September 2, 2016

Alberta Transportation
2nd Floor, 803 Manning Road NE
Calgary, Alberta
T2E 7M8

Ross Dickson
Project Service Technologist - Construction

Dear Mr. Dickson:

CON0017609 Southern Region GRMP - Call-Out Reports
S049 - Hwy 504:02-01 Embankment and Foundation Earth Slide (km 23.917)

1 INTRODUCTION

As part of the Geohazard Risk A Management Plan (GRMP) Contract for Southern Region, Klohn Crippen Berger Ltd. (KCB) was requested by Alberta Transportation (AT) to conduct a call-out inspection of a combined embankment and foundation slope failure on the south side of Highway 504, approximately 5.2 km east of Warner, Alberta along H504.

The site is located using a hand held GPS at 49°17.459' N, 112°7.815'W (WGS 84) on Highway 504:02 (km 23.917) in Contractor Maintenance Area (CMA).

The site was inspected on June 16, 2016 by Chris Gräpel, M.Eng., P.Eng., Tim Keegan, PhD.,P.Eng., and Andrew Brunsdon, P.Eng. of KCB, with Mr. Ross Dickson, and Roger Skirrow, P.Eng of AT. An overall site plan of the area is presented in Figure 1. Photographs from the inspection are included in Appendix I for reference.

This call-out report represents the first documented engineering site visit to the A049 - Hwy 504:02-01 Embankment and Foundation Earth Slide. This report was prepared by KCB for AT Southern Region under Contract No. CON0017609. The results of our site inspections, assessments, and our recommendations for remediation works are presented herein.

2 BACKGROUND

This is a new site that was brought to AT’s attention when the Maintenance Contractor (MC) had to repair the guard rail after it was undermined by the evolving head scarp. They also noticed recent movement on the head scarp predominantly at the west end and pavement breaking off as the result of slide movement (see Photo 3). The landslide appears to be a large translational earth slide on the south slope of Hwy 504 at the east end of a high embankment fill (see Photo 1).

The average annual daily traffic (AADT) along Hwy 504 near the site is 240 eastbound (Reference No. 65170).

3 SITE OBSERVATIONS

Figure 1 illustrates the basic arrangement of the various features observed at the site during the June 16th, 2016 site inspection. The following observations were made during the site visit:

- Photo 3 illustrates retrogression or movement of the head scarp which resulted in some minor damage along the south edge of the pavement that also undermined the guard rail.
- The pre-existing head scarp at the west end, including the right lateral scarp, appears to have undergone significant recent, predominantly, downward movement in the order of 0.2 to 1.0 m. The amount of movement on the head scarp diminishes towards the east abruptly pinching out near where the embankment is at full height.
- There was no back dipping evident on the wedge shaped back graben; the foot wall of the scarp is planer; dips at roughly 45° + phi/2, and the cracks are open a few inches. This is indicative of the back scarps that form in the extension region of a translational landslide.
- Also indicative of a translational slide movement was the observation of an open back scarp approximately 1/3 way down the slope just above the contact with the natural ground.
- At the toe of the slope is a well-developed toe roll showing signs of resent movement. There is no evidence of upward movement at the toe which is an additional indicator of horizontal movement.
- The culvert through the embankment just west of the observed slide movement shows no signs of distress.
- The south highway ditch which carries drainage eastward through a through-cut discharges its flow into the slide area however appears to run down the slope west of any of the scarps. However this should verified.

4 ASSESSMENT

A review of readily available topographic, geologic, and surficial soil maps indicates that the highway is situated in Stagnant Ice Moraine. Deposits associated with these landforms include sediments resulting from the collapse and slumping of englacial (inside) and supraglacial (on top) debris due to the melting of buried stagnant ice at the glacier margin; sediment is mainly till but locally includes stratified glaciolacustrine or glaciofluvial sediments; characterized by low- to high-relief hummocky topography. (Alberta Geological Survey, 2013).

The embankment at the subject site crosses a large south-west north-east trending gully that has post-glacially down-cut through these deposits. The gully flows 0.5 m north-east into a large glacial outwash channel. Large deep seated translational landslides are evident on the right bank of the gully, one directly opposite the subject landslide, the East Landslide, and a second approximately

0.3 km upstream, the West Landslide. Both appear to have resulted in landslide dams in the past remnants of which are still present today (see ponding upstream of East Landslide).

The presence of a back scarp as shown in Photo 1, infers that a reverse graben has formed providing further evidence of translational slide movement. Translational landslides are usually controlled by a horizontal weak layer at depth. Also of note is that the head scarp is significantly higher (undergone more movement) at the west end and essentially pinches out towards the east corresponding to the location where the embankment fill is at its full height. This supports the premise that the slide is controlled by the natural deposits and has likely mobilized on a pre-existing rupture surface in a horizontal weak layer. Additional evidence supporting the inference of a pre-existing horizontal rupture surface in a weak layer is the observation of an even larger translational landslide in the opposing north facing slope as illustrated in Photo 4. It is suggested that the knoll of natural ground, shown in Photo 1 is a pre-existing toe graben of a post-glacial translational landslide. The knoll was apparently utilized by the road builder to buttress the southwest corner of the abutment of the embankment. Sometime later the load introduced by the embankment fill may have contributed to reactivate the slide on the pre-existing rupture surface.

The primary failure mode surmised from our understanding of the site involves reactivation and/or retrogression of the pre-existing translational earth slide. The preparatory and trigger causal factors that contribute to the relatively moderate likelihood that the failure mode will occur include:

- The driving forces in a translational landslide do not dissipate until the back graben butts into the horizontally oriented basal rupture surface or encounters the other side of the valley.
- Relatively large movements on the back scarp at the west end, infer that the back and basal rupture surfaces have formed, shear strength is at residual, and there are open cracks at the back of the landslide.
- Likelihood of strain softening (peak to residual shear strength) along the rupture surface in the foundation deposits is considered to be low given the inference that the basal rupture surface is pre-existing and has been subjected to large shear strains.
- The primary trigger for reactivating the landslide is inferred to be snow melt or rain filling the cracks at the back of the landslide.
- Without further investigation it is not possible to estimate the potential for retrogression.

5 RISK LEVEL

Risk levels have not been prepared for this site to date.

Risk levels for AT GRMP sites are determined according to the following:

Risk Level (RL) = Probability Factor (PF) x Consequence Factor (CF)

Where:

- PF varies from 1 (inactive, very low probability of slide occurrence) to 20 (catastrophic slide is occurring); and
- CF varies from 1 (minor consequences, no impact to driver safety, maintenance) to 10 (safety of public at risk, loss of infrastructure, rapid mobilization of large slides).

A risk level for this site, assessed as a landslide, is as follows:

PF (11) x CF (5) = RL (55)

The probability factor of 11 reflects that:

- Ground conditions and "potentially active" and "active" destabilizing processes, described in Section 4, are still seasonally prevalent at the site and involve moderate but potentially increasing rates of movement.
- This being a new site, there are still considerable unknowns and uncertainty regarding this geohazard which, on its own, increases the relative likelihood of failure.

The consequence factor of 5 reflects that the failure mode can occur rapidly and can result in downward collapse of the road surface. The following consequences can be expected:

- Abrupt drop of a portion the road surface resulting a significant danger to traffic safety; and
- Partial loss of embankment is likely from the failure mode resulting in costly repair and partial closure of the road or significant detours would be a direct and unavoidable result of a slide occurrence.

6 DISCUSSION

In general, the primary failure mode surmised from our understanding of the S49 site involves reactivation and/or retrogression of the pre-existing translational earth slide that is likely to occur and would have significant consequences (Risk Level 55). The remediation will need to address the destressed and cracked embankment slope and foundation subject to slide reactivation and/or retrogression due to water filling cracks.

7 RECOMMENDATIONS

7.1 General

The remediation of the slide will require an engineered design to be prepared so that either the local maintenance contractor or, more likely due to the size of the job, an outside contractor can construct repairs. The proposed short-term and long-term repair recommendations for the embankment earth slide and damaged culvert are discussed in the following subsections.

7.2 Short Term

In the short term the MCI should continue to monitor the retrogression of the head scarp towards the highway and install hazard signs and a speed reduction if the head scarp encroaches further into the pavement due to ongoing movement of the slide. Monitoring of the site should be coordinated with adverse weather conditions such as rapid snow melt, intense rainfall, or significant antecedent rainfall. To avoid water entering cracks in the slide mass, runoff from the paved surface into the slide area should be intercepted and directed eastward by construction of an asphalt curb along the north edge of the pavement and the scarps should be sealed off at surface by grading them closed or by inserting clay plugs at surface using a track excavator. If the head scarp drops any further on the north edge, such that it presents a danger to road users and mitigation measures, a temporary barriers should be installed until the landslide repair is completed.

The geotechnical investigation envisioned for the translational earth slide remediation design consists of a series of hollow or solid stem auger boreholes drilled through the slide mass and at the head of the slide (through the east bound lane) (estimated depth30 and 45m respectively) to assess fill and soil/bedrock conditions and to install instrumentation to monitor depth to groundwater within the embankment fill and foundation soils and bedrock and to assess the depth and kinematic character of movement across the slide mass. Disturbed and undisturbed samples would be taken to complete an index and strength testing laboratory program to develop material parameters to use in the design of landslide repair.

The rough order of magnitude costs for preliminary engineering for the translational earth slide remediation design including surveying, drilling investigation, and assessment of design options and final design, including preparing a set of drawings, a Class C cost estimate and special provisions for maintenance contractor repair work is between $100,000 to a $120,000. The timing of repair may necessitate maintenance contractor completing the work. Tendering costs will be in addition to the rough order of magnitude costs presented herein. A detailed proposal for further engineering services can be prepared upon request and after discussion with AT.

Recommended long-term actions for the subject site are discussed in the following section.

7.3 Long Term

The translational earth slide remediation, considered a 2017 project, will require an engineering design to be prepared so that the contract can be tendered and the selected contractor can construct repairs. Based on our site observations and subject to change based on the results of the investigation, the option discussed with AT on site and is considered a candidate for implementation involves installation of a buttress berm across the bottom of the gully and buttress against both valley slopes. This would require installation of an appropriately sized culvert to carry stream flows through the buttress berm. The added advantage of this mitigation is that it may serve to buttress the toe of the East Landslide however this would need to be assessed.

A rough order of magnitude construction cost estimate for remediation of the translational earth slide, subject to confirmation with investigation and design work, is approximately $500,000 to $600,000.

7.4 LiDAR and Photogrammetry Monitoring

Also in the short term, it is recommended to implement the use of remote sensing, namely a combination of Terrestrial LiDAR and drone captured Photogrammetry, to monitor, investigate, and help manage the activity and character of this new landslide before and after the remediation measures are carried out. The resulting high resolution surfaces can be used in change detection; desk top investigation of the slide area; and a multitude of other purposes. It is proposed to use Terrestrial LiDAR only for the first scan to provide accurate bare earth georeferencing which can be used for multiple subsequent photogrammetry surveys. In talking with the U of A we may be able to utilize Dr. Martin's newer LiDAR scanner which has a capable range of up to 3 km. Our understanding is that this would be on the condition that the scans were shared with the U of A for research purposes. Following is a summary of the advantages and disadvantages of each method for reference.

- **Terrestrial LiDAR** scanning has the advantage of being very accurate; provides geo-referencing; and can provide bare earth surfaces. Disadvantage is that the imagery is lower resolution(relative to photogrammetry); line-of-sight scanning means it does not provide 360° scans of objects or terrain features; and scans can take up to 30 min's.
- **Photogrammetry** has the advantage of providing high resolution 3D imagery; quick and inexpensive; can provide 360° scanning of objects and terrain; and provide very high density point clouds that can be used to map micro features such as rock structure or widths of a crack. Disadvantage to photogrammetry is that it requires geo-referencing either from ground survey or LiDAR and cannot provide bare earth surfaces from heavily vegetated terrain.

The estimated cost of a photogrammetry survey is $10,000, including travel expenses, site photographs, data processing, and assessment of results. The added cost of a onetime use of the U of A scanner would add an estimated $3,000. We recommend that photogrammetry surveys be carried on once a year in the spring before the leaf's come out. Of course single site cost would come down if multiple sites were surveyed during the same trip.

8 CLOSING

This is a draft report only and we solicit your review and comments within 4 weeks of submission. Upon issue of the final report, we request that all draft reports be destroyed or returned to Klohn Crippen Berger Ltd. This draft report should not be relied upon as a final document for design and/or construction.

This report is an instrument of service of Klohn Crippen Berger Ltd. The report has been prepared for the exclusive use of Alberta Transportation for the specific application to the CON0017609 Southern Region GRMP - Call-Out Reports S049 - Hwy 504:02-01 Embankment and Foundation Earth Slide. The report's contents may not be relied upon by any other party without the express written permission of Klohn Crippen Berger. In this report, Klohn Crippen Berger has endeavored to comply with generally-accepted professional practice common to the local area. Klohn Crippen Berger makes no warranty, express or implied.

Yours Truly,

KLOHN CRIPPEN BERGER LTD.

Tim Keegan Ph.D., P.Eng.
Senior Geological Engineer, Principal

Attachments
Figures
Appendix I Photographs

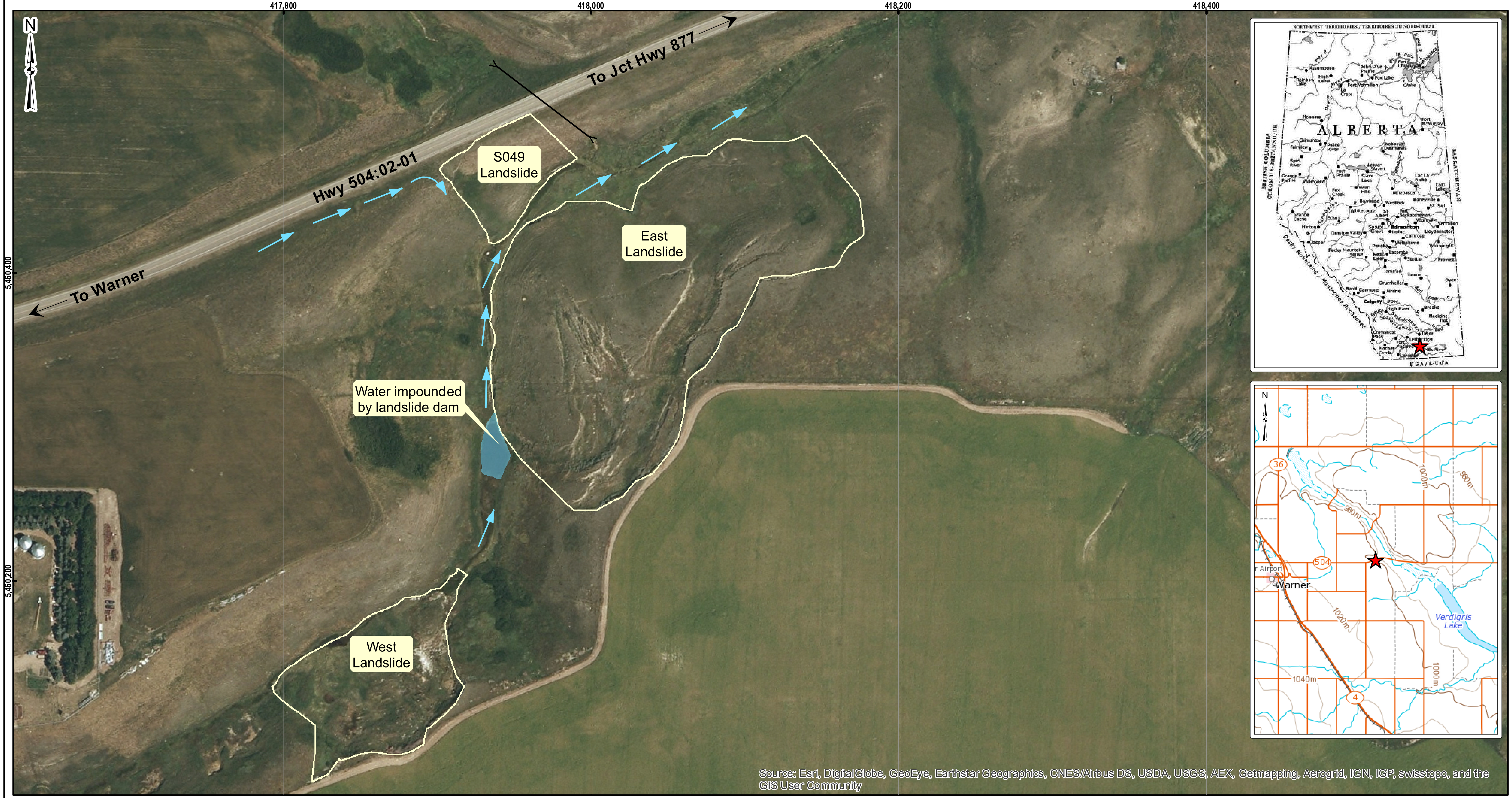
REFERENCES:

Alberta Transportation (AT). 2015. Traffic Counts Reference No. 105260. Retrieved August 9, 2016 from: <https://www.transportation.alberta.ca/3459.htm>

Alberta Geological Survey (AGS). 2013. Map 601 Surficial Geology of Alberta. Published March 25, 2013.

Kucera, V., 1988, The Effect of Acidification on Corrosion of Structures and Cultural Property. Chapter 6, Acidification in Tropical Countries, Edited by H. Rodhe and R. Herrera @ 1988 SCOPE. Published by John Wiley & Sons Ltd.

FIGURES



Legend

Culvert

Flow Direction

Metres
0 100

NOTES:
1. HORIZONTAL DATUM: NAD83
2. GRID ZONE: UTM Zone 12N
3. IMAGE SOURCE: World Imagery from ESRI ArcGIS Online. Image dated July 15, 2012

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PROJECT
SOUTHERN REGION GEOHAZARD RISK MANAGEMENT PROGRAM

TITLE
Call-Out Overview
S050 - Embankment Earth Slide and Damaged Culvert
Hwy 549:02-01, km 4.831

SCALE	PROJECT No.	FIG No.
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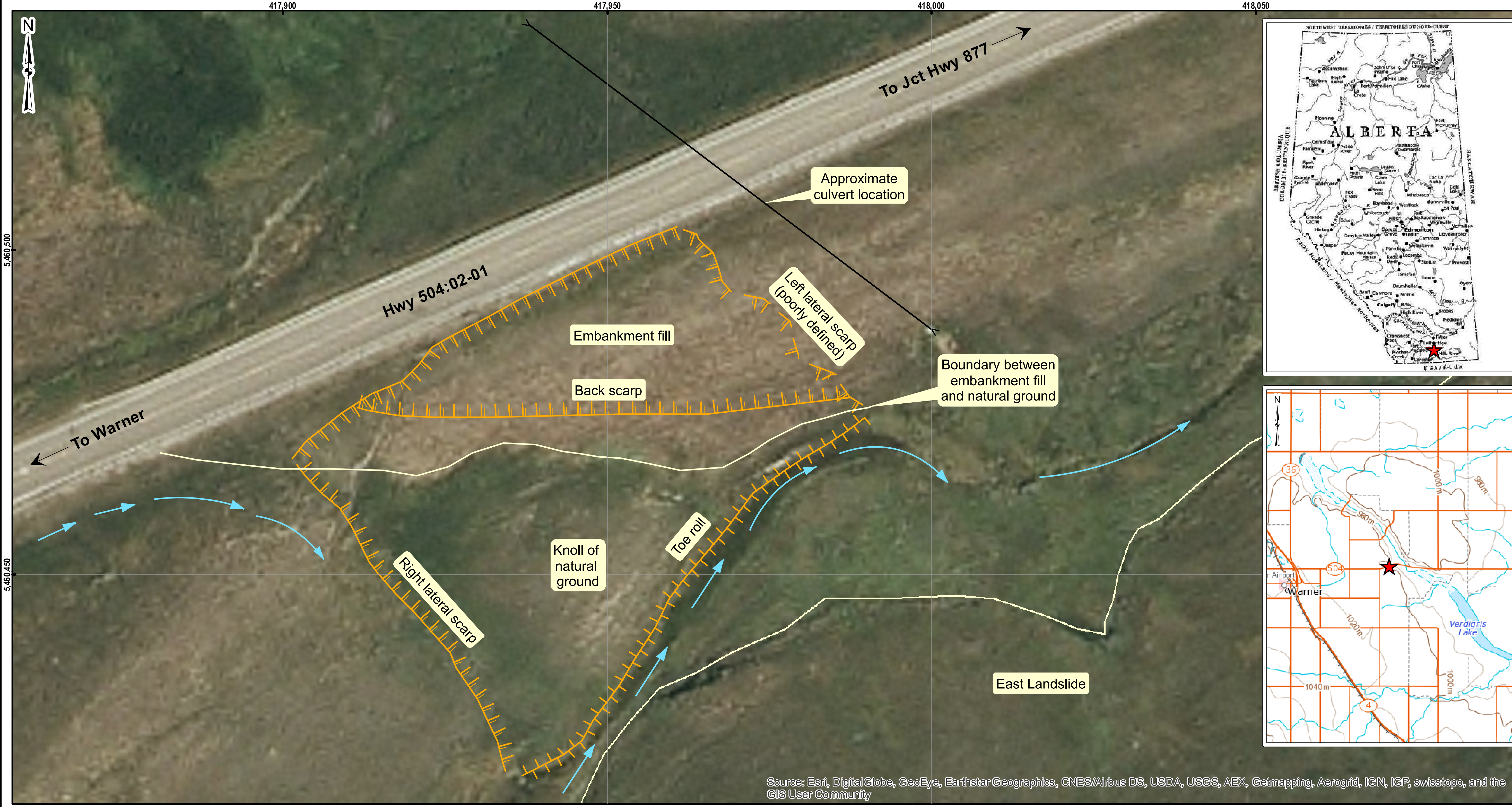

Legend

- Scarp
- Toe Roll
- Culvert
- Flow Direction

Metres
0 25

NOTES:
1. HORIZONTAL DATUM: NAD83
2. GRID ZONE: UTM Zone 12N
3. IMAGE SOURCE: World Imagery from ESRI ArcGIS Online. Image dated July 15, 2012

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PROJECT
SOUTHERN REGION GEOHAZARD RISK MANAGEMENT PROGRAM

TITLE
Call-Out Site Plan
S050 - Embankment Earth Slide and Damaged Culvert
Hwy 549:02-01, km 4.831

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APPENDIX I

Photographs

Appendix I
Photographs

Photo 1 **High embankment slope instability, translational slide. Presence of back scarp infers a reverse graben has formed which is evidence of translational slide movement usually along a horizontal weak layer at depth. Higher head scarp at west end indicates slide is exhibiting hinged movement, dropping more at the west end where more of the slide mass involves natural ground and a pre-existing basal rupture surface exists and is controlling movement. Photos northward taken June 16, 2016.**

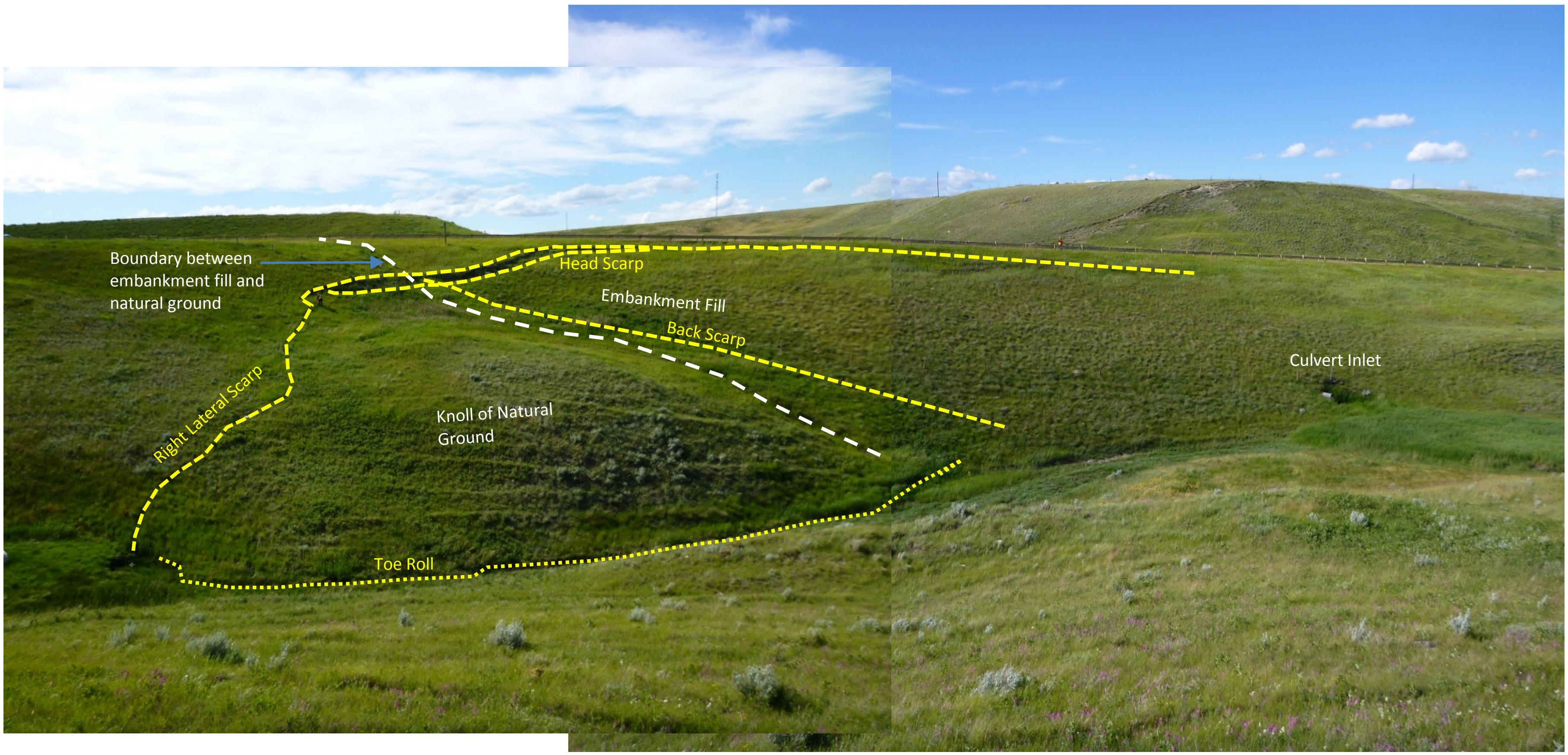

Photo 2 View up right lateral scarp. Photo towards north east on June 16, 2016.

Photo 3 Head scarp right at edge of pavement. Loss of pavement ~ 15 m length and guardrail was pulled into lane by maintenance. Photo towards west on June 16, 2016.

Photo 4 **Large translational landslide on north facing slope south of the subject site. The supports the hypothesis that a horizontal weak layer is controlling translational slide movement in the vicinity. Photo towards south on June 16, 2016.**