

Geohazard Reviews of Highway Corridors Through Mountainous and Foothills Terrain, Southwestern Alberta



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ABSTRACT

Alberta Transportation has completed geohazard reviews of the Highway 40/541, 742 and 940 corridors in the Front Ranges and Foothills of southwestern Alberta. The purpose of this work was to gather information on the geohazards present along the corridors and the associated risks to the highways that have not been assessed to date under Alberta Transportation's Geohazard Risk Management Program for the provincial highway network. The information from the reviews has been used to estimate the Risk Level for these sites and prioritize them amongst other geohazard sites currently being monitored by Alberta Transportation. This paper discusses the geohazard conditions along these highway corridors, the methodology for the reviews and summarizes the results and their application.

RÉSUMÉ

Alberta Transportation a complété une revue des géorisques aux abords des routes 40/541, 742 et 940 dans la région des Front Ranges et Foothills, dans le sud-ouest de l'Alberta. Le but de ces travaux était de recueillir de l'information sur les géorisques existants le long de ces corridors, de même que sur les risques associés pour ces routes qui n'avaient pas encore été évaluées par Alberta Transportation dans le cadre de son programme de gestion des géorisques du réseau routier provincial. Les informations recueillies ont été utilisées pour estimer le niveau de risque et prioriser ces sites parmi d'autres faisant actuellement l'objet d'un suivi par Alberta Transportation. Cet article présente les géorisques relevés le long de ces corridors routiers, la méthodologie utilisée pour leur identification, les résultats et leur application.

1 INTRODUCTION

Alberta Transportation (AT) completed geohazard reviews of several highway corridors in the Front Range and Foothills of southwestern Alberta between 2006 and 2009. The purpose of the reviews was to gather information on geohazards present along the corridors and the associated risks to the highways that had not been assessed to date under AT's Geohazard Risk Management Program (GRMP) for the provincial highway network.

The information from the reviews has been used to estimate the Risk Level for identified geohazard sites along the highway corridors. The estimated Risk Levels for these sites are then used to rank these sites amongst all of the geohazard sites across Alberta that are being monitored under AT's GRMP.

The reviews were performed using a practical and straightforward methodology that strikes a cost-effective balance between screening-level reviews and more detailed risk assessment and quantification methods while exercising due diligence with respect to geohazard risks to the highways.

2 SETTING, GEOLOGICAL AND CLIMATIC CONDITIONS ALONG THE CORRIDORS

The following highway corridors were reviewed:

Highway 40/541 – a two lane, paved highway extending south from Highway 1 near Canmore, AB and connecting to Highway 22 at Longview, AB. This corridor follows the Kananaskis and Highwood River valleys and passes through Highwood Pass, which at 2206 m (7236 feet) elevation is the highest public highway in Canada. The total length of the corridor is approximately 150 km, of which approximately 90 km is within mountainous terrain. The middle segment of this corridor through the Highwood Pass is closed to traffic between December 1st and June 15th of each year.

Highway 742 – a two lane, gravel surfaced highway extending south from Highway 1 at Canmore, AB and connecting to Highway 40 at Kananaskis Lakes. This corridor follows the Spray River valley (currently flooded by the Spray Lakes Reservoir) and the Smith-Dorrien Creek valley. The total length of the corridor is approximately 66 km and it is open to traffic year-round aside from temporary closures during heavy snowfalls and when required due to snow avalanche conditions.

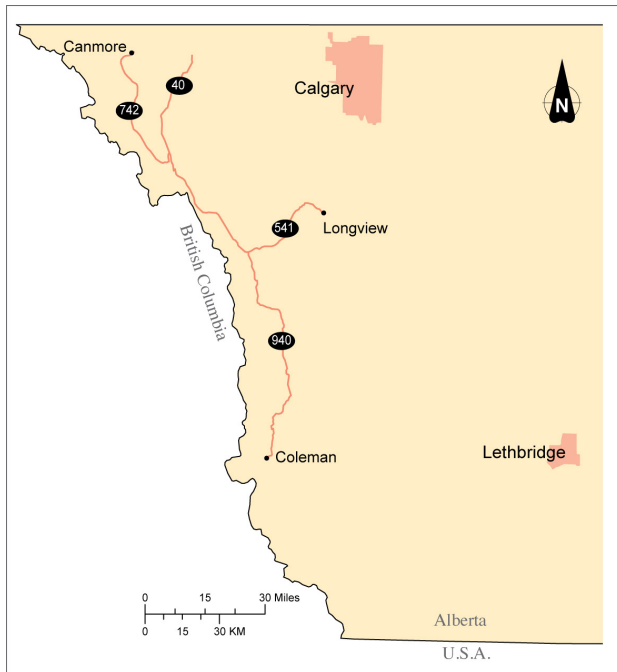


Figure 1. Locations of the Highway 40/541, 742 and 940 corridors, Southwestern Alberta.

Highway 940 – a two lane, gravel surfaced highway extending south from Highway 40 at Highwood House, AB and connecting to Highway 3 at Coleman, AB in the Crowsnest Pass area. This corridor follows various creek and river valleys through foothills and Front Ranges terrain. The total length of the corridor is approximately 106 km. Portions of this highway corridor are closed to traffic from December 1 to April 30.

The locations of the highway corridors that were reviewed are shown on Figure 1

2.1 Bedrock Geology

The highway corridors are located within the Foothills and Front Ranges of the Rocky Mountains, which are the easternmost belt of the Canadian Cordillera region and bounded to the east by the Interior Plains (Clague, 1989). The Canadian Cordillera is a northwest-southeast trending mountain chain composed of the western edge of the North American Plate which was deformed during the orogeny that created the Rocky Mountains (Clague, 1989). As a result, this area is characterized by currently inactive thrust faults striking northwest/southeast with relatively strong and older sedimentary rocks forming the mountain ranges and younger, relatively weaker rocks underlying the valleys (Hu and Cruden, 1992).

2.2 Surficial Geology

The dominant geomorphic processes in the areas of the highway corridors were glacial, with post-glacial, active fluvial and colluvial processes shaping the current surface (Jackson, 1987).

The surficial geology in the study area is summarized as follows:

- Coarse alluvial deposits along the valley bottoms, as well as alluvial fans and aprons located at the base of valley slopes where tributary creeks and streams flow into the main rivers. The highways that run along the lower portion of the valley slopes and the valley floors often cross these fans.
- Glacial deposits and recent colluvium on the lower to mid valley slopes. The glacial deposits vary widely in composition from clay to boulders, as well as in thickness with some areas on the lower portion of the valley slope and road cuts having exposed bedrock. The colluvium deposits on the valley slopes include actively developing talus slopes due to ongoing rock fall as well flexural toppling of underdip bedrock slopes in some areas around the Highwood Pass.
- Exposed bedrock and associated discontinuous talus deposits on the upper valley slopes, ridge tops and summits.

2.3 Seismicity

Seismic hazards, including the potential for seismically induced landslide and rock slide events, were not considered during these evidence-based reviews because no damaging earthquakes have occurred since construction of the highways. In addition, the potential for seismic related hazards such as soil liquefaction or the breaching of natural dams is judged to be very low for these areas.

2.4 Climate

The Foothills and Front Ranges of the Canadian Cordillera in southwestern Alberta are characterized by long, cold winters (with short interludes of relatively warmer, dry chinook conditions) and short, cool summers (Gardner et al, 1983). Within each corridor area there are variations in climatic conditions that are largely a function of elevation, local topography, and slope aspect.

Climate data are available from approximately 15 Environment Canada climate stations relatively well-distributed at locations along or near the highway corridors. Some of the stations have continuous data extending back as far as 1905, but more typically the individual stations have operated from the 1960's or 1970's onwards and with gaps in the data records.

Two key climate factors with respect to geohazards along the highway corridors are:

Freeze/Thaw Cycles – the frequency and amplitude of freeze/thaw cycles each year influences the intensity of weathering and hence rock fall from natural rock slopes and rock cut slopes along the highways. Data from the climate stations indicate that freeze-thaw cycles occur throughout each year at elevations along the highway corridor including influxes of warm chinook air masses during winter months.

Precipitation – the duration, intensity and timing of precipitation influences the amount of weathering and erosion of soil and rock material from slopes as well as flow volumes along drainage courses. The above-noted Environment Canada climate stations also provide precipitation data. During the corridor reviews it was determined that the precipitation data from the handful of climate stations with reasonably complete records from recent decades were not applicable across the entire corridor areas due to significant variations in precipitation as a function of elevation, local topography and slope aspect. In addition, the available data do not reflect short duration, high intensity rainfall events (e.g. over a period of hours) that are often triggering factors for debris flow events. For example, Cullum-Kenyon et al (2003) note that the August 1999 debris flow along Five Mile Creek that blocked Highway 1 west of Banff, AB was apparently triggered by a localized convective rainstorm that was not recorded at the nearest climate station that was located in the town of Banff approximately 5 km away.

3 POTENTIAL GEOHAZARDS ALONG THE HIGHWAY CORRIDORS

The following types of geohazards were considered during the reviews

Slope Instability And Erosion – lead to deposits on the roadway, both from natural slopes adjacent to the roadways and also in cut and fill slopes along the roadways. Rock fall was the most frequently encountered hazard of this type. The primary consequence of rock fall along the roadways is the filling of ditches with rock fall debris and the associated maintenance requirements to clean the ditches and occasionally rocks from the road.

Debris Flows – soil, organics and rock debris flows along drainage channels occur in mountainous terrain when triggered by high-intensity rainfall events. Such debris flows can cause significant damage to roadways and present significant risk to motorists. Debris flows have impacted highways in southwestern Alberta in recent years, including an August 2004 debris flow that blocked Highway 742 as well as blockages of Highway 1 at Five Mile Creek in 1999 (Cullum-Kenyon et al, 2003) and Highway 40 adjacent to Elpoca Mountain in 1975 and 1979 (Gardner (1982). In addition, debris flows in the Front Ranges in west-central Alberta have crossed Highway 11 west of Nordegg and Highway 40 north of Grande Cache in recent years.

Fluvial Erosion – erosion along the banks of drainage channels can lead to oversteepening and retrogressive instability of the adjacent slopes. This can be a hazard to the highway at locations where the highway crosses drainage channels (either bridged or over culverts) or parallels the crest of slopes along a bank. The Highway 40/541, 742 and 940 are generally along major river valleys and are therefore potentially exposed to this hazard along much of their length.

Snow Avalanches – impact the Highway 742 corridor at a number of sites (Jamieson and Geldsetzer (1996) and Field (2009)). There are also numerous avalanche paths with the potential to impact Highway 40 through the Highwood Pass area. However, this segment of Highway 40 is closed between December 1st and June 15th of each year, therefore there is no risk to motorists from the avalanche hazard along that segment of the highway. The Highway 940 corridor is not in proximity to any significant avalanche-prone terrain.

Anthropogenic Features – geotechnical hazards related to man-made features such as cut slopes, fill embankments and retaining walls were also considered during the reviews. This is consistent with the working definition of “geohazard” used under AT’s GRMP.

4 GEOHAZARD REVIEWS

4.1 Previous Reviews

The 2006 to 2009 reviews bring together and build upon previous work of others:

- Studies of hazards from rock slope movements in Kananaskis Country, including areas around the Highway 40 and Highway 742 corridors (Cruden and Eaton, 1987) and well as geomorphology and rock fall conditions in the Highwood Pass area along Highway 40 (Gardner, 1980 and Gardner et al., 1983).
- Site-specific geotechnical and geohazard studies along the Highway 40 corridor (McAfee and Cruden, 1996) and a similar area along the nearby Highway 1 corridor (Cullum-Kenyon et al, 2003).
- A report of a 1991 snow avalanche event that struck a parked vehicle at a site on Highway 742 (Jamieson and Geldsetzer, 1996).

4.2 Review Intent

Geohazard reviews of entire highway corridors have not been routinely performed since AT implemented the GRMP in 2000. Highways 40/541, 742 and 940 were selected for corridor-level reviews after a number of debris flow and rock fall events between 1999 and 2004 were noted which brought to attention the presence of geohazards along these corridors.

The intent of the reviews was to identify and make a preliminary assessment of geohazard sites along these

highways and identify sites that warrant further assessment or mitigative work under AT's GRMP. The estimated Risk Level for the sites has been used to prioritize them amongst other geohazard sites currently being monitored under AT's GRMP.

The guiding principle for the reviews was to strike a practical and cost-effective balance between screening-level reviews and more detailed risk assessment and quantification procedures while exercising due diligence with respect to geohazard risks to the highways.

4.3 Review Methodology

The steps for these corridor-level reviews were as follows:

Information Review – review published references with geological and geohazard information for the corridors as well as airphotos of the highway corridor areas. This was done in order to develop an understanding of the physical setting and geological conditions along the corridors in preparation for the field reviews. Sites with potential geohazards based on their appearance on the airphotos and/or published information were flagged for field reviews.

Field Reviews – field reviews of the corridors were performed to ground-truth the conditions at sites identified from the information reviews and to check for other geohazard sites that were not previously identified. This step included discussions of the conditions along the corridors with highway maintenance contractor personnel along with a field review and discussion of avalanche hazard sites along Highway 742 with Public Safety Officers from Alberta Tourism, Parks and Recreation (Parks Division, Kananaskis Country).

The field review of each identified geohazard site included a preliminary site assessment using the relatively simple qualitative approach used in AT's GRMP. Each site was inspected and assessed by a geotechnical/geological engineer and a Probability Factor (PF) and Consequence Factor (CF) is assigned to each site with reference to the frequency-severity matrices used in the GRMP. The general geohazard matrix from AT's GRMP (Figure 2) was used along with matrices for debris flow hazards, rock fall hazards and snow avalanche hazards (Figures 3 to 5, respectively) that were developed for the corridor reviews. The Risk Level is then calculated as follows:

$$\text{Risk Level} = \text{PF} \times \text{CF} \quad [1]$$

The Risk Levels determined from any of the four matrices are intended to be comparable.

The PF can vary between 1 and 20 and the CF can vary between 1 and 10, therefore the Risk Level can vary from 1 to 200. AT uses the Risk Levels and other factors

when determining the priority of sites for the application of risk management measures.

Reporting and Compilation of Results – a report documenting the corridor reviews and preliminary assessments of each site was compiled, along with a summary of the Risk Levels for each assessed sites. The sites identified during the corridor reviews were then added to the master list of geohazard sites for AT's Southern Region. Several of the identified geohazard sites in this corridor review were of significant concern and annual inspections are now being undertaken to these sites. A relative comparison of Risk Levels for geohazard sites across the entire province is done annually by AT in order to determine priority areas for risk management funding.

4.4 Review Results

The corridor reviews identified a total of 86 geohazard sites with a maximum Risk Level of 78 (AMEC, 2006 and AMEC, 2009).

The identified sites can be categorized as follows:

- 43 sites (50%) – debris onto highway (rock fall sites constituting 40 of these sites)
- 26 sites (30%) – debris flows and other issues at creek crossings
- 6 sites (7%) – gully or ditch erosion into or undermining the road surface
- 5 sites (6%) – instability of engineered retaining structures or embankment fills
- 3 sites (3.5%) – potential high volume, low frequency rock avalanches
- 3 sites (3.5%) – snow avalanches (excluding the seasonal closure segment of Highway 40 through the Highwood Pass)

A histogram of the Risk Levels for the identified sites along Highways 40/541, 742 and 940 is provided in Figure 6, along with a histogram for AT's entire GRMP site inventory for comparison. Of note, no sites with multiple hazard types were found during the Highway 40/541, 742 and 940 corridor reviews and it was not necessary to cumulate the Risk Levels from individual hazards at any site.

It is judged that 86 sites from the corridor-level reviews likely result in the Highway 40/541, 742 and 940 corridors being over-represented in AT's GRMP geohazard site inventory of 293 sites (as of the spring of 2010) because similar corridor-level reviews have not been completed to date for other areas. Nonetheless, in terms of the highest Risk Level sites identified in the corridor reviews, the two sites with Risk Levels higher than 60 in the 322 km reviewed equates to roughly one site with Risk Level higher than 60 per 161 km along the Highway 40/541, 742 and 940 corridors. This is much greater than the average of roughly one site with a Risk Level higher than 60 per 1476 km of highway for the

General Geohazards			
Probability Factor		Consequence Factor	
Weight	Description	Weight	Description
1	Inactive, occurrence very improbable.	1	Hazard does not impact pavement, minor consequences of occurrence, no immediate impact to driver safety, treatable as a routine maintenance issue. For example, shallow cut slope where slide may spill into ditches or fills where slide does not impact pavement.
3	Inactive, occurrence or remobilization improbable.	2	Hazard may result in loss of service of portion of roadway. Private land, waterbodies or structures may be impacted (generally not including bridge approach fills or headslopes). Hazards affecting the use of roadways and the safety of motorists, but not requiring closure of the roadway.
5	Inactive, remote probability of remobilization, uncertainty level moderate, or active but very slow or indeterminate level of activity.	4	Partial closure of the road or significant detour required as a result of hazard occurrence.
7	Inactive, high probability of remobilization or additional dangers, uncertainty level high, or Active with perceptible movement rate and defined zone(s) of movement/occurrence.	6	Closure of the road or significant detour required as a result of hazard occurrence.
9	Active with moderate steady, or decreasing, rate of ongoing movement or occurrence.	8	Major consequence, extended road closure pending development of a rough detour or diversion (e.g. reduced speed limit detour lane). Additional consequences could include: - capacity of local maintenance equipment exceeded - damage to public and private structures - injuries
11	Active with moderate but increasing rate of movement or occurrence.	10	Sites where a large rapid movement is possible with catastrophic consequences for public safety along with the destruction of infrastructure (public and private structures).
13	Active with high rate of movement or occurrence, steady or increasing.		
15	Active with high rate of movement or occurrence with additional hazards or dangers.		
20	Catastrophic situation is occurring.		

Figure 2. Frequency-severity matrix for geohazards (general).

Debris Flow Geohazards			
Probability Factor		Consequence Factor	
Weight	Description	Weight	Description
1	Inactive, debris flow very improbable. No historical or current visual evidence of debris flow activity.	1	Debris flow contained by the ditch or able to be conveyed past the road alignment via a sufficiently sized culvert or clear span bridge.
3	Inactive, debris flow improbable.	2	Debris flow onto roadway easily removable by maintenance crews. No damage to the road surface. Road closure not required and/or road still passable with reduced speed limit.
5	Inactive, remote probability of a debris flow based on channel morphology and presence of debris in the potential source zone.	4	Partial closure of the road or significant detours would result from a debris flow. Debris flow onto roadway that requires partial closure of the road or significant detours while maintenance crew uses heavy equipment to clear debris and restore road surface. Damage to the road surface possible.
7	Inactive, occasional debris flow; a debris flow has occurred in the historic past and/or debris buildup in the channel/source area is considered to be ongoing.	6	Complete closure of the road would result from debris flow while maintenance crew uses heavy equipment to clear the roadway and/or remove debris flow deposits plugging culvert or ditch. Geotechnical inspection required to assess post-debris flow stability of road fills. Damage to the road surface likely from debris flows.
9	Debris accumulation normally present in the source area. Fan is considered to be active, with debris flows occurring after the melting of an exceptional snow accumulation or an exceptionally intense rainfall.	8	Same as weighting of 6, along with damage to bridges, bridge accesses or other infrastructure facilities.
11	Active, one or two debris flows per year triggered by annually recurring weather conditions.	10	Sites where the safety of the public is threatened by debris flows, where there will be loss of infrastructure facilities or privately-owned structures if a debris flow occurs.
13	Active, several debris flows each year.		
15	Active, frequent debris flows each year, the area producing debris flows is expanding.		
20	Active, a large volume of debris is impounding a large and rising reservoir of water upstream. Overtopping and dam-break is expected.		

Figure 3. Frequency-severity matrix for debris flows.

Probability Factor		Rock Fall Geohazards		Consequence Factor	
Weight	Description	Weight	Description	Weight	Description
1	Inactive, fall occurrence very improbable.	1	Rock fall contained by ditch if cleaned as required to maintain capacity.	1	Rock fall onto roadway removable by maintenance crews by hand or with shovels. Road closure not required. Minor damage to the road surface that can be repaired during annual patching and sealing of the road. Minor to no damage to vehicles being struck by falling rocks or striking rocks deposited onto road.
3	Inactive, fall occurrence improbable.	2	Rock fall onto road that could damage a vehicle (e.g. flat tire, dent body of vehicle). Rocks bounce or roll onto the road surface but likely not with a trajectory through the windows or windshield of a passing vehicle.	2	Individual rocks or the total volume of rocks deposited on the road large enough to: - Damage vehicles or cause accidents if struck by traffic or damage vehicles and injure occupants if they strike a moving vehicle. - Cause partial closure of the road or require a detour lane prior to cleanup. - Damage to the road surface may require temporary repair in order to re-open road.
5	Remote probability of fall occurrence.	3	Individual rocks or the total volume of rocks deposited on the road large enough to: - Damage/destroy vehicles and severely injure occupants if struck by traffic or damage/destroy vehicles and severely injure/kill occupants if they strike a moving vehicle. - Cause complete closure of the road, with a rough detour/diversion possible within hours to days. - Days to weeks required to restore the road to normal service. - Possibly significant damage to the road surface.	3	Same as weighting of 6, but with several days required to develop a rough detour/diversion around the rock fall site.
7	Inactive but occasional fall occurrence (e.g. seasonal, following freeze/thaw cycles) and/or a fall has occurred in the historic past.	4	Individual rocks or the total volume of rocks deposited on the road large enough to: - Damage/destroy vehicles and severely injure occupants if struck by traffic. - Bury vehicles if they strike a moving vehicle. - Cause complete closure of the road, with a temporary, rough detour or diversion possible in days to weeks. - Require complete reconstruction or rerouting of the road after the rock fall.	4	
9	Active, falls can occur after exceptional weather (e.g. the melting of greater than average snow accumulations or exceptionally intense precipitation).	6		6	
11	Active, one or two falls probable each year triggered by annually recurring weather conditions.	8		8	
13	Active, several falls occur each year and/or the frequency of falls is increasing in comparison to equivalent time periods in previous years.	10		10	
15	Active, many falls occur each year and/or the area producing rock falls is expanding. Frequent rock falls during specific times of the year.				
20	Active, a large volume of rock is surrounded by open cracks. Toppling or sliding of the displacing mass is accelerating. Sites where rapid development of a large fall is possible.				

Figure 4. Frequency-severity matrix for rock fall geohazards.

Snow Avalanche Geohazards			
Probability Factor		Consequence Factor	
Weight	Description	Weight	Description
1	Inactive, snow avalanches very improbable. No historical or current visual evidence of snow avalanche activity.	1	No snow deposited on the highway by avalanches.
3	Inactive, snow avalanche improbable.	2	Negligible, if any, snow deposited on the road surface by avalanches. Can be cleared during routine snowplowing of the road. or Operational road closure typical during entire avalanche season
5	Inactive, remote probability of a snow avalanche along obstructed avalanche path and dependent on snowpack conditions in any given winter season.	4	Road closure required while heavy equipment clears snow from the road surface. Vehicles struck by an avalanche would be at least partially buried but likely not swept off the road.
7	Visible snow avalanche path. Occasional avalanches during winters with significant snow accumulation and exceptionally unstable snowpack conditions.	6	Road closure required while heavy equipment clears snow from the road surface. Vehicles struck by avalanches would be fully buried and/or possibly swept off the road.
9	Avalanches probable during winters with significant snow accumulation and unstable snowpack conditions.	8	Extended road closure during snow clearing. Avalanche control measures possibly required prior to re-opening the road.
11	Active, one or two snow avalanches per year triggered by annually recurring weather and snowpack conditions.	10	Sites where the safety of the public is threatened by snow avalanches, where there will be loss of infrastructure facilities or privately-owned structures if a snow avalanche occurs.
13	Active, several snow avalanches each year.		
15	Active, frequent snow avalanches each year.		
20	Frequent, large snow avalanches during typical winter conditions each year.		

Figure 5. Frequency-severity matrix for snow avalanches.

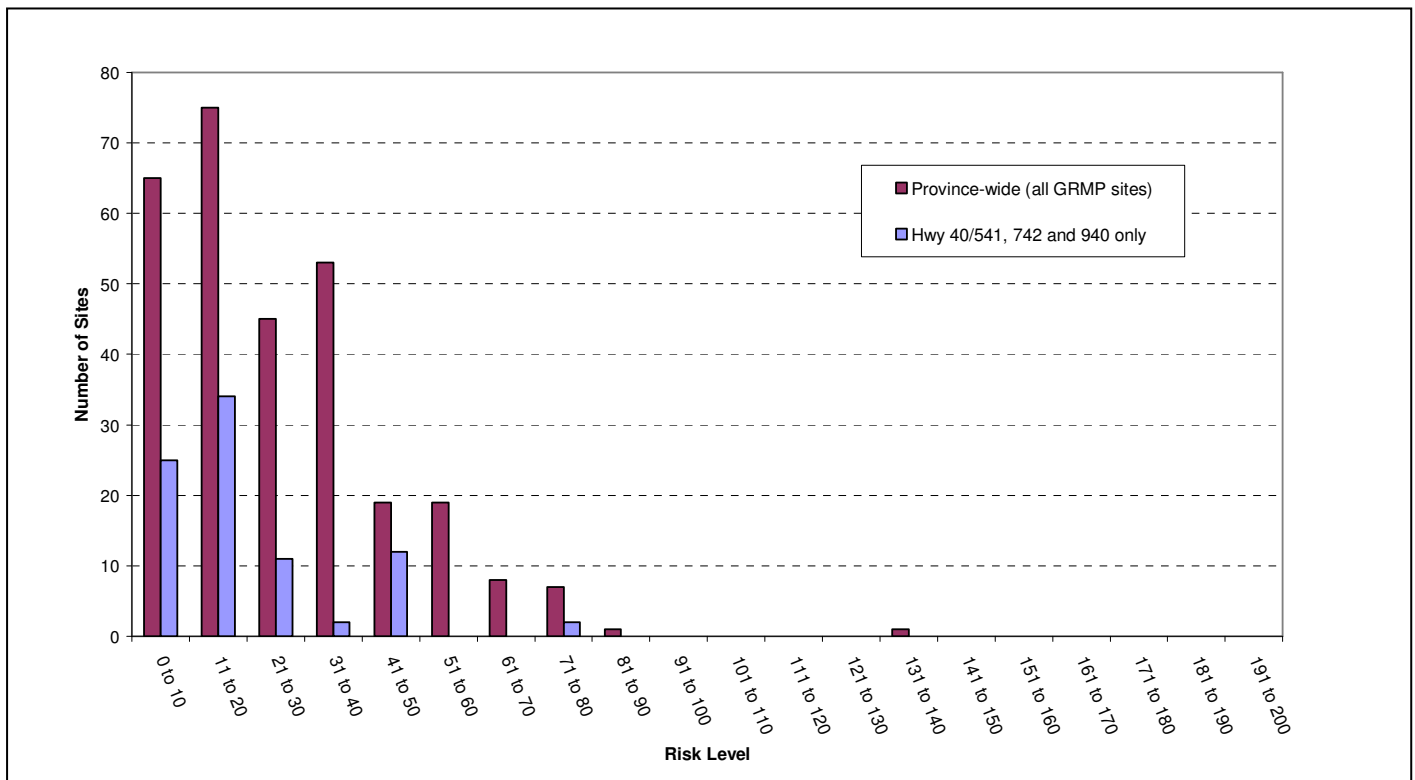


Figure 6. Histograms of Risk Levels for identified geohazard sites.

approximately 31,000 km of roadway province-wide. It can be concluded that the corridor reviews have identified a number of meaningful geohazard sites that were not previously recognized.

5 CONCLUSIONS

In summary, the corridor reviews found that there are numerous geohazard sites along the corridors, dominated by sites with risks from rock falls or other slope movements. The Risk Levels for the sites are generally relatively low when ranked using AT's GRMP system and typically manageable via the routine maintenance of the highways. However, the Risk Levels at specific sites are high enough to warrant more detailed assessment, increased maintenance attention and/or mitigation or repair under AT's GRMP.

The following improvements to the management of the geohazard risk along these highway corridors have been realized since the completion of the reviews:

- Annual inspections of the highest Risk Level sites along these corridors have been started under the GRMP.
- A number of assessed rock slope sites are now available for inclusion in a single rock slope scaling work package currently planned for 2010 or 2011, rather than less proactive mitigative measures for rock fall that have in the past been performed at the local level on a somewhat reactionary basis.
- The ranking of the snow avalanche hazard sites along Highway 742 within AT's GRMP has provided a basis for AT to direct funding towards the avalanche control work performed during each winter in that area by Alberta Tourism, Parks and Recreation. When warranted based on the ongoing monitoring and forecasting of avalanche conditions throughout Kananaskis Country, the north end of Highway 742 is temporarily closed to traffic and avalanches with the potential to impact the highway are artificially triggered by heli-bombing, and the road re-opened after the avalanche deposits are cleared from the highway. Alberta Parks has performed such avalanche control work for the benefit of the highway on an "as possible" basis in previous years, and the additional funding now being provided by AT ensures sufficient resources for this task.

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