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Glissements de terrain

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Sensitive clay flows along the South Nation River, Ontario, Canada and their impact on land use

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ABSTRACT: In the past 100 years, 4 retrogressive earthflows, which range in size from 15 to 30 ha and display retrogressive distances of up to 680 m, have occurred along a 20 km reach of the South Nation River, 50 km east of Ottawa, Canada's capital. In addition, numerous scars of earlier landslides of a similar size have been recognized hi the same area. These slides occur in sensitive marine clays of the Champlain Sea basin. Slope instability in this area has been a concern for local residents especially in view of the large landslides that occurred in 1971 and 1993. In both cases, the river was blocked causing extensive flooding. Following the 1971 failure, the site for a proposed bridge for a 4-lane highway was relocated 15 km upstream of *the* original site. Between 1987 and 1990, a 1700 in long rock berm was constructed to protect 41 homes and in 1991 the population of the village of Lemieux was relocated. The landslide of 1993 occurred within 700 m of the former town site. A geotechnical evaluation of the potential for failure of the river banks has been undertaken and estimates made of the potential for landslide retrogression. Approximately 35 existing residences lie within the area of potential retrogression and are considered to be at risk. Preliminary remedial measures have been evaluated as part of an environmental assessment of the area. The most cost effective measures for most of the remaining 35 homes would be to move the home beyond the zone of potential landslide retrogression or to purchase the properties from the local residents rather than to stabilize the slope.

I INTRODUCTION

Landslides in sensitive marine clay are a hazard to the residents living adjacent to the South Nation River, a northeasterly flowing tributary of the Ottawa River (Fig. 1). In particular, a 20 km reach of the river which lies approximately 50 km east of Ottawa, Canada's capital, is subject to large scale retrogressive earth flows.

Residents of the area have lived with the risk of these landslides since the area was first settled by Europeans in the early to mid 1800s. The area is sparsely populated and rural in character. Mixed farming predominates but is declining; considerable tracts of former farm land have been reforested. More recent rural development has being residential in character. The principal community in the immediate area is the Town of Casselman (pop. 2500).

A number of geotechnical and environmental evaluations (Golder Associates, 1985, 1988a,b, 1989, 1993a,b; Gore & Storrie, 1988, 1994) have been conducted in an attempt to find a solution which would minimize potential impacts of future slope failures.

2 GEOLOGICAL SETTING

During glaciation, down warping of the earth's crust under the weight of the ice sheet, depressed the St. Lawrence and Ottawa valleys below sea level. Upon retreat of the glaciers from the immediate area, this depressed land was flooded by the Champlain Sea. Clay and silts were rapidly deposited from debris-laden, glacial meltwater streams. In some parts of the basin, deep water sediments, clays and silts, were deposited in thicknesses of up to 100 m.

As the glacier withdrew from the vicinity, the land began to rebound, the sea regressed, and depositional environments changed. Shallow water sediments, silts and sands, were deposited on top of earlier fine sediment. Finally, as the Champlain Sea retreated from the region, a large delta grew southward, from the north end of the valley into the St. Lawrence valley forming an extensive, and locally thick, cap of sandy and silty river sediments over much of the marine deposits.

As land emerged from the sea, the proto Ottawa drainage system eroded down through the marine sediments, cutting terraces and forming deep valleys. Massive landslides occurred along the steepened slopes. To this day, clay flows remain a

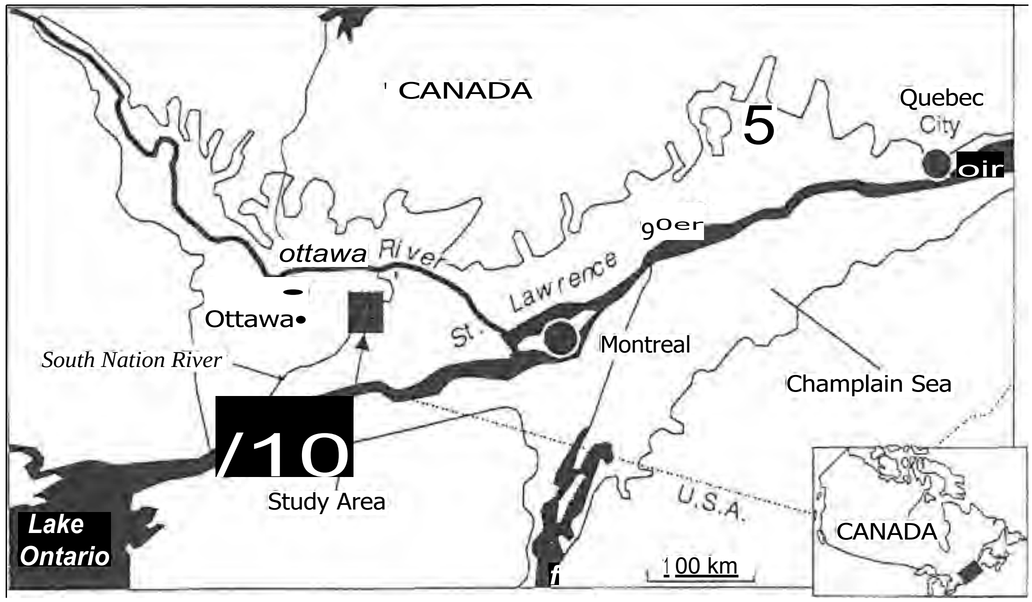

Figure 1. Location of study area. Maximum extent of the Champlain Sea is shown in grey.

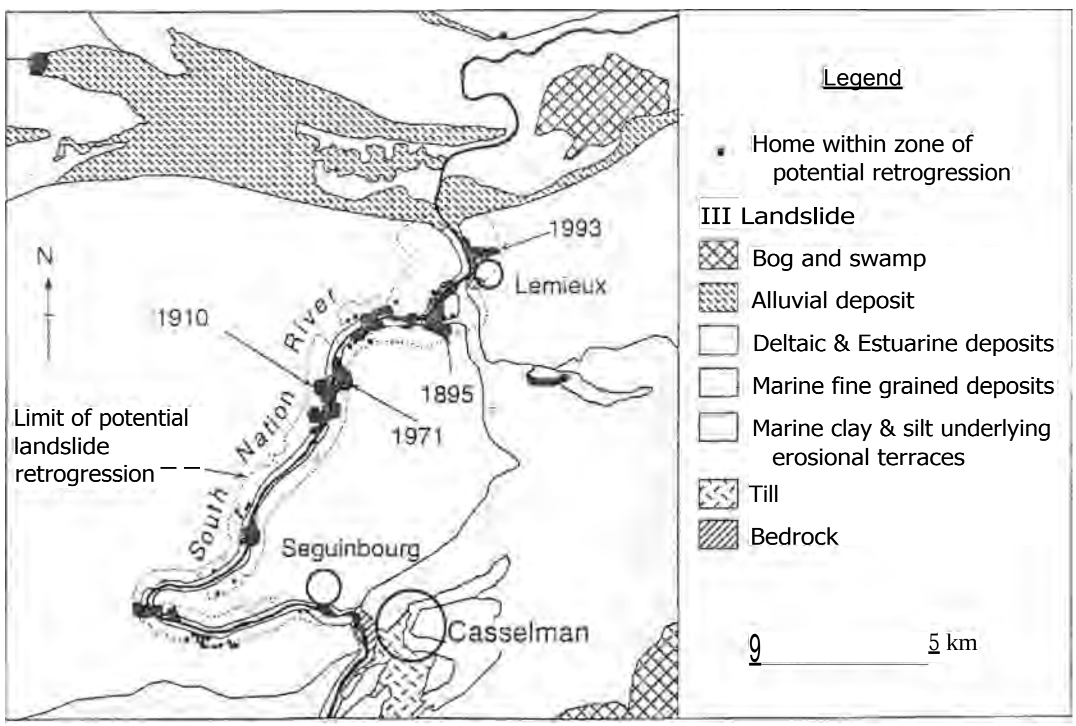

Figure 2. Study area along South Nation River, Casselman to Lemieux, showing surficial geology (after Richard, 1982), dates of landslides if known, limit of potential landslide retrogression and homes located within area of potential retrogression (Golder Associates, 1993).

hazard in areas underlain by thick deposits of sensitive marine clays, particularly where the clays are overlain by the sand unit. The latter acts as a water reservoir, contributing to high pore water pressures in the underlying unstable clay.

3 GEOLOGY

The surficial geology of the area has been documented by Gadd (1976) and Richard (1982).

The stratigraphy of the study area is characterized by deltaic and estuarine fine to medium grained silty sands which are underlain by marine clays and silts of the Champlain Sea (Leda clays) (Fig. 1, Fig. 2). The sand unit varies in thickness from 1.8 to 6m. The water table within these sands is usually within a meter or so of the ground surface and in the spring or following heavy-rains standing water is common on open fields.

Two major units can be distinguished within the marine clays. The upper unit consists of clay, silty clay and silt locally overlain by thinly interbedded sand and silty sand. The upper parts are generally mottled or laminated reddish brown and bluish grey. At depth laminations are less frequent and blue grey clays predominate. The lower unit is a blue grey clay, sometimes mottled. Typically the clay is underlain by coarse glaciofluvial or glacial lacustrine sediments or till up to 1 m thick. These deposits overlie relatively flat lying limestone. The South Nation River has down cut through the sand plain into the underlying marine clays. Down cutting is continuing.

4 LANDSLIDE HISTORY

Since 1850, five large retrogressive landslides have been documented between Casselman and Lemieux (Table 1). The scars of an additional 7 or 8 older landslides are evidence that the process has been ongoing for some considerable time (Fig. 2). The two most recent landslides occurred in 1971 and 1993 (Fig. 3 and 4).

Table 1. Large retrogressive landslides between Casselman and Lemieux, South Nation River, Ontario. The location of the 1850 landslide is not documented.

Age of landslide	Size (ha)	Retrogression (rn)
	11.6	251
	5.4	263
	10.6	464
1895	24.4	600
28 Feb 1910	15.3	300
16 May 1971	28.0	490
20 June 1993	17.0	680

Figure 3. 1971 South Nation Landslide. Debris fills river valley, upper right. Photo by W.J. Eden.

Figure 4. 1993 Lemieux Landslide. Debris dammed river, raising water level 12 in. Photo by G.R. Brooks.

4.1 *South Nation Landslide*

On May 16, 1971, 4.5 km upstream of the hamlet of Lemieux, a large clay flow destroyed 28 hectares of farmland (Eden et al., 1971; Mitchell, 1971). The width of the landslide was 750 m with a headward retrogression of 450m. About 6 million cubic metres of sediment flowed into the South Nation River, damming the river for months. Prior to the event, the ground was saturated following heavy snow melt and a wet spring. The 1971 South Nation Landslide occurred in a year memorable for sensitive clay flows — the catastrophe at St. Jean Vianney, Quebec, which took 31 lives, occurred 12 days earlier.

4.2 *Lemieux Landslide*

On June 20, 1993, a. large, sensitive clay flow occurred along the east bank of the South Nation River immediately downstream of the former town site of Lemieux (Evans and Brooks, 1994; Brooks et al., 1994). Initial failure occurred within the scar of a much earlier rotational slide. It involved 17 ha and retrogressed distance of 680 m. The clay flow involved about 2.8 million cubic metres of sand, silt and clay, much of which flowed into the valley of the South Nation River, burying 3.3 km of the valley bottom. This debris dammed the South Nation River, eventually flooding the valley bottom for 18 km upstream. By late June 22, 1993, the South Nation River overtopped the landslide dam. Water levels have since lowered as the river gradually incised into the dam. The local township estimates that direct costs of this ' event are $4 million; if indirect costs are included, the estimate is $12.9 million (Gore & Storrie, 1994).

There was no obvious trigger for the June 1993 failure, although an elevated water table seems to have been an important factor in the failure. The winter of 1993 had an above normal snowfall with heavy snowfall occurring in March and early April. This fact, combined with a rapid spring melt and heavy spring rainfall resulted in water tables near or at the ground surface (Brooks et al., 1994). A small slump of the river bank was noted the week prior to the event (D. Legarec, personal communication).

The Lemieux landslide occurred as the result of a loss of strength in a sensitive clay zone lying between 8 and 23 m beneath the surface (Evans and Brooks, 1994). The initial fluidization caused most of the overlying silt and clay to also liquefy and flow, thereby fracturing and carrying the stiffer surface (cap) sediments as rafted blocks within the mass of remolded clay. The failure began at the river, probably as a reactivation of the older landslide. Through consecutive failures at the headwall, the landslide eroded retrogressively headward for 680 m into the surrounding plain. The landslide widened through lateral spreading and subsidence, translation, and rotation of blocks separated from the sidewalls, creating embayments into both the north and south sidewalls. The event probably was over within 1 hour (Brooks et al., 1994).

5 GEOTECHNICAL INVESTIGATIONS

Prior to the 1970s there was little geotechnical interest in the area as no major retrogressive slide had occurred since 1910. In 1966 subsurface investigations were carried at several locations along the South Nation River by the Department of Highways to select a suitable crossing location for a new 4 lane highway between Ottawa and Montreal. Plans for a bridge in the vicinity were abandoned following the 1971 landslide event. A suitable site was chosen 15 km upstream to avoid problems posed by potential landslides. This however considerably lengthened the highway route. The landslide was investigated by a number of researchers (Eden et al., 1971; Mitchell, 1971, 1978).

The Ministry of Natural Resources (MNR) undertook an examination of the river banks and evaluated the factor of safety for slopes along the South Nation River and its major tributaries. Maps showing the risk of failure were produced (Poschmann et al., 1983). Preliminary setback lines for safe development were then established (Klassen, 1986, 1988)

The need for an examination of the soil and hydrological conditions, a more rigorous evaluation of the potential for failure, and the extent of possible retrogression was recognized by the South Nation River Conservation Authority. This lead to the following geotechnical investigations:

Phase I, borehole sampling, testing and ground water monitoring and evaluation of the potential for landslide retrogression at each site, (Golder Associates, 1988a,b).

Phase II, detailed contour mapping, cross sections of river banks, determination of site specific landslide retrogression and the requirements for riverbank stabilization (Golder Associates, 1989).

Landslide retrogression distances were determined for various sites, based on available information, using the following equation modified from Mitchell (1978), and referred to as Golder's method 'D'. The equation is used for slopes in the Casselman Lemieux area where N_s (stability number) is z5 and 5.12 .

$R = (N_s - 4)\ 180$, where

R = retrogression distance (m)
Ns = Cu
= unit weight of the soil
H = height of the slope (m)
C_U = undrained shear strength (kPa)

This method is conservative in that it slightly overestimates the potential retrogression distance (i.e. all existing landslide scars have a retrogression distance less than estimated by this method of calculation). Where the results of Nilcon vane shear testing indicates no potential for retrogression, a minimum 100 m set back distance from the crest of the slope is suggested as prudent. This would minimize future development in areas where localized instability may exist.

Phase III, detailed investigations at selected sites to determine the actual potential of landslide retrogression (Golder Associates, 1993a,b). Stability analyses carried out for the steeper, less stable sites indicated factors of safety in the range of 1 to 1.3; for this study a factor of safety greater than 1.5 was considered to indicate long term stability provided that the slope is not steepened by toe erosion.

Environmental assessments were undertaken for the town of Lemieux and for the Casselman Lemieux section of the South Nation River. These reports reviewed alternatives and presented recommendations for eliminating risks to life caused by the potential for retrogressive landslides. (Tables 2 & 3) (Gore and Storrie, 1988, 1994).

Further investigations were carried out to evaluate the potential for retrogression at selected locations (Morey Houle Engineering Consultants, 1995, 1996).

Detailed subsurface geotechnical and geophysical investigations were undertaken at the site of the Lemieux landslide during the summer of 1995 by Terrain Sciences Division, Geological Survey of Canada.

6 REMEDIAL MEASURES

Subsequent to the southerly realignment of the Ottawa-Montreal highway, several other major initiatives to reduce the risk posed by landslides have been undertaken. At Seguinbourg, downstream from the town of Casselman, a rock berm was constructed to protect 1700 m of the river bank from toe erosion and to stabilize the bank. This work was undertaken between 1987 and 1990 to protect 41 residences. All of the residents of the town of Lemieux have been relocated at government expense and the village (approx. 28 homes) was abandoned in 1990.

At the time of the release of the Class Environmental Assessment for the South Nation River, 37 homes within Cambridge Township remained within the area of potential landslide retrogression and are at risk. The Ontario government is subsidizing the cost of the physical relocation of homes and home purchase for those who wish to move. Stabilization of the river banks is the preferred option for the majority of residents. Stabilization is in most instances the most costly remedial option (Table 2).

Table 2. Cost comparison of remedial options (modified from Gore and Storrie, 1994).

Zone*	No. of homes	Estimated cost (1000$ Can) Stabilize	Buy-out	Relocate	Option (least cost)
1	3	580	690	530	relocate
2	2	240	590	470	stabilize
3	2	600	100	150	buy-out
4	2	520	300	260	relocate
5	2	260	220	330	buy-out
6	2	430	190	170	relocate
7	5	1,920	530	440	relocate
8	9	1,950	1,110	1,450	buy-out
5a	2	2,500	220	250	buy-out
11	1	1,070	150	110	relocate
14	1	800	210	150	relocate
18	4	1,280	280	340	buy-out
20	2	1,300	20	32,4	buy-out
Total	37	13,430	4,840	5,020	3,840

* Zone allocated for planning purposes.

7 SUMMARY

Landslides in the Casselman-Lemieux area have caused severe local and downstream impacts and have traumatized local residents. In addition, there has been considerable direct and indirect costs attributed to landslide damage and clean up. Fortunately there has been minimal personal injury and no loss of life.

The results of geotechnical investigations and the assessment of environmental impacts provide a sound technical basis for considering the implications of the landslide risk in the development of master plans for development and for the protection of local residents and property. Hopefully remedial measures will be taken prior to the occurrence of any new life threatening landslide event.

Geological and geotechnical investigations to refine the hazardous areas are continuing as well as research into the causes, controls and trigger. mechanisms for the landslides.

ACKNOWLEDGMENTS

The geological and geotechnical work recently undertaken by Morey Houle Engineering Consultants Ltd. and the Geological Survey of Canada has been supported through the cooperation and financial assistance of the South Nation River Conservation Authority and the Municipality of Cambridge.

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FROM THE SAME PUBLISHER:

Oliviera, R., L.F.Rodrigues, A.G.Coelho
& A.P.Cunba (eds.) 90 5410 503 8
7th International Congress International Association of Engineering Geology — *Proceedings/ Comptes-iendus, Lisboa, Portugal, 5-95-9 September 1994*
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90 5410 589 5
Barends, ELI.Brouwer & FILSchroder (eds).
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Plotnikov, L.M. 90 54 10 220 9
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February 6, 2006

South Nation Conservation
PO Box 69
15 Union Street
Berwick, Ontario
KOC 1G0

Attention: Mr. R. Pilon, P. Eng.

Richard
I will be meeting with municipality to go over the findings. See me if you have questions.

RE: RETROGRESSIVE LANDSLIDE POTENTIAL OVERVIEW
PROPOSED WATER RESERVOIR SITE
CASTOR RIVER, TOWNSHIP OF RUSSELL, ONTARIO

Dear Sirs:

This letter provides our comments from a geotechnical point of view regarding the expected potential for retrogressive landslide along the Castor River at a site between the Towns of Russell and Embrun, Ontario. The comments are based on a general theory of the causes of landslide retrogression, a cursory review of a slope stability study report for the subject site provided to us by the South Nation Conservation, and review of the surficial geological map for the subject area. „, The above mentioned slope stability study report consists of the Jacques Whitford Limited (JWL) Report for Project No. 0N011761 entitled " Slope Stability Study, Proposed Water Reservoir, Old Forced Road, Township of Russell, Ontario.

A General Theory of Landslide Retrogression

It is considered that retrogressive landslides and earth flows are initiated by a simple rotational failure of a slope in a 'drained' strength condition (no negative porewater pressures). This initial slope failure may encompass the entire slope or only a portion of the overall slope face. Retrogression occurs when the slide debris from this initial simple rotational slope failure flows out of the failure area and leaves an unstable backscarp which in turn fails. Continued reoccurrence of this phenomena results in retrogression of the landslide as long as the slide debris flows out of the failure area and the slope material continues to fail in a drained state. However as the slide continues to regress, negative porewater pressures develop due to lateral stress relief causing an undrained strength condition to exist in the backscarp materials. This has the effect of increasing the strength of the soil 'comprising the slope and will terminate the landslide retrogression unless the conditions of the backscarp allow the criteria for undrained failure to be satisfied.

The criteria for undrained failure of a slope backscarp can be related to the slope stability number. The stability number, N_s, of a slope is defined as the ratio of the height of the slope and the unit weight of the slope material to the undrained shear strength of the slope material. If the stability number of a backscarp is calculated to be greater than 4, the conditions for backscarp failure are satisfied and the landslide retrogression will continue.

The ability of the slide debris to flow out of the failure area has been empirically correlated with the liquidity index of the cohesive slope soils. The correlation has been based on determining the liquidity index of the soils within slopes where historically, retrogressive landslides have occurred. Slope soils with a liquidity index of 1.0 to 1.2 or greater have been correlated with historical retrogressive landslides.

JWL Report

A review of the above noted JWL report indicates that the Castor River slope conditions at the site subject of the JWL report meet the theoretical conditions for retrogressive landslide potential with regards to conditions for a simple rotational failure of the slope in a 'drained' strength condition, liquidity index of the slope soils of 1.0 to 1.2 and greater and calculated stability numbers for the slope greater than 4.0.

Review of the Surficial Geology Map

The surficial geology map reviewed consists of the Geological Survey of Canada Surficial Geology Map 1507A, Russell, Ontario. The map includes, together with surficial soil information, pertinent other geological information, one of which is the locations of significant historical landslides or landslides which have retrogressed hundreds of metres back of existing or abandoned major watercourses. No such significant landslides are indicated for the Castor River between Russell and Embrun.

Discussion

As mentioned above general retrogressive landslide theory indicates that a retrogressive landslide may occur where, after initial "drained" rotational slope failure, the debris from the failure, and that from subsequent slope failures occurring in the "undrained" condition, flows out of the failure area. For the slide debris to flow out of the failure area, sufficient potential energy must exist in the failing slope material to cause significant remoulding of that slope material. As indicated above, present theory correlates slope soil liquidity index to the ability of the failing slope material to be sufficiently remoulded to flow. However, this correlation has been based on the study of slopes where due to the height of the slopes sufficient potential energy has existed in the slopes to cause remoulding of the slope soils that had a liquidity index of 1.0 to 1.2 or greater. For the known retrogressive landslide potential area along the South Nation River between the Town of Casselman and the former Village of Lemieux, the slopes are typically some 18 to 24 metres high. The Castor River slopes at the subject site and, in general, between Russell and Embrun are significantly lower.

In summary, it is considered that although the slope and slope soil conditions at the JWL subject site are indicated to meet current theory for potential retrogressive landslides, it is considered that insufficient potential energy exists in the slope to cause sufficient remoulding/flow of the slide debris and the development of a retrogressive landslide.

We trust this letter provides sufficient information for your present purposes. If you have any questions concerning this letter please do not hesitate to contact our office.

Yours truly,

Kollaard Associates Inc.

C. R. orey, WEn

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