October 6, 2022

Alberta Transportation
Main Floor, Provincial Building
9621 96 Avenue
Peace River, Alberta
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Ed Szmata
Construction Technologist

Dear Mr. Szmata:

CON0022166 Peace Region (Grande Prairie South) GRMP
Hwy 40:36 rockfall, km 8.395 to 17.161
Call-Out Report

1 INTRODUCTION

As part of the Geohazard Risk Management Program (GRMP) contract for the Grande Prairie South region, Klohn Crippen Berger Ltd. (KCB) was requested by Alberta Transportation (AT) to conduct a call-out inspection for rockfalls along multiple GRMP sites along Hwy 40:36 between km 8.395 to km 17.161. The site is located on the west side of Hwy 40 with the south limit of the call-out area being approximately 8 km north of Grande Cache, Alberta. The call-out area includes the GP049, GP036, an un-numbered site near a rockfall fence erected by a third party, and the newly (in 2022) created GP053 (formerly part of GP008A) GRMP rock slope sites.

The approximate UTM coordinates of the south limit of the call-out area are 5981300 N, 358436 E (UTM Zone 11, NAD 83) and the legal land description is NW 29-57-08-W6M. A plan showing site locations presented in Figure 1.

The site was inspected by Mr. Chris Gräpel, P.Eng. of KCB, Dr. Renato Macciotta, P.Eng. of the University of Alberta (subconsultant to KCB), Ed Szmata and Dwayne Loewen of AT, and Mike Schiffer of Ledcor (the highway maintenance contractor, HMC) on July 14, 2022. The site inspection was conducted at the request of AT after a heavy rainfall event in late June 2022 resulted in rockfall particles reaching the highway surface. An Unmanned Aerial Vehicle (UAV) flight of the site was completed by KCB at the GP049, GP053 sites in 2022 and the GP036 site in 2021 during Section B tours to capture aerial imagery of the site. Photographs from the 2022 call-out inspection are included in Appendix I. Images from the 2022 and 2021 UAV videos are included in the figures.

This call-out report was prepared for AT under Contract No. CON0022166. KCB's site observations, assessments, and recommendations for short-term and long-term remedial actions are presented in this report.

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2 BACKGROUND

AT requested a call-out to the area due to new rockfall events that impacted the highway or came close to impacting the highway during a heavy rainfall event in late June 2022. Hwy 40:36 is a two-lane paved highway oriented north-south near the Smokey River Coal Mine, north of Grande Cache, Alberta. The site is located within Contract Maintenance Area (CMA) 504. The 2021 Average Annual Daily Traffic (AADT) from Traffic Count Station No. 25592 (2021) for this highway is 820 vehicles north bound and 1020 vehicles south bound.

This call-out involves several sites along a length of highway approximately 8.8 km long with multiple rock slopes north of Grande Cache, AB to the south and just north of the Smoky River Coal mine.

The surficial geology according to the Alberta Geological Survey (AGS 2013a) along the subject section of the Smoky River valley is composed of fluvial deposits on the lower section of the valley and riverbanks; these deposited sediments include poorly to well sorted, stratified layers of sand, gravel, silt, clay, and organics. The surficial geology in the upper hills of the valley is composed mainly of colluvial deposits which are sediments from gravity induce movements that include bedrock and surficial material from fluvial deposits. Near GP053, moraine deposits (i.e., till) are found between the upper hills and lower section of the valley, these deposits include a mixture of clay, silt, and sand, with the presence of pebbles, cobbles, and boulders.

GP036, GP049, and GP053, are part of the Bullhead Group and Fort St. John Group in the Foothills region of Alberta (Prior et al 2013). The Bullhead group is composed of the Gething and the Cadomin formations of the lower Cretaceous. The Fort St. John Group is composed of multiple formations including the Shaftesbury of the upper and lower Cretaceous, and the Boulder Creek, Hulcross, Gates, and Moosebar of the lower Cretaceous (Prior et al 2013). The detailed geology description of the Smoky Coal mine located between GP049 and GP053 by Forgeron (2016) indicates that the bedrock of near the three sites belongs to the Gates Formation, which is composed mainly of interbedded layers of sedimentary rock, including fine-grained and medium-grained sandstone, conglomerate, mudstone, carbonaceous mudstone, and thick coal seams (Prior et al 2013).

The area upslope of the sites varies between undeveloped mountain-side terrain to mine waste dumps, mine pits, and mine haul and access roads developed on the mountain side. The GP049 slope is below undeveloped mountain-slope terrain. The GP036 site is partially below a mine area. We understand from discussions with AT that the rockfall fence was installed at the un-numbered rock fence site in 2013 or 2014 to protect the public using Hwy 40 from fly rock during blasting and waste dump construction. Review of air photos from the early 1980s indicates the GP053 rock slope and highway was constructed downslope of a pre-existing mine access road when Hwy 40 was constructed north towards Grande Prairie.

In 1998 AT completed gradeline improvements to the highway near the subject sites. The original highway near the subject sites had a lower speed limit (50 km/hr) with sharp curves. Some curves on the highway were adjusted with the gradeline improvements to achieve a higher speed limit but in some cases the height of rock slope that needed to be constructed was too great and a lower speed limit of 80 km/hr was accepted by AT to avoid large-volume rock slope excavation. As a result, some of the original rock slopes were excavated further with drill and blast methods while other lengths of slope were not. AT said that the frequency and severity of rockfall events has been increasing since 1998.

A TransCanada high pressure natural gas pipeline is in the west ditch at the toe of the slope. It is understood from discussions with AT that the pipeline is shallow and that any excavation of rockfall particles from the ditch must be undertaken with a pipeline representative present.

We reviewed weather from nearby weather stations. Our review of precipitation data is presented in Figure 2. Note that since 1990, the four highest daily precipitation events have occurred since 2017 with daily precipitation between approximately 69 mm to 81 mm and these corresponded to rockfall and debris flow events at various locations on Hwy 40:36 as shown on Figure 2. The intensity of daily rainfall events and the frequency of intense rainfall events also appears to have increased.

Our monthly average air temperature data review is presented in Figure 3. The air temperature data appears to indicate that since 1999 the extreme temperatures appear to have increased (i.e., colder in winter, warmer in summer) but the locations of the available weather stations are on high ground compared to near valley bottom for the subject sites which could result in the available data not being representative of site conditions. AT reports that in recent years (2019 for instance) there have been warmer winters with very little snow compared to previous years. AT has observed water running down slope later in the year than usual, as late as the end of November. AT has observed freezing and thawing conditions in the winter months that historically was not previously experienced in this area of the province.

We reviewed the available background information which included previous Section B reports, the history of rockfalls at the sites. A Thurber Engineering Ltd (Thurber) call-out report for rockfall and debris flow events near the GP049 site dated December 23, 2020 indicated that rockfall and debris events have occurred at the call-out area in late June 2022, mid-June 2020, 2019, and 2017. These events appear to correlate to the high precipitation years (recorded at the Government of Canada Kakwa weather station) shown in Figure 2.

3 SITE OBSERVATIONS

The site was visited on July 14, 2022. The weather during the site visit was approximately 18° C, partly overcast, and calm. Photographs are included in Appendix I and the locations of sites are presented in Figure 1. We included oblique air photos taken with our UAV of each site in Figures 3 through 8.

A high-pressure gas pipeline is in the ditch with marking signs at the toe of the GP049 and GP036 rock slopes.

We visited the sites from south to north. KCB's observations made during the site visit are in the following bullets. Recommendations for rockfall mitigations are made within this section and are highlighted in ***green, bold italics*** so the location-specific recommendations discussed in the field with AT during our field work can be related to the observations and photographs.

The height of slope, degree of post-construction weathering, and slope conditions at and above the brow varied for all slopes visited. Topography around the slopes in forested areas might be available through existing LiDAR surveys for the area (AT believes there might be some 2012 data associated with a pine-beetle survey).

- ***The geometry of the slopes, existing ditches, and surrounding topography should be surveyed with remote sensing methods involving UAVs and merged with available LiDAR data.***

GP049-I Site (Figure 3, Photos GP049-I-1 to -4)

- The rock slope is approximately 200 m long and approximately 25 to 30 m high.
- The bedrock structure includes near horizontal bedding of sedimentary rock with bedding layers varying from a few centimeters to approximately 1.2 m thick.
- The ditch is 5 to 6 m wide at the ditch bottom, approximately 8 to 9 m from edge of highway embankment to rock slope and is approximately 1.0 m deep.
- There is a mid-slope slope bench on the south half of the slope approximately 8 to 10 m above the highway that has a talus slope and trees growing on the bench. The mid-slope bench ends around the mid-point the slope length. The origin of the bench is unknown but may have been required to remove naturally weak or fractured rock during rock slope construction. The crest of the bench appears to be deteriorating with dilated joints and weathering of some rock blocks. Blast-indicted damage maybe responsible for some of the poor condition of bedrock.
- At the south end of the slope (Photo GP049-I-1) the rock slope below the bench (4 to 8 m above the highway is deteriorating to an approximate 45°-degree slope with several pieces overhanging. The formation of a scree (sand and gravel surfacing on the rock slope has obscured the type of bedrock that is weathering) might be allowing energy dissipation for some rockfall blocks to be attenuated, but some particles (non-"platy" particles) are rolling off the slope and down into the ditch.

- ***The slope could be scaled to remove loose particles.***

- Rockfall particles were observed within 1 m of the edge of pavement (Photo GP049-I-2). There are some rockfall particles in the ditch but the ditch bottom is not blocked yet.
  - ***The ditch should be cleaned of rockfall particles, scree, and talus.***
- Not all of the upper slope above the mid-slope bench could be viewed from the highway, but it appears in the drone videos taken in spring 2022 to be of similar quality to the rest of the upper slope. Overhanging blocks of bedrock and loose particles were visible in the upper slope (Photo GP049-I-3. The upper slope appeared to be a dilated, weak rock mass.
  - ***The upper rock slope should be scaled to remove loose particles. However, we believe the entire rock slope will continue to deteriorate so regular scaling will be required in the future. An attenuation drape (i.e., fine mesh covering of the slope) would confine the path of rockfall and dissipate energy through drape friction and promoting contact with the rock slope.***
- Soil is exposed at the brow of the slope (Photo GP049-I-4) and appears to be a till material that contains cobles and boulders which presents additional rockfall hazards.
  - ***An attenuation drape could mitigate the rockfall hazard from the soil at the brow of the slope***.

GP049-II (Figure 4, Photos GP049-II-1 to -6)

- The rock slope is approximately 250 m long and approximately 10 m high.
- The bedrock structure is different than the -I site in that the bedrock planes are inclined 45° to 60°, dipping generally to the north or northeast (Photo GP049-II-1 and -2). The bedding layers in the bedrock appear to be thinner than at the -I site. Some of the bedding layers in the bedrock mass are coal seams. The quality of the bedrock and condition of the rock slope appears to be better at the -II site than at the -I site.
- The ditch is approximately 7 m wide and 1.5 m deep. AT have said that they have very few to no rockfalls from this slope reaching the highway.
- The ditch is partially full of rockfall particles. With further rockfall, the ditch bottom could become blocked and promote rockfall reaching the road in the future.
- The coals seams appear to be weathering faster than the adjacent bedrock seams which causes undermining of the overlying bedrock which then generates rockfall (Photo GP049-II-3 and -4). The talus slopes of deteriorated coal and fine-grained particles allows some rockfall particles to roll to the toe of the talus slope and up the highway slope towards the pavement.
  - ***The ditch should be cleaned of rockfall particles and talus cones.***

- Tall vegetation at the side of the highway obscures observation of rockfall particles but quick review of the ditch slope indicated rockfall particles within 1.0 m of the edge of pavement (Photo GP049-II-4).
- The orientation of bedding planes and the orientation of the slope is such that weathering of more fractured and thinly bedded layers of bedrock lead to undermining of more competent, thicker layers of bedrock, creating potential for future rockfall events (GP049-II-5).
  - ***The slope should be scaled to remove the hazard posed by loose particles that could become future rockfall events.***
- The brow of the slope at its highest point appears to be bedrock with more widely spaced discontinuities with dilated joints, with potential to generate rockfall events. This part of the slope is immediately above where a rockfall particle 1.2 m x 1.2 m x 0.3 m was located within 1.0 m of the edge of pavement (Photo GP049-II-5)
  - ***The brow of the slope should be scaled.***
- The fracturing of the bedrock may have been worsened by construction blasting.
- Zones of bedrock interbedded with coal seams are also weathering faster than surrounding bedrock which appears to be removing confinement for larger rock blocks (Photo GP049-II-6).
  - ***The coal seams could be shotcreted to mitigate weathering and exacerbation of existing rockfall hazard.***

GP036 (Figure 5, Photos GP036-1 to -15)

- The rock slope is approximately 250 m long and approximately 25 to 30 m high.
- The ditch is 8 to 9 m wide and approximately 0.6 m to 1.0 m deep.
- The bedrock structure is different than the GP049 sub-sites in that the bedrock planes are non-planar with some evidence of limited folding and faulting inclined 60° to 70° dipping generally to the south or southwest (Photo GP049-II-1 and -2). The bedrock bedding planes have been distorted during mountain building and are not planar. The degree of non-planar distortion in bedding planes varies across the rock slope from near vertical to dipping approximately 60° (Photo GP036-1). The bedding layers in the bedrock vary in thickness from quite thin (tens of centimeters) to several meters thick. Some of the bedding layers in the bedrock mass are coal seams which appear to have been disrupted by faulting. An old coal mine adit is visible mid-slope in a coal seam approximately 8 to 10 m wide.
- The GP036 site has a possible fault structure in the middle of the slope that is infilled with soil (Photos GP036-1 and -2). An ephemeral creek is eroding a valley into the soil and was flowing (less than 1 L/s) at the time of our site visit.

- The GP036 site had several rockfalls in the rainy weather of late June 2022. The largest rockfall particle was measured to be 1.5 m x 1.2 m x 0.6 m and it reached between the right wheel path and the mid-point of the southbound lane (Photos GP036-2, -3, and -4). The site of the June 29, 2022 rockfall is also the site of several other rockfall events, some which reached the pavement in the past and were pushed back into the ditch (Photo GP036-5).
    - ***The ditch should be cleaned of rockfall particles and talus cones.***
- Evidence of surface water drainage over the slope face was observed. Small rills were eroded into fine-grained talus cones (Photo GP036-3).
- There are several coal seams in the slope above where the June 29, 2022 rockfall event shown in Photo GP036-5 landed on the highway. The coal seams are weathering/eroding faster than the surrounding bedrock and leaving more competent adjacent bedrock seams undermined. In this location, the undermined bedrock blocks are south of the coal seam (Photo GP036-6).
    - ***The areas around the coal seams and the slope overall should be scaled to address loose blocks on the slopes that will eventually become rockfall hazards.***
    - ***Parts of the slope could be covered with an attenuation mesh/drape to confine the flow path of future rockfall particles and reduce fall energy.***
    - ***The coal seams could be shotcreted to limit future weathering. However, shotcrete will eventually deteriorate with time and any plans to install an attenuation drape/mesh should considered in conjunction with plans to shotcrete weak areas to reduce the rate of weathering.***
- Weaker bedrock units (such as coal, but also more closely fractured or weak bedrock) are eroding faster than the surrounding more competent bedrock. In some cases the weathering has created deep channels (0.5 m to 1.0 m deep) in the bedrock surface. These "channels" become preferential pathways for smaller particles (sand, gravel, cobbles) to be funneled down. Talus slopes are accumulating at the base of the weathered "channels" (Photos GP036-7, -8, -10, and -11).
- Soil with cobbles and coarse gravels (and possibly boulders) is present at the brow of the slope in various locations (Photos GP036-1, -6, -7, -8, and -14). The larger particles in the soil mass are a hazard that could generate future rockfall events from the crest of the slope.
- Historic rockfall activity at the GP036 site resulted in AT installing a row of lock blocks at the edge of the highway and then installing a guardrail to address the hazard associate with the lock blocks (Photo GP036-9). The guardrail has been impacted by direct strikes of rockfall events indicating the combination of lock/block height, ditch width, and ditch depth is not adequate to contain rockfalls from hitting the highway surface.
- A potentially large rock block that could be a future rockfall hazard was identified on the slope (Photo GP036-10). A bedrock discontinuity "plane" (distorted and non-planar, as

previously discussed) appears to underlie a large block of rock with some overhang. The north side of the large rock block is a layer of fractured rock and a seam of coal which is weathering faster than the rest of the slope. The discontinuity between the undulating discontinuity and the block of rock appears to be dilated. Continued weathering of the coal seam could result in loss of confinement, resulting in overstressing the remainder of the attachments for the large block to the slope, causing a large rockfall event that would likely bury the entire highway.

  - ***The large block should be assessed for either anchoring with bolts or trim blasting.***

- The north part of the slope appears to be more competent bedrock with less weathering and deterioration. The coal seam with the adit exposed mid-point of the slope also appears to be more competent and is not weathering at the same rate as other coal seams on the GP036 slope (Photo GP036-12 and -13).
  - ***Scaling of the slope and brow area should be completed.***
- Historic rockfall events appear to have travelled across the highway and the railway tracks. The location of the blocks suggests they fell after the train tracks were constructed (Photo GP036-16).
- There is a large hanging block near the brow of the slope which appears to have been the source of historic rockfall events (Photos GP036-14 and -15).
  - ***The large hanging block should be assessed for either anchoring or trim blasting.***

Un-numbered site – Rockfall fence site (Photos Rockfall Fence Site 1 and 2)

- The rock slope at this location is approximately 50 m long and between 20 and 25 m high.
- The ditch is 3 to 4 m wide and 0.5 to 1.0 m deep.
- The bedrock structure appears to have different orientation of bedding planes than the GP036 site but the orientation of the slope face could be responsible for the difference. The bedrock slope is irregular with a high ridge above the highway oriented obliquely to the highway with some dilated fracture zones, but the trajectory of rockfalls appears to deflect particles away from the highway.
- There is limited tree growth on the lower portion of the slope where some thin talus materials have accumulated.
- AT have not reported any recent rockfall reaching the highway at this site.
- The coal-mine operators installed a rockfall fence in the past (AT to confirm year) to protect the highway from blasting work further upslope. The rockfall fence is visible in Photo No Site Number 1.
- There is a large block of rock (estimated 1.5 m x 2.0 m x 3.0 m) on the treed slope between the highway and the railway tracks. The timing of rock block fall is not known but could have pre-dated the expansion of the mine above the slope. The presence of the mine infrastructure upslope would tend to capture large blocks falling from further upslope.

- Some rockfall blocks were noted in the ditch below a zone of closely bedded and fractured bedrock that has preferentially weathered with time (Photos Rock Fall Fence -1 and -2).
    - ***The slope should be scaled and the ditch cleaned of rockfall blocks.***

GP053

The GP053 site has been subdivided into three subsites:

- GP053-I which is south of a patch of wolf willows;
- GP053-II which is north of the wolf willows; and
- GP053-III which is a low rock cut slope at the north limit of the GP053 site.

In general, the GP053 ditch appears to be the narrowest compared to the height of slope above the ditch. The degree of ditch infilling with talus and rock fall particles is also generally greater in various locations along the ditch than on other sites discussed in this report.

The ditch geometry varied for all GP053 rock slopes at various points at the toe of slope and edge of highway embankment.

- ***The actual ditch geometry and how it varies along the slope should be confirmed with topographic survey.***

GP053-I (Figure 6, Photos GP053-I-1 to -5)

- The rock slope is approximately 200 m long and approximately 15 to 20 m high.
- The ditch is 3 to 4 m wide from the edge of the highway embankment to the rock slope and 1.0 m to 1.2 m deep. In some locations the ditch is partially infilled with talus cones and rockfall particles with the ditch bottom being 1.0 m or less in width.
- The bedrock structure at this site consists of near vertical bedding planes (dip estimated between 70° to 80°) dipping to the south to southwest (Photo GP053-I-1 and -2). The rock mass appears to have relatively tight bedding planes but the rock mass is fractured perpendicular to the bedding planes which generates rockfall events.
- Talus cones of fine-grained material (sand and gravel) and rockfall particles were observed in the ditch (Photo GP053-I-3).
- The bedrock structure changes in the north part of the -I slope to a gentle fold with dip of approximately 20°, dipping to the southeast towards the highway (Photo GP053-I-4).
- The bedrock units appear to be weathering uniformly with no preferential weathering along weaker bedrock units (such as coal or fractured bedrock).
- Possible ripple marks could be seen on one exposed face of bedrock on the upper slope.
- There is a mine road at the crest of the slope as shown in Figure 6 (wooden powerline poles are shown in Photo GP053-I-1).

- There is a mid-slope bench that has a partially vegetated talus cone (Photos GP053-I-1 and -2). Rock block particles that could roll on the talus slope (as opposed to platy particles that would tend to slide) could be launched off the talus slopes on the mid-slope bench.
- Small rockfill particles, 0.5 m or less, were observed near the guardrail on the opposite side of the highway (Photo GP053-II-5).
  - ***The slope should be scaled and the ditch cleaned of rockfall blocks and talus material.***
- The height of the slope, the condition of the brow of the slope, and the condition of the rock slope combined with how close it is to the highway appears to indicate that an attenuation mesh is required on this portion of the slope.
  - ***The need for removing the talus slope on the mid-slope bench and the need for an attenuation mesh on this portion of the GP053 slope should be assessed with rockfall analysis.***

GP053-II (Figures 7 and 8, Photos GP053-II-1 to -7)

- The rock slope is approximately 500 m long and approximately 7 m to 10 m high.
- The ditch is 3 to 4 m wide from the edge of the highway embankment to the rock slope and 1.0 m to 1.2 m deep. In some locations the ditch is partially infilled with talus cones and rockfall particles with the ditch bottom being 1.0 m or less in width.
- The bedrock structure at this site consists of near bedding planes dipping into the slope (dip estimated between 60° to 70°) dipping to the northeast (into the slope) (Photo GP053-II-1 to -7). The rock mass appears to be of similar quality to the -I site, with one location showing more intact and massive bedrock that still shows drill-and-blast-hole "barrels" (Photo GP053-II-2).
- The coal seams at this rock slope are eroding faster than the adjacent bedrock seams (Photos GP053-II-4, to -6). The talus cones in the ditch are largest near the coal seams as shown in Figure 7.
  - ***The coal seams could be shotcreted to reduce the rate of weathering and loss of confinement for rock blocks adjacent to the coal seams.***
- Rockfall particles that are platy tend to slide down the talus seams whereas other particles are able to either roll downslope or fall and bounce on a rock surface and potentially impact the ditch and/or highway (Photos GP053-II-3 and -7).
  - ***The slope should be scaled and the ditch cleaned of rockfall blocks and talus material.***
- A mine access road is located on the hillslope above the GP053-II rock slope. The mine access road is located at the crest of the rock slope in the north quarter of the rock slope (Photo GP053-II-6) and as shown in Figure 7. Soil located the brow of the slope might be fill associated with the mine access road. Mine-road grading and drainage practices might also contribute to rockfall or other debris falling over the crest of the road.

- ***AT could discuss mine access road drainage patterns with the mine operator to assess if mine access road drainage could be diverted away from the road slope.***
- ***The need for a rockfall attenuation mesh covering this portion of the slope should be assessed using rockfall analysis.***

GP053-III (Photo GP053-III-1 and -2)

- The rock slope is approximately 100 m long and approximately 4 m to 5 m high.
- The bedrock structure is different at this site from the previous sites with steeply dipping bedding planes (estimated 60 to 70°) dipping to the south. The bedding planes vary from a few centimeters thick to over 1 m thick. More fractured or possibly blast damaged zones appear to have been removed, likely during construction, leaving an uneven slope surface (Photos GP053-III-1 and -2).
- The ditch is 3 to 4 m wide from the edge of the highway embankment to the rock slope and 1.0 m wide or less across the bottom of the ditch. The ditch is between 1.2 m to 1.4 m deep.
- The talus cones are relatively small and do not block the entire ditch bottom.
- In one location the ditch is infilled with rockfall particles. In general, the ditch appears to be containing the rockfall particles. While AT reported no rockfall particles reach the highway at this site, the rockfall particles in the ditch are a roadside hazard.
  - ***The slope should be scaled and the ditch cleaned of rockfall blocks and talus.***

4 ASSESSMENT

KCB's assessment of the conditions at the various sites is as follows:

General comments that apply to all sites

- The bedrock structure varies between the different rock slopes sites and between subsites for each GRMP site. The bedrock structure can change over short distances (GP049-I versus GP049-II, GP053-I, and the variability and non-planar bedding planes, including faulting, at the GP036).
- Only one area of the rock slopes (GP053-II) viewed during the call-out inspection showed any sign of drill and blast method being used (i.e., half-barrel patterns in the rock slope). This is likely due to post-construction deterioration of the bedrock slopes after construction. Although it cannot be proven, KCB's experience with blasting is that the drill and blast excavation may have damaged the rock slope, leaving it more prone to post-construction deterioration. Weaker or more fractured bedrock slopes exposed to concentrated runoff or groundwater seepage discharge would have eventually deteriorated even with careful drill and blast excavation techniques being used. The condition of the GP049-I and GP053-III slopes could indicate that weaker or blast-damaged materials were removed during construction.
- Ongoing deterioration of the rock slopes has resulted in a pattern of weathering and rockfall that will continue to generate rockfalls at all sites.
- The preferential or more rapid weathering of weaker bedrock units (e.g., coal, highly fractured or thinly bedding bedrock) is resulting in undermining of more competent bedrock, which, when the undermined bedrock is fractured and less competent, creates rockfalls. The coal seams on all slopes appear to be weathering the fastest. The weathering of the coal seams could be controlled by treating the face of the slope with shotcrete. The undermined and unsupported blocks of rock loosened by weathering of coal or other weak bedrock materials will need to be scaled.
- The bedrock at the brow of the slopes, where visible from the highway, was weathered with dilated joints. These loosened bedrock blocks will need to be removed with scaling. Future frost deterioration of rock mass will continue. In some locations an attenuating mesh may be required to contain future rockfall materials from these sources.
- Soil present at the brow of slopes contains cobbles and coarse gravel particles. These materials will weather readily and generate rockfall hazards. The brow of the slope at the GP049 and GP036 slopes is on steep ground which is inaccessible to and not trafficable by heavy equipment. The un-numbered rock fence site and parts of the GP053 rock slope have mine haul roads at or near the brow of the slope that could allow for work being done near the crest of the slope with access agreements in place between AT and the mine operator.
- Surface water drainage appears to flow over the crest of all rock slopes, though evidence of surface water flow was only observed where soil materials near the highway could be assessed for signs of erosion. Limited evidence of water flow over the crest of the slope

was observed during our site inspection, though surface water flow over the crest is expected during snow melt and rainfall events.

- The highway ditches are generally narrow and shallow relative to the height of rock slope and will therefore have limited capacity to capture rockfalls (the ditches at GP049-II and GP053-III appear to be exceptions, at least based on site observations presented in this call-out report). The formation of talus slopes and accumulations of rockfall particles in the ditches is increasing the potential for rockfall particles to reach the highway. In the case of talus slopes, platy particles will tend to slide on the talus, but particles that can roll will be more likely to reach the highway. Particles that fall from height and bounce on a bedrock surface will likely reach the highway due to the generally narrow ditches at the sites visited. Mitigations used to address rockfall hazard will need to consider energy reduction and controlling the trajectory of rockfall particles such as using an attenuation mesh/drape.

Site specific comments that are not covered by the preceding general comments are given in the following bullets:

GP049-II

- The relatively good performance of the GP049-II slope (i.e., AT reports no rockfalls reaching the highway) indicates that scaling and ditch clean out, with some shotcreting of coal seams, is all that is required at this site, subject to more detailed assessment.

GP036

- Some large blocks or overhangs were noted at the GP036 site that could generate larger volumes of rockfall materials. These areas will need either anchoring, if their rock mass properties are appropriate for anchoring, or removal with trim blasting.

GP053-III

- The relatively low height and good performance of the GP053-III slope (i.e., AT reports no rockfalls reaching the highway) indicates that scaling and ditch clean out is all that is required at this site, subject to more detailed assessment.

KCB's assessment of the climatic trigger for rockfalls and in this area of Hwy 40:36 is presented as follows:

- Figure 2 indicates that the intensity and frequency of heavy rainfall events appears to be increasing in recent years.
- The rockfall and debris flow events that occurred in 2020 and 2022 appear to be likely to occur again in the future.
- Increased frequency or more intense rainfall may promote additional rockfall hazard and might cause existing problem areas to shed rock blocks sooner than during historical weather conditions. However, increased precipitation may also accelerate weathering of weaker bedrock materials which, upon removal, may undermine more blocks of bedrock creating additional rockfall hazard.

- Assessment of impact of increased rainfall on debris flows along this section of Hwy 40:36 is beyond the scope of the call-out report but should be considered further by AT.
- The apparent increase in the extreme air temperatures, specifically during winter, would result in greater frost penetration. AT's observation of warmer air temperatures and running water in early winter months would increase the potential for additional freeze-thaw cycles with associated expansion of existing discontinuities would tend to increase rockfall hazard. AT should review historic rockfall records (if there are any) to aid in the assessment of if there is a cold-weather climatic trigger for rockfall events.

The development of mine infrastructure above Hwy 40:36 and the subject rock cut slopes represents a change in site drainage conditions since the highway was constructed. Depending on the timing of the construction of the mine infrastructure, drainage patterns may have been altered, diverting drainage from one area to another, with potential concentration of drainage discharging towards some parts of the rock cut slopes and highway. Operation mine water management practices, which are unknown to KCB, might also result in water interacting with the rock slopes differently than in earlier years.

5 RISK LEVEL

The risk level has not been previously prepared for the site. Risk levels for AT GRMP sites are determined according to the following:

Risk Level = Probability Factor X Consequence Factor

Where the AT risk level is defined as follows:

- Probability Factor varies from 1 (inactive, very low probability of fall occurrence) to 20 (active, a large volume of rock is surrounded by open cracks. Toppling or sliding of the displacing mass is accelerating. Sites where rapid movement of a large fall is possible).
- Consequence Factor varies from 1 (rockfall contained by ditch if cleaned as required to maintain capacity) to 10 (individual rocks or total volume of rocks deposited on the road large enough to: damage destroy vehicles and severely injury occupants, bury vehicles, cause complete closure of the road, with a temporary, rough detour or diversion possible in days to weeks and/or complete reconstruction or re-routing of the road after rockfall).

The risk level was determined for each site using AT's risk level system for rockfalls and is presented in Table 1.

Table 1 – Risk level ratings for subject rock slope sites

Site	Probability	Consequence	Risk	Notes
GP049-I	12	4	48	No change to 2022 Section B risk ranking
GP049-II	6	4	24	AT have not reported rockfall from this slope, but rockfall is accumulating in the ditch and near the edge of pavement closest to the slope
GP036	16	5	80	Probability and consequence increased from 2022 section B ranking (56) because of observation of open joints around potential large mass of rock
Un-numbered	6	4	24	Not visited or ranked in 2022
GP053-I	12	5	60	No change to 2022 Section B risk ranking
GP053-II	12	5	60	No change to 2022 Section B risk ranking
GP053-III	12	1	60	Height of slope and width of ditch appears to result in ditch being able to contain rockfall if cleared regularly

6 RECOMMENDATIONS

Recommended short-term and long-term remedial actions for the site are discussed in the following subsections.

6.1 Short-Term

KCB recommends the following short-term actions:

- AT should remove rockfall blocks and talus material from the ditches at each site to improve storage volume for future rockfall events; and
- AT's rockfall event reporting could be improved by maintaining a record of rockfalls that reach the road, including date of event, approximate location, volume of particles, and maximum particle size. It appears that AT may already be doing this, but a formal record could be prepared by the HMC or MCI based on e-mails to AT and the regional geotechnical consultant.

6.2 Long-Term

KCB's recommendations the following long-term actions are presented in this section based on the observation-by-observation of rock-slope conditions with associated recommendations presented in Section 3.

- The rock slopes and brow of slopes should be scaled to remove loose particles.
- The rockfall hazards at each site should assessed to evaluate the effectiveness of rock slope stabilization mitigations such as bolting, trim blasting, shotcrete, and attenuation mesh. The scaling work could be conducted by the contractor selected to complete rock slope stabilization mitigations.
- The design of bolting, trim blasting, shotcrete, and attenuation mesh will require assessing bedrock structure and orientation of bedding planes and discontinuities and orientation of the rock cut slopes. The geo-mechanical properties and characteristics of the bedrock rock mass at each rock slope should be characterized and assessed in a detailed field program. The bedrock discontinuities and cut slope orientation should be mapped in detail by hand at the base of the slope and over the entire slope with photogrammetric methods and plotted on a polar plot for each site and sub-site. Mapping and rock mass characterization should be completed before the snow falls so that the bedrock surface is not partially or completely obscured with snow.
- The rockfall hazard at each site should be assessed with rockfall modelling using the updated geo-mechanical data collected for each site to assess the required energy rating of the attenuation mesh and also to assess if the existing ditch geometry would be adequate if regular ditch cleaning was conducted with no other rock slope mitigation.

- The environmental aspects of the proposed rock scaling and construction of rockfall hazard mitigations will need to be assessed with an Environmental Evaluation that meets AT's requirements.
- The subject rock slopes will be included in the KCB-AT-UofA research program or study in the upcoming year. KCB's field work on any future rockfall mitigation design assignment will be coordinated with UofA's field work.
- A tender will be prepared to procure contractor services and construction drawings should be prepared to illustrate the extent of scaling, and any other rock slope mitigations needed (e.g., bolting, trim blasting, and attenuation mesh).
  - The proposed work is specialized construction work not usually done for AT (CN and CP Rail conduct such work regularly). AT should consider an invitational tender or pre-qualification of bidders.
  - If AT wants to have this work done in 2023, AT should aim for a tender to be awarded in late winter (end of March) so that specialty contractors are not all booked up for summer 2023 work.

The cost of cleaning out the ditches at all rock slope sites discussed in this report using the highway maintenance contractor is estimated to be between $25,000 and $40,000.

The cost of scaling, mesh, trim blasting or bolting, and shotcrete is estimated to be:

- GP049-I and -II: $350,000 to $500,000 (70% mesh).
- GP036: $550,000 to $700,000 (70% mesh).
- GP053-I, -II, and -III: $700,000 to $800,000 (100% mesh on -I and -II sites).

The cost of the mesh is the most expensive item so defining more clearly where mesh is required in detail design will have the largest impact on the tendered price. The cost estimate presented in this report has been based on meshing between 70% and 100% of the rock slope faces (estimated % mesh is presented in brackets for each site in the cost information above). The GP053-I and -II sites have the narrowest and shallowest ditches so, for the purposes of construction cost estimating, we have assumed that the entire slope at GP053-I and -II would be covered in mesh, much like the S017-I Mount Baldy site or the S018-I Galatea site.

7 CLOSURE

This report is an instrument of service of Klohn Crippen Berger (KCB). The report has been prepared for the exclusive use of Alberta Transportation (Client) for the specific application to the Peace Region (Grande Prairie South) Geohazard Risk Management Program (Contract No. CON0022166), and it may not be relied upon by any other party without KCB's written consent.

KCB has prepared this report in a manner consistent with the level of care, skill and diligence ordinarily provided by members of the same profession for projects of a similar nature at the time and place the services were rendered. KCB makes no warranty, express or implied.

Use of or reliance upon this instrument of service by the Client is subject to the following conditions:

1. The report is to be read in full, with sections or parts of the report relied upon in the context of the whole report.
2. The observations, findings and conclusions in this report are based on observed factual data and conditions that existed at the time of the work and should not be relied upon to precisely represent conditions at any other time.
3. KCB should be consulted regarding the interpretation or application of the findings and recommendations in the report.
4. This report is electronically signed and sealed and its electronic form is considered the original. A printed version of the original can be relied upon as a true copy when supplied by the author or when printed from its original electronic file.

Please contact the undersigned if you have any questions or comments regarding this report.

Yours truly,

KLOHN CRIPPEN BERGER LTD.

Chris Gräpel, M.Eng., P.Eng.
Senior Civil Engineer, Associate

Cc: Renato Macciotta, Ph.D., P.Eng.

CKG:bb

ATTACHMENTS
Figure
Appendix I Site Photographs

REFERENCES

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

Alberta Geological Survey (AGS), 2013b. Map 600. Bedrock Geology of Alberta. Published June 17, 2013.

Alberta Transportation (AT). 2021. Traffic Counts Reference No. 29750. Retrieved September 1, 2022 from: Turning Movement Summary Diagram 00029750 (alberta.ca)

Alberta Transportation (AT). 2021. Traffic Counts Reference No. 30730. Retrieved September 1, 2022 from: Turning Movement Summary Diagram 00030730 (alberta.ca)

Forgeron, Steve. 2016. The standardization of geological assessment at underground coal mines in Canada - Report. Ugcoal.ca. Available at: http://www.ugcoal.ca/projects/geocoal/index.htm [Accessed 27 September 2022].

Prior, G.J., Hathway, B., Glombick, P.M., Pana, D.I., Banks, C.J., Hay, D.C., Schneider, C.L., Grobe, M., Elgr, R. and Weiss, J.A. (2013): Bedrock geology of Alberta; Alberta Energy Regulator, AER/AGS Map 600.

Toth, J., 1977. The Hydrogeological Reconnaissance Maps of Alberta. In: Alberta Research Council Bulletin 35 - Contributions to the Hydrogeology of Alberta, Alberta Research Council Groundwater Division, 1977, p.1-12.

FIGURES

Legend

- ★ Site Location
- ☆ Un-numbered Site Location
- —— All-Weather Road

0 2.5 Kilometres

NOTES:
1. HORIZONTAL DATUM: NAD83
2. GRID ZONE: UTM ZONE 11N
3. IMAGE SOURCE: 2022 MICROSOFT CORPORATION, 2022 MAXAR CNES, DISTRIBUTION AIRBUS DS

CLIENT: Alberta

Klohn Crippen Berger

PROJECT: PEACE REGION (GRANDE PRAIRIE DISTRICT-SOUTH) GEOHAZARD RISK MANAGEMENT PROGRAM

TITLE: Site Location Plan
Rock Slope Sites
Hwy 40:36, km 8.395 to 17.161

SCALE	PROJECT No.	FIG No.
1:40,000	A05116A01	1

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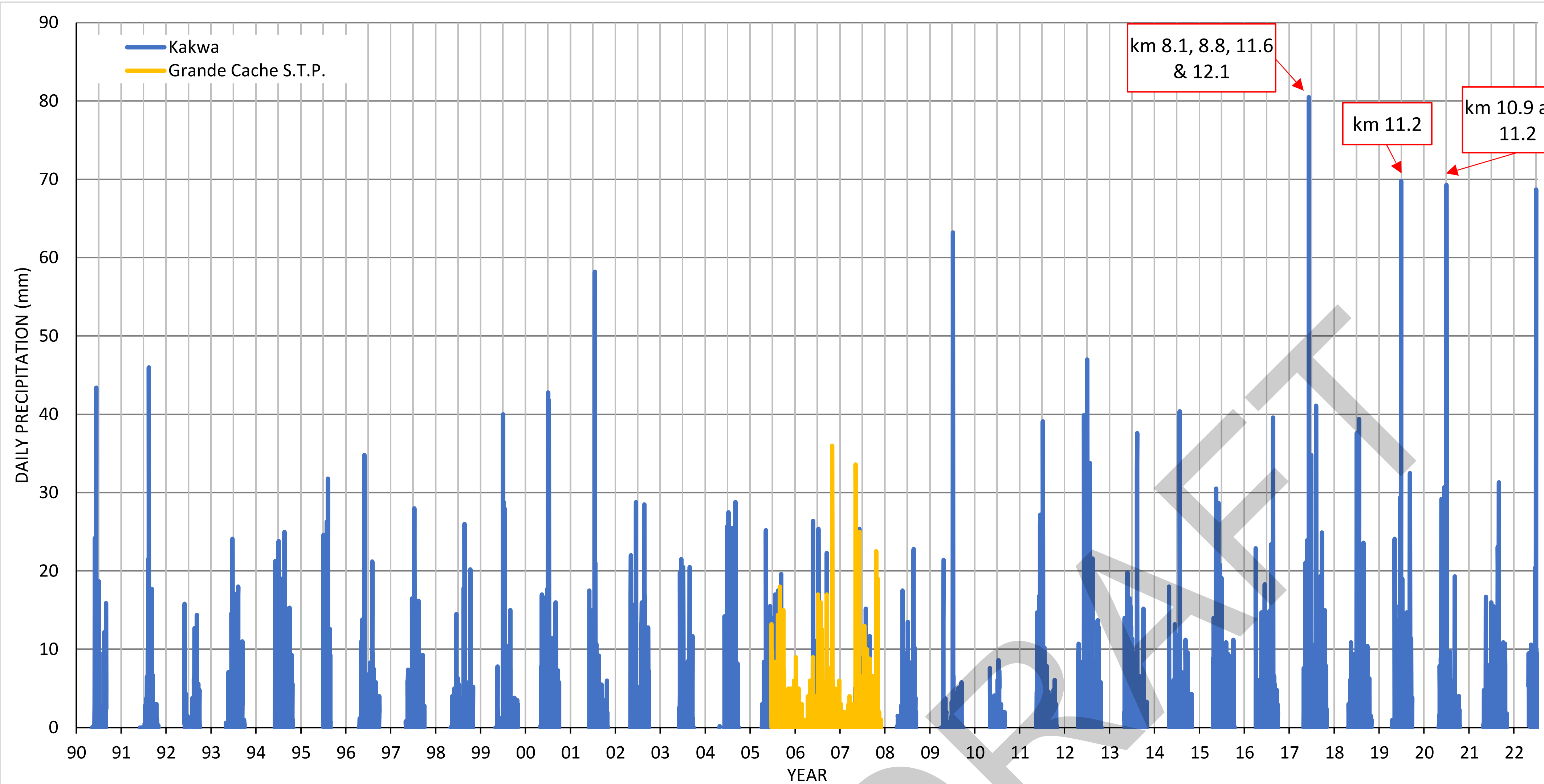
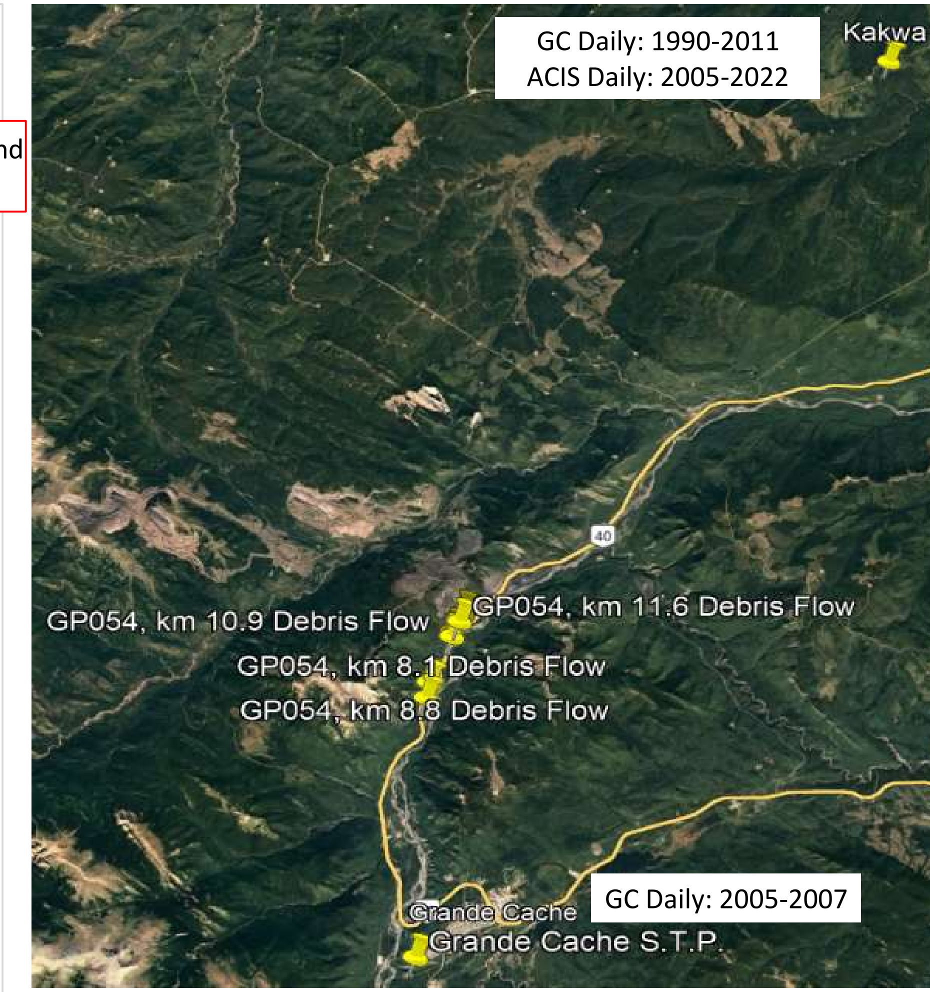




NOTES:

1) DATA DOWNLOADED FROM GOVERNMENT OF CANADA OR ALBERTA CLIMATE INFORMATION SERVICE (ACIS) WEBSITES.

2) DATA DISCONTINIOUS BEFORE 1990 SO NOT INCLUDED.

3) KAKWA AND GRANDE CACHE S.T.P. STATIONS LOCATED APPROXIMATELY 30 KM AND 12 KM FROM SITE.

CLIENT

Alberta

Klohn Crippen Berger

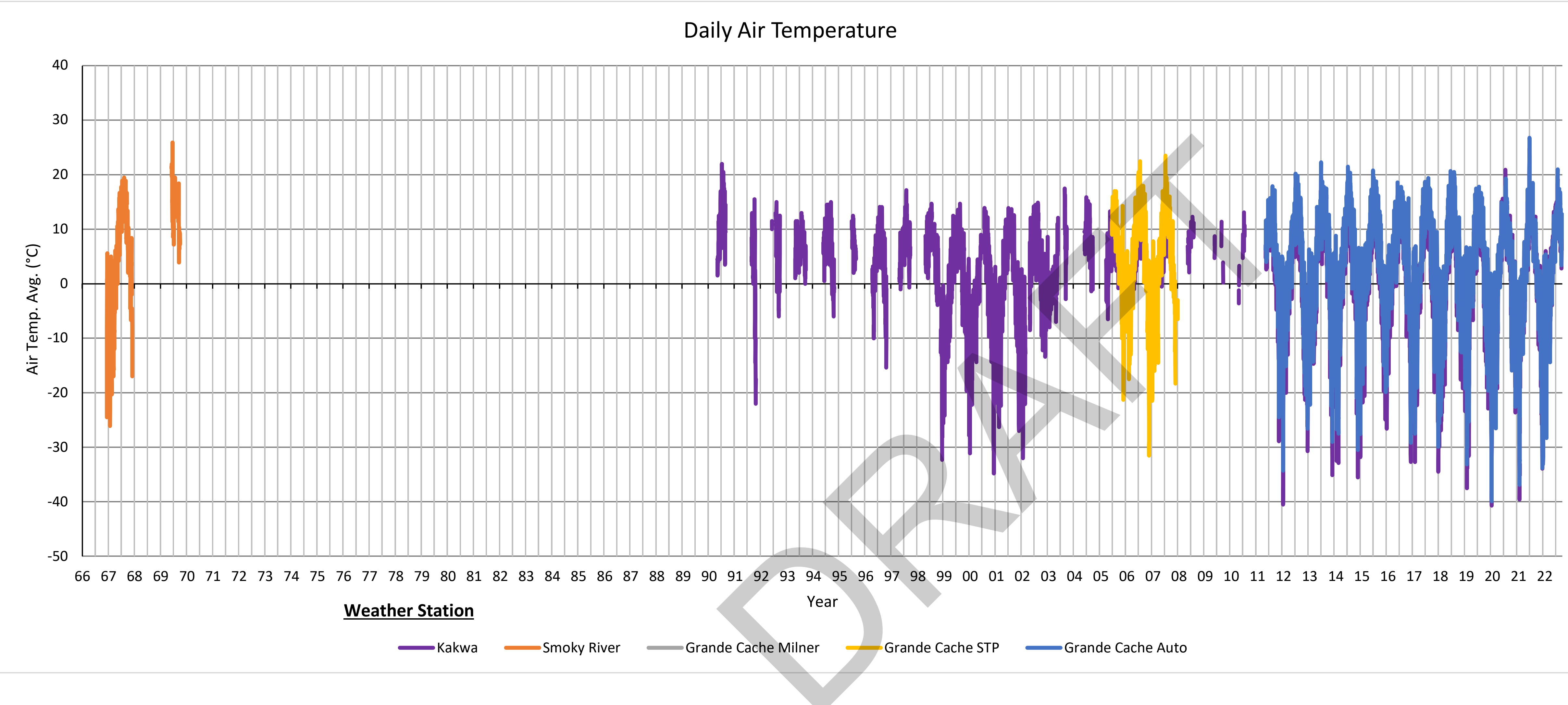
PROJECT

PEACE REGION (GRANDE PRAIRIE DISTRICT - SOUTH)
GEOHAZARD RISK MANAGEMENT PROGRAM

TITLE

Rainfall Data
Rockfall Sites
Hwy 40:36; km 8.119 to 12.262

SCALE	PROJECT No.	FIG No
-	A05116A01	2



NOTES:

1) DATA DOWNLOADED FROM GOVERNMENT OF CANADA OR ALBERTA CLIMATE INFORMATION SERVICE (ACIS) WEBSITES.

2) KAKWA AND GRANDE CACHE S.T.P. STATIONS LOCATED APPROXIMATELY 30 KM AND 12 KM FROM SITE.

CLIENT Alberta	PROJECT PEACE REGION (GRANDE PRAIRIE DISTRICT - SOUTH) GEOHAZARD RISK MANAGEMENT PROGRAM
Klohn Crippen Berger	TITLE Air Temperature Data Rockfall Sites Hwy 40:36; km 8.119 to 12.262
	SCALE - / PROJECT No. A05116A01 / FIG No 3

CLIENT
Alberta

Klohn Crippen Berger

PROJECT
PEACE REGION (GRAND PRAIRIE DISTRICT - SOUTH) GEOHAZARD RISK MANAGEMENT PROGRAM

TITLE
Site Plan
GP049-I Rockfall 5.5 km South of McIntyre Mine
Hwy 40:36, km 8.395

SCALE

PROJECT No. A05116A01

FIG No. 4

CLIENT	PROJECT
Alberta	PEACE REGION (GRAND PRAIRIE DISTRICT - SOUTH) GEOHAZARD RISK MANAGEMENT PROGRAM
Klohn Crippen Berger	TITLE Site Plan GP049-II Rockfall 5.5 km South of McIntyre Mine Hwy 40:36, km 8.395

SCALE	PROJECT No.	FIG No.
	A05116A01	5

CLIENT	PROJECT
Alberta	PEACE REGION (GRAND PRAIRIE DISTRICT - SOUTH) GEOHAZARD RISK MANAGEMENT PROGRAM
Klohn Crippen Berger	TITLE Site Plan GP036 Rockfall 2.0 km South of McIntyre Mine Hwy 40:36, km 12.061
	SCALE / PROJECT No. A05116A01 / FIG No. 6

CLIENT

Alberta

Klohn Crippen Berger

PROJECT

PEACE REGION (GRAND PRAIRIE DISTRICT - SOUTH) GEOHAZARD RISK MANAGEMENT PROGRAM

TITLE

Site Plan

GP053-I Rock Slope South of McIntyre Mine

Hwy 40:36, km 16.295 to 17.161

SCALE	PROJECT No. A05116A01	FIG No. 7

CLIENT	PROJECT
Alberta	PEACE REGION (GRAND PRAIRIE DISTRICT - SOUTH) GEOHAZARD RISK MANAGEMENT PROGRAM
Klohn Crippen Berger	TITLE Site Plan GP053-II Rock Slope Middle of McIntyre Mine Hwy 40:36, km 16.295 to 17.161
	SCALE / PROJECT No. A05116A01 / FIG No. 8

CLIENT

Alberta

Klohn Crippen Berger

PROJECT

PEACE REGION (GRAND PRAIRIE DISTRICT - SOUTH) GEOHAZARD RISK MANAGEMENT PROGRAM

TITLE

Site Plan

GP053 Rock Slope North of McIntyre Mine

Hwy 40:36, km 16.295 to 17.161

SCALE	PROJECT No.	FIG No.
	A05116A01	9

APPENDIX I

Site Photographs

Appendix I

I GP049-I

Photo GP049-I – 1 **Rock mass at GP049-I site is has near horizontal bedding planes. Brow of rock slope has overhanging blocks that should be scaled. Photo taken July 14, 2022, facing west.**

Photo GP049-I – 2 **Rockfall in ditch has reached the edge of the highway. Photo taken July 14, 2022, facing northwest.**

Photo GP049-I – 3 **Higher portion of rock slope above mid-slope bench sparsely vegetated with small trees. Note overhanging blocks on upper slope above bench that should be scaled. Photo taken July 14, 2022, facing west.**

Photo GP049-I – 4 **Soil at brow of slope at north end of -I site contains cobbles and rock mass looks reasonably competent. This location could be addressed with an attenuating drape. Photo taken July 14, 2022, facing west.**

II GP049-II

Photo GP049-II – 1 **Rock mass structure is different than at GP049-I site (inclined bedding, 45° to 60°), 400 m to the north of the GP049-I site. Photo taken facing west on July 14, 2022.**

Photo GP049-II – 2 **Higher rock slope at north end of GP049-II site. Some overhanging particles where inclined bedding planes have been undermined by historical rock falls or construction blasting. Photo taken facing northwest on July 14, 2022.**

Photo GP049-II – 3 **Ditch at GP049-II is approximately 10 m wide and 1.5 m deep and appears to be containing most rock fall particles. Tall vegetation obscures seeing rockfall particles near edge of pavement. Note buried pipeline marker in ditch. Photo taken facing north on July 14, 2022.**

Photo GP049-II – 4 **One of three observed rockfall particle 0.3 m x 0.2 m x 0.1 m located within 1.0 m from edge of pavement.**

Photo GP049-II – 5 **Undermining of more competent bedrock layers created by weathering and erosion of less competent bedrock layers creates rockfall hazard on the entire slope. One source of rockfall blocks is located near brow of slope, located above a large rockfall block (1.2 m x 1.2 m x 0.3 m) located 3 m from pavement edge. Brow of slope has bedrock that has dilated joints and potential for large blocks of rock to detach. Photo taken July 14, 2022, facing west.**

Photo GP049-II – 6 **Talus cone located below zone of interbedded highly fractured rock and coal. Coal appears to weather/erode creating a talus cone, leaving overlying bedding planes of more competent rock unsupported, creating some rockfall hazard. Photo taken July 14, 2022, facing west.**

III GP036

Photo GP036 – I **Rock slope at south end of GP036 site. Rockfall activity does not reach the road at this site. Note soil infilling of possible fault feature at right of photo. Photo taken July 14, 2022, facing northwest.**

Photo GP036 – 2 **Soil-infilled possible fault structure between rock slopes. South end of north part of site shown in this photo. Largest rock fall in July 2022 rainfall and rockfall event is shown by red circle. Photo taken July 14, 2022, facing northwest.**

Photo GP036 – 3 **Largest rockfall particle from July 2022 rainfall event (0.6 m x 1.5 m x 1.2 m). Rockfall particle fell at southern limit of guardrail and was pushed to this location off road. Photo taken July 14, 2022, facing southwest.**

Photo GP036 – 4 **June 29, 2022 rockfall on the highway. Photo taken July 29, 2022, facing southwest by AT.**

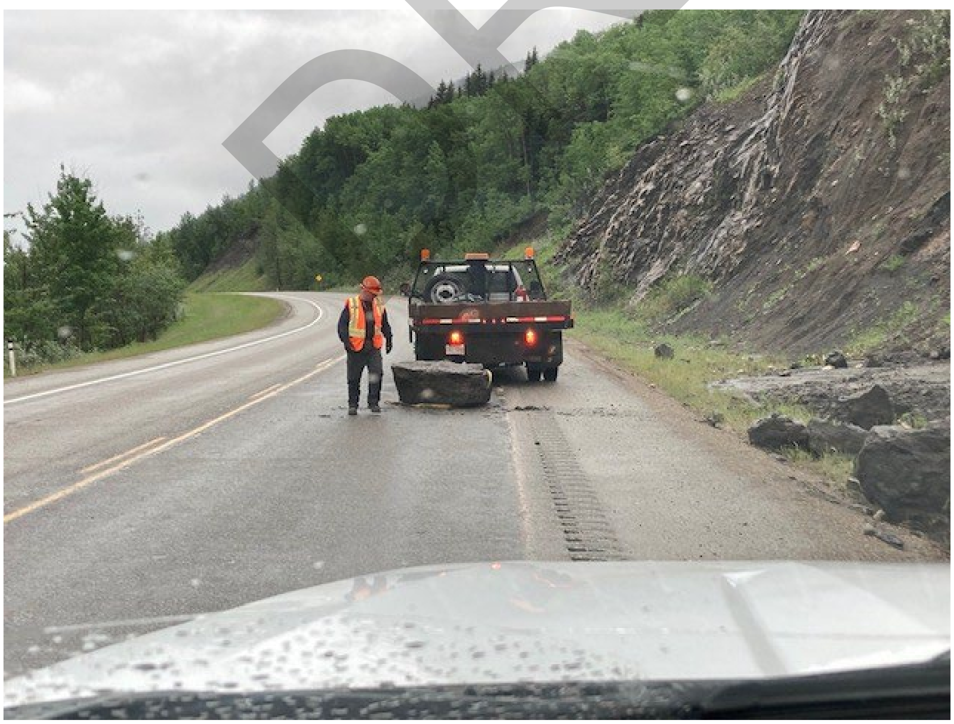


Photo GP036 – 5 **Collection of rockfall blocks at south limit of north rock slope near southern limit of guard rail. Photo taken July 14, 2022, facing northeast.**

Photo GP036 – 6 **Upper part of north slope above June 29, 2022 rockfall event show in Photo GP036 – 4. Photo taken July 14, 2022, facing northwest.**

Photo GP036 – 7 **Upper slope, progressing to the north. Note gravel deposit at brow of slope. Note also weathering and removal of weaker rock units (such as coal) which is creating some overhangs and loss of confinement for the rock slope face, leading to rockfalls. Photo taken July 14, 2022, facing northwest.**

Photo GP036 – 8 **Upper slope. Yellow line shows north limit of photo -6. Note uneven weathering of rock slope face which is creating overhangs and rockfall potential as well as preferential fall paths for smaller rockfall particles. Photo taken July 14, 2022, facing northwest.**

Photo GP036 – 9 **Portion of slope with deteriorating lock blocks and guard rail at edge of pavement. Note weathering coal seams, rockfall particles in ditch, and pipeline marker at toe of slope. Photo taken July 14, 2022, facing northeast.**

Photo GP036 – 10 **Potential rock block on upper slope that could be further undermined by weathering of soft rock and coal seams. Some dilated (open) joints at toe. Red arrow indicates dilated joint. Green circles indicate bedrock joint or shear plane on left and below the rock block that could be behind the rock block. Yellow arrow indicates soft rock and coal seams that are weathering and eroding which could unload the north side of the rock block and cause a large rockfall event. Red circle in inset photo shows extent of rock block. Photo taken July 14, 2022, facing northwest.**

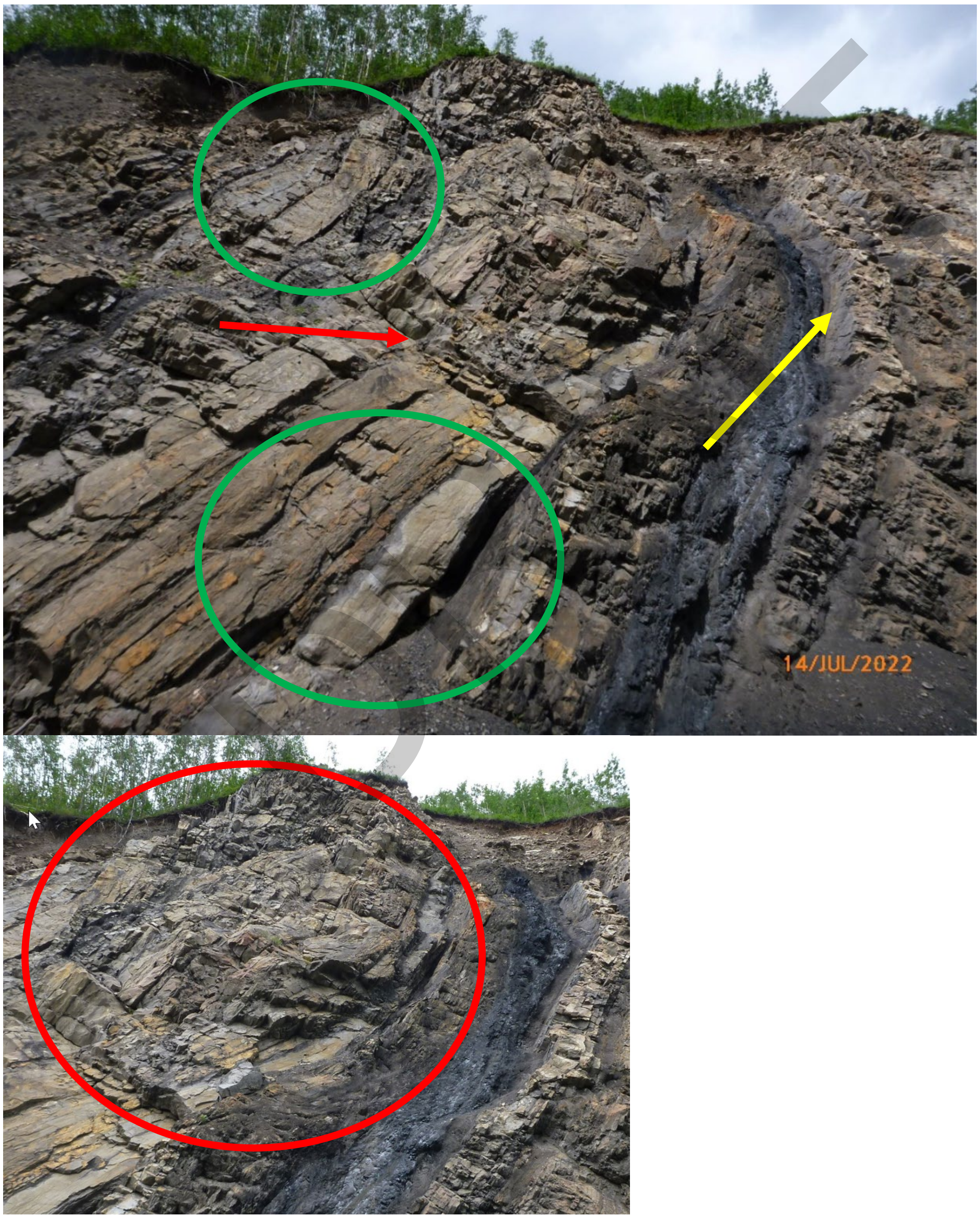


Photo GP036 – 11 **Additional coal seams and soft rock layers that have weathered and eroded, leaving blocks of rock unsupported. Photo taken July 14, 2022, facing northwest.**

Photo GP036 – 12 **More competent section of rock slope between coal seams (adit coal seam is to the right (north). Photo taken July 14, 2022, facing northwest.**

Photo GP036 – 13 **Rock slope to the north of coal seam adit. Photo taken July 14, 2022, facing northwest.**

Photo GP036 – 14 **Rock slope at north limit of rock cut slope. Red circle indicates overhang in upper third point of slope (shown in Photo -15). Photo taken July 14, 2022, facing northwest.**

Photo GP036 – 15 **Overhang at upper third of slope shown in Photo 13. Photo taken July 14, 2022, facing northwest.**

Photo GP036 – 16 **Large blocks of rock that appear to have rolled downhill past the railway tracks. Photo taken July 14, 2022, facing south.**

IV ROCKFALL FENCE SITE/NO SITE NUMBER

Photo Rockfall Fence Site 1 **Rock slope north of GP049 downslope of mine rockfall fence. Photo taken July 14, 2022, facing northwest.**

Photo No Site Number 2 **Rock slope north of GP049 downslope of mine rockfall fence. Several overhanging rock blocks are present on the more fractured zones of this rock slope. Photo taken July 14, 2022, facing north.**

V GP053-I

Photo GP053-I – 1 **Typical rock slope with uneven weathering of bedding planes. Weathering of weak, fractured or coal seams is causing stronger seams to be undermined. Deeper troughs preferentially funnel rockfall particles into talus cones. Note talus cones on mid-slope bench which could launch rockfall from upper part of slope. Photo taken July 14, 2022 facing northwest.**

Photo GP053-I – 2 **Rock slope with relatively even weathering of bedding planes. Note talus cones on mid-slope bench which could launch rockfall from upper part of slope. Photo taken July 14, 2022, facing northwest.**

Photo GP053-I – 3 Talus cones and rockfall particles in ditch and close to edge of pavement. Photo taken July 14, 2022, facing southwest.

Photo GP053-I – 4 Different (second) structure of bedrock with different orientation of bedding planes. Note non-planar distortion of bedding planes in a gentle fold. The near vertical bedding plane bedrock structure shown in Photos GP053-2 is located at the lower lefthand corner of this photo. Photo taken July 14, 2022, facing northwest.

Photo GP053-I – 5 **Rockfall particles under guardrail on opposite side of the highway from rock slope. Photos taken July 14, 2022, facing southwest and northeast respectively.**

VI GP053-II

Photo GP053-II – 1 **Different structure (third) of bedrock with different orientation of bedding planes. Note overhangs forming on south side of bedding planes caused by previous rockfall. Photo taken July 14, 2022, facing northwest.**

Photo GP053-II – 2 **Rock slope with half barrels (green arrows) from rock cut blasting. Red circle indicates dilating bedrock joints in an overhang near top of slope. Photo taken July 14, 2022, facing northwest.**

Photo GP053-II – 3 **Ditch with talus slopes and rockfall particles. Photo taken July 14, 2022, facing northeast.**

Photo GP053-II – 4 **Weathered and eroded soft or highly fractured rock and coal seams are being eroded to create overhanging rock blocks which then become rock fall. Note trees at brow of slope. Photo taken July 14, 2022, facing northwest.**

Photo GP053-II – 5 **Section of slope that is weathering and eroding with zones of more competent rock elevated above the slope. The loss of support for the more competent rock layers eventually leads to rockfall. Photo taken July 14, 2022, facing southwest.**

Photo GP053-II – 6 **More competent, more massive layers of bedrock that are undermined do not experience as much rockfall or slope deterioration upon erosion of soft rock and coal seams. A mine access road is located behind the crest of the slope as shown in Figure 7. Photo taken July 14, 2022, facing northwest.**

Photo GP053-II – 7 **Talus slopes and rock blocks in the ditch. The rock blocks in the ditch appear to get closest to the highway by rolling down the talus slope. Photo taken July 14, 2022, facing northeast.**

GP053-III

Photo GP053-III – 1 Low rock cut at north end of GP053 site. Rock slope is generating rockfall but height of slope and depth and width of ditch are containing rockfall particles. Note that orientation of bedding planes if different from previous zones of the GP053 site. Photo taken July 14, 2022, facing northwest.

Photo GP053-III – 2 Rock slope and ditch with few rockfall particles. Photo taken July 14, 2022, facing northeast.