CONTROLS ON STABILITY OF THE THOMPSON RIVER LANDSLIDES

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ABSTRACT

Several large landslides are located along Thompson River valley between the towns of Ashcroft and Spences Bridge, British Columbia. Initiation and landslide activity was attributed to irrigation practices by early observers. Recent investigations conducted for the Canadian National and Canadian Pacific Railways have identified at least four other factors controlling stability and ongoing landslide activity: the presence of thick, high plastic glaciolacustrine clays underlying younger glacial tills and glaciolacustrine silts; ongoing bank erosion and channel degradation of Thompson River; artesian groundwater pressures, possibly influenced by increasing precipitation levels; and a delayed pore pressure response to falling river levels in late summer and early fall.

Plusieurs grands glissements de terrain sont localisés le long de la Vallée de Thompson entre les villes de Ashcroft et Spences Bridge, Colombie-Britannique. Les premiers observateurs ont attribué le déclenchement et l'activité des glissements de terrains aux pratiques d'irrigation. Les investigations récentes entreprises pour les chemins de fer du « Canadian National » et du « Canadian Pacific » ont identifié au moins quatre autres facteurs contrôlant la stabilité et l'activité des glissements de terrain: la présence de grandes épaisseurs d'argiles plastiques glaciolacustres surmontées de tills glaciaires et de silts glaciolacustres plus récents; l'érosion active des talus et la dégradation des chenaux de la rivière Thomson; la condition artésienne de la nappe phréatique, probablement influencée par une augmentation des précipitations; ainsi qu'une réponse retardée des pressions interstitielles suite à la diminution des niveaux de la rivière à la fin de l'été et au début de l'automne.

1. INTRODUCTION

1.1 Setting

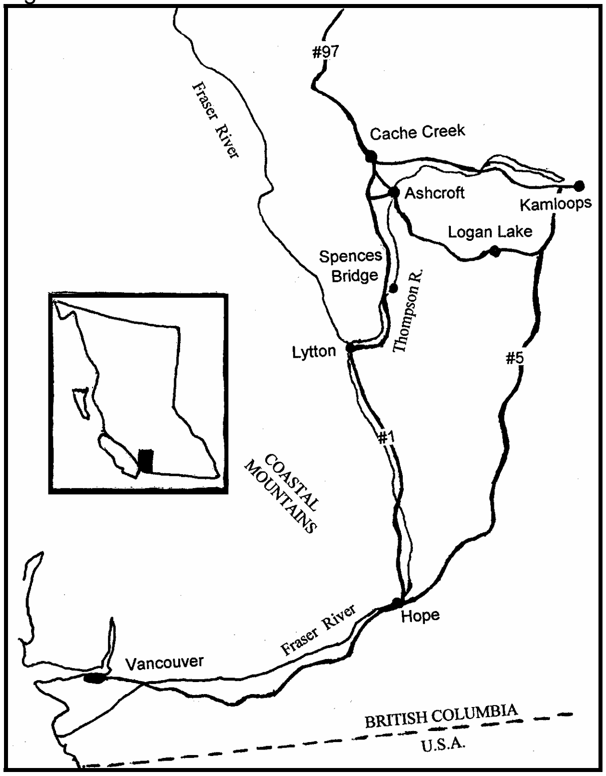
Thompson River flows south between the towns of Ashcroft and Spences Bridge, British Columbia, approximately 350 km northeast of Vancouver (Figure 1). The river has downcut through thick glacial sediments and is relatively immature, so that floodplains are absent along most reaches. Valley slopes in the glacial sediments are typically 75 to 125 m high with slope angles from toe to valley crest typically ranging from 15 to 30 degrees.

1.2 Resources and Infrastructure

The study area is host to numerous resource activities including timber harvesting and mining. The most notable mineral resource is copper, which is mined by Highland Valley Copper near Logan Lake. Upper glaciofluvial terraces, where irrigated, support feed crops and extensive cattle ranching. The river itself has significant fisheries value and is home to a world-class river rafting industry.

Thompson Valley is an important transportation corridor. The Canadian Pacific Railway (CPR) and Canadian National Railway (CN Rail) occupy one, and in many cases, both banks of the river. In addition to freight trains, VIA Rail passenger trains operate year-round, and Rocky Mountaineer offers Jasper to Vancouver rail tours along the CN Rail line between the months of April and October. The TransCanada highway also runs parallel to several sections of the river.

Figure 1: Location



1.3 Landslides

Thompson Valley has a long history of landslides, some of which are identified in Table 1. Early after the CPR was constructed through the valley in 1885, landslides had become so problematic to operations that an assessment by engineering geologist Robert Stanton was commissioned. Stanton's observations are documented in the 1897-98 Proceedings of the Institution of Civil Engineers (Stanton, 1898). In his report, he identified several large (up to 63 ha) landslides between Ashcroft and Spences Bridge. The landslides were attributed to irrigation activity on the terraces above the river.

Since Stanton's time, irrigation practices have changed dramatically. Despite a transition from water-intensive ditch-and-furrow irrigation to more efficient sprinkler systems, the landslides of the Thompson Valley have continued to move from time to time. We discuss four other factors which may control ongoing landslide activity.

Table 1: Landslides Discussed in this Paper

Railway/Slide	Description	Date(s)
1. CPR Spences Bridge	Slides dammed Thompson River in 1899 and 1905	1880 1899 Aug. 1905
2. CN/CPR Nepa	CN/CPR Crossover	Pre-1897 Feb. 1977 Fall 1997
3. CN/CPR South Slide	Pre-dates railway	Pre-1885 Winter 1977 Fall 1997
4. CPR North Slide	Dammed Thompson River in 1880	Oct. 1880 Oct. 2000
5. CN Ashcroft 53.4	Possibly triggered by North Slide	1880?
6. CPR Goddard	1982 reactivation caused 6 day track outage	Oct. 1886 Oct. 1976 Sept. 1982
7. CN Ashcroft 51	History of movement in Fall/Winter	1897 Fall 1972 Winter 1977 Fall, 2000

2. GEOLOGY AND GLACIAL HISTORY

2.1 Bedrock Geology

The Ashcroft area is part of the Thompson Plateau, a subdivision of the Interior Plateau Physiographic Region. It is characterized by rolling uplands separated from each other by deep valleys.

Local bedrock includes Triassic and Jurassic volcanic and sedimentary rocks belonging to the Quesnel Terrane. These are overlain by Middle to Upper Jurassic sedimentary rocks of the Ashcroft Formation (Gordey et al., 1991).

Rocks of the Ashcroft Formation represent local subcrop. They comprise dark, carbonaceous silty shale, which is commonly interbedded with thin layers of sandy siltstone, sandstone, and rare argillaceous limestone (Travers, 1982).

2.2 Glacial History

The region has experienced multiple glaciations in the Late Pleistocene, including:

- Okanagan Centre Glaciation, ending about 44,000 years ago, which deposited the Okanagan Centre Drift;
- Olympic Interglaciation, ending about 19,000 years ago, which deposited the Bessette Sediments; and,
- Fraser Glaciation, ending about 11,000 years ago, which deposited the Kamloops Lake Drift (Fulton and Smith, 1978).

Glacial ice likely accumulated first in the Coast Mountains south west of Ashcroft during the onset of the each glaciation (Ryder, 1981). Ice flowed down tributary valleys and formed dams on Thompson and Fraser River downstream of Ashcroft. Glacial lake sediments were deposited behind these dams and were later overridden by ice. Glacial lakes also formed at the end of each ice age as ice and sediment again formed barriers south of Ashcroft. For example, Kamloops Lake Drift comprises three distinct stratigraphic units, including an Upper Stratified Unit deposited in Glacial Lake Deadman, a Middle Unstratified (till) Unit and a Lower Stratified (glaciofluvial and glaciolacustrine) Unit.

As discussed in further detail below, a high plastic lacustrine or glaciolacustrine deposit near the base of the stratigraphic sequence is responsible for the majority of the large landslides along Thompson Valley. This deposit appears to predate the Fraser and Okanagan Centre Glaciations, and may be Middle or Early Pleistocene age (Clague and Evans, 2002). The older units are difficult to distinguish as they are buried beneath thick deposits of colluvium derived from overlying till and glaciolacustrine silt.

2.3 Holocene Activity

Following the Fraser Glaciation, the Thompson River rapidly downcut through the glacial sediments, forming a series of fluvial terraces in the process. Where downcutting of post-glacial Thompson River encountered high plastic clay deposits (presumably deposited in an old pre-glacial valley), large landslides often resulted (Figure 2). Elsewhere, steep erosional slopes stand with little evidence of deep-seated instability.

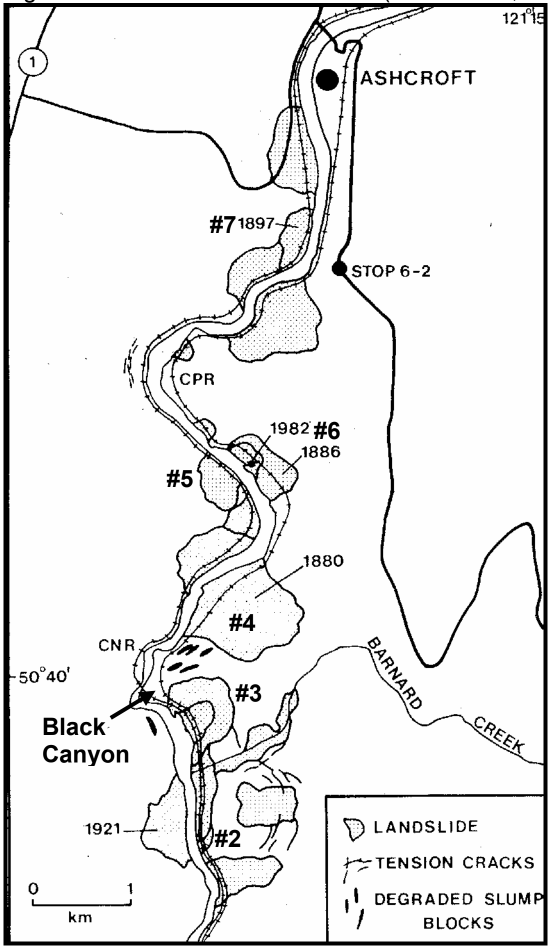
3. GEOTECHNICAL INVESTIGTIONS

Several geotechnical site investigations have been undertaken by the authors following 1997 and 1999 flood events on the Thompson River. Additionally, extensive investigation was carried out at the Goddard Slide in 1982 after slope movements resulted in a six day closure of the CPR line. A brief description of each investigation is provided below.

3.1 Nepa/South Slide

In 1998/99, CN Rail and CPR undertook the construction of a railway crossover near the Basque/Nepa area, approximately 10 km south of Ashcroft. The crossover extends through a small (6 ha) slide, that was presumed to have developed in the late 1800's.

Figure 2: Landslides near Ashcroft (after Evans, 1987)



Note: numbers identify landslides listed in Table 1

During the design investigation, tension cracks above the rail grade were identified. Slope inclinometers and piezometers were installed in relatively shallow (<20 m deep) boreholes. Soils encountered included colluvium and glacial drift overlying glaciolacustrine silt and clay. A toe berm and river armouring were incorporated into the final crossover design to improve stability and limit the potential for future river erosion.

The South Slide is located about 2 km north of Nepa. It involves a much larger area of instability, encompassing about 27 ha, that is reported to have failed prior to construction of the CPR grade. The north margin of the slide abuts a bedrock ridge which forms a constriction in the Thompson River, referred to as the Black Canyon. At this location, the CN Rail grade crosses from the right bank to the left bank of the river, and traverses south across the toe of the South Slide about 20 m below the CPR grade.

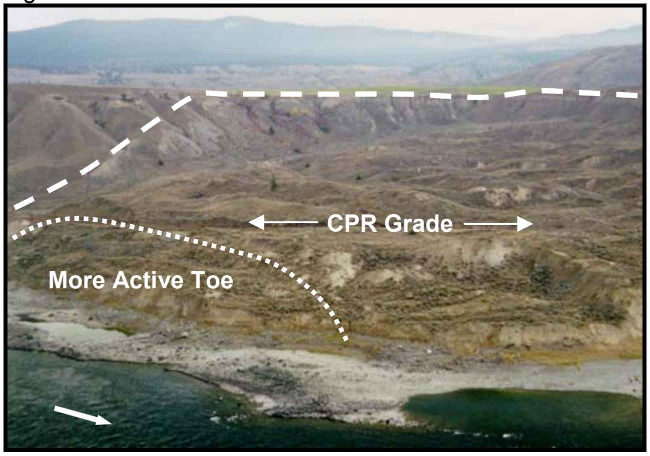
A large groyne structure below the CN Rail grade had been damaged during 1997 flooding, resulting in extensive scour at the toe of the South Slide. Cracks in the CN Rail embankment were reported in February 1998, leading to geotechnical investigation. Borings encountered thick deposits of glaciolacustrine silt and clay.

Stability analyses were conducted for several slide blocks, starting at the toe of the slope and extending up to the crest of the South Slide. The analyses indicated that small failure blocks located close to the slide toe were extremely sensitive to bank erosion and scour, while scour and bank erosion had little impact on the stability of the larger failure blocks. Repairs to the groyne and addition of a toe berm to replace material lost during the flood event were undertaken, and the slope has performed adequately since.

3.2 North Slide

The North Slide is located immediately north of Black Canyon on the left side of Thompson River (Figure 3). Movement along 150 m of the toe of the North Slide in October 2000 resulted in between 5 and 15 cm of settlement at the CPR grade. A detailed geotechnical investigation, including drilling, test pitting, instrumentation, and historical airphoto comparison was conducted.

Figure 3: Northern Half of North Slide

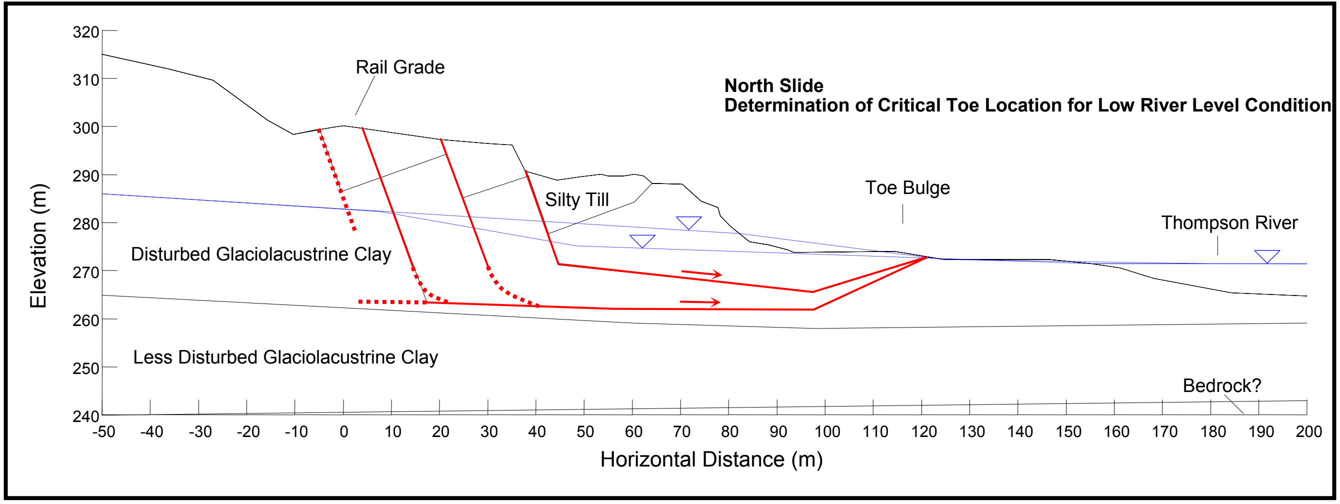


The program identified a thick deposit of stiff, high plastic glaciolacustrine clay underlying silty glacial till. The glaciolacustrine deposit contained layers of softer brown clay, stiffer dark grey clay, and grey silt. Test pits through a toe bulge on the river floodplain revealed preferential shearing through the soft brown clay.

Slope monitoring showed evidence of two shear zones located 25 and 35 m below the rail grade (approximate elevations 265 and 275 m above sea level (asl)), with peak observed movement rates on the order of 150 mm/yr (Figure 4).

A comparison of airphotos taken between 1928 and 1997 suggests that the slopes below the rail grade have been quite active, likely in response to ongoing bank erosion. In some locations, historical bank erosion rates have averaged up to 0.7 m/yr.

Figure 4: Simplified Section Through Toe of North Slide



A management strategy including the installation of tip-over posts (linked to the rail signals) and ongoing monitoring was adapted to reduce the potential for train derailment and to gain a better appreciation of the retrogressive behaviour of the landslide. To date, it has been possible to manage movements at the rail grade through normal maintenance and track lifting operations.

3.3 Goddard

A reactivation of the Goddard Slide in late September of 1982 required 6 days of emergency remedial construction to put the CPR grade back into service (EBA, 1982). A geotechnical investigation was conducted by EBA Engineering Consultants. A brief summary of their observations is provided here.

A 400 lineal metre section of the toe of the Goddard Slide experienced over 30 m of lateral movement in less than 3 days, with most of this movement occurring in a four to five hour period. Slide debris moved out into the river, after which movement rates decreased dramatically. Re-direction of river flow as a result of movement of the toe of the Goddard Slide may have negative impacts on stability of the CN Ashcroft 53.4 slide on the opposite bank.

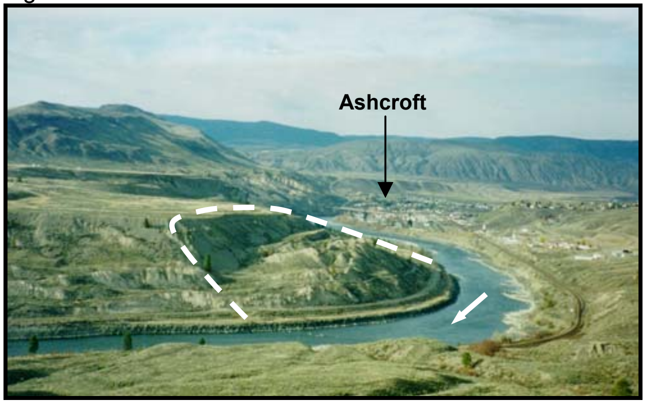
Geotechnical drilling was undertaken and slope inclinometers and piezometers were installed. Soils encountered included: sand from 346 to 340 m asl; stiff to hard low plastic glaciolacustrine silt from 340 to 270 m asl; and high plastic varved glaciolacustrine silt below 270 m asl. Movements in the slope inclinometers occurred as deep as 262 m asl.

EBA attributed reactivation of the Goddard Slide to irrigation on the terraces above the landslide, while others identified bank erosion and rapid drawdown of Thompson River as likely causes (Morgenstern, 1986).

3.4 Ashcroft 51

The Ashcroft 51 Landslide is located approximately 2 km south of Ashcroft and is traversed by the CN Rail line (Figure 5). An inspection of the slide toe in February 2001 identified 100 m of tension cracks along an old toe berm below the rail grade. In response, a detailed geotechnical investigation was conducted.

Figure 5: Ashcroft 51 Landslide



A shear zone was identified approximately 4 m below a contact between silty glacial till overlying laminated silt and high plastic glaciolacustrine clay. The elevation of the shear zone was approximately 274 m asl. Surface observations and slope inclinometer data indicated the movements were retrogressive in nature, with movement rates below the rail grade approximately an order of magnitude higher than those above the rail grade. Tip-over posts were installed and a monitoring program implemented as a temporary risk management strategy.

Monitoring in the fall of 2001 showed a dramatic increase in slide movement rate and a 6 m extension to the toe berm was constructed to improve the stability of the rail grade. Movements slowed above the rail grade, but have continued to date near the crest of the toe berm. The face of the toe berm extension was constructed with a relatively steep slope to minimize impact on fish habitat and migration, but options to reconfigure the berm with to a more stable geometry slope are currently being evaluated.

4. CONTROLS ON SLIDE ACTIVITY

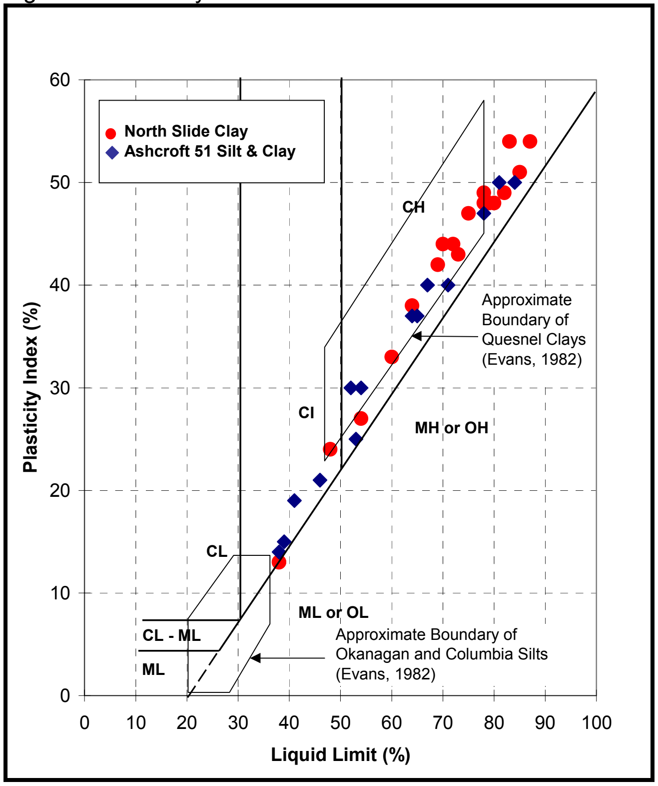
The investigations outlined above have identified at least four factors that appear to control the stability of the Thompson River landslides. Each control must be understood and accounted for if long-term risk management strategies are to be successful.

4.1 Shear Strength

The age and origin of the laminated silt and high plastic clay deposit are not yet clear. However, we do know that the engineering properties of the clay sampled beneath each of the large landslides identified above are significantly different than those of the extensive glaciolacustrine silts exposed in the walls of Thompson Valley.

Core samples of the clay revealed rhythmically laminated light brown high plastic clay, grey plastic clay and grey silt, characteristic of a deep glacial lake deposit. Occasional thin (<2 mm) black sand seams were encountered. Typical Atterberg Limits are illustrated in Figure 6. Clay-size fraction often exceeds 70%, with clay activity in the range of 0.6 to 0.9, suggesting illite clay mineralogy.

Figure 6: Plasticity Chart



Stark and Eid (1994) provided guidance on estimating residual shear strength on the basis of liquid limit and clay fraction. Their empirical correlation predicts residual friction angles on the order of 9 to 13 degrees, which correspond with strengths obtained from back analysis of the North and Ashcroft 51 Landslides. It is not surprising, then, that where oversteepened valley slopes and weak plastic foundation soils coincide, large landslides with high mobility can develop as shear strengths approach residual values.

As an aside, Stark and Eid (1994) showed that the residual friction angle of clay soils is stress dependent as high normal stresses promote alignment of clay particles during shear. This suggests that resistance at the toe of a slide (where normal stresses are lower) may be greater than beneath the middle of the slide. This emphasises the additional significance of preserving mass at the toe of the Thompson River landslides, where frictional strength may be 3 to 4 degrees higher than along other portions of the slip surface. The effect can be modeled using a non-linear strength envelope, which was noted to better predict the location of a toe bulge at the North Slide.

4.2 Channel Degradation and Bank Erosion

Thompson River is relatively immature and prone to channel scour and bank erosion. Many of the large landslides in the valley have pushed slide debris well into the river, constricting the channel and locally increasing flow velocity. The silt and clay slide debris are subject to rapid rates of erosion.

For example, a historical review of airphotos spanning 1928 to 1997 shows that despite ongoing bank movement into the river, as much as 50 m of bank was lost to river erosion at the toe of the North Slide (NHC, 2001). The effect of an additional 5 m of bank erosion was analysed and shown to decrease stability by 2.5 percent on both the shallow and deep shear surfaces.

At the Ashcroft 51 Landslide, bathymetric surveys identified a 6 m deep scour hole centred about 30 m downstream of the middle of the reactivated slide toe. The effect of scour was shown to decrease stability of slide blocks extending beneath the rail grade by 1.5 to 2 percent for every metre depth of scour.

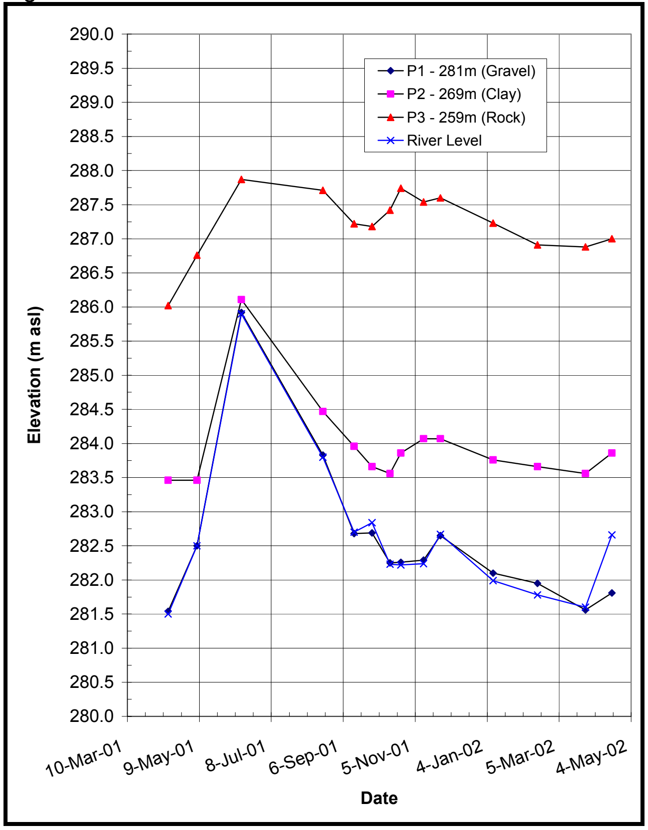
Assessment of the timing of flooding (presumably accompanied by bank erosion and scour) and accelerated slide activity provides additional evidence of the influence of river erosion on the stability of slopes along Thompson River. Some of the top flood events recorded since 1911 (NHC, 2001) include:

- 1921 – may have triggered a landslide across from Nepa Slide (Figure 2);
- 1972 and 1974 – may have triggered reactivation at Nepa, South Slide, Goddard and Ashcroft 51 (Table 1); and,
- 1997 and 1999 – linked to reactivation at Nepa and South Slide, and possibly North Slide and Ashcroft 51.

4.3 Pore Pressures

Investigations at North Slide and the Ashcroft 51 Landslide identified artesian pore pressures beneath the toe of each slope. It is believed that fractured bedrock forms a confined aquifer that controls pore pressures at the base of the laminated silt and clay unit, while river level controls pore pressures at the top of the silt and clay unit near the toe of each landslide (Figure 7). The excess pore pressures reduce effective stress along shear surfaces and contribute to the instability of the slopes.

Figure 7: Piezometric Elevations at Ashcroft 51 Landslide



At North Slide, the upward hydraulic gradient within the glaciolacustrine clay ranged from about 0.3 (June 14, 2001) to 0.4 (October 24, 2001), while at the Ashcroft 51 Landslide, the upward gradient ranged from 0.2 (June 13, 2001) to 0.4 (October 24, 2001). In the fall, pore pressures near the top of the glaciolacustrine unit drop more quickly than those at the base of the clay, resulting in larger upward hydraulic gradients.

We can assume that an increase in the piezometric elevation of the bedrock aquifer would have a negative impact on the stability of the Thompson River landslides. In the late 1800's, ditch-and-furrow irrigation systems applied large quantities of water to the terraces above the landslides, and may have contributed to recharge of this aquifer. However, if modern irrigation systems currently employed on the terraces are being utilized properly, they should provide limited excess moisture that can infiltrate through the thick soils overlying bedrock. Further work may be required to demonstrate that this is the case.

Precipitation falling on poorly drained slide topography, and in the hills surrounding Thompson Valley is an additional factor controlling regional groundwater recharge.

Precipitation data from climate stations near Kamloops, British Columbia, show a significant increase in precipitation levels since the beginning of the 20th century (Figure 8). Thus, despite improvements in irrigation practice, the soils at the base of the Thompson River landslides may still experience abnormally high pore pressures which contribute to ongoing landslide activity.

4.4 River Drawdown and Loss of Toe Load

A review of published and engineering records of landslide activity in Thompson Valley shows a trend towards instability in fall and winter. Not only have small-scale instabilities at slide toes developed in the fall, but so have some of the larger-scale movements like Goddard (October 1886) and North Slide (October 1880). Rapidly falling river levels between June and September likely contribute to this phenomenon. A similar process of wide-scale instability in the fall along riverbanks through Winnipeg, Manitoba has been documented by Tutkaluk et al. (1998).

As indicated in Figure 7, the piezometric elevation along the base shear surface at Ashcroft 51 (elevation 274 m asl) was significantly higher than river level throughout the fall and winter of 2001. Therefore, when river levels rose in spring and summer, the mass of the water provided an increase in the stabilizing force at the toe of the landslide.

Stability analyses were undertaken to evaluate the influence of the annual cycle of rising and falling river level and piezometric elevations on stability of the toe of the Ashcroft 51 Landslide. The factors of safety of the lower three blocks in Figure 9 were evaluated at a number of time intervals between April 13, 2001 and March 25, 2002. The results are plotted in Figure 10.

Figure 10 suggests that the river water toe load has the greatest influence at the slide toe, where the calculated factor of safety varied by approximately 30 percent between the high and low water condition. At Block 2, which encompasses the soil mass between the ditch line and the toe of the slide, the factor of safety only varied by 6 percent, while the factor of safety for blocks extending further up the slope only changed by 1-2 percent throughout the year.

As the Ashcroft 51 Landslide, like most slides in the Thompson Valley, displays a retrogressive behaviour, the loss of slide toe stability as a result of falling river level may have a significant impact on the mobility of the entire slide, despite what appears to be a relatively insignificant influence on the overall factor of safety. A domino effect may result as movement at the toe causes a loss of support for each of the slide blocks above it.

Figure 8: Precipitation Data for Kamloops, BC

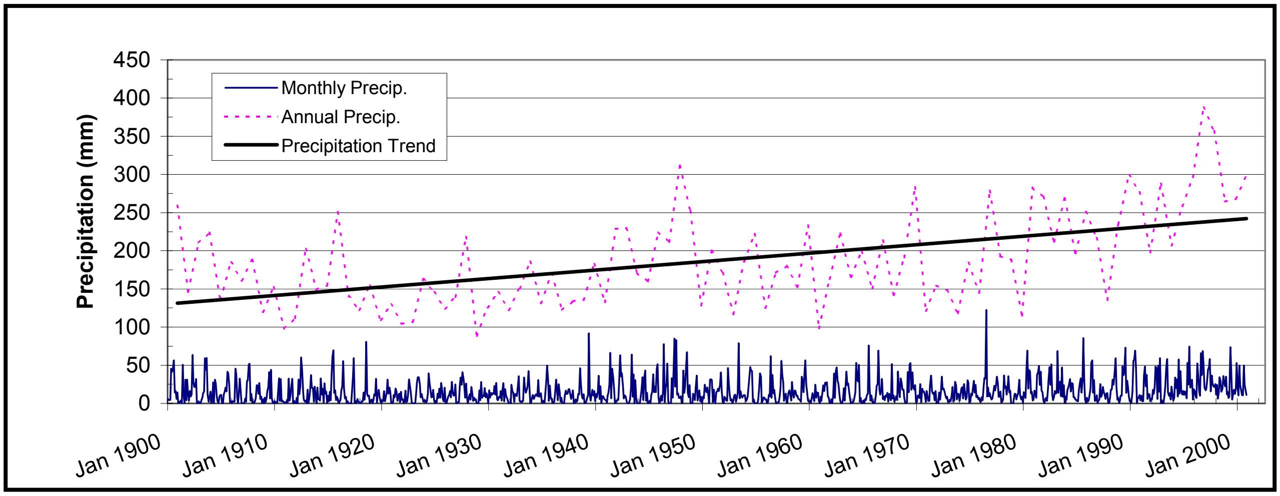


Figure 9: Simplified Geometry for the Ashcroft 51 Landslide

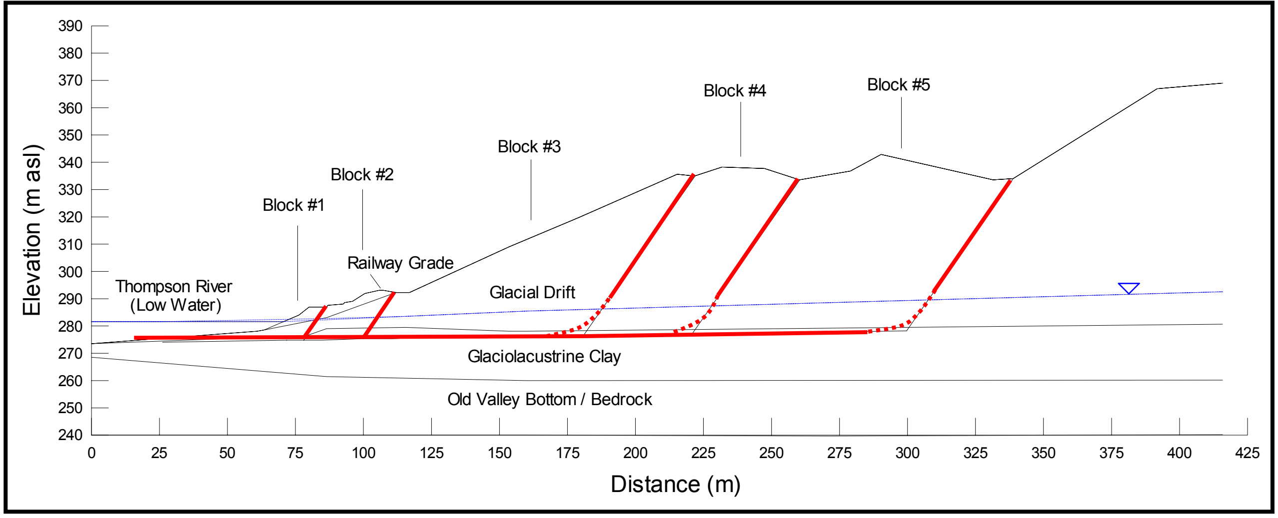
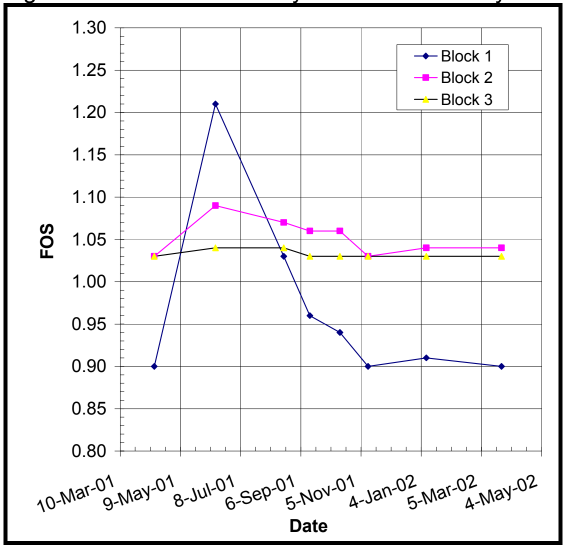


Figure 10: Annual Variability of Factor of Safety



5. DISCUSSION

Since Stanton's assessment in the late 1800's we have made significant progress in our understanding of the Thompson River landslides: we have identified a weak soil unit and an artesian pore pressure condition that control deep seated slope movements; we understand that the landslides are retrogressive in nature and are sensitive to small changes in stability at their toe; we have witnessed a correlation between falling river level and a decrease in slope stability, accompanied by increased slide activity; and have begun to quantify the impacts of river scour and bank erosion.

However, much work remains if we are to effectively manage the hazards posed by the Thompson River landslides on the security of downstream inhabitants, the vitality of the river's salmon fishery, and the safety and viability of the transportation corridor. Four main areas are identified where further work is required. Three are scientific in nature, while the fourth pertains to social issues.

5.1 Potential for New Slides

Where Thompson River has dissected valley sediments and encountered the silt and high plastic clay unit, large landslides have resulted. It is possible that this unit is present beneath other sites along Thompson River where landslides have not yet occurred. A better understanding of the distribution of the high plastic clay (likely coincident with the location of a deep, pre-glacial valley south of Ashcroft) will shed light on the potential for development of new landslides along Thompson River.

5.2 Catastrophic Movements of Existing Slides

The Spences Bridge and Goddard Slides have reactivated with catastrophic consequences. As these were not first-time slides, we require greater insight as to what caused the high mobility of these secondary failures, and whether other landslides also have this potential.

5.3 Relative Importance of Factors Controlling Stability

A number of factors have been identified which appear to control ongoing activity of the Thompson River landslides. Additional knowledge of which factors have the greatest impact on slide activity and which factors can reasonably be controlled is required to assist with developing long-term management solutions.

5.4 Requirements for a Consensus-Based Approach

The Thompson River landslides and the means available to control them can impact a number of stakeholders. A process of disseminating the results of scientific and engineering studies, and collaborating with each of the stakeholders is required in order to establish sound hazard management strategies that satisfy the social and economic objectives of all parties involved. This will undoubtedly involve a multi-disciplined, consensus-based approach.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the permission of CN Rail and CPR to publish information from the geotechnical investigations sited within.

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