Recent Experience with Landslide Assessments, Cariboo Region, Interior of British Columbia.



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ABSTRACT

Several findings from a recent landslide assessment done in the central interior of British Columbia, Cariboo Region, are presented. The dominant landforms and features in this region are related to Quaternary geology, and in particular, melting of glacial ice. Air photo interpretations are discussed from the point of view of the geological/geomorphologic interpretation as well as from the anthropogenic development in the area of concern. The topographic control of surface drainage capture is presented and the use of a simple GPS for the location and correlation of features is discussed.

RÉSUMÉ

Plusieurs conclusions d'une évaluation écrasante récente faite dans l'intérieur central de Colombie-Britannique, la région de Cariboo, sont présentés. Les landforms et les caractéristiques dominant dans cette région sont relatées à la géologie Quaternaire, et en particulier, le fondant de glace glaciale. Les interprétations de photo aérer sont discutées du point de vue de l'interprétation de géologique/géomorphologie, et aussi que du développement d'anthropogenic dans le secteur d'inquiétude. Le contrôle topographique de prise de drainage de surface est présenté et l'usage de GPS simple pour aider de localiser et corelater les caractéristiques avec les dessins d'enquête sont discutés.

1 INTRODUCTION

The subdivision approval process for regional areas of British Columbia, done by the BC Ministry of Transportation and Infrastructure, (BCMoTI), requires that an appropriately qualified geotechnical engineer provide a detailed landslide assessment and report for land that is believed to be susceptible to slope instability. This is not a new process in Canada, or in this province; however, guidelines prepared by the Association of Professional Engineers and Geoscientists in British Columbia, (Gerath), 2006, are relatively new. The "Guidelines for Legislated Landslide Assessments for Proposed Residential Development in British Columbia" (Guidelines), provides direction for the roles and responsibilities of the engineer, approving officer and the subdivision developer.

The Guidelines have streamlined the landslide assessment process, particularly in defining the role of the client prior to the assessment, during the review, and after the landslide assessment has been completed. The Guidelines can be discussed and/or given to the client at the start of the project, providing the engineer flexibility in the landslide analysis and review. This should help recover costs when findings are made that require extensive investigations to verify and/or quantify. For example, tension cracks may be found at the top of a slope in an isolated area above a development that would impact on it, therefore drill work is needed to sample, test and characterize the potential for a landslide. The Guidelines recognize the need to have a good agreement with the client and that fees may need to be reassessed as the landslide assessment progresses.

The primary objective of this presentation is two fold; first to discuss the formation of an effective and realistic geological model to help with the stratigraphy and groundwater interpretations, even if only intuitively; and secondly to discuss several effective techniques used within a landslide assessment. The key to an effective assessment, however; remains the reporting of clear, concise rationale for the landslide assessment with appropriate supporting documentation.

2 PHYSIOGRAPHY, GEOLOGY AND TOPOGRAPHY

The Cariboo Region is located between Kamloops and Prince George, extending from the Cariboo Mountains in the east, bisected by the Fraser River and extending through the Chilcotin plateau to the Coast Mountains in the west. The first European to cross the Cariboo overland was Alexander MacKenzie, reaching Bella Coola on July 22nd, 1793. In the 1850's, gold was discovered, starting the Cariboo gold rush which initiated land development through the region. However, the legacy of placer mining provides little to no geological mapping and landslide interpretations related to areas where the population settled.

The Cariboo region is typified by thick plateau basalts giving rise to the Interior and/or Fraser Highland plateau, in turn dissected by the Fraser, Chilcotin, and Quesnel Rivers. However, bedrock outcrops are generally few and far between in the valleys and upland plateau areas. Quaternary glaciation produced thick deposits overtop of the bedrock, predominantly till, but also deposits of glaciofluvial and glaciolacustrine materials.

2.1 Typical Landslide Geology

The landslide activity in the Cariboo is typically associated with lacustrine deposits and groundwater seepage. The lacustrine deposits are typically silt and often combined with confined glaciofluvial deposits. Landslide activity is also associated with steep glacial till with or without confined glaciofluvial deposits.

Landslides have also been associated with bedrock predating the flow basalts. Older sedimentary deposits include weak mudstones, siltstones, shale, tuff and interlay with relatively porous sandstone / conglomerate that have potential for high pore water pressure. Ancient landslides involving the sedimentary bedrock have been interpreted in geological hazard mapping projects done within the past 10 years, (Bosdet), 2006.

During the last 15 years ancient landslides have reactivated in the cities of both Williams Lake and Quesnel. They are very slow moving, deep seated and mobilize weak residual shear strength. Both reactivations postdate residential and commercial development, and long term stabilization of these landslides is challenging.

2.2 Glaciation

10,000 years ago, the interior of British Columbia was still covered in ice during the latter stages of the Wisconsin Glaciation, (Ryder and Clague), 1989. The writer has interpreted that the ice in the large broad valleys such as the Fraser, Quesnel and Chilcotin were some of the last areas to become completely free of ice based on physical evidence in the valleys and plateaus. Meltwater channels are common across higher valleys in the Interior Plateau, including the Lightning Creek, Swift River, Maud Creek, Beaver Creek and Cariboo River to name a few of the more prominent in north-eastern Cariboo Region. There are eskers and kame-kettle deposits typically associated "downstream" of the meltwater channels. Hydraulic pressure under and/or within the ice, and subsequent ablation of the ice mass is believed to have allowed some glaciofluvial deposits to be located topographically upslope of the meltwater flow direction. Isolated lacustrine deposits can be found on the side slopes of drainages within the upland plateau regions that defy the existing drainage patterns and are therefore believed to be associated with large early flows from deglaciation. Misfit streams on the plateau are also indicators of significant past flow events, along with buried Tertiary valleys covering rich gold deposits, such as the world famous "Bullion Pit", adjacent to the Quesnel River.

However, the major, lower lying drainage valleys of the Quesnel, Chilcotin and Fraser rivers contain extensive deposits of lacustrine and glaciofluvial sand and gravel associated with major meltwater flows. Terraces formed along the valley walls as the deep valley ice slowly melted down in association with major blockages or "Ice Dams" downstream. The breakage of the ice dams resulted in successive lowering of the major valley drainages and produced washouts and landslides onto the lower valley slopes of assorted tills and mixed glaciofluvial and lacustrine sediments, essentially, an "ablation till". This material is weaker than basal till, and prone to landslide activity.

Recognition of typical glacial deposits in the Cariboo Region, their characteristics, and a perceived model of the glacial history is a key to understanding the potential for landslide activity. Air photos and topographic maps are good tools for this task. Air photo interpretation of the glacial geomorphology is therefore an important tool in the understanding of landslide activity. Good field reconnaissance skills are very important in the absence of early air photo interpretation work, including the identification of geological constraints, mapping skills for features of interest, and recognition of the forces promoting and resisting active landslide movement.

2.3 Topographic Expression

The topographic expression should paint a picture for the geotechnical investigation, and topographic maps at varying scales should be procured and reviewed through the course of the landslide assessment. The topography generally controls the drainage capture in a basin. The larger the drainage capture focused onto potentially unstable terrain, then the more likely there has been, and will continue to be landslide activity. The typical worst case scenario for unstable terrain is steep slopes above eroding streams with groundwater seepage.

Topographic mapping should be used for sizing the drainage capture area, or drainage basin, but it does not necessarily require a planimeter or a geographical information system (GIS) to do the calculations. An outline of the drainage sketched onto a reasonably accurate topographic map, printed to a common scale can be divided into simple shapes and a quick yet order of magnitude drainage area determined. Elevation may play a role on the drainage capture, or there may be some quirky factor that potentially allows drainage from a different drainage source. The drainage capture provides a good indication of how surface water can influence land stability. The topographic expression can also provide for consideration of local and regional groundwater patterns that can potentially influence the terrain stability; assuming that a realistic geological model is developed as the landslide assessment progresses.

2.4 Mapping and Locating Features of Interest

The hand held Global Positional System, (GPS) has revolutionized field mapping. Improvements to the antennae and both the horizontal and vertical accuracy continue to be made. The cost for GPS units has decreased substantially. Software is readily available and the field data can be quickly downloaded into these programs directly from the unit allowing topographic mapping to be used as a base for the features captured on the GPS. An accurate field traverse can be recorded by using the track mode on the GPS. The perimeter of features of interest can be traversed to provide a detailed map with very little effort. The crest of a ridge and the toe of a slope can easily be shown on a detailed drawing, again with little effort. Field notes can be tied to a location by recording a waypoint on the GPS. In this manner, features of interest should be located with waypoints. Physical landmarks such as property pins corners of buildings, stream alignments and road intersections, etc, should also be located with the GPS so that the field information can be transferred to the surveyor's drawings and other maps of interest for the assessment.

3. Air photo interPretation

Air photos provide an incredible volume of information, important to different professions for different values. The province of British Columbia has developed a library of air photo prints and negatives available for forestry, mining, transportation corridors, natural gas pipe lines, hydro electric and transmission projects and other users; all interpreting the photos for their specific reasons.

For landslide assessment purposes, air photos are a snap shot of the anthropogenic activities to date, the topographic expression, and of primary importance, the geomorphology. Air photos taken from different flight line locations, flight elevations, (photo scale), and different time frames help to fill in gaps for the land stability dynamics and development history of the site. This is extremely valuable information, particularly if the photos can be reviewed prior to the initial field review work. Unfortunately, air photos take some time to procure; therefore the field work often precedes the air photo interpretation because of time constraints such as the onset of winter field conditions.

In BC, the Provincial Government aborted the photo print service in January of 2010, leaving digital photos as the only available media, (VanDine, 2010). It's been the author's experience that air photos developed from negatives provide far better quality images than prints made from digital air photos.

The air photo reference(s) along with the year flown, photo scale and whether or not the photo is colour or black and white should be referred to when reporting a landslide assessment. Table 1 is a list of historical air photos reviewed for a specific landslide assessment.

Table 1. List of Air Photos

Year	Scale	Photo Series	Photo #s	Colour or Black & White
2005	1:20,000	BCC 05044	013 & 014	Colour
1986	1:15,000	30 BCC 530	9 & 10	Colour
1986	1:60,000	15BC 86084	215, 216 & 217	Black & White
1980	1:20,000	15BC 80006	069 & 070	Black & White
1979	1:10,000	15BC 79006	235, 236 & 237	Black & White
1972	1:26,000	BC 7394	252, 253 & 254	Black & White
1956	1:15,000	BC 2296	59, 60 & 61	Black & White
1949	1:27.000	BC 857	33 & 34	Black & White

3.1 Flight Height, Perspective and Timing

High elevation air photos provide a good overview of regional site characteristics. The regional topography is evident, with entire valleys and mountains visible. The 1:60,000 scale 1986 air photos in Table 1 provides stereo coverage of two valleys and the upland area between them. The entire drainage basin can be reviewed, and some indication of regional groundwater flow pattern may be determined from these large scale photos.

An air photo review and interpretation should consider the geomorphology first and foremost. Moderate flight elevation photos provide a good scale for interpretation of the surficial geology. The photos giving some of the best geomorphology in Table 1 include the 1956, 1:15:000 photos and the 1986, 1:15,000 scale photos. The 1956 air photos have the added benefit of limited development, with very few roads, little to no industrial development and very little residential development.

Low flight lines provide details not readily apparent on the moderate and high flight lines. Localized landslide activity can be seen. Development history is best seen on photos taken on lower flight lines. The images are usually clear and more detailed. However, the "bigger picture" can be missed, and the number of photos required for the review will increase considerably.

The perspective on each set of air photos differs based on the flight line location, regardless of flight height, with flight lines directly above the area of concern giving the best information. If one flight line directly overhead is not available, two overlapping sets of air photos give two perspectives of the area of concern that may reveal some important features, and in addition, they provide additional coverage adjacent to the area of concern.

Historical air photos provide a vital snapshot into the anthropogenic development that may have contributed to landslide activity. The air photos in Table 1 range over a period of 56 years, during which the area of concern started out with only small rural homes, progressing with residential development in subdivisions and new local collectors. A major highway was then constructed through the toe of an ancient landslide in the mid 1970's, and a 1,000,000 imperial gallon concrete reservoir constructed in the middle of the landslide during the early 1980's. Water leakage occurred and creep movement was experienced over an area of 10's of hectares during the 1990's. The actual landslide movement is not evident on any of the air photos, but it caused damage to buildings and the failure plane was detected in borehole inclinometers and movement was monitored by remote land surveys. Regardless, the air photos provide a very good picture of the development history, and of course, the geomorphology, with a range of flight line heights and perspectives.

3.2 Air Photo Figures

Air photos can be an effective way to present information obtained from the review. The geomorphology is probably best presented on a separate topographic figure since the air photo is a relatively "busy" template. However, air photos can be used to show the changes in active processes, like fluvial processes that may undercut a river bank resulting in landslide activity. They can also be used as successive snap shots to indicate anthropogenic activity that is directly related to a Regardless of how they are used, landslide event. caution needs to be exercised in respecting the distortion and scale differences between flight lines taken at different flight heights and different locations. In short, landslides occur on steep terrain and each photographic image is unique; each is slightly distorted based on the distance from the camera's lens mounted on the plane to each point on the ground, as captured on the photo negative.

Judgement is required in taking the information from an air photo and comparing it with those taken at other dates. However, if done with careful forethought and diligence, the results are well worth the effort.

Computer air photo image resolution is becoming more affordable. The software should provide options for presenting the interpretations on landslide assessment report figures, and help with distortion issues.

4 FRASER RIVER EMBANKMENT CASE HISTORY

This case history is discussed and presented to illustrate the techniques described herein and to provide insight into a recent landslide assessment done by the author in the Cariboo Region of British Columbia. A BCMoTI approving officer identified "a natural hazard for the land use intended", for the proposed amalgamation of two large parcels of land into one. No building was permitted until a geotechnical investigation had been done and a safe area for building identified. Figure 1 shows the site location, roughly 15 kilometres south of Quesnel at a scale of 1 to 100,000.



Figure 1. Site Location

The site is located on a broad, 2km wide terrace with a steep, 80 to 85 metre high embankment leading down to the Fraser River. The western property line of the northern parcel borders directly along one kilometre of the Fraser River, with the southern 200 metres involving a portion of a large historical landslide. The remaining northern area has concerns primarily related to the rate of erosion of the embankment. The southern property is set back from the Fraser River on top of the embankment; however, the large historical landslide site continues to the west of the embankment on the neighbouring property that fronts along the Fraser River. The Kersley landslide occurred during the investigations, (1,000,000 m³). See Figure 1. It is located 2 kilometres south of this site and provides insight into the Fraser embankment stability.

4.1 Geological Setting

A thick basal till is evident along the embankment at the northern half of the site, resisting erosion from the Fraser River. There is little to no embankment along the opposite, western shore of the Fraser River, with the valley wall located over 1.5 km to the west. The basal till extends below the southern portion of the site at depth. A different, ablation till can be seen to be near full thickness of the terrace at about one kilometre south of the site.

Glaciofluvial sand and gravel overly the basal till, thickening in depth towards the south where South Sisters Creek flows, just south of the site, and thinning and fining into silty sand and lacustrine silt deposits towards the north end of the site. South Sisters Creek has limited drainage capture and is misfit to the drainage canyon flowing into the Fraser River. It is aggrading back up and into the canyon, leaving silty alluvium deposits in the gorge, overtop of the glaciofluvial. The glaciofluvial deposits across the terrace have a fining upwards sequence, with lacustrine silt over the top few metres. There are also some thicker deposits of lacustrine silt along the edge of the relic landslide that are interpreted to have in-filled ice kettles left from the earlier glaciofluvial deposits.

4.2 Historical Landslide

The historical landslide is shown on Figure 2, a 1963 air photo, which is the earliest obtained for this site.



Figure 2. 1963 Air Photo with the Landslide Extents

The landslide clearly occurred prior to the 1963 air photos being taken. Figure 3 shows the surveyor's subdivision plan with the outline of the northern end of the landslide. The subdivision plan indicates that the existing present natural boundary extends up to 30 meters west of the original boundary that was surveyed in 1905, which placing it prior to the historical landslide.

The field reconnaissance traverse was done in conjunction with a GPS survey, so the crest of the embankment and toe of the slope were traversed, and features of interest recorded using way points. Several legal pins were used to tie the field work to the surveyors plan. Figure 3 shows the field traverse as the dotted line, using the surveyor's subdivision plan as a base map. The arrows indicate the direction of travel taken during the field traverse.

Mature, back-tilted fir trees were found on the landslide debris, consistent with a deep seated rotation, along with juvenile vertical timber, roughly 80 years old, both fir and aspen. The mature timber curves sharply back to the azimuth, which indicates a large, single event rather than slow rotational creep. Logs are partially buried in the debris within the high water mark of the Fraser River, exposed as the toe of the debris is eroded.



Figure 3. Field Traverse at the Historical Landslide Site

There is at least one spring below the headscarp, and groundwater seepage is evident throughout much of the debris along the lower slopes. The landslide scarp exposes the upper glaciofluvial sand and gravel, and deeper deposits of glaciolacustrine silt in the area labelled as the gully in Figure 3. Although speculation, the deeper silt deposit on the adjacent property may have extended along the length of the landslide, blocking drainage from the glacial fluvial sand and gravel behind it, and ultimately leading to this large landslide. The island in the Fraser River appears to be related to the landslide as remnant debris. Figure 4 is from the 2006 air photo series and shows the 1963 air photo landslide extents. The island has eroded at the northern end, with little growth to the south end as might be expected in typical fluvial processes.



Figure 4. 2006 Air Photo with 1963 Landslide Extents

4.3 Basal Till and Hoodoo Field Review

The embankment has steep slopes to the north of the historical landslide site. There are cliffs of dense till soils, with remnant columns extending out from the slopes capped with tough, partially cemented, coarse till.



Figure 5. Basal Till. Steep slopes, slow erosion and the formation of hoodoo topography. Note the upper lacustrine deposits.

These erosion features are called hoodoos. The hoodoos extend out from the crest of the embankment at two or three prominent locations. Small streams were found along the Fraser River banks between these dominant sets of hoodoos that originate well up the slope of the embankment, from buried gravel seams in the glaciolacustrine deposit. The crest of the embankment is recessed where the springs are located, with higher erosion rates. Figure 5 is a photo of the basal till, showing the steep cliff face with the Fraser River in the background to the north-west.

There is a peculiar feature found along the crest of the embankment, above one of these recessed areas. An old fir tree was found overhanging the embankment by almost 4 metres. The old fir has several large roots firmly tied back into the slope. The tree is estimated at least 200 years old and in all likelihood, much older based on its difficult growing site. The tree, as a seedling, started at the very edge of the embankment and established a strong root system into the solid portion of the bank, in order to grow to the size it has without toppling down the slope. Figure 6 below is a photo of the overhanging tree.



Figure 6. This tree has struggled to keep ahead of the eroding embankment. It provides a conservative erosion rate estimate over its 200 plus years.

4.4 Kersley Landslide

Roughly two weeks after the field reconnaissance was done, on November 1^{st} , 2007, a landslide involving 1,000,000 m³ of debris occurred only 2 kilometres south of the site. The landslide produced a wave onto the opposite bank and partially blocked the Fraser River. It resulted in an abrupt 0.4 meter drop in the hydrograph reading at Margurite station, located over 40 kilometres downstream.

A field reconnaissance of the Kersley landslide was done on December 12th, 2007 to provide a perspective on the relative size and nature of the landslide. A hand held GPS survey was done along the original crest of the embankment and along the crest of the new head scarp. The crest of the embankment to the south and north of the recent landslide were located to orient the new landslide position. The results of the GPS traverse are given on Figure 7 using the orthophoto base map shown.

The air photos reviewed for the Kersley landslide show an older landslide to the immediate north, coalescing with the recent landslide in the timbered portion located west of the original embankment. The headscarp at the southern end of the 2007 landslide is near vertical for an estimated 40 metres in height, and the embankment crest placed at up to 50 metres from the original. There are topples and sloughs occurring.



Figure 7. Kersley Landslide, November 1st, 2007

The pre-landslide embankment slope at the southern end of the Kersley landslide was up to about 100m vertical to 150m horizontal, which is 67% or 34° . The slopes in the area of the smaller landslide are up to 100m vertical to 100m horizontal, which is 100% or 45° . The new crest of the slope from the original toe has been extended by up to 50 meters resulting in a 100 meter vertical to 200m horizontal offset, which is at 50% or 27° .

4.5 Landslide Assessment

The assessment done for this case study is qualitative in nature, since soil properties have not been estimated and a quantitative stability analysis was not done. However, the observations made at the historical landslide site, the hoodoos, and the recent Kersley landslide provide valuable insight into the stability response and rates of erosion at this site and allow for a conservative building set back line.

The primary hazard to development at the southern portion of the site is landslide activity along the Fraser River embankment. The landslides are a result of erosion on the steep debris slopes and removal of debris at the toe by the Fraser River that further propagates landslide cycles. The Fraser River effectively removed the majority of old landslide debris at the toe prior to the recent Kersley landslide based on the air photos.

The historical landslide failure at the site was a single, large event that cut into the embankment by 10 to 50 meters, and pushed the toe of the slope out into the river. The river has been eroding the debris at the toe for a period of well over 50 years based on the air photos. It has not yet eroded the bank to where the original toe was when the first event occurred. The slopes are estimated to have been in the order of 45°, or 100% before the landslide event. The landslide cut away from the crest by about 110 meters from the original toe, reducing the original slope angle to approximately 77%, or 38°.



Figure 8. Setback for Building Development

The period for a landslide cycle has been considered in this assessment, since landslide activity has been occurring, and will continue for the foreseeable future. A landslide cycle involving a major event, with complete removal of the debris is assumed to be 500 to 1000 years before the area could be subjected to another major landslide. A set-back line from the toe of the prelandslide embankment of 4 horizontal to 1 vertical, (14°, or 25%), as indicated on Figure 8 was determined to give low risk for future development in conjunction with recommendations to limit surface erosion. This set-back will allow seven successions of landslide activity before the embankment works back to it. This is a conservative time frame in the order of 5,000 years, during which the slope should be monitored and surface drainage controlled. Remedial works can be done on the river.

The second significant mode of slope instability is slow but inevitable erosion by denudation, topples and falls of the thick glacial till embankment and resulting in the formation of the hoodoos. The overhanging fir tree has been used to provide a conservative estimate for the rate of erosion. 4 metres has eroded over a 200 year life span, which is 1 metre every 50 years, or 2 cm per year. Since the overhanging tree is in the recessed area, the rate is considered to be one of the highest rates at this site. Therefore, in 5,000 years, the crest of the embankment in the area of the hoodoos should be no more than 100 meters from its current location. A 150 meter set-back from the crest of the embankment is indicated on Figure 8. This provides low risk for building, allowing for potentially higher erosion rates over a 5,000 year time frame, during which the slope should be monitored and surface drainage controlled. Again, future remedial works can be done on the river to stabilize the landslide cycle at a time when it becomes necessary.

5 CONCLUSIONS

In conclusion the case history described herein provides a landslide assessment that, although qualitative in nature, provides several effective techniques used to analyze the land stability and develop a conservative, safe building set back for development. Air photo interpretation is a key to providing valuable information on the geomorphology and geological site model, along with providing a historical picture of landslide activity and site development. A hand held GPS is a valuable tool to track the field reconnaissance when combined with topographic maps and the surveyor's subdivision plans.

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