Geotechnical Considerations from the June 2013 Southern Alberta Flood

Roger Skirrow, Director Geotechnical and Materials Section, Alberta Transportation

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Abstract

Climate change has the potential to create a cascade of impacts on interrelated and integrated systems. The capacity of natural systems and society to adapt to new extremes and vulnerabilities and to mitigate appropriately are being studied by scientists, policy makers, industry and others. With respect to highways or linear corridors, and more specifically, the geotechnical component of these structures there are expected and unexpected consequences to climate change. The geotechnical consequences are mostly related to changed conditions at known and potential geohazard locations and the mitigation of these geohazards where they intersect with existing highway corridors. This paper provides a brief overview of significant and likely consequences of climate change on geohazards that occur along Alberta highways. The major flood of June 2013 is used to support the assessment. The cause of climate change is not germane to this discussion; this paper accepts the notion that climate change is or will occur through natural cycles and anthropogenic inputs.

Introduction

Climate change and the effect on natural ecosystems and specifically geohazards has been studied in Canada[1], Italy[2], Nepal[3] , England[4] , Switzerland[5] and many other countries over the past 20 years. There is a compelling narrative being repeated within the scientific literature that needs to be listened to by decision makers and public policy agencies. Whether or not climate change is or isn't occurring, or whether it is anthropogenic, part of a larger natural cycle, or some combination thereof is not important in the context of this discussion. An exception is the understanding that climate change models have been developed by various agencies and these models have been used by several of the researchers quoted in this paper to predict geomorphologic changes to the natural environment. Therefore some aspects of this paper are founded on science that this author presumes to be valid. There is and should be a healthy and respectful skepticism about the input parameters and analytical techniques used within any engineering or scientific model. This is especially valid for the superposition of geotechnical models onto climate change models due to the complex nature of the model analytics, choice and accuracy of input parameters and the profound implications of the model output. This paper discusses in broad terms climate change characteristics and their effect on geotechnical related site considerations. Resiliency of the infrastructure to future geohazard events, especially those related to climate change is discussed in the context of the June 2013 southern Alberta flood event.

Climate Change Characteristics

The commonly held implication of the current climate change cycle is one of rising temperatures and increasingly extreme weather events. Rising temperatures are predicted for virtually all parts of the world with temperatures in the northern latitudes rising the fastest. Global temperatures are rising at about 0.2 deg. C per decade[6]. This could lead to increases in wildfires and prolonged droughts in some areas where rainfall amounts are reduced and evapotranspiration is increased due to higher temperatures and shifts in vegetation type and wind patterns. Changes in vegetative cover are expected in response to climate change. Drought tolerant crops can be planted to respond to climate change while other marginal cropland may become more viable as temperatures rise. The ability of natural forests to adapt to climate change is unlikely to match the rate of climate change. This will expose forests to drought conditions that will weaken their natural defenses. Research predicts an increase in insect pests and associated damage to forests from insect pests and wildfires. The geotechnical impacts of drought are considered to be musty related to erosion susceptibility as vegetative cover is lost, and shrinkage of clays as they dry. These are significant issues to be dealt with by highway agencies as increased erosion of embankment and cut slopes and ditches will require greater maintenance or rehabilitation efforts and costs that are not currently budgeted for.

The thermally sensitive nature of permafrost is a primary concern of engineers working in these environs. Roads are designed to minimize disruption to the permafrost; lessons learned from construction of the ALCAN highway. Very minor increases in temperature can destabilize the balance between annual thaw and annual freeze and can create drastic consequences. Alberta has very little permafrost along its highway corridors. However, there is a 280 km long ice and snow road that provides a land link from Fort McMurray northward to Fort Chipewyan. The road operates from mid-December to mid-March and the bulk of Fort Chipewyan's supplies are trucked during this 3 month window. Fort Chipewyan is otherwise only accessible by air, or through some effort, water. It is likely that this road will take longer to establish and will degrade earlier in the year, thereby limiting access of supply trucks to Fort Chipewyan. Similarly the ice bridge season will be shortened or perhaps not feasible at ferry crossings that utilize ice bridges during winter months.

Alberta is landlocked and unlikely to experience any impacts from a rise in ocean levels and more frequent hurricane events. Extreme weather events that are related to precipitation will likely prove to have the most significant impact on Alberta. The literature appears to support the conjecture that rainfall events will become more extreme and these extreme events will occur more frequently. An increase of very heavy precipitation is expected to be most pronounced in eastern Canada and diminish westward. As one report states: "Increased frequencies of extreme precipitation events and increased interannual climate variability are likely to result in increased damage to roads, railways and other structures as a result of flooding, erosion and landslides. Asphalt surfaces, particularly those with significant heavy truck traffic, are especially susceptible to damage during heat waves, which are expected to increase in frequency."[7]

Design philosophies that are based on historic 1:100 design events or similar antecedent events will have to be recalibrated to match the new norm. Recalibration on the design event will have to be done frequently to keep pace with the increasing frequency of extreme events.

Geotechnical Impacts

Evans and Clague[1] studied the occurrence of catastrophic geomorphologic processes related to climate change. The assessment dealt primarily with glacier processes and the impact of accelerating retreat of glaciers. The significant aspect of the assessment related to this paper is the finding that river channels are being altered as a result of climate change. These increasing unstable and shifting river channels create bank erosion and avulsion issues along highway corridors in mountain environmental.

Xu, Grubabine et al[3] discuss the concept of a cascade of impacts on related ecosystems and communities in the Himalayas. They emphasize the lack of research on the adaptive capacity of the natural environment and on the resilience of local cultures in the Himalayas. This aspect of the study bears further examination since only recently have more holistic and systems approach studies been undertaken in western Canada[7].The shift in ecosystems likely to be experienced in the Himalayas are also being experienced in the alpine regions of Europe (Alps[5,8] , Dolomites[2]) and are by extrapolation likely to occur in Alberta if they are not already. The engineering response to questions of systems resiliency is usually to design more robust systems, such as using larger and greater amounts of rip rap. Future natural system adaptations or land development policy may make some of these resiliency construction projects less effective, or perhaps not required. All geohazards are a combination of probability of occurrence and consequence. A land use policy that prevents developments on alluvial fans where debris flows are a primary geohazard might reduce the geohazard consequences sufficiently to mitigate the geohazard risk regardless of the return period of the geohazard event. In mountain terrain where developments on alluvial fans are already well established there is a need to focus on alternative mitigation schemes to divert or otherwise control the geohazard or in extreme cases relocation of those developments on the alluvial fan.

Whether it is possible to predict the change in geohazard frequency in relation to climate change has been studied by Crozier[9] and Rebetez et al[5] among many others. Crozier used a theoretical model and empirical findings to show landslides would occur more frequently as a result of climate change. He used a widespread landsliding event in New Zealand to conclude there is a strong theoretical base and therefore an opportunity to predict future events on a broad scale. Rebetez showed that debris floods were likely to be triggered if rainfall over a three day span exceeded 4 standard deviations. This declaration has application to the Alberta flood of 2013, discussed later in this paper.

Rather than predict landslide frequency based on rainfall events, Borgatti and Soldab[2] accepted that landslides are a result of climatic events and used the occurrence of landslides as a proxy for climate changes. Digging into relict landslides and using dendrochronology and other means they showed that the paleo-climate did affect landslide frequency as far back as 8200 BP. This conclusion is helpful to support the postulate of a current landslide-climate change relationship that might otherwise be based on only several decades of observations and therefore would be controversial. These ancient landslides occurred during a time of increased rainfall, elevated temperatures and vegetation changes on a regional level. This cycle is similar to the current climate change conditions.

A more direct correlation of landslide activity related to climate change is provided by Collison et at[4].. Based on observed landslide geomorphology in SE England Collison et at[4] modelled the impact of climate change on the frequency and magnitude of landslides. They determined that large scale landslide occurrences may actually be reduced while shallow small scale landslide may increase in frequency and distribution. Rainfall events were modelled to become fewer but more intense whereas the current rainfall pattern is light but steady for extended time periods. Shallow landslides commonly result from saturation of near surface soils as would occur during two or three day intense rainfall events. However, increased temperatures and evapotranspiration rates would limit the temporal and spatial persistence of these elevated groundwater tables which are required to drive deeper seated large scale slope failures. An additional finding was that summer precipitation was not expected to change significantly while winter precipitation was expected to increase by 10%. The frequency of landslides was therefore expected to increase primarily only in the winter months, an important consideration for risk management policy developers. Of note the expected increase in precipitation in Alberta is about 16% over the next four decades.

Expected geotechnical impacts to Alberta Transportation related to climate change

Based on the limited literature review discussed previously the following trends are anticipated to result from climate change:

- Increased frequency of extreme weather events, especially multi-day precipitation events
- Increased amount of rainfall within these extreme events
- Extensive and frequent flood events
- More extreme temperatures, which in Alberta might also mean extreme winds

The geotechnical consequences are likely to be:

- Accelerated lateral mobility of watercourses resulting in bank erosion
- River avulsion
- Extreme flood levels
- River scour and transport of greater amounts of debris and larger bed loads
- Saturation of near surface soils resulting in widespread landslides
- More backcountry landslides damming watercourses and the eventual dam outbreak events resulting in increased frequency and distribution of debris flood and debris flow events.
- Less predictable weather, rapidly changing conditions
- Loss or alteration of vegetative cover exposing soil directly to erosive forces

The geotechnical consequences affecting highway corridors are expected to be:

- Partial or complete washout of portions of road surface where the highway is aligned parallel to watercourses, such as along valley bottoms.
- Erosion, by overland flow or by lateral water course bank erosion or avulsions, of a portion of a highway embankment that if left unattended would erode further to eventually affect the road surface.
- Saturation of embankments along flooded watercourses leading to rapid drawdown induced slope failures shortly after the flood waters subside.
- Undersized centreline culverts that will could washout, cause erosion of outlet protection, plug with debris, cause flooding and erosion along ditches
- Undersized bridges, specifically smaller bridge sized culverts that may plug with debris, washout or cause flooding in adjacent properties.
- Increase bed load forces and lateral migration of water courses may erode river guide bank structures, bridge headslopes or approach fills.
- Structural damages to bridge pier and substructure, exposure of foundations due to scour
- Loss of road or road blockages due to debris floods, debris flows, rockfall and landslide events
- Increased vulnerability and risks that may become hazards during the next extreme rainfall event.
- Increased ditch and slope erosion, creation of rills and eventual formation of gullies that are environmentally undesirable and may be a hazard to highway users.
- Impacts to construction projects, difficulty with moisture conditioning of embankment fill and delays due to extreme rainfall events

- The demand for large rip rap for use in flood repair and flood mitigation projects may exceed industry capacity
- Increased use of erosion control products that are drought tolerant and able to withstand heavy rainfall flows.
- Current design standards and practices may not reflect the demands imposed by repeated extreme weather conditions. A shift from continually repairing highway infrastructure to building more robust, and capital intensive, engineering designs may be required.

Southern Alberta Flood of June 2013

The southern Alberta flood of June 2013 provides a case study that can be related to the espoused relationship between climate change and geohazard activity. The event itself is well documented elsewhere so this paper will not review the overall societal damage incurred. As background a rainfall contour map is provided as Figure 1.

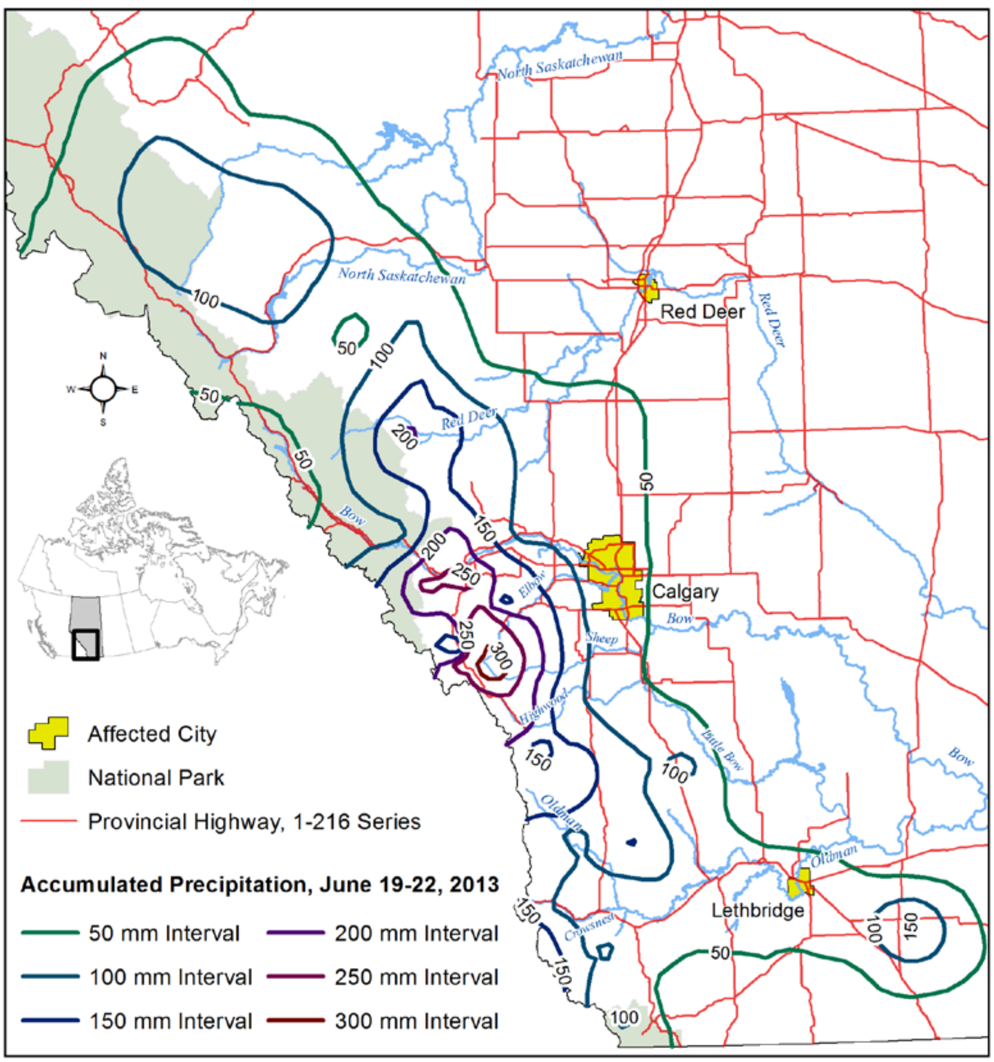
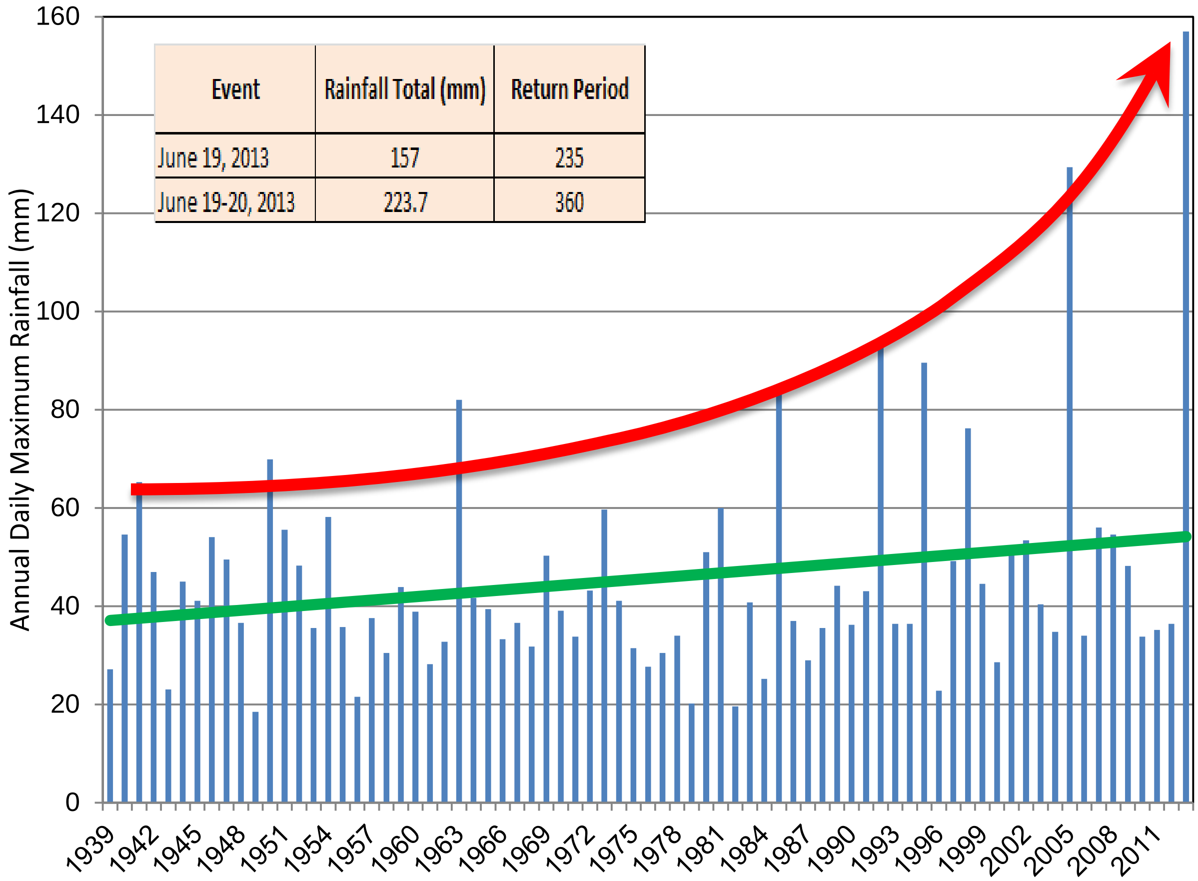


Figure 1: Southern Alberta Rainfall Isopachs June 19-22. 2013

The posit is that climate change is occurring and more extreme rainfall events are occurring more frequently. Figure 2 is provided as support, although other interpretations are possible.



Event	Rainfall Total (mm)	Return Period
June 19, 2013	157	235
June 19-20, 2013	223.7	360

Figure 2: MSE Kananaski Climate Station Data

The green line in Figure 2 is the trend line of annual daily maximum rainfall since 1939. It shows a gradual increase in annual daily maximum rainfall of about 2 mm per decade. The red line approximates the trend of extreme annual daily maximum rainfall events. It shows a much more rapid increase in rainfall, in the order on 30 mm per decade. The frequency of occurrence of extreme events also appears to be increasing. Events exceeding 80 mm per day have occurred 5 times in the past 30 years and only once in the 50 years prior. Of additional note is if the very extreme events (>80 mm) are removed from the green trend line, the green line would be flat or slightly downward trending.

Table 1 shows some peak flows for various watersheds affected by the Spring 2013 flood. The flood through Calgary and High River both were estimated to be at a 200 year return period. Several of the same watercourses also experienced a 1:200 year flood in 2005. There would appear to be some support that heavy rainfall events are becoming more commonplace. There are obvious implications to engineering tasked with adapting designs to match a climate reality that is out of sync with design codes.

River	Location	2013 Flow (cubic meters/second)	Return Period (Years)
Bow	Calgary (upstream of Elbow River)	1780	100
Bow	Bassano Dam	4200	200
Elbow	Upstream of Glenmore Reservoir	1220	200
Highwood	Upstream of Town of High River	1820	200
Sheep	Upstream of Turner Valley	720	100
Red Deer	Upstream of Glennifer Reservoir	1800	50

Table 1: Peak Flow During June 2013 Flood Event

Another indication of the increasing occurrence and rapidly escalating consequences of flood are the tabulated costs of southern Alberta floods. The past four major widespread floods in southern Alberta have increased in compensation and repair cost from 1995 ($0.28B) to 2005 ($0.58) to 2010 ($1.18) to 2015 ($6.6B).

The extreme rainfall event of June 2013 occurred over a three day period. The insert on Figure 2 suggests a 2 to 3 day rainfall return period for this event of about 300 years. The 3 day accumulated rainfall period has some resonance in literature as being a major trigger for debris flow and debris flood events if it exceeds 4 standard deviations. Since three day rainfall totals are cumbersome to accumulate a simple comparison using single day maximum rainfall was completed. Based on the Kananaskis climate station data the average single day maximum rate is 45 mm, and 4 standard deviations is 88 mm, producing a trigger level of 133 mm. The 2013 rainfall event was measured at 157 mm, exceeding the trigger level. The posit in this case was that debris flood and debris flow events would be significantly increased if the trigger level was exceeded.

As support for this a review of Alberta Transportation records for debris flood and debris flow events was undertaken. These events are apparently rare, and occasionally dealt with by operations forces without documentation of these efforts. Based on the available information the typical occurrence rate for these sorts of geohazards is about 1 per year. During the 2013 rainfall event a total of 174 landslides, debris flow and debris flood events were documented. This was in addition to 157 road washout locations, 135 major erosion sites and more than 200 blocked culverts.

Many of the predicted geotechnical issues were experienced during the 2013 rainfall event. Debris flow and floods affected highway corridors in alpine areas primarily in the Kananaskis and Bow Valley areas. These events typically had very short duration, carried massive sediment loads ranging in texture from clay to boulders with entrained woody debris. Where the debris flows intersected a highway the flows either extended completely over the highway creating a blockage, or travelled along the uphill ditch and entered and blocked culverts. Some examples are shown in Figure 3 and 4.

Figures 3 and 4: Debris Flow Causing Road Blockage, Culvert Plugging and Erosion (Highway 40)

Centreline culverts were blocked at more than 200 locations. At many locations the culvert blockage resulted in alteration of the ditch flow, erosion of the uphill ditch and occasional erosion of the downhill embankment wherever overtopping of the road occurred. Culvert washouts were always associated with the initial plugging of the culvert with debris. Figure 5 and 6 show a culvert blockage condition and a culvert washout condition, respectively.

Figures 5 and 6: Culvert Plugging (Cougar Creek, Highway 1) and Culvert Washout Conditions (Highway 40)

At several bridge locations entire headslopes were washed away leaving the abutment piles exposed. At other bridge locations approach fills were overtopped and washed out. Bridge scour surveys and structural inspections were carried out on hundreds of structures in the few months after the Spring 2013 event. 30 bridges were severely damaged and had to be closed for repairs while 90 other bridges required minor repairs that did not require closure. Some examples are shown on Figure 7 and 8.

Figures 7 and 8: Loss of Headslope at Bridge Locations (Elbow River, Hwy 66 and Sheep River, Hwy 22)

Highway washouts were primarily a result of lateral migration and bank erosion of watercourses that were adjacent to and ran parallel to the highway. In some cases the watercourse avulsed from a well-established stream path and moved hundreds of metres away. Riverbank armoring established to deal with historic stream paths was often left high and dry. In many cases the road was completely washed for hundreds of metres while in others only a single lane was affected. There are many locations where the toe of an embankment has been eroded but the overall embankment is still supporting the road surface. These locations will likely be the location of the next washouts. Examples of road washouts are provided on Figures 9 and 10.

Figures 9 and 10: Examples of Complete and Partial Road Washout (Highway 758 Elbow River, Hwy 40, Highwood River)

Landslides were common and were mostly related to shallow sloughing of localized small scale events. This expression is consistent with that predicted by Collison et al[4] who predicted the most prevalent landslide morphology would be that of a shallow and localized slide or slip. Many of these slides occurred on backslopes, and more commonly on backslopes with minimal vegetative cover. The consequences of these slides were nominal and were for the most part left in the failed state with the exception being when the slide blocked ditch drainage. Small scale slides related to erosion of the toe of an embankment were also common. While these slides do not affect the upper portion of the embankment there is a strong likelihood that retrogression of the slide will overt time impact the highway proper. An example of the type and scale of landslide is presented in Figure 11.

Figure 11: Example of Backslope Slip (Highway 68)

A somewhat unexpected consequence of the rainfall event was a large increase in rockfall accumulations. Some mountain roads that were being evaluated for a regional rock scaling operation, to reduce rockfall risk levels, were effectively clean of loose rocks by the heavy rains. Conversely some areas that were considered stable are now at risk due to the erosion of cover materials. The increase in rockfall accumulations and landslide occurrences in the backcountry were major contributors to the large numbers of debris flow events experiences along Hwy 1, 1A, 40 and other mountain roads in southwest Alberta. An example of the flushing effect of the water, both overland and through natural rock face fractures, is provided in Figure 12.

Erosion of slopes and ditches were common wherever normal ditch flow conditions were altered, such as at blocked centreline culverts. Overland flow caused erosion where vegetative cover was sparse and hillsides were steep, as is the case in many hillsides adjacent Hwy 40 through Kananaskis Park. These were typically treated by filling the gullies with surplus materials taken from location where debris flows had deposited material on the highway. As such the immediate concerns related to erosion were minor. The longer term issues related to ongoing climate change have yet to be recognized or realized as the case may be.

Figure 12: Example of Rock Cut Flushed by Rainfall (Highway 3)

Conclusion

This paper presented a snapshot of some of the issues and concerns related to a relationship between climate change and increase geohazard probability. The generally held supposition that climate change is occurring and will result in extreme weather conditions appears to be supported by outcomes of the southern Alberta flood of 2013, Rainfall events are becoming more frequent and extreme. Geohazards related to these rainfall events are profound, widespread and will present a challenge to engineers, policy makers and the general public. Many of the predicted geotechnical issues were realized during the 2013 heavy rainfall event. The remaining geotechnical consequences are related to design and construction and policy considerations. These aspects are likely to adapt slowly to the climate change outcomes and may not be realized for several decades.

In response to the outcome of the 2013 flood various levels of government in Alberta has undertaken engineering studies to assess vulnerabilities and determine geohazard mitigation strategies. Many projects have been implement to date, primarily within municipalities (flood diversion works, debris flow retention barriers) and transportation corridors and water infrastructure (river bank armouring, guidebank enlargement, increased rip rap sizing). Mapping of alluvial fans, associated with debris flow damage, has been undertaken by two ministries and hazard maps are in the process of development. The success of these projects and designs are expected to help guide future design philosophy and project delivery decisions.

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