GEOTECHNICAL HAZARD MAPPING
QUESNEL FRINGE AREA
CARIBOO REGIONAL DISTRICT
BRITISH COLUMBIA

Submitted to:

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November 2009

KX13163

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EXECUTIVE SUMMARY

Cariboo Regional District (CRD) is conducting a review of the Quesnel Fringe Area Official Community Plan, and wishes to consider the presence and implications of potential terrain hazards on future development within the Quesnel Fringe Area. AMEC Earth and Environmental, a Division of AMEC Americas Limited (AMEC), was retained by the CRD to conduct a study of potential terrain hazards within the Quesnel Fringe Area to identify terrain hazards which may impact future development, and rank the relative level of risk associated with identified hazards within the study area. AMEC was also requested to provide technical guidance for regional planners seeking to accommodate future development proposals, to taking into account potential development constraints associated with identified terrain hazards and assigned risk levels.

The study methodology included review of previous geotechnical studies of terrain instability in the study area and consideration of topography, surficial and bedrock geology, supplemented by air photo review and focused ground reconnaissance. Terrain attribute information was compiled in an Arcview GIS database, and a series of maps was developed to illustrate the study results, including an inventory of previously identified areas of terrain instability, digital elevation model with slope classes, and maps identifying areas of low, moderate and high risk form terrain hazards which may impact development.

The study considered the potential presence of natural hazards associated with rockfall and rolling rock, colluvial fans, debris flows, landslides, and steep slopes within the study area. Potential hazards associated mainly with landslides and steep slopes were considered to be the predominant concerns within the study area, as the landforms or terrain conditions associated with the other natural hazard types considered are not common or of very limited extent within the study area. A ranking of high risk was assigned to areas underlain by terrain instability from landslides, including landslides which are known to be active, and those where the level of activity is not known or unclear. A ranking of moderate risk was assigned to areas of steeper slope gradient, including buffer zones adjoining the crests and toes of sloping terrain. The size of the buffer region was established using an inferred long term stable slope configuration of 25° and projecting these gradients back from the crests and toes of the sloping terrain areas. Some small areas of steeper slopes with bedrock outcrop present along the southwestern border of the study region were also ranked as moderate risk from potential rolling rock hazard. For the purposes of this study areas of low risk include those parts of the study area not underlain by landslide features, and with a slope gradient less than 15° from horizontal.

Detailed geotechnical characterization and assessment was recommended to consider future developments proposed in areas subject to both moderate and high risk rankings. The assessments need to consider characterization of the potential terrain hazard and/or landform features present, the nature of the development and potential associated impacts on slope stability both within the development footprint and on adjoining lands downslope. The assessments should also address feasibility of the proposed development and identify options for mitigation of identified concerns, including site specific hazard mitigation options, design provisions and requirements, and development covenants as appropriate. For planners and development officials,

there should be some consideration of the scale of development, as smaller projects may not have the same influence on terrain stability as larger scale projects, depending on the site conditions present and specific nature of the development proposal.

The study was conducted at a regional scale, and therefore may not fully represent actual hazard locations and slope features within the study area. With respect to slopes in particular the study was conducted using available elevation information from 1:20000 public mapping with a 20 metre contour, consequently some slopes with gradients of potential concern but with less than 20 metres of relief could have been overlooked due to the study methodology. consequently it was recommended to give consideration to acquisition of more detailed ground contour information, such that the slope features ranked as moderate risk could be defined with a higher level of accuracy than the present model represents. Consideration should also be given to periodic updating of the identified hazards as more studies are conducted and additional information becomes available over time.

It should be acknowledged by planning staff and development proponents that the technical requirements of detailed geotechnical assessment, required to support proposed development in areas with moderate to high risk from terrain hazards are extensive, and in some instances may exceed the value of a proposed development by a considerable amount. The CRD way wish to consider some mechanism by which a detailed study potentially affecting a number of properties all exposed to the same hazard or underlain by a similar terrain feature, could be undertaken to the mutual advantage of all interested parties.

AMEC Earth & Environmental, a division of AMEC Americas Limited (AMEC), has conducted a regional scale study of natural terrain hazards within Quesnel Fringe Area of the Cariboo Regional District (CRD). This report is provided to accompany the maps developed as a result of the study. The study was undertaken following the methodology described in our proposal document PK06-075, "*Proposal for Geotechnical Hazard Assessment Quesnel Fringe Area Cariboo Regional District*", dated September 20, 2006. Acceptance of the proposal and authorization to proceed was granted by the CRD on April 25, 2007. The study area includes presently developed and potential future development within the Quesnel Fringe Area, a region of the CRD which adjoins the City of Quesnel.

1.0 INTRODUCTION

AMEC understands that the Cariboo Regional District (CRD) is implementing a review process for the Quesnel Fringe Area Official Community Plan (OCP). As part of the review process, the CRD wishes to consider the presence and potential implications of various aspects of the physical landscape with respect to future urban development within the present limits and potential future boundaries of the OCP, as defined in the Request for Proposal documents issued in the summer of 2006. The requested assessment study was to include consideration of the following items:

- review of previous geotechnical studies conducted in the area;
- overview assessment of geotechnical hazards within and affecting the Quesnel Fringe Area;
- identification of potential hazard and hazard areas on map products which could be incorporated into the CRD's existing Arcview GIS database;
- delineation of the identified hazards into categories of relative risk levels for:
  a) high risk areas where future development of any kind requires completion of a site-specific geotechnical investigation and hazard assessment;
  b) potentially hazardous areas with recommendations concerning which type of development may or may not require additional geotechnical study, and
  c) areas of low risk from apparent natural terrain hazards.

Detailed assessment of regional groundwater systems and their impact on development and slope stability was not part of the terms of reference, and was not carried out as part of this study.

The study area is an irregular shaped region centered on the City of Quesnel which extends towards the north, south and west from the City's municipal boundary (see Figure 1 Key Plan). The study area limits provided to AMEC by CRD include the region presently identified within the CRD Quesnel Fringe Area OCP, which extends between 10 Mile Lake in the north and Durrell Road in the south, roughly 13 km from downtown Quesnel, and some additional areas which are under consideration for inclusion in an updated OCP. The eastern limit of the study area follows approximately along the eastern shores of Dragon Lake and the western limit by Milburn Lake, off the Nazko Road. The study area does not include regions within the City of Quesnel, or the Sinnce-Tah-Lah, Quesnel IR 1, Dragon Lake IR 3 and Rich Bar First Nations reserves. For clarification, it should be noted that there is an "inlier" or small region administered by CRD which is surrounded by the City of Quesnel located in the vicinity of River Park Road, which was included in the study area. Figure 2 attached illustrates the study area limits and depicts the included and excluded regions (i.e. areas administered by agencies other than CRD) within the designated study area.

2.0 AVAILABLE RESOURCES AND METHODOLOGY

The methodology used to conduct AMEC's assessment was as described in our proposal, and consisted of a combination of office review of available information regarding the study area, and observation of terrain conditions during two reconnaissance visits made by AMEC staff on May 27 to 29, 2008 and September 8 to 11, 2008. The assessment methodology used for the study is outlined below as follows.

- Acquisition/access to various digital information to use as base mapping, such as TRIM topography (20 m contour interval), property and administrative boundaries, roads, water bodies and transfer of this information to a GIS database (using ESRI Arcinfo Version 9.2 software).

- Review of available historical engineering/technical reports which identify the locations of terrain instability from landslides or other natural hazards (not including river flooding which is outside the scope of work) and depiction of these features representing an inventory of known hazards. Where multiple reports were sourced for the same terrain feature, the location of the feature was established using the most comprehensive/detailed study available. Areas of terrain instability identified in previous engineering reports are presented in Figure 3. The size, shape and location of unstable terrain features have been preserved as accurately as possible from the original documents. It should be noted that terrain hazard features were numbered sequentially as they were encountered during the reviewing process. During the course of the review process some features/reports were determined to be fully outside the study area and consequently, there are gaps in the report reference numbers listed in the Geotechnical Report Key on Figure 3. A complete list of engineering and technical reports that were reviewed by AMEC as part of this study (both inside and outside of the OCP study area) is included in Appendix A. It should also be noted that, as there is no central repository for engineering reports, it is possible that other reports may exist which AMEC was not able to review as part of this study. Sources of information used by AMEC for the study are tabulated below.

- Acquisition and review of stereo airphoto coverage of the study area to identify and delineate other terrain features subject to natural hazards not included in historical technical reports, and transfer of identified polygons to a GIS database. Photos were reviewed at a variety of time periods and scales to assess historical terrain hazards and to interpret both large and small scale landforms.

- Ground truthing/field review of selected portions of the study area to confirm preliminary findings/hazard boundary locations identified in the air photo review. In addition, mapsheets were produced prior to the field exercise identifying known hazards documented in previous works. Field reconnaissance focused primarily on features highlighted during the airphoto review which had not previously been identified in the historical literature. Site locations were accessed by roadside inspections and/or foot traverses: where sites of interest were located on private lands we tried to find locations where the sites of interest could be viewed without trespass onto private land. A handheld GPS and digital camera were used to record approximate observation locations and document areas of interest.

- Preparation of map layers representing various identified potential terrain hazards, including GIS modeling of terrain attributes such as:
    - Areas of similar slope gradients, for areas of low slope (0-15°), gentle to moderately steep slopes (15-32°) and areas with steep slopes (>32°)
    - Slopes with bedrock exposures which may be a source of rolling rock hazards.
    - Identified and inferred terrain features associated with landslides and ground instability.

A summary of information made available to or obtained by AMEC for reference during the study included:

Source	Contact	Available Information	
AMEC, Prince George, BC	Nick Polysou P.Eng., AMEC Regional Manager	AMEC Prince George (including predecessor companies) has conducted a number of geotechnical projects in the Quesnel area. Reports were identified and forwarded to project staff in Kamloops for review and incorporation into the study as appropriate.	
Ministry of Transportation And Infrastructure, Kamloops, BC and Quesnel, BC	Tom Kneale P. Eng. John Cook, P.Eng.	MoTI maintains a library of reports relating to subdivision applications, route geotechnical surveys and slope stability investigations. AMEC staff viewed the reports at MoTI offices and made copies of relevant figures in the reports reviewed for reference in the study as appropriate.	
Cariboo Regional District, Williams Lake, BC	Derek Robinson, Building Inspector Arnold Jenner, GIS Analyst	The CRD provided information from their databases including digital maps of the site orthophoto and topographic base map coverage.	
BC Geological Survey	http://webmap.em.gov.bc.ca/mapplace/minpot/bcgs.cfm	Online bedrock geology maps were obtained.	
Geological Survey of Canada	http://gsc.nrcan.gc.ca/index_e.php	Online surficial geology maps were obtained.	
GeoBC Crown Registry and Geographic Base	http://www.basemaps.gov.bc.ca/	Digital orthophoto coverage for the southern region of study area (not available from the CRD) was purchased along with stereo airphoto coverage taken at various scales and time periods. The list of photos reviewed is presented below;	
Airphoto Series	Year	Scale	Photos
15BCB96013	1996	1:40,000	58-60, 64-68, 178-188, 216-218
15BCB96008	1996	1:40,000	114-115, 137-139

Source	Contact	Available Information	
BC5328	1969	1:31,000	97-98, 114-127, 174-178, 222-229, 258-261
BC5462	1969	1:31,000	138-150
30BCC97157	1997	1:15,000	144-154
30BCC97136	1997	1:15,000	70-80, 138-146
30BCC97156	1997	1:15,000	144-153
30BCC97187	1997	1:15,000	20-31
30BCC97135	1997	1:15,000	200-205
30BCC97115	1997	1:15,000	45-49
30BCC97085	1997	1:15,000	167-171
30BCC97115	1997	1:15,000	183-185

3.0 PHYSIOLOGY AND GEOLOGIC SETTING

The study area includes parts of three main regional physiographic regions: the Fraser Plateau to the west of the Fraser River, the Fraser Basin (a deeply incised valley system along the Fraser River and main tributaries) and Quesnel Highland to the east of the Fraser Basin. Within the Fraser Plateau the study area includes part of the Chilcotin Plateau, an upland sub-region west of the Fraser River bounded to the north and south by the Nechako and Thompson Plateaus respectively. In the study area, the Fraser Basin is defined as the region proximate to the Fraser and Quesnel Rivers lying below about 900 m elevation ASL. The Quesnel Highlands encompass areas to the east of the Fraser River from Bowron Lake in the north to Mahood Lake to the south, with upland elevations typically ranging between 1200 m and 1500 m ASL rising gradually to the east while valley floors are situated at approximately 450 m ASL.

The study area and this part of central BC was subject to complete ice cover during the Pleistocene glaciations. Ice accumulation, passage, and subsequent melting resulted in rounded and softened higher elevation peaks and ridges on the uplands and significant deposition on many of the plateau surfaces (Holland, 1976).

The overall topography consists of an undulating plateau with the prominent landform feature being the deeply incised valleys of the Fraser and Quesnel Rivers. Secondary drainages including Baker, Dragon, Higdon, Bouchie and Barlow Creeks have also eroded into the plateau surface to varying extents. Terraces, point bars and meander scars are visible along the valley sidewalls. Landslide features are also evident on many of the river terraces and valley sidewall slopes within the study area. Dragon Lake is the largest of several water bodies located within the study area, which also include 10 Mile, Milburn and Bouchie Lakes.

The BC Geological Survey has mapped six major rock types underlying the study area, ranging from the Permian age Cache Creek Complex (a marine sedimentary sequence) to the Chilcotin Group flood basalts which erupted as recently as the Pleistocene Epoch (1.6 Million years to 100,000 years before present). Figure 4 attached provides an illustration of the underlying bedrock geology as identified in the available regional geological mapping. A brief description of the bedrock geology and major rock types in the study area is as follows.

The underlying bedrock in the study region can be subdivided into two main groups, divided by a northwest-southeast trending contact which parallels the Fraser River in the north of the study area, and bisects Dragon Lake on the southern side of the study area (see Figure 4). To the east of this contact, the bedrock primarily consists of a suite of volcanic and volcaniclastic rocks of the Triassic to Jurassic age Nicola Group, with a number of smaller granitic intrusive bodies, and some sedimentary rocks also ascribed to the Nicola Group along the southeastern boundary of the study area south of Dragon Lake. To the west of this contact, the bedrock underlying the Fraser River basin and upland plateau to the west in the study area includes a series of sedimentary and volcanic bedrock formations, ranging in age from 280 million years (Permian to Triassic age Cache Creek Group sedimentary rocks) to the relatively recent Chilcotin Group basalt lavas deposited in the Pleistocene Epoch, from 1.6 million to 10,000 years before present. The suite of bedrock units in this part of the study area also includes volcanic and altered volcaniclastic rocks of the Eocene age Kamloops Group (55 million years), and younger sedimentary rocks derived from Kamloops Group materials and other sediments (Australian Creek and Fraser Bend Formations), which are potential "bad actors" for development of large scale deep seated landslide features in the study area. This is because the clay minerals comprising these rocks can include a particular composition known as bentonite clays, which have a very low angle of internal friction and correspondingly low shear strength.

The depositional sequence of these rock units is not uniform throughout the study area and has been locally influenced by erosion and deposition within the prehistoric to modern Fraser River basin, and in local areas development of large scale landslide features which may have had repeated cycles of movement and dormancy over time. In summary, the study region has a complex geological history but poor exposure of the underlying bedrock geology. There is a wide range of rock types present, and reasonably well understood regional structural geology relationships and depositional sequence of older to younger rocks. However, the complex evolution of the Fraser River basin, repeated glaciations, and large scale landslides has resulted in creation of very complex geological conditions which vary widely within the study area.

Recent sediments deposited during the Quaternary Period are a result of a series of ice advances and retreats with interstades where lacustrine and fluvial depositional environments were dominant. Clague (1988) identified three till units which underlie deposits of the most recent Fraser Glaciation, indicating sediments were deposited from several pre-Fraser ice advances. Coarse grained sands and gravels overlie the tills which grade into silts and clays as the area became inundated by rising water caused by blockage of the drainage by advancing ice or landsliding. During the Fraser Glaciation, the silts and clays were in turn scoured and covered by basal till. Finally, between 10,000 and 12,000 years ago, another ice dammed lake formed due to differential rates of retreat as ice persisted in the Fraser Valley to the south. Laminated silts and clays were then deposited in the area.

To summarize the surficial geology, the upper plateau areas of the OCP are covered in glacial drift or outwash deposits of variable thickness which obscure 95% or more of the underlying bedrock. Areas closer to the Fraser River (including the majority of the study area) are covered in a glaciolacustrine blanket. These deposits form two distinct bands on either side of the Fraser River. It is inferred that the outer edges define the extent of the glacial lake that occupied the valley. A combination of sands, gravels, tills, lacustrine, Tertiary age deposits and landslide debris are exposed in the valley walls. Modern alluvial sediments are found along point bars and inside bends of the Fraser and Quesnel Rivers as a result of recent channel migration across the floodplain. Figure 5 illustrates the extent of the most recent surficial geology information available for the study area. Relatively recent regional scale surficial geology mapping has been carried out for the northern half of the (map sheets 93 G/001 and 93 G/002) but has not been conducted for the southern half of the study area (map sheets 93B/099 and 93B/100).

The surface topography of the study area is depicted on Figure 6. The available ground surface elevation information (20 m contours from 1:20,000 provincial TRIM mapping) was used as the basis for a digital elevation model of the land surface within the study region. From this, AMEC used GIS attribute modelling to depict the locations of portions of the study area with similar slope conditions. On consideration of levels of risk which may be associated with future development on sloping terrain, and taking into consideration the range of geomorphic features, soil groundwater and bedrock conditions present within the study area, AMEC considers that the appropriate way to characterize ground slopes was to classify the existing slopes into one of three slope classes as follows:

- areas of low slope: 0 to 15°, including flat to gently sloping to low sloping terrain;
- areas of low to moderately steep slope: terrain sloping from 15° to 32°; and
- areas of moderately steep to steep slopes: terrain with slope greater than 32°.

4.0 POTENTIAL TERRAIN HAZARDS

Following assembly of the GIS database and review of the available reports AMEC considered the potential range of natural terrain hazards which might be present, and could potentially affect parts of the study area. The list of potential hazards considered by AMEC and reviewed as part of the study process included: rockfall/rolling rock hazards, colluvial fans, debris flows, landsliding/terrain instability and steep slopes. Each of these hazards is discussed in subsequent sections in relation to how applicable, widespread or severe the respective hazard is within the Quesnel Fringe study area and how its presence may influence land use planning and future development within the study area. An explanation of the relative risk rating associated with each hazard is also provided.

It should be noted that the scope of work for this study is limited to an overview assessment of geotechnical hazards. AMEC has endeavored to identify and accurately depict all relevant terrain features at a regional scale. The list of hazards assessed is considered to be representative at a regional scale, but at a detailed or individual property scale may not be fully comprehensive. It is also likely that hazard boundaries identified and digitized from previous reports will be refined in more detailed studies, and that the level of accuracy of feature location reported in this study is dependent in most instances on the level of mapping accuracy inherent in the previous reports carried out. Furthermore, in some parts of the study area, identification of some terrain features which represent natural hazards has been inferred based on air photo interpretation and visual indicators in the field. Consequently, the nature of natural hazards identified in this study is qualitative and approximate, rather than quantitative. Intrusive investigation and detailed quantitative risk assessment were both beyond the scope of this project and were not conducted as part of this study.

Based on the information reviewed, our observations, analysis and synthesis of the terrain conditions present, AMEC has considered each type of terrain hazard which was anticipated to be present within the study area, and has designated a relative risk ranking for each hazard. Effectively, we have assigned rankings as low (or not significant), moderate, or high: all other parts of the study region not designated are considered to have a low risk with respect to impact from terrain hazards. There is no effective national or provincial standard established for ranking of natural hazards. The reader is directed to Appendix C of APEGBC's Practise Guideline document, "*Guidelines for Legislated Landslide Assessments For Residential Development in British Columbia*", May 2008 for a discussion of hazard rating criteria which have been used in some jurisdictions. For the purposes of this study, qualitative risk rankings are defined as follows:

- high risk: due to the terrain conditions present or inferred, there is a high probability that the area may be impacted by earth movement or natural hazards which could have significant to catastrophic consequences for infrastructure and/or development with permanent structures, and/or development will have a significant detrimental impact on the stability of adjoining terrain down slope;

- moderate risk: there is some potential for the area to be impacted by terrain hazards with significant consequences, or for development to detrimentally impact adjoining terrain, depending on the nature/scale of the development and/or terrain conditions present;

- low risk: the type and/or scale of development and nature of terrain conditions present is such that there is low likelihood of impact from natural terrain hazard, low potential for significant consequences in the event of impact, and low likelihood of negative detrimental impact on adjoining downslope terrain.

Section 5.0 of the report includes further discussion of the map products developed as a guide to planners seeking to use the assessment results as input to consideration for future development planning. Areas of identified hazards developed as part of the study are presented on Figure 7 Areas of Unstable Terrain - High Risk, and Figure 8 Sloping Terrain And Other Features With Moderate Risk.

4.1 ROCKFALL AND ROLLING ROCK

Terrain instability on valley sidewall slopes formed in bedrock can be manifested as localized rockfall from exposed bedrock outcrops, as a result of weathering and mass wasting processes. These processes are frequently most active in regions with steeply sloping and irregularly-shaped bedrock outcrops. Such rockfall and rolling rock events typically occur on an infrequent basis, as a result of an extreme weather event such as rapid melt of a heavy snowpack, rain on snow event or exceptional rainstorm. It should be noted however that the potential impact of such events (as well as their frequency) may be increased in the event that the upslope vegetation cover is compromised as a result of timber harvesting and/or wildfires. The main hazard to be considered is potential exposure to impact from or deposition of rolling rock fragments generated by rockfall events, downslope from source areas of bedrock. It should be noted that there also may be a potential for downslope rolling rock hazards associated with steep slopes in soil materials with coarse clasts such as cobbles and boulders, which may be present in some parts of the study area.

Mitigation of this type of terrain hazard can typically be achieved by application of one or more of several mitigation options: control of rockfall hazards at their source, development of an appropriate setback criterion from the anticipated runout zone, and catchment/diversion of debris upslope from the development. With regards to development setbacks in particular, consideration of a "rockfall shadow area" is commonly used in BC as a tool in establishing the extent of a potential downslope hazard region. The "rockfall shadow area" was generally defined as a downwards projection from a potential rockfall source at an angle of 27.5° (Evans & Hungr, 1993). Rockfall typically originates from bluffs steeper than 37.5° but can also occur on gentler slopes.

Rockfall source areas are not common within the study area and were only encountered above the eastern shores of Dragon Lake (some basalt bluffs are also exposed in the diatomite mine area southwest of Baker Creek). Several quarries mining coarse grained diorite were operating at the toe of the slope on the east side of Dragon Lake. Based on our field reconnaissance, the rock appears generally competent, and no large fragments broken off and deposited from higher elevations were observed close to the roadside. The rock outcrop areas along the southeastern boundary of the study region are illustrated on Figure 8, where potential source areas were defined as slopes steeper than 27.5° with bedrock at surface.

For the purposes of this study, rolling rock hazards are assessed to represent a hazard of moderate risk. We have opted not to define specific rockfall shadow areas downslope from potential rockfall source areas on a specific hazard map. This is because the parts of the study area affected by or exposed to hazard from rolling rock are of quite limited areal extent; and because the rock outcrops as identified are surrounded by relatively steep soil slopes, which have been also been deemed as a potential terrain hazard of moderate risk. In other words, in this part of the study area slope segments subject to potential rolling rock hazard are also subject to potential instability of the soils draped onto the bedrock of which was assessed to represent a similar level of risk to potential development as hazards from rolling rock. Hazards associated with steep soil slopes are discussed in Section 4.5 below.

4.2 COLLUVIAL FANS

Geotechnical concerns associated with development on colluvial fans can be significant in terms of post development consequences and impacts. The range of potential concerns associated with colluvial fans includes susceptibility to differential settlement on wetting of foundation soils (or settlement of collapse-susceptible soils), and erosion and depositional processes associated with extreme runoff events. Review of the reports by others, and the results of our assessment of terrain conditions within the study area did not result in identification of any areally significant landform features considered to represent colluvial fans. Consequently colluvial fans are not considered to represent a significant terrain hazard within the study area, at least at the scale of mapping undertaken as part of this study. However, it is possible that local hazard from small colluvial fan features could impact individual properties or small portions therefore, not otherwise identified as part of this study.

4.3 DEBRIS FLOWS

Debris flow events are a potential concern within development areas, as they can represent a range of consequences ranging from inconvenient to disastrous in terms of impact to life and property, and are often not very predictable in terms of frequency and behaviour for an individual event or specific land area. Debris flows and torrents are usually initiated by heavy rainfall within relatively small, steep drainages or gully systems. They are often triggered by a shallow slide along a gully sidewall or headwall which enters the channel, entrains debris from bedrock soil and vegetation, and travels downslope either along an existing channel or within a new channel developed during the event. In terrain with intermediate gradients, slide debris may be stored in the channel and possibly re-mobilized during future large rainfall events adding to downstream consequence. Deposition of the debris is often the component of an event which results in impact to development.

Based on the study assessment process and results, some sidewall slopes within the study area may be steep enough for initial sliding to occur, however the channel gradients were less than what is needed for sustained flow. In discussion of debris flow initiation, the BC Ministry of Forests - Forest Practices Code guidebook for gully assessment considers a minimum channel gradient of 30% a required criteria for flow initiation (2001). The larger stream channels (excluding the Fraser and Quesnel Rivers) within the study area, including Baker, Dragon, Bouchie, Higdon, Barlow Creeks and many of the smaller drainages had channel gradients that were typically less than 25% gradient. Consequently, AMEC has not identified debris flow events as a significant terrain hazard impacting the study area. However, it is possible that smaller scale events could impact local parts of the study area in the event of unseasonable climate conditions or other extenuating circumstances.

4.4 LANDSLIDES

4.4.1 Active Landslide Features

Landslides are the most common terrain hazard found in the study area, many of which are currently active. Slide types include earthflows, rotational slumps and planar slides, both shallow and deep seated. The majority of active slides are found within valley sidewalls and are ultimately driven by stream downcutting and erosive action, but their origin can be attributed to a number of factors. Stream erosion steepens valley wall slopes over times and locally undercuts banks, resulting in increasing gradients and downslope forces serving to initiate landslide movement. Isostatic uplift, where the land surface is "rebounding" following depression by the weight of glacial ice cover, may also have played a role in destabilizing some areas underlain by low strength soil or bedrock materials. Similarly, an increase in groundwater pressures can also directly relate to a decrease in a natural material's stability. In addition, the Eocene age volcanic/volcaniclastic deposits found extensively throughout the Quesnel area have been shown to have low angles of internal friction and shear strengths, and are particularly susceptible to sliding with moderate gradients and/or pore water pressures. For example AMEC's land stability study commissioned for the West Quesnel area (a relatively gently sloping region largely outside the study area but similar to other large scale slide features within the study area) included a numerical back analysis indicating that along zones of displacement, residual shear strength friction angles were as low as 6°. The weak nature of the altered bedrock is partially explained by its clay rich mineralogy but also because of pre-shearing induced either by glacial drag or ancient earth movements (Rouse and Matthews, 1979).

Mitigation of active landslides can be accomplished in a number of ways targeted at a reduction in the driving forces and/or increasing those resisting movement. Application of water management such as surface water diversion, trench drains, passive horizontal drains or active pumping wells can assist in removal of water from a slide mass. Upslope land management strategies such as the implementation of vegetation management practices, controlling land use and/or residential development can help reduce total or rates of water input. Resistive prescriptions such as soil nails, earth anchors, or piling can be useful in 'pinning' unstable material to competent substrate however their effectiveness is often limited to shallower slides. Berm construction or armouring the toe with rip-rap increases the soil mass strength by loading or by preventing undercutting and erosion. Otherwise, mitigation of risk associated with landslides is often achieved by avoidance of exposure to the hazard, via establishment of an appropriate setback from the crest and/or toe of a known landslide feature.

The Bouchie, Baker, Dragon and Barlow Creek as well as the Fraser and Quesnel River valleys have areas prone to active earth movement/landslides. The locations of active and potentially active slides are shown on Figure 3 and 7. As previously discussed, natural hazards identified in previous engineering reports are presented in Figure 3. Their size, shape and location have been preserved as accurately as possible from the original document. Figure 7 includes the locations of landslide features and/or other terrain instability identified in both previous engineering reports and additional areas of terrain instability identified as part of the airphoto interpretation and field work/ground truthing process conducted for this study. Additional areas of instability have only been included if clear evidence of active landsliding was evident in the airphotos and/or observed in the field. It should also be noted that the outlines of Moose Heights, Paradise Road and Relict Bouchie Lake slides from the previous reports have been modified to reflect the apparent slide boundaries observed in recent stereo airphoto coverage. A brief description of the each of the slides and a list of reports pertaining to them is presented in Appendix A.

Development on areas of active sliding or ground movement is unsuitable due to risk to infrastructure and human life. A site specific geotechnical assessment is strongly recommended before any new development is to be approved on areas identified as or proximate to active slides. Where development currently exists on known active slides, a geotechnical assessment should be required where the proposed land-use change will remove forest cover, significantly alter ground loading, change groundwater discharge or surface water infiltration patterns or require site grading (cutting or filling). For example; a home renovation proposing to add additional bedrooms will increase septic effluent and potentially increase sliding risk and should have a geotechnical assessment before approval. Construction of a garage on previously cleared land however will not likely exacerbate the sliding problem. As discussed, upslope development may also negatively impact the stability of an active slide and should be considered as part of the planning policy. Residential development may be acceptable proximate to an active slide given an appropriate setback. It is cautioned however that each landslide feature is likely unique in terms of its physical attributes, and that development of an appropriate setback criteria is highly dependent on both site conditions present and the nature of the proposed development. In some situations, the cost for completion of the detailed geotechnical assessment needed to appropriately characterize the site could well exceed the value of a particular development proposal. Section 5.0 discusses the use of the mapping products produced in this study in greater detail.

4.4.2 Inactive Landslides - Unknown Level of Activity

During the course of the study, AMEC has identified terrain features with characteristics of instability associated with earth movement, but with an unknown or unclear level of activity. Typically within such terrain features, backscarps and slide debris depositional zones are present, however these terrain elements appear subdued as a result of erosion and the re-establishment of vegetation since the last significant earth movement episode or event. Displacement has occurred at these locations in the past as a result of downslope forces exceeding the material's internal resistance. Movement stops once equilibrium is achieved and forces balance. Consequently, inactive or dormant slides are often marginally stable and may be subject to reactivation.

Large terrain features previously identified or inferred to be inactive on which there has already been some level of development include the Moose Heights Slide in northern Quesnel and the area southeast of Bouchie Lake. The locations of the inactive landslide features are also illustrated on Figures 3 and 7 similar to the active features described in the preceding section.

Though the stability of inactive slides is unknown, AMEC considers for the purposes of this study that they represent a level of risk or hazard to future development comparable to that of active slide features. Consequently, AMEC also considers inactive slides to represent a high risk with respect to potential future development. Alteration of ground conditions associated with a particular development within an inactive landslide feature could potentially result in re-activation of earth movement of the feature, and considerable impact to existing development. In recognition of this concern, development should not be approved in such areas without detailed geotechnical investigation to characterize the terrain feature and fully assess the potential impact of the development.

4.5 STEEP SLOPES AND SLOPE CRESTS

The topography of the majority of the study area can be described as an undulating plateau with rolling hillsides and with steepened terrain along incised drainage channels. Steep slopes also exist along the edges of terraces and bedrock knolls. Figure 6 presents a slope map showing the local gradients within the study area. AMEC considers that in general, there is potential for geotechnical hazard associated with development on sloping terrain. For the purposes of purely slope based risk assessment, the hazard and risk levels are considered to be low in areas of low slopes, and increase in areas of greater slope gradient. On review of the available information and considering the range of soil, groundwater and bedrock conditions present, for the purposes of this study AMEC has defined the upper bound of low risk from sloping terrain at 15° or 27% gradient from horizontal. For terrain with slopes greater than 15°, AMEC has applied a risk rating of moderate as for some developments in areas with slope exceeding 15° and underlain by particular combinations of soil, bedrock, and groundwater conditions, development could be particularly challenging and result in detrimental impacts to downslope areas. In applying this level of risk for sloping terrain, AMEC has taken into consideration the notion that inherent in developments on sloping terrain there is often a requirement for site regrading or re-contouring, involving alteration of the existing topography by excavation and/or fill placement, both of which activities could exacerbate slope stability concerns. Similarly developments which involve alteration of existing surface runoff and drainage patterns could also have a potential detrimental influence on downslope stability conditions. Consequently, AMEC considers that in areas of moderate hazard, it is appropriate to require development proponents to provide suitable detailed geotechnical characterization of development site and full consideration of the impact of development on slope stability, surface and groundwater conditions, both within and downslope from the potential development site.

Development hazards associated with steeper slopes which may be subject to attrition and localized earth movement from natural erosional processes (as opposed to deep seated terrain instability associated with large landslide features) are typically mitigated through application of an appropriate development "setback" from natural features which define the sloping terrain such as the slope crest and slope toe. The setback distances are established through application of a site-specific setback criterion which is developed by a geotechnical engineer or geoscientist, usually based on the results of a detailed geotechnical assessment, topographic mapping and stability analysis. Generally, the setback criterion established will make appropriate provision for future attrition of the slope, with development located either away from the crest or toe of the slope feature, such that future slope attrition would be much less likely to have a significant impact on the development and development activity would not have a significant impact on the slope.

In recognition that the setback distances for sloping terrain will vary depending on the height of the slope, steepness of the slope and underlying soil, bedrock, and groundwater conditions present AMEC has applied a generalized model algorithm to areas of sloping terrain large enough to be identified at the regional scale of mapping of the study. We have considered that in most parts of the study region not underlain by low strength materials, a slope gradient of 25° represents a generic long term stable slope configuration for most of the natural slopes. So, we have applied a projection of 25° slope gradients from the crests and toes of the identified slope features to create a buffer area around the perimeter of the slope feature, within which geotechnical assessments should be conducted. The regions of moderate risk due to terrain slope are illustrated on Figure 8. It should be noted that many of the existing landslide features identified also include regions with sloping terrain, thus some parts of the study area rated as moderate risk due to slope may also be rated as high hazard, because they fall within an identified landslide feature.

It is cautioned that as the study was conducted at a regional topographic mapping scale there may be some areas of steeper slopes which may represent a potential concern not captured by the slope assessment process. AMEC identified all areas of larger slopes using the TRIM contour data (20 m contours), which would only capture slopes with a height of 20 m or more. We have also sought to include other lower elevation slope areas which may be of potential concern using airphoto interpretation and ground reconnaissance. However it is possible that other areas of sloping terrain affecting individual properties too small to have been identified at a regional scale may be present in some parts of the study area.

Geotechnical assessments should be undertaken with identified regions of moderate risk due to slope gradient, such that characterization of the site can be completed, detailed impact assessment including slope stability analysis is undertaken, and the appropriate setback criteria established for the proposed development. Further discussion of the types of land uses and application of the map products for land use planning is provided in Section 5.0 below.

5.0 LAND USE PLANNING

Figures 7 and 8 present the main results of this study, representing locations of identified natural terrain hazards within the study area which need to be used together to assess proposed land use. In the preceding section each of the potential terrain hazards is discussed, including their extent within the study area and relative risk rating applied. Our assessment results indicate that the parts of the study area underlain by landslide features shown on Figure 7, whether known to be active or with an unknown level of activity, constitute the parts of the study area with high risk for impact from natural hazard to existing and future development. AMEC recommends that future development of almost any kind within high risk areas should require completion of a site specific detailed geotechnical assessment. The components of the assessment should include:

- site characterization of soil, groundwater, and if relevant bedrock conditions;
- consideration of the potential impact of the development both on site and down slope, in terms of global slope stability, potential changes to surface runoff patterns, potential impact to groundwater interception/discharge and infiltration;
- commentary on feasibility of development, discussion of alternatives to mitigate potential concerns; and
- appropriate design provisions to mitigate on site and down slope impacts such that the proposed development would not have a detrimental impact on slope stability, including setback criteria and restrictive development covenants where appropriate.

With respect to residential developments, such detailed geotechnical assessments should generally follow the current edition of a guidance document prepared by the Association of Professional Engineers and Geoscientists of BC, "Guidelines for Legislated Landslide Assessments For Residential Development in British Columbia" (May 2008).

For future developments in high risk areas, any development or land use change which will involve removal of forest cover, placement of significantly different surcharge loads (i.e. from building structures or fill placement), a change in groundwater discharge/recharge patterns, surface water drainage patterns, and a change in site elevations through earthwork activities (i.e. excavation to remove soil and/or bedrock, fill placement) should be subject to formal geotechnical engineering assessment. However, experienced planning and/or building officials who are familiar with the local site conditions and development concerns associated with terrain hazards could use discretion and judgment in deciding whether the size and/or nature of a particular development may be of concern. For example, it is less likely that placement of a small structure involving no significant change in site topography could have a detrimental impact on stability of a site within a high risk area, so storage sheds or similarly small structures not intended for occupancy, or temporary structures not requiring fixed foundations could still be placed within a site designated as high risk, without triggering a detailed geotechnical assessment. Similarly, some degree of discretion may be appropriate for existing structures requiring maintenance/reconstruction (depending on the scope of the work and underlying cause of maintenance/reconstruction) such as decks, driveways, and foundation walls/footings. Where reconstruction/maintenance of existing structures can be carried out with no significant change in vegetation cover, loading, ground topography, drainage etc., detailed geotechnical assessment may not be needed for approval of such development, although some geotechnical assessment may still be required if the work involves formation of temporary slopes during reconstruction. It should be noted that detailed geotechnical assessment may also be required for development of buried infrastructure such as waterlines, pipelines, ducting and the like, or surface access routes for other utilities or rights of way.

With respect to future developments in moderate risk areas (as shown on Figure 8) the same overall criteria used to review developments in high risk should be applied to determine if a detailed geotechnical assessment is required to support a particular development application. Any development or land use change which will involve significant removal of forest cover, placement of significantly different surcharge loads, significant change in groundwater discharge/recharge patterns and surface water drainage patterns, or change in site elevations through earthworks, would require completion of an appropriate geotechnical assessment. Similar to high risk areas though, planners should use judgment to screen applications where the scale of proposed development is not likely sufficient to generate a potential concern with respect to loads, site grading, drainage etc. Therefore, applications for new subdivisions, new structures on existing lots (including new septic fields, in-ground pools, retaining walls) where a change greater than 1 m in ground topography is required, including any permanent dwelling or storage structure, should be subject to detailed geotechnical assessment.

With respect to terrain stability in areas of both moderate and high risk within the study area, consideration of site drainage and recharge effects associated with development deserve special attention and consideration during the development planning process. Many of the slopes, soils and bedrock materials present in the study area are particularly sensitive to changes in moisture content, such that the stability of a site in either a moderate or high risk area could be severely impacted if a significant change in moisture content occurs as a result of deliberate concentration/redirection of runoff or seepage discharge, or in the event of a leak from a well, waterline or pool. The geotechnical assessments conducted in such areas should consider the potential consequences of water leakage/saturation of foundation or slope materials in the event of a leak, and where applicable provide detailed design provisions for mitigation of this potential concern. Such provisions can take the form of design measures incorporated into the development plan (i.e. such as direction on roof drain discharge requirements, site drainage features etc.), special development restrictions within a subdivision or strata parcel, and/or incorporation of specific development constraints by means of restrictive covenant stipulations registered against the title of the parcel in question. In larger regions of similar concern, it could also include designation by the planning agency as a special planning area where such concerns must be assessed or addressed. Depending on the development configuration and local site conditions, such constraints could include a range of measures intended to safeguard both the development site and downslope properties, such as:

- requirement for double lining of in-ground pools,
- proscription of in-ground pool installation,
- provision of double sleeving for in-ground water lines,
- leak detection devices for in-ground water lines including irrigation systems.

6.0 STUDY LIMITATIONS AND RECOMMENDATIONS

It should be acknowledged that there are some practical limitations of this study of terrain hazards within the Quesnel Fringe OCP, which may impact level of accuracy of the hazard assessment and the map products produced as a result. These limitations are inherent with the methodology, available topographic base mapping and regional nature of the study, and may therefore result in some inaccuracy of the apparent hazard areas illustrated on the maps. It is possible that some areas affected by natural hazards may have been over-represented or under-represented. This is in part due to the reliance placed on review of existing reports and the level of accuracy of those reports as described above. It is also possible, despite our efforts to review known reports, that some reports may exist which identify areas of unstable terrain which were not available for our review. However, this potential concern should be offset to a certain extent by the study methodology followed, in which AMEC completed a review of aerial photos at a regional scale, seeking to identify other potential areas of concern not previously identified or in our view not accurately identified. It should also be acknowledged, as indicated in Section 4.0 above, that local hazards may be present which impact smaller parts of individual properties, not readily identifiable at the regional scale of mapping and assessment inherent in this study.

We are somewhat concerned that given the size of the study area and range of geomorphic conditions present, that reliance on the available TRIM data with 20 m elevation contours could potentially result in under-representation of areas of moderate risk due to steeply sloping terrain. We are confident that the study methodology has captured all of the larger terrain regions with steeper slopes within the study area. However in terms of some potential developments, a steeper slope area with less than 20 m of relief could represent a significant concern for potential development. It is also likely that the edges of some features and corresponding setback distances are not as accurately portrayed as they could be with a more detailed topographic model.

Consequently it may be prudent for CRD to consider acquisition of more accurate topographic reference information in all or parts of the Quesnel Fringe OCP, especially in parts of the OCP where development pressures/densities are likely to be greatest in the coming years. With more accurate or higher resolution topographic information, it would be possible to complete a better digital elevation model, identify areas of moderate to steep slopes with greater accuracy/confidence, and therefore improve the reliability of the risk assessment associated with slopes. Figures 6, 7 and 8 could then be revised using more reliable/detained slope information, to illustrate areas of moderate risk with higher levels of accuracy and confidence than the present model represents. AMEC considers that acquisition of digital contour information at a contour interval of say 1 to 2 m may be more appropriate for accurate hazard delineation in some parts of the study area. In addition to contour delineation or digital elevation model construction by photogrammetric methods, use of LiDAR (Light Detection And Ranging) imagery should also be considered, as lidar techniques can successfully delineate ground surface features in areas with dense forest cover.

It should also be acknowledged that the main advantage of the present study results is that the map products were developed in GIS form and represent a database which can be updated over time. AMEC considers that CRD should endeavor to retain a library of all geotechnical assessment reports conducted within the Quesnel Fringe OCP area, and recommends that consideration is given to periodic review and updating of the hazard mapping, such that new or revised boundaries of unstable areas can be added to the maps over time. In this way the databases can be used to best advantage to provide an effective tool to aid future land use and development planning decisions over time.

With respect to completion of detailed geotechnical studies to consider development impacts, some additional comments can be made. As indicated above, completion of a detailed study for a particular site could be a costly exercise, exceeding the cost of a small development. In some parts of the study area, it may not be cost effective for proponents to undertake sufficiently detailed studies for "piecemeal" or patchwork developments occupying small parts of a larger terrain feature with a similar level of risk. Similarly, some degree of care will be needed if a variety of practitioners carry out such assessments, to ensure that characterization of site conditions, hazard delineation, risk ratings etc. can be performed relatively consistently within a particular risk area or for different properties potentially affected by the same terrain hazard or feature. An alternate approach which could be considered is for designation of a particular region within the study area as a "special planning zone", within which the CRD, either on its own or in conjunction with funding partners, undertakes to coordinate an appropriate detailed geotechnical assessment. In this way a larger terrain feature or previously identified risk area could be assessed in greater detail, to provide better planning guidance and information for land owners contemplating future development on individual properties.

7.0 CLOSURE

We trust this report provides the information required at the present time. If you have any questions or comments, please contact the undersigned.

Yours truly,

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KX13163 final report.doc

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