luvisol (W)	6	-	6	-	-	-	P-tA, tA-P-wB, wS-tA-wB in zones 4, 5, and 6S; wS-wB, bS-wB in zones 2 and 3	tA, P, wB	Summits of broad hummocks typically well drained and offer restricted but good construction sites
								Orthic Grey Luvisol (W)		-		6	-	-			
								Brunisolic Turbic Cryosol (W)	-	-	-	-	6	6			
								Rego Gleysol (P)	4	-	-	-	-	-	bS-Fm-Er in zone 6S; bS-Fm-lichen-Er in zones 4 and 5; bS-lichen-Er in zones 2 and 3	Wi, Al	
								Gleysolic Turbic Cryosol (P)		-	4	4	4	4			
t,g,s,S, t,g,s,Sx, s,siS, s,siSx, rS, rSx	Debris avalanche; earthflow, mudflow, flowslide, & slump deposits	Material derived mainly from glaciolacustrine silts and clays, till. Material derived mainly from shale bedrock	Variable	Debris avalanches commonly occur as thin narrow tongues; earthflows and mudflows as bulbous masses; and slump deposits as blocks		Fine grained material may contain segregated ice in zones 2, 3, 6N, and northern part of 6S; presence controlled by exposure, elevation, drainage, and/or organic cover	Variable	Cumulic Regosol (W)	-	-	4	-	4	4	bS-wB-Wi-fireweed or unvegetated in zones 2, 3, and 5	Firewood, Wi	Shale bedrock commonly fails as debris avalanches in mountainous regions; large-scale failures are common along major river scarps in fine textured glacial deposits and in shale bedrock
								Gleyed Cumulic Regosol (I)	-	-	2	-	1	1			
								Rego Gleysol (P)	-	-	4	-	5	5			
								Gleysolic Turbic Cryosol (P)	-	-	-	-			Wi, bS-Wi in zones 2, 3, and 5	Wi	

LEGEND AND NOTES TO ACCOMPANY SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAPS, SIBBESTON LAKE, DISTRICT OF MACKENZIE, 1981.

RUTTER AND BOYDELL SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAP LEGEND

Description of Map Units For Bedrock and Mountain Terrain

MAP SYMBOL	NAME	TOPOGRAPHY	PRINCIPAL BEDROCK UNITS**	SURFICIAL DEPOSITS	UNIFIED CODE	MICRORELIEF	SOILS AND VEGETATION***	ENGINEERING COMMENTS
L* D L,D D,L L,Sh **M**	Mountains developed in carbonate rocks -limestone and dolomite with minor shale	Mountains up to 1500 m with sharp ridge crests and steep slopes. Ram Plateau area forms a level surface, dissected by deep canyons	L includes Headless, Landry, and Nahanni formations in Mackenzie Mountains and Flett Formation, in Silent Hills and Liard Range D includes Arnica, Manetoe, and Sombre formations in Mackenzie Mountains L,D includes Whittaker and Sunblood formations in Mackenzie Mountains D,L includes Delorme Formation in Mackenzie Mountains and Camsell Formation in Camsell Range L,Sh includes Funeral Formation in Mackenzie Mountains	Bare rock with discontinuous patches of limestone and dolomite rubble, bedrock colluvium with a matrix of fines and sand and/or reworked till on crests and steep slopes; variable thicknesses of bedrock rubble and colluvium and/or reworked till at base of slopes; discontinuous veneer of till on plateau areas	GP-GC	Well developed stone polygons, stripes, and nets on flat to sloping ground. Numerous small solifluction lobes in McConnell Range of Franklin Mountains	Steep slopes: no soil development; lichen on bare surfaces. Base of slopes: Orthic Eutric Brunisol or Brunisolic Turbic Cryosol; above timberline Brunisolic Turbic Cryosol; lichen, ericaceous plants above timberline; white spruce, trembling aspen below timberline. Ram Plateau: Orthic Eutric Brunisol, Brunisolic Turbic Cryosol, or Orthic Regosol; lichen, ericaceous plants, some white spruce	Steep slopes and high relief present serious difficulties to engineering activities such as road, pipeline, and related construction; limestone and dolomite are highly resistart and could be used for construction material; coarse deposits of rubble make suitable construction sites and sources of aggregate
S S,Sh S,Si,Sh **M**	Mountains developed on sandstone with shale, siltstone, or limestone combinations	Mountains up to 1600 m with rounded summits, long moderately steep slopes, and extensive debris mantles	S includes Mount Clark Formation in Franklin Range and an unnamed Proterozoic sandstone in Moose Prairie area S,Sh Mattson Formation S,Si,Sh includes Trout River and Redknife formations on Mackenzie Plain	Bare rock with discontinuous patches of sandstone, and limestone rubble, bedrock colluvium with a matrix of fines and sand and/or reworked till on crests and steep slopes; variable thicknesses of bedrock rubble and colluvium and/or reworked till at base of slopes	GP-GC	Stone polygons, stripes, and nets developed on flat to sloping ground	Steep slopes: no soil development; lichen on bare surfaces. Base of slopes: Orthic Eutric Brunisol, Brunisolic or Regosolic Turbic Cryosol, Orthic Regosol; above timberline Brunisolic Turbic Cryosol; lichen, ericaceous plants above timberline, white spruce, trembling aspen below timberline	Steep slopes and high relief present serious difficulties to engineering activities such as road, pipeline, and related construction; sandstone and limestone are stable and resistant and could be used for construction materials; shale is unstable and is subject to mass wasting; detachment slides and rotational slumping commonly occur when organic cover and/or vegetation are removed or altered; fine grained colluvium contains ice
S,Sh **H**	High hills developed on sandstone and shale with minor limestone member	Rounded summits and moderately steep slopes off the lower areas of the main mountain ranges	S,Sh Mattson Formation S,Si,Sh includes Trout River and Redknife formations on Mackenzie Plain	Discontinuous patches of clayey, silty, sandy colluvium, sandstone and limestone rubble, reworked till, and/or bare rock on slopes and summit areas; variable thicknesses of bedrock rubble and colluvium and/or reworked till at base of slopes	GC-GP	Stone polygons on flat surfaces. Terracettes and poorly developed stripes on slopes	Orthic Eutric Brunisol, Brunisolic or Regosolic Turbic Cryosol; trembling aspen, white birch, white spruce	Shale is highly unstable and is subject to mass wasting; detachment slides and rotational slumping commonly occur when organic cover and/or vegetation are removed or altered; fine grained colluvium contains ice; sandstone and limestone rubble could be source cf aggregate
Sh,Si,S Sh Sh,S Sh,S,Cg Sh,L,Si **H**	High hills developed on shale with limestone and siltstone members	Well rounded summits with moderate slopes, forming much of the lower areas between Franklin Mountains and Front Ranges of Mackenzie Mountains to the west	Sh,Si,S Fort Simpson Formation Sh includes Horn River and Klassen formations Sh,S Fort St. John Formation and Cretaceous shale and siltstone of the Interior Plains Sh,S,Cg Buckinghorse Formation Sh,L,Si Upper Devonian shale, limestone, and siltstone of the Interior Plains	Discontinuous patches of clayey, silty, sandy colluvium, sandstone, and limestone rubble, reworked till and/or bare rock on slopes of summit areas; variable thicknesses of bedrock rubble and colluvium, and/or reworked till at base of slopes	CL-ML	Stone polygons on flat surfaces. Terracettes and poorly developed stripes on slopes	Brunisolic or Regosolic Turbic Cryosol; trembling aspen, white birch, white spruce	Shale is highly unstable and is subject to mass wasting; detachment slides and rotational slumping commonly occur when organic cover and/or vegetation are removed or altered; fine grained colluvium probably contains ice; sandstone and limestone rubble could be source of aggregate
S,Si,Sh **L**	Low hills developed on sandstone and shale with a small area of limestone	Moderate to gentle slopes and rounded summits containing little or no glacial drift indicate bedrock control of topography in formerly glaciated areas	S,Si,Sh includes Trout River Formation	Veneer of clayey, silty, sandy colluvium; some with till and/or rubble	GC-GP to ML		Orthic Eutric Brunisol, Brunisolic or Regosolic Cryosol, Orthic Regosol; trembling aspen, white birch, white spruce	Shale is highly unstable and is subject to mass wasting; detachment slides and rotational slumping commonly occur when organic cover and/or vegetation are removed or altered; fine grained colluvium may contain ice in northern areas or at higher elevation

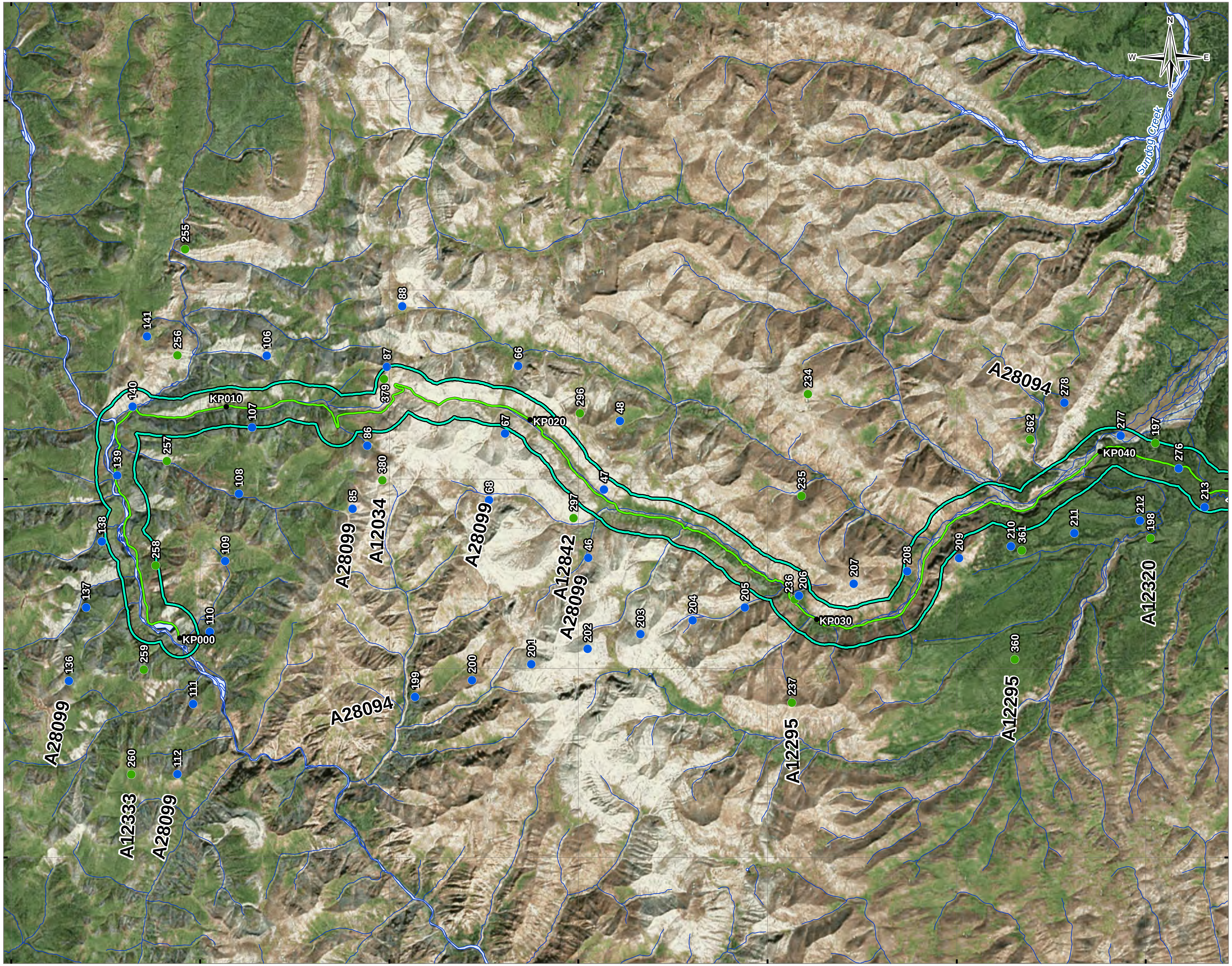
* Lithologic information from G.S.C. Papers 58-11, 59-11, 60-19, 61-13, and Bulletin 63

** Even though principal bedrock formations are listed, other bedrock units with the same lithologies may occur within these areas. Also describes complex units too small to be mapped separately

*** In poorly drained areas Cryic Rego Gleysols with ericaceous plants and black spruce are present below timberline, and ericaceous plants and lichen are present above timberline

LEGEND AND NOTES TO ACCOMPANY SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAPS, SIBBESTON LAKE, DISTRICT OF MACKENZIE, 1981.

APPENDIX C
AIR PHOTO INDICES



LEGEND

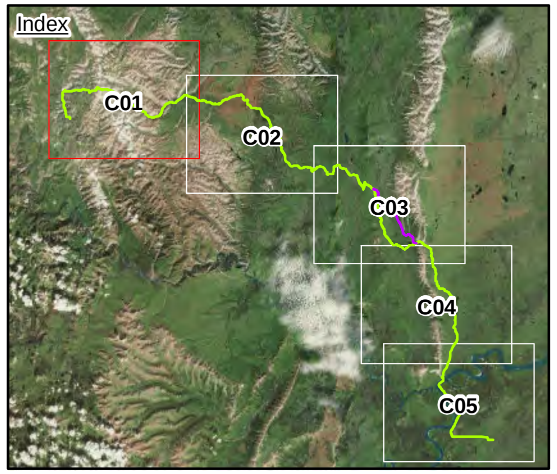
1 km Buffer
Prairie Creek Access Road (Feb 24, 2015)

Air Photo Year

- 1949
- 1994

Watercourse
Waterbody

Index



NOTES
Base data source: CanVec, Imagery from ESRI; Earthstar Geographics(1999)
Air photos were acquired from the National Air Photo Library (NAPL) of Canada in Ottawa. The photo and roll number of air photos acquired are given in Appendix B.

STATUS
ISSUED FOR USE

PRAIRIE CREEK ALL-SEASON ROAD

Air Photo Index

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	CANADIAN ZINC CORPORATION

Scale: 1:100,000
2 1 0 2
Kilometres

FILE NO.
Y14103320-01_003_AirPhotos.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

TETRA TECH EBA

Figure C01

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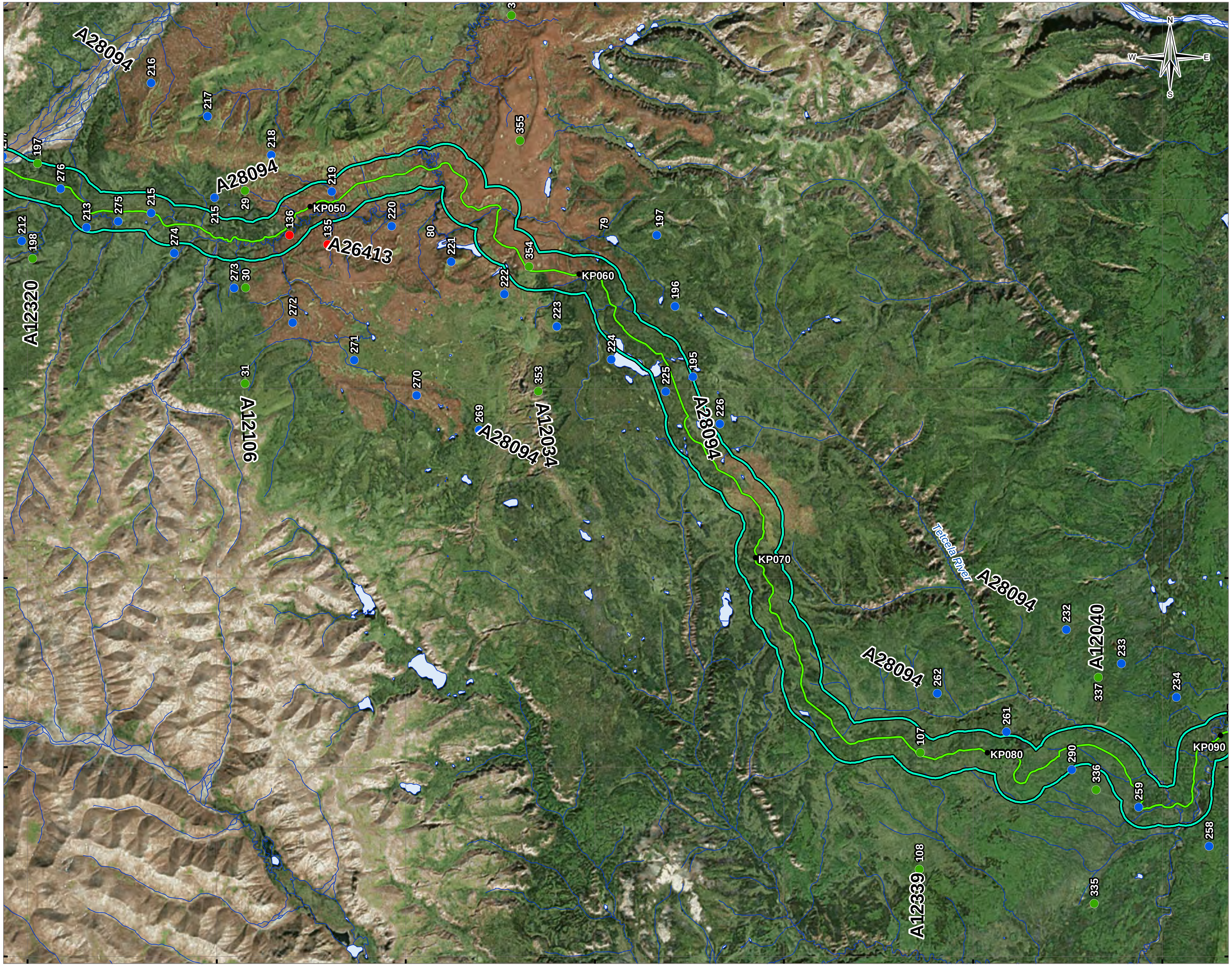
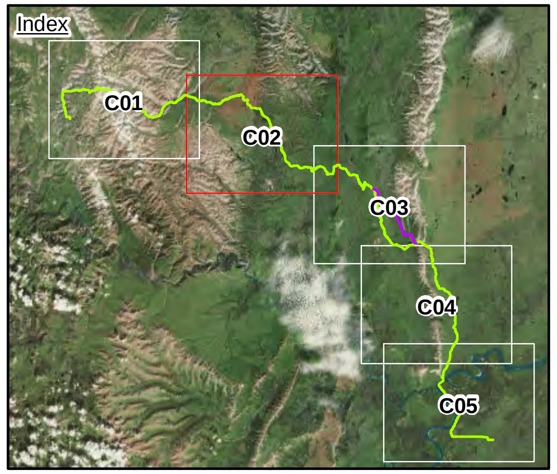


LEGEND

- 1 km Buffer
- Prairie Creek Access Road (Feb 24, 2015)

Air Photo Year

- 1949
- 1983
- 1994
- Watercourse
- Waterbody



NOTES
Base data source: CanVec, Imagery from ESRI; Earthstar Geographics(1999)
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STATUS
ISSUED FOR USE

PRAIRIE CREEK ALL-SEASON ROAD

Air Photo Index

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	CANADIAN ZINC CORPORATION

Scale: 1:100,000
2 1 0 2
Kilometres

TETRA TECH EBA

FILE NO.				
Y14103320-01_003_AirPhotos.mxd				
PROJECT NO.	DWN	CKD	APVD	REV
Y14103320-01.003	MEZ	SL	SMC	0
OFFICE	DATE			
Tt EBA-VANC	December 3, 2015			

Figure C02

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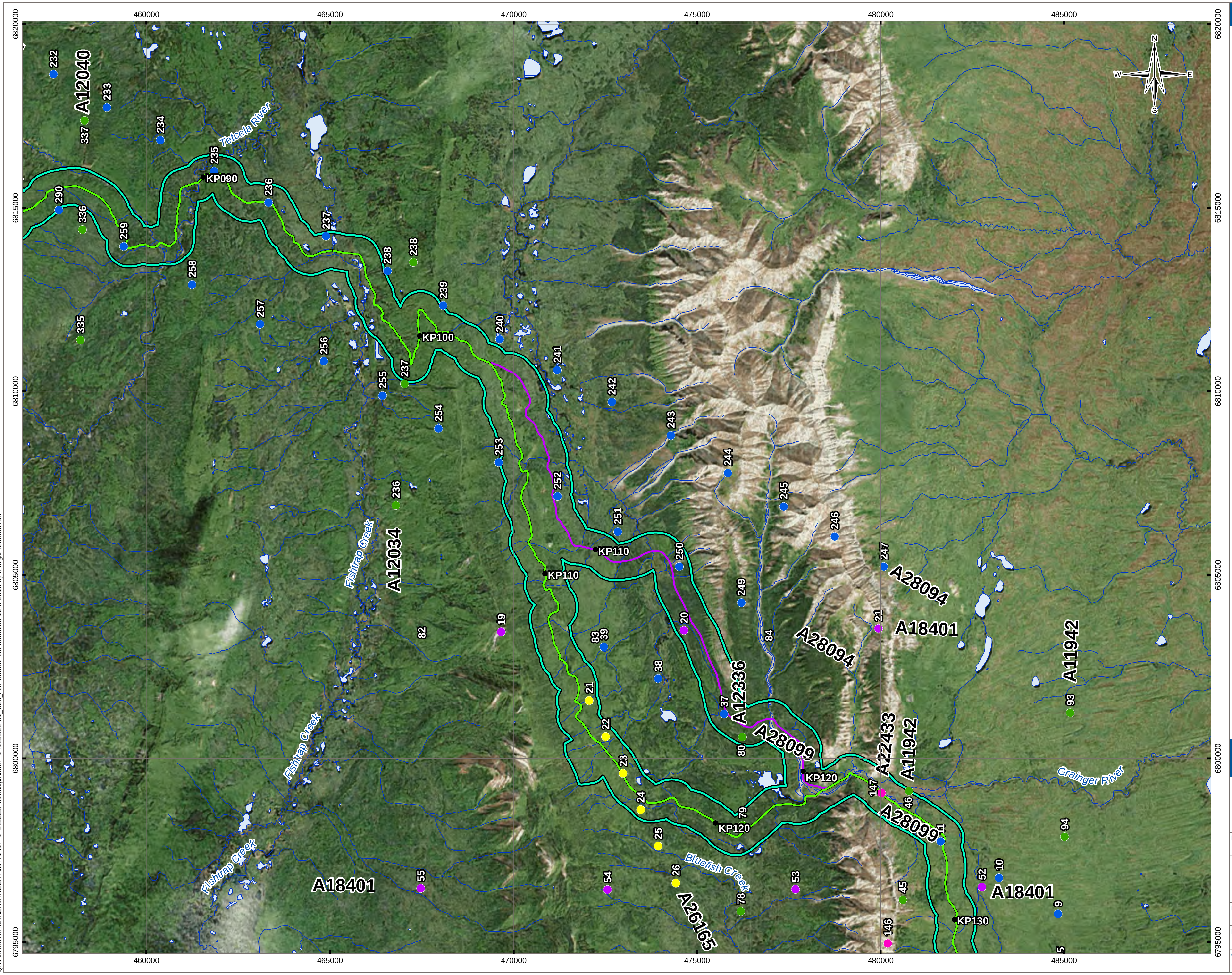

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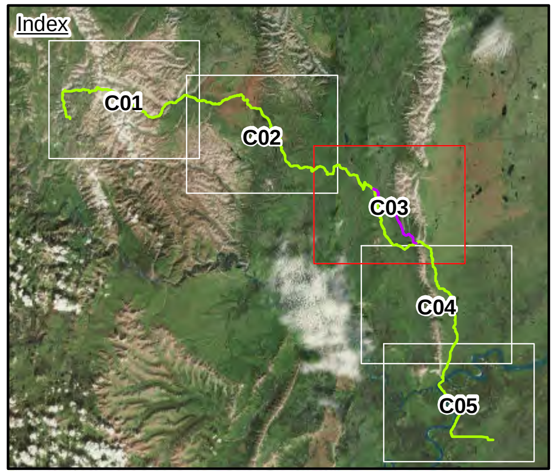
LEGEND

- 1 km Buffer
- Prairie Creek Access Road (Feb 24, 2015)
- Alternative Alignment (July 30, 2015)

Air Photo Year

- 1949
- 1963
- 1971
- 1982
- 1994
- Watercourse
- Waterbody



NOTES
Base data source: CanVec, Imagery from ESRI; Earthstar Geographics(1999)
Air photos were acquired from the National Air Photo Library (NAPL) of Canada in Ottawa. The photo and roll number of air photos acquired are given in Appendix B.

STATUS
ISSUED FOR USE

PRAIRIE CREEK ALL-SEASON ROAD

Air Photo Index

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	CANADIAN ZINC CORPORATION

Scale: 1:100,000
2 1 0 2
Kilometres

TETRA TECH EBA

FILE NO.
Y14103320-01_003_AirPhotos.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

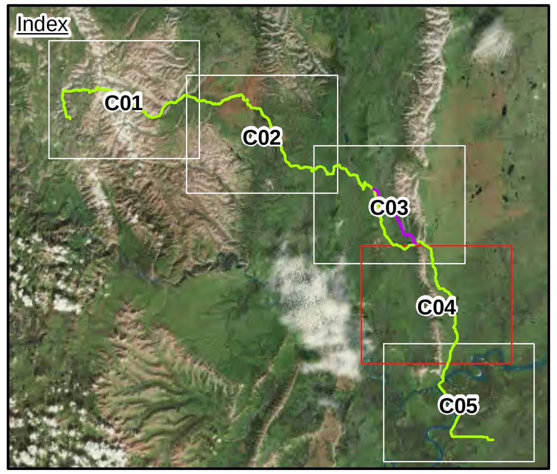
Figure C03

LEGEND

- 1 km Buffer
- Prairie Creek Access Road (Feb 24, 2015)

Air Photo Year

- 1949
- 1963
- 1971
- 1982
- 1983
- 1994
- Watercourse
- Waterbody



NOTES

Base data source: CanVec, Imagery from ESRI; Earthstar Geographics(1999)
Air photos were acquired from the National Air Photo Library (NAPL) of Canada in Ottawa. The photo and roll number of air photos acquired are given in Appendix B.

STATUS

ISSUED FOR USE

PRAIRIE CREEK ALL-SEASON ROAD

Air Photo Index

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	CANADIAN ZINC CORPORATION

Scale: 1:100,000
2 1 0 2
Kilometres

TETRA TECH EBA

FILE NO.				
Y14103320-01_003_AirPhotos.mxd				
PROJECT NO.	DWN	CKD	APVD	REV
Y14103320-01.003	MEZ	SL	SMC	0
OFFICE	DATE			
Tt EBA-VANC	December 3, 2015			

Figure C04

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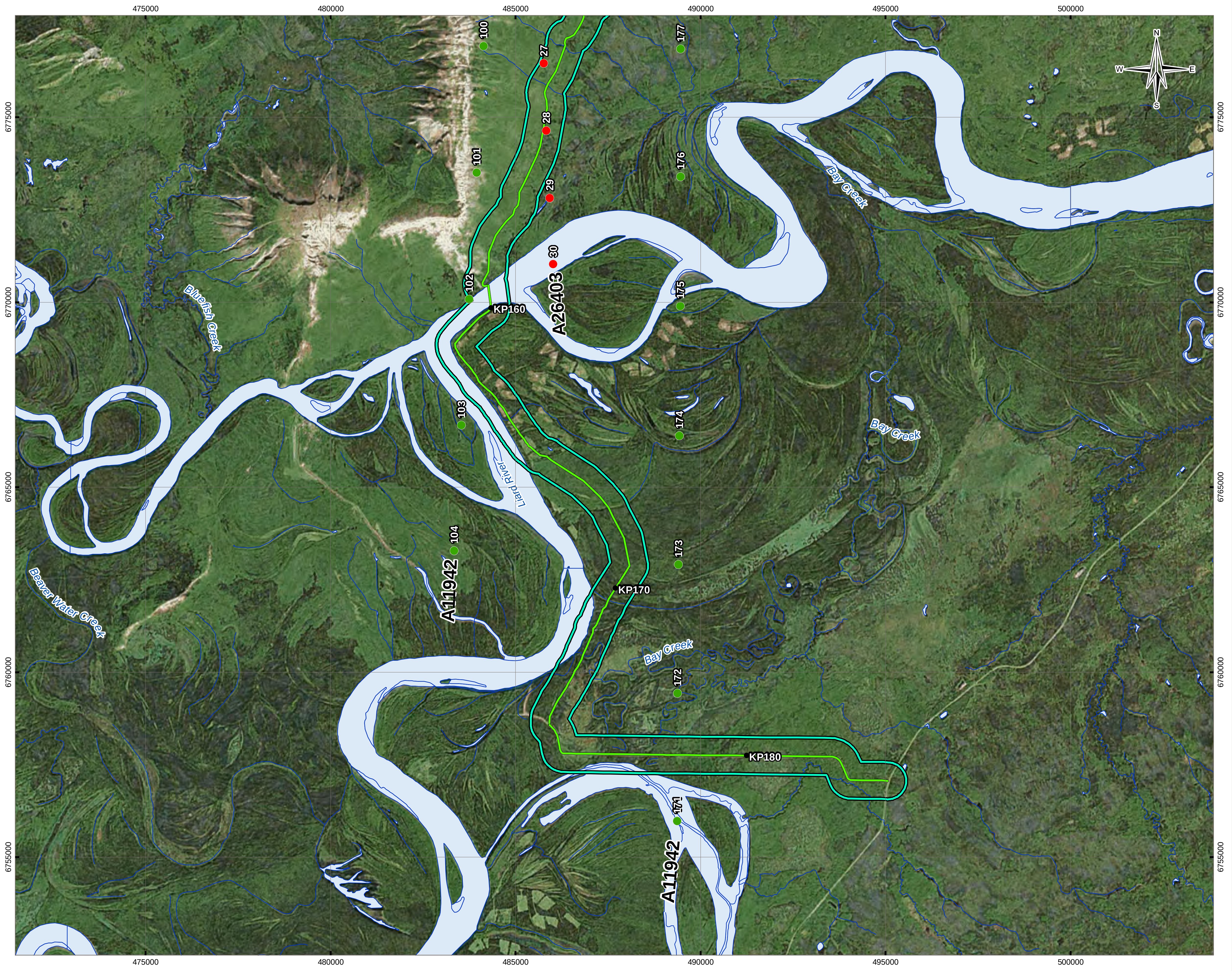

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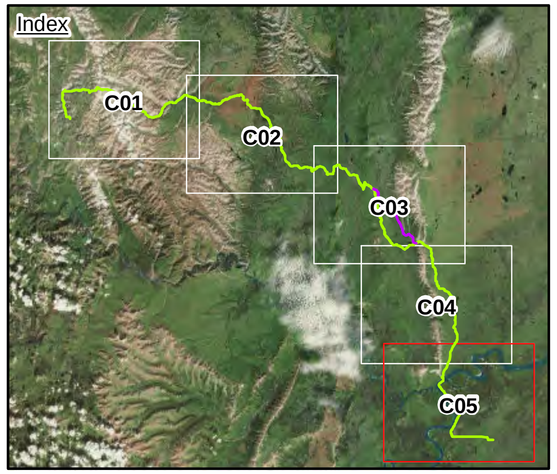
LEGEND

1 km Buffer
Prairie Creek Access Road (Feb 24, 2015)

Air Photo Year

1949
1983
Watercourse
Waterbody



NOTES
Base data source: CanVec, Imagery from ESRI; Earthstar Geographics(1999)
Air photos were acquired from the National Air Photo Library (NAPL) of Canada in Ottawa. The photo and roll number of air photos acquired are given in Appendix B.

STATUS
ISSUED FOR USE

PRAIRIE CREEK ALL-SEASON ROAD

Air Photo Index

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	CANADIAN ZINC CORPORATION

Scale: 1:100,000
2 1 0 2
Kilometres

TETRA TECH EBA

FILE NO.
Y14103320-01_003_AirPhotos.mxd

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

OFFICE	DATE
Tt EBA-VANC	December 3, 2015

Figure C05

APPENDIX D
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.

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.