MP 112 SLOPE STABILITY, SOUTH NATION RIVER OGS

Ontario Geological Survey
Miscellaneous Paper 112

Slope Stability Study
of the South Nation River and Portions of the Ottawa River

by
A.S. Poschmann, K.E. Klassen,
M.A. Klugman, and D. Goodings

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Ministry of Natural Resources
Ontario

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A project funded by the South Nation River Conservation Authority, the Federal Department of Regional Economic Expansion, and the Ontario Ministry of Natural Resources.

1983

Ontario

Ministry of
Natural
Resources

Hon. Alan W. Pope
Minister

W.T. Foster
Deputy Minister

South Nation River
Conservation Authority

Printed in Canada

ISSN 0704-2752
ISBN 0-7743-8219-8

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This project was funded by the South Nation River Conservation Authority, the Federal Department of Regional Economic Expansion, and the Ontario Ministry of Natural Resources.

Parts of this publication may be quoted if credit is given. It is recommended that reference to this report be made in the following form:

Poschmann, A.S., Klassen, K.E., Klugman, M.A., and Goodings, D.
1983: Slope Stability of the South Nation River and Portions of the Ottawa River; Ontario Geological Survey, Miscellaneous Paper 112, 20p. Accompanied by Geotechnical Series Maps 2486 and 2487, scale 1:50 000.

Critical Reader: O.L. White
Scientific Editor: Guy Kendrick

1000-83-Twin Offset

FOREWORD

SLOPE STABILITY STUDY OF THE SOUTH NATION RIVER AND PORTIONS OF THE OTTAWA RIVER

This report is the second report of its type to be published by the Ontario Geological Survey. Prepared by the staff of the Eastern Region Office of the Ministry of Natural Resources, the report draws attention to the existence of potentially unstable slopes along the valley of the South Nation River and its several tributary streams together with part of the Ottawa River. The clay soils forming these slopes owe their origin to material deposited in the waters of the Champlain Sea which covered the area during deglaciation about 13 000 years ago.

The objective of this report is not only to alert the general public, planners, and the municipalities to the potential hazards, but also to encourage developers and land owners to arrange for adequate geotechnical investigation of all land in the vicinity of river banks and slopes well in advance of any construction or development thereon.

E.G. Pye
Director
Ontario Geological Survey

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GEOTECHNICAL SERIES MAPS

(back pocket)

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Map 2487 (coloured)—Slope Stability Study of the South Nation River and Portions of the Ottawa River, Southern Sheet, Southern Ontario, scale 1:50 000.

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CONVERSION FROM SI TO IMPERIAL			CONVERSION FROM IMPERIAL TO SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm²	0.155 0	square inches	1 square inch	**6.451 6**	cm²
1 m²	10.763 9	square feet	1 square foot	**0.092 903 04**	m²
1 km²	0.386 10	square miles	1 square mile	2.589 988	km²
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm³	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm³
1 m³	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m³
1 m³	1.308 0	cubic yards	1 cubic yard	0.764 555	m³
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

1 ounce (troy)/ton (short)	20.0	pennyweights/ton (short)
1 pennyweight/ton (short)	0.05	ounce (troy)/ton (short)

NOTE—Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries published by The Mining Association of Canada in cooperation with the Coal Association of Canada.

Slope Stability Study
of the
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Portions of the Ottawa River

by

A.S. Poschmann[1], K.E. Klassen[2], M.A. Klugman[3], and D. Goodings[4]

INTRODUCTION

The South Nation River and the Ottawa River are two of the largest rivers in southern Ontario. The South Nation River drains an area of about 3700 km^2. The Ottawa River drains an area of about 145 000 km^2. The South Nation River descends 84 m over a distance of 177 km from its source to its junction with the Ottawa River (Chapman and Putnam 1966). Extensive deposits of glacially derived marine clays that were laid down in the Champlain Sea occur in the study area.

The tendency for river banks and slopes composed of Champlain Sea clays in southeastern Ontario to fail and cause large and small scale landslides, is causing an increasing amount of interest and concern. Costly damage to buildings and loss of life may result from construction on unstable clay slopes. Because of these problems, the Ontario Ministry of Natural Resources is endeavoring to classify the clay slopes according to their stability in areas once covered by the Champlain Sea.

The classification of the slopes in this sensitive clay is intended to alert developers and planners to the need for determining the geotechnical evaluation of the stability of a slope at a specific site. Thus, unstable slopes can be identified and the necessary remedial or protective measure designed. These measures should be based upon the geotechnical investigations carried out prior to any development of a site. Property damage and inconvenience can then be reduced.

It must be stressed that this classification of the slopes is presented as a guideline, and not as a site specific value for engineering design.

The methods used in this report are a refinement of those developed in the report 'Slope Stability Study of the Regional Municipality of Ottawa-Carleton' (Klugman and Chung 1976) to classify slopes in these postglacial marine clays. The study involved locating and mapping different types of failures that occur in slopes in the Champlain Sea clays. The slope heights and inclinations were measured at points on the slopes considered to be representative of a section of slope. These survey data were used to calculate the 'Factor of Safety', which is a numerical representation of the stability of a slope. These Factors of Safety were used in the process of classifying the slopes. Each class identified offers guidelines for determining the amount of geotechnical investigation necessary to ensure the safe use of a site.

The slopes examined in this report are contained in the South Nation River watershed, and along the Ottawa River from Ottawa to Treadwell. Treadwell is located approximately 8 km east of the mouth of the South Nation River. Financial support was provided by the South Na-

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Approved for publication by the Chief, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto, 6 April 1983.
This report is published by the permission of E.G. Pye, Director, Ontario Geological Survey, Toronto.

tion River Conservation Authority, the Ontario Ministry of Natural Resources, and the Federal Department of Economic Expansion under the Eastern Ontario Subsidiary Agreement.

ORIGIN AND CHARACTERISTICS OF THE CHAMPLAIN SEA CLAYS

HISTORY OF DEPOSITION

The sensitive clays of southeastern Ontario, which are commonly known as the Champlain Sea, or Leda clays, were deposited during the late stages of the Wisconsinan glaciation. At that time, the retreat of the Laurentide ice sheet enabled the Champlain Sea to invade the St. Lawrence Lowlands and Ottawa Valley, and much of southeastern Ontario.

The Champlain Sea began to transgress across southeastern Ontario sometime before 12 800 B.P. At that time, the land surface was inundated as far as Clayton, Ontario (Gadd 1978a, 1978b). The sea continued migrating westward to reach a limit which extends from west of Pembroke, to west of Smiths Falls, then south to Brockville on the St. Lawrence River (Figure 1). Much of the land surface was submerged to depths up to 190 m. Isostatic rebound then began to progress more quickly than the general worldwide rise in sea level which occurred at the end of the glacial period (Kenney 1964). The influx of fresh water from Lake Ojibway-Barlow progressively decreased the salinity of the regressing sea. By 10 200 B.P., the Champlain Sea was sufficiently drained from southeastern Ontario for a fluvial regime at Bourget, Ontario to become established (Gadd 1978a, 1978b).

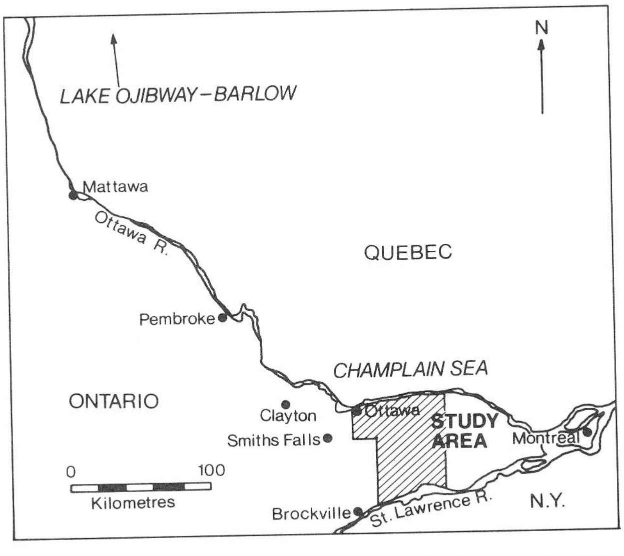


***Figure 1**—Diagram to show Champlain Sea, Lake Ojibway-Barlow, and location of study area.*

The surficial geology of the area under study in this report was included in the regional study of Chapman and Putnam (1966) and, in more detail, in maps prepared by Gwyn and Lohse (1973), Gwyn and Thibault (1975), Sharpe (1979), and Richard (1982a, 1982b, 1982c, and 1982d).

The Champlain Sea clays are highly variable in texture and composition because of changes in environment during the transgression and regression of the sea, and the subsequent fluvial reworking of the clays.

Underlying much of the study area, is a thin deposit of rhythmically stratified silt and silty clay, which is in contact with glacial features left by the retreating ice sheet. Fransham and Gadd (1977) proposed that this varved sequence represents material deposited in the transgressing sea in close proximity to the glacier. The conditions under which deposition occurred would thus be controlled by the large volume of melt water coming from the ice sheet; and the process of rhythmic deposition would not be impeded.

The influx of fresh water diminished with the retreat of the glacier. The clays deposited under the increasingly saline conditions show a gradation from clearly varved fresh water to massive marine clays (Fransham and Gadd 1977; Gadd 1978a, 1978b).

The marine clays deposited in a deep sea environment are typically dark grey, but light layering or black sulphurous mottled clay do sometimes occur.

A continuing uplift of the land surface resulted in the placement of shallow, pro-delta deposits over the top of the massive clays. These materials are usually layered, red and grey, or light and dark grey, and contain seams of silt. Beds with a high clay content are darker red or grey than the more clay deficient layers. Material deposited in more shallow and less saline waters contain more pronounced silt and silty clay layers than material deposited in a deep sea environment.

Sequences deposited in the regressing Champlain Sea contain reworked clay-sized material from areas that had been uplifted and subjected to erosion. It is this clay to which the red tint of the beds is attributed (Johnston 1917). The red colour is particularly evident in the material deposited in the estuarine environment of the ancestral Ottawa River. Inflow from Lake Ojibway-Barlow provided a large volume of fresh water. This water eroded the clay deposits to the northwest and reworked and deposited the material further to the east.

A 2 to 4 m thickness of sand overlies the Champlain Sea clays. This fine-grained sand, believed to have been deposited by fluvial activity after the withdrawal of the sea, now covers large areas of southeastern Ontario. In some locations, the contact between the clay and the sand is gradational.

The thickness of the Champlain Sea deposits varies greatly, and is dependent on the bedrock topography and the amount of erosion subsequent to deposition. At the western limit of the Champlain Sea, shoreline features were not well developed or if they did develop, have been eroded away. In the natural depressions in the bedrock, considerable thicknesses of Champlain Sea clays still occur. Near Arnprior, 91.5 m of clay can be found at the site of a gravity clay fill dam (Wong *et al.* 1975) at Waba. Much further east at Treadwell, a depth of 104.7 m was measured (Fransham, Gadd, and Carr 1976a, 1976b).

CHARACTERISTICS OF THE CHAMPLAIN SEA CLAYS

The term clay, when used with reference to the Champlain Sea clay, applies only to the particle size of the sediment and not to the composition. Even this usage of the word 'clay' can be a misnomer because the Champlain Sea deposits are highly variable. The more massive deposits have a clay size fraction as high as 80%, while the layered material in the shallower deposits can have as little as 30% clay. Silt and sand horizons are quite common.

The clay-sized fraction of the Champlain Sea clays is composed of rock flour. Rock flour is rock material ground to a fine consistency by glacial action. In the Champlain Sea clays, the rock flour is composed predominantly of feldspar, quartz, and amphibole with minor amounts of clay minerals, these are usually illite, chlorite, and vermiculite. The percentage of the constituent minerals is highly variable, though quartz generally dominates.

The Champlain Sea clays are stratified deposits with differences in physical properties both laterally and vertically because of changes in the environment of deposition. Extensive studies of the properties of the clay have been carried out at site-specific localities. These localities have been at the sites of particularly noteworthy landslides, or at the sites of large bridges and dams. No regional studies of the relative geotechnical properties of the clays have yet been undertaken in Ontario.

The most important property common to the clays at all these locations has been the 'sensitivity' of the material. Sensitivity is the ratio of the undisturbed strength of the soil to the remoulded (disturbed) strength. The natural strength, which is lost when the soil is disturbed, is due to bonding and orientation of the clay particles.

The bonding in the clays is not fully understood; however, several theories have been proposed. One theory, which appears to have wide support, is that the clay in its natural state, has particles cemented together in an open flocculated structure, rather like a house of cards. The strength of the clay in this state depends on the cementing and the degree of openness in the structure. If the clay material is disturbed or remoulded, the flocculated structure breaks, the particles realign, and the strength decreases. Weak or strong clays may have high or low sensitivities.

The Champlain Sea clays from various locations exhibit high liquidity indices. This index gives an indication of the flocculated nature of the material. High silt content will lower the index and modify the structure in the deposit.

SLOPE FAILURE

Slope failure in Champlain Sea clays produces easily recognizable landforms that can be seen clearly on aerial photographs. The stability of all slopes is dependent on the geometry of the slope, the physical properties of the material composing the slope, and the pore water pressures existing within the material. Thus, slopes with a similar geometry can vary in stability. This is due to differences in stratigraphy, structure, and the season of the year. Seasonally, variations occur because of the differences in the amount of precipitation and the fluctuating water table.

Failure in the clays can take one of several forms. A common failure type is the simple rotational slip of a segment of slope. The curvature of the slip surface can vary greatly.

When the failure arc can be drawn as a portion of a circle with an almost infinite radius, the failure is called a sheet slide (Figure 2a). When the curvature is more pronounced, it is known as a simple rotational slip (Figure 2b).

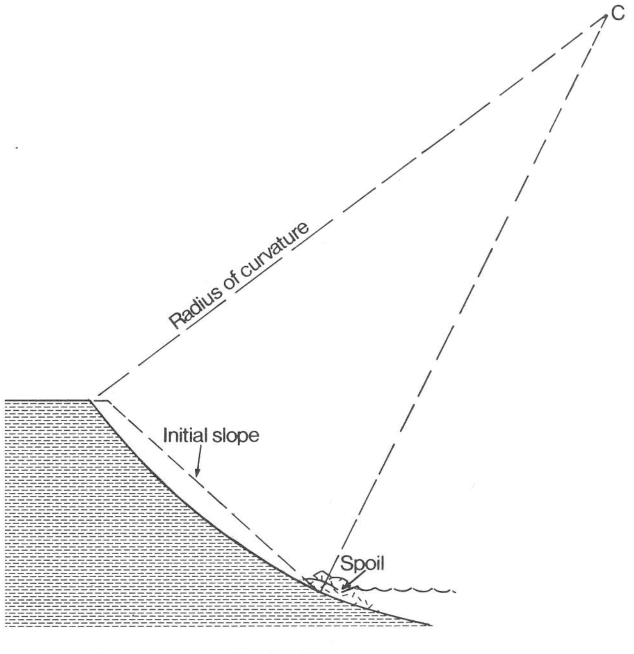


Figure 2a—*Cross section of a sheet slide.*

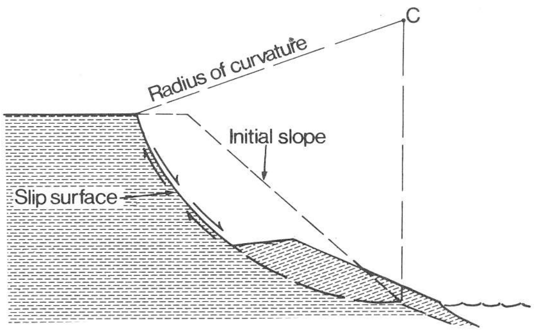


Figure 2b—*Cross section of a simple rotational shear.*

Often one small rotational slip will initiate failure of successive segments of slope which can continue through numerous slides to form a reverse-sloped, terracing effect in the slope (Figure 3a). This type of failure is termed a retrogressive rotational slide.

A variation of the same kind of failure is the retrogressive flowslide. The slope segments in the retrogressive rotational failure slip a short distance along the failure arc, and the slope segments in a retrogressive flowslide exhibit extreme rotation. In large retrogressive flowslides, it is possible to see intact clay pinnacles rising from the debris. These pinnacles form as a result of the rotation of the failed slope segments, and are composed of intact clay (Figure 3b).

If a failure in a slope develops and retrogresses through the upland without the rotational sliding associated with a retrogressive rotational failure or a retrogressive flowslide, that failure is called an earthflow. Earthflows are believed to be initiated by the failure of a small segment of slope which normally has a remoulded effect on the clay in the slope. The remoulded material will flow, cause more of the slope to fail, and activate more clay (Figure 4). Clay pinnacles can often be seen in the debris of earthflows, but they are composed of remoulded clay squeezed between blocks of intact material.

Earthflows terminate when the character of the uplands material changes, or when a balance is achieved between the spoil material and the backslope, or when the outlet becomes constricted.

When an earthflow is held in check because of the build-up of materials at its outlet, neither the slope nor the spoil can be considered stable. Removal of material from the outlet may start afresh the flow of spoil. In 1977, the South Nation River was blocked when spoil from a slide that had occurred in 1971 moved again. The river had, over the 6-year period, eroded material from the outlet and allowed the spoil to shift. This reblocked the outlet. As erosion continues, it is likely that the process will repeat itself. Earthflows and retrogressive flowslides leave thumbprints on the land surface that last for thousands of years.

Two other types of failure commonly occur. One type is the erosional slumping that occurs at the toe of slopes due to erosion caused by the flow of water in the adjacent river or stream. Such failures tend to be small because the erosional effect of the water action is concentrated in the limited area of the immediate river bank. These slopes are short and steep, often with overhanging vegetation.

The second failure type occurs not in the clay itself, but in the fine sand and silt that overlies the clay in many areas. This kind of failure has been referred to by Mitchell and Klugman (1979) as internal erosion. Like the earthflow, it is a rapid mass wasting process without a rotational slip. What remains is a gully with near vertical sides and a low gradient. Little spoil is left in this resulting gully, or creek bed, because the water content in the failed material is such that the silt and sand flow as a slurry.

Instability in clay slopes is most often initiated by changes in the geometry of the slope profile. Erosional activity by nature or disturbance by man can oversteepen a slope, causing instability. Even though the geometry of

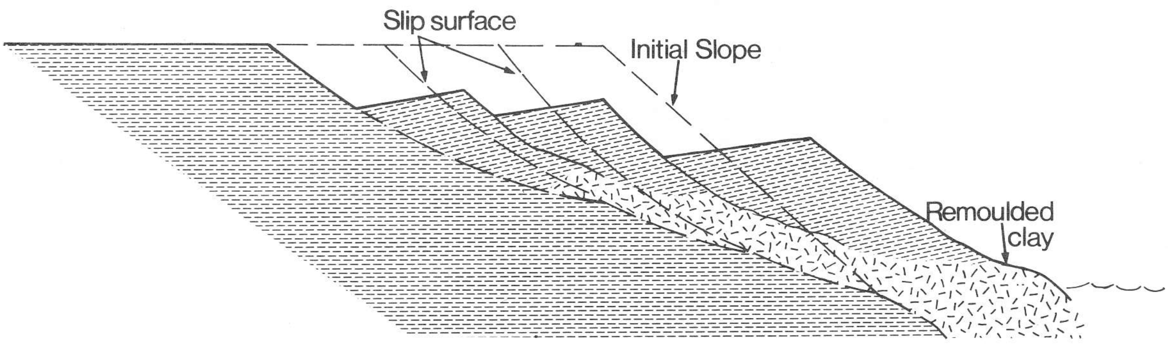


Figure 3a— *Cross section of a retrogressive rotational shear.*

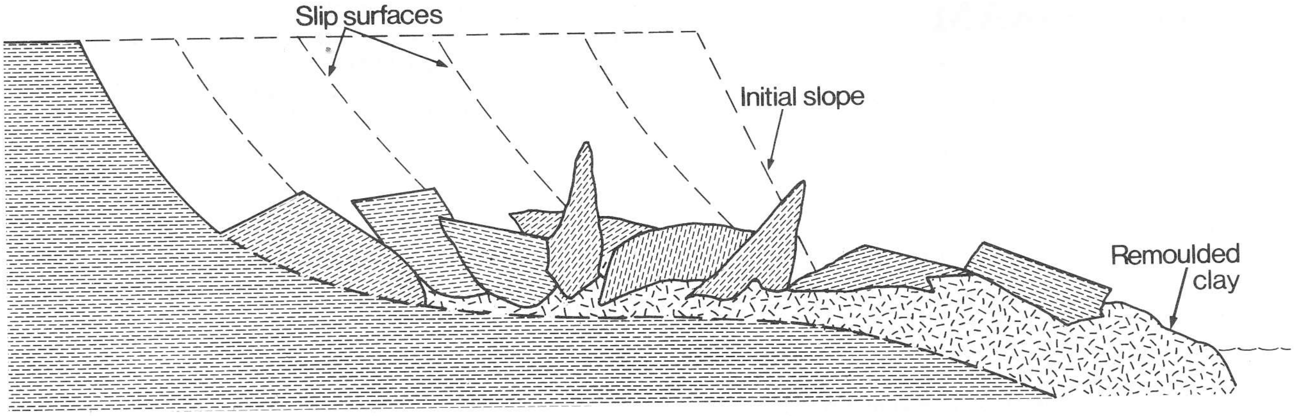
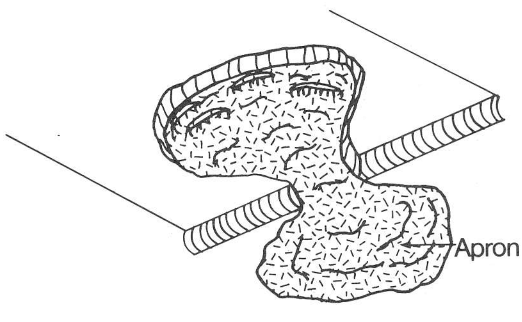


***Figure 3b**—Cross section of a retrogressive flowslide.*

the slope may be unstable, actual slope failure may not occur until the pore water pressures and other conditions or processes are conducive to failure.

Many slope failures have occurred in the area of the South Nation River watershed. These are usually small landslides or failures, measuring from a few thousand cubic metres of material up to many hectares. Old scars indicate that many larger failures, 25 ha or more, have occurred in this basin. The most recent of these large slides occurred in 1971, 2.5 km upstream from the village of Lemieux on the South Nation River, when 36 ha of pastureland failed.

Both large and small failures, which occur every year, can cause considerable local distress. The principle concerns of this study are to delineate the areas of potential failure, and to record past failures. The responsible authorities should ensure that any area slated for development has been properly assessed for safety against possible slope failures or landslides.



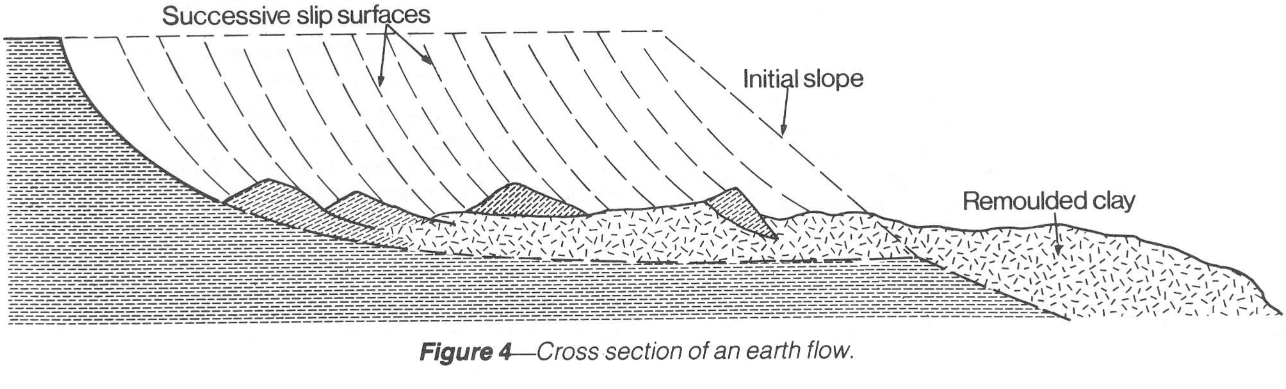


***Figure 4**—Cross section of an earth flow.*

FIELD PROGRAM

The field program was started in 1976 and completed in 1980. All creeks and river banks in the South Nation River basin were examined. Slope failures and landslide scars were recorded where recognized. Large slope failures previously mapped by the Geological Survey of Canada were, after field checking, incorporated into the maps of this present report (Fransham *et al.* 1976a, 1976b).

The field work was carried out by canoe on the South Nation, Castor, and Ottawa Rivers. This allowed easy access to the river banks. Where the volume of water was insufficient for canoeing, as was the case on its tributaries, the examination of the slopes was carried out on foot. The locations of the survey points and slide scars were accurately located on airphoto overlays during the examination of each site.

AIRPHOTOS

The airphotos used in the field were 1971 photographs at a scale of 1:17 000. This scale proved large enough for efficient and accurate plotting of locations. All river banks were examined in stereo pairs prior to entering the field. The method of interpretation has been described in the thesis, "Air Photo Classification and Glossary of Landslide Problems in the Ottawa and St. Lawrence Lowlands" (Poschmann 1978). Pertinent features and areas of possible interest were noted on the overlays that were attached to alternate photographs. In the field, the overlays were used to record the locations of the slope survey sites along with the data collected in the field, as well as other features such as landslide scars. These data were then transposed from the overlays to NTS topographic maps at a scale of 1:50 000. The survey points were numbered and the different failure types appropriately indicated in the following categories; earthflows, retrogressive flowslides and retrogressive rotational slides, rotational slides, sheetslides, failing slopes, and internal erosion features.

SLOPE MEASUREMENT

In order to determine the stability of a particular slope, it is necessary to obtain information on its profile. This was done in the field using a metre stick and clinometer.

The profile of a portion of a river bank was measured at a point in that segment considered to be representative of the whole. This point is referred to as a survey point. At each survey point, the height of the bank was measured by traversing the slope with a metre stick, and the inclination was taken with a clinometer held parallel to the slope. These measurements illustrate the slope profile only on the day the survey was taken. Hence, they are time dependent. In addition, because the information is used to represent conditions on a length of the slope, the computed data cannot be considered to be site specific.

Slopes with profiles that showed variations in inclination with height were measured in segments to better delineate the true slope. Survey points were taken wherever there was a change in the height or inclination of the slope. Profiles of the failed surfaces of all types of landslides were surveyed, along with the profile of the adjacent slope. The adjacent slope profile serves to illustrate the probable slope conditions prior to the failure and is used to classify the slope in that sector.

Measurements were particularly important on slopes >2 m in height or with a grade greater than 1:4. The maximum error in height was 1 m in slopes of 10 m or more, and due to the irregularities in the surfaces, the maximum error in the angle of inclination was 2°.

Special note was taken of bedrock when it was present in slopes, and also of existing flood plains. Their presence requires consideration in slope classification as both considerably affect the stability of the slope.

ANALYSIS

The stability classifications for slopes in Champlain Sea clays are based on the Factors of Safety calculated for each slope. The Factor of Safety is simply a number relating the magnitude of the forces holding a slope together to the magnitude of the forces that are seeking to level it. Theoretically, a Factor of Safety greater than 1.0 indicates that a slope is held together by forces larger than those seeking to fail it and the slope is stable. Conversely, if the Factor of Safety is less than 1.0, the slope is unstable, and the forces seeking to fail the slope are larger than the forces resisting them, and failure occurs.

A Factor of Safety equal to 1.0 is the critical condition in the ideal case where the soil characteristics and strength parameters, and the height, inclination, and saturation of the slope are accurately known. Given the conditions, it is possible to construct a graph, shown in Figure 5, illustrating the relationship between slope height, inclination, and the Factor of Safety.

Nevertheless, it has been found in these clays, that a factor of 1.5 rather than 1.0, is the critical Factor of Safety that must be used. This is well demonstrated in Figure 6, which is a plot of the failed and unfailed slopes related to height, inclination, and the Factors of Safety 1.0 and 1.5. An examination of the graph shows there are some slopes that have failed with Factors of Safety greater than 1.5. They represent only 6% of the surveyed slopes, and are due to factors as yet unidentified.

To calculate the Factor of Safety, the geometry of the slope, the groundwater conditions, and the strength of the soil need to be known. The slope profile and groundwater conditions, r_u (pore water pressure) are measured in the field. The strength parameters ϕ' (effective angle of internal friction) and c′ (effective cohesion) are determined by laboratory testing.

The field program for this study involved measurement of the slope profiles only. Values for r_u, ϕ', and c′ have been assumed. These assumed values are based

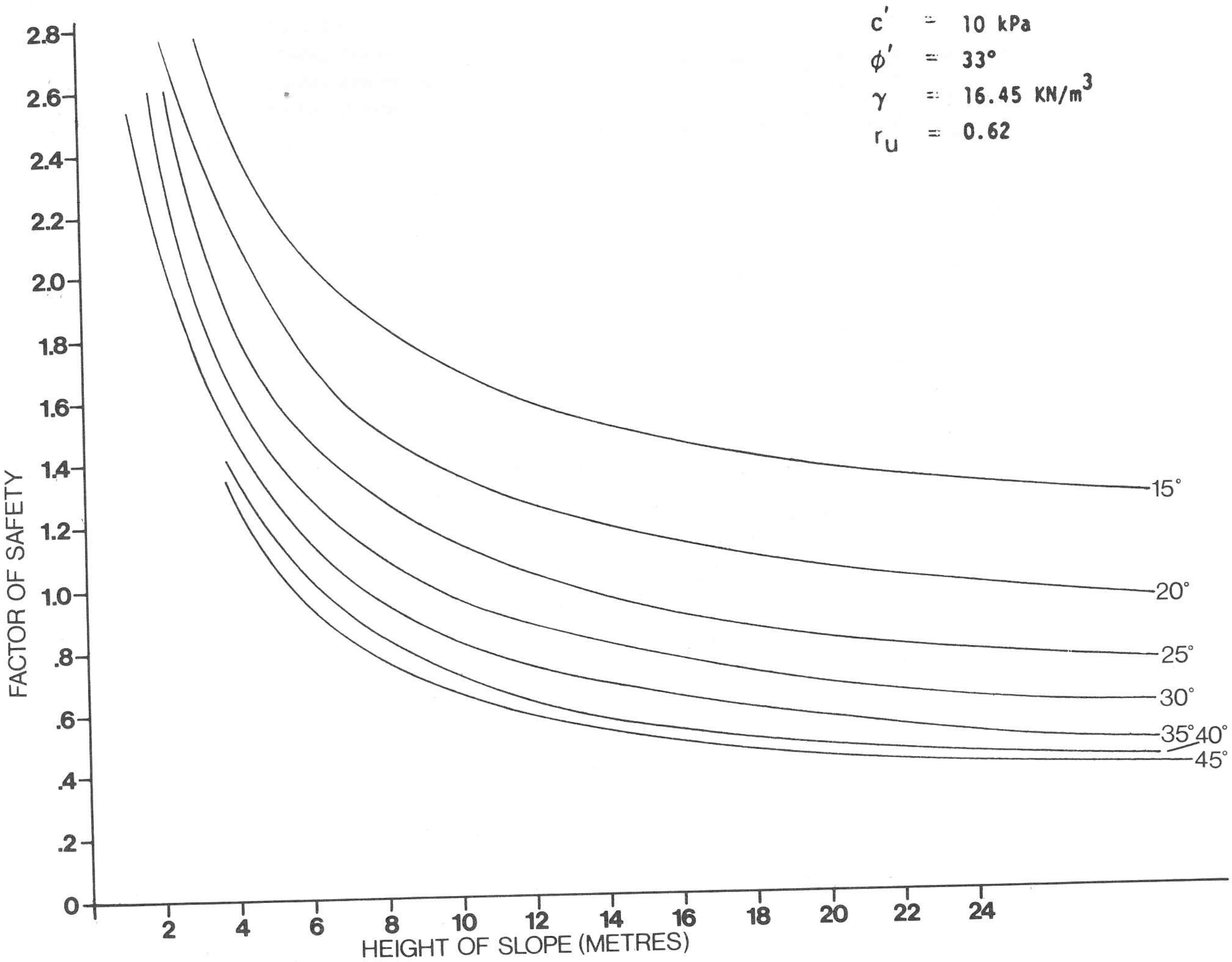


Figure 5*—Diagram showing the relationships between the slope inclinations, the slope heights, and the Factors of Safety as computed for a study in the Ottawa area (Klugman and Chung 1976).*

principally on publications by personnel of the National Research Council and their associated workers, from soils reports of the Ontario Ministry of Transportation and Communications, from consultant's reports throughout the area, from University theses, and limited testing by D.J. Goodings as a preliminary correlation with published data.

Slopes were assumed to be hydrostatically saturated. That is a situation where the top of the groundwater table coincides with the land surface and there is no motion in the fluid. This is a typical condition in the spring when most landslides occur. The parameters c′ and ϕ' were assigned the values 10 kN/m^2 and 33° respectively. Table 1 shows that these values are realistic for use in the calculations used to categorize the clay slopes in the semi-quantitative classifications used in this report.

As a precaution against over-simplication, a range of Safety Factors for each condition was also calculated for ϕ' values of 30° and 35° by Klugman and Chung (1976). Their study found that these 2 conditions did not significantly affect the segments of the classification.

Two conditions are noted here in the analysis. The first condition occurs when bedrock is encountered at the foot of a slope. When bedrock was found, it was followed up into the bank as far as possible. Bedrock can act in a slope in 1 of 2 ways:

1. by forming an impermeable layer, which will keep the watertable high in a clay slope and increase the chances of failure by helping to saturate that slope and by acting as a slip surface for the clay to fail along, or
2. by composing most of the slope and reinforcing the thin clay mantle on top

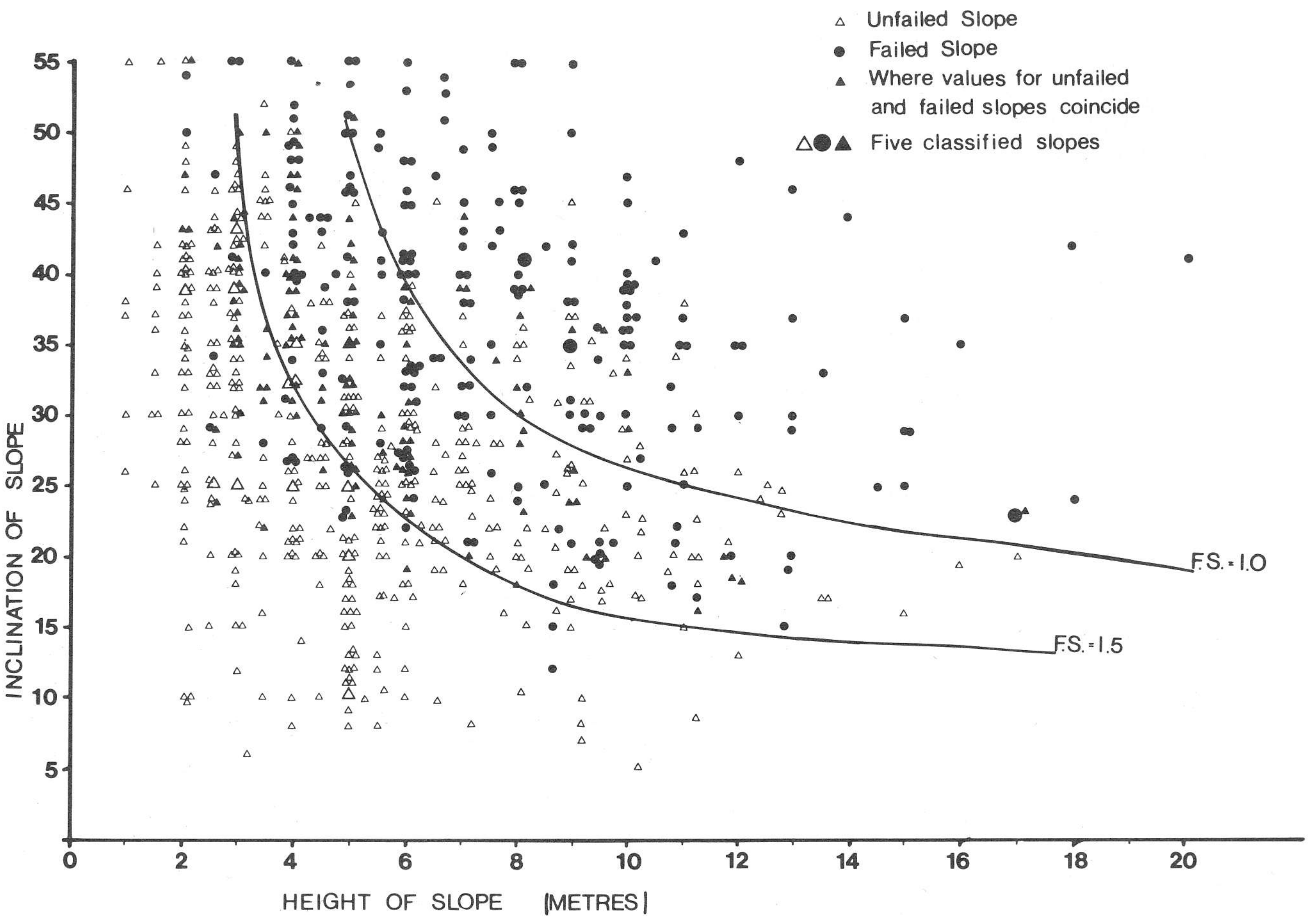


Figure 6—*Diagram showing the relationships of failed and unfailed slopes in the study area to height, inclination, and the Factors of Safety of 1.0 and 1.5.*

All calculations on such slopes were conservative, assuming from the last point of outcrop that the remaining part of the slope was not defended by bedrock. Slopes totally composed of rock are noted as such on the maps.

The second condition concerns the existence of 2 slopes, the river bank and an upper slope, separated by a terrace or floodplain. When the river bank was low, and an examination of the airphotos revealed that the floodplain was inundated during spring runoff, the upper slope was measured and a Factor of Safety established. In this case, the upper slope represents the worst slope conditions, saturated but not submerged. When the river banks are high, and the terrace is not flooded every spring, both slopes were measured and the lowest Factor of Safety was used to classify the slope.

SLOPE CLASSIFICATION

The slopes have been grouped into 6 classes based on the computed Factors of Safety. The specific values used in the classification are presented only as a guide to slope conditions, not as a firm basis for engineering design or development. Under all circumstances, site-specific studies and/or inspections should be carried out at all sites before any planning or development is undertaken.

A dual classification is given for each of the 6 classes of slope. One is a numerical value based on the calculated Factors of Safety, and the second is a parallel corresponding verbal description for each class. It is stressed that the classification system is generalized. This

TABLE 1 **SOME VALUES FOR 'EFFECTIVE ANGLE OF INTERNAL FRICTION Ø' ', 'EFFECTIVE COHESION c' ' AND 'PORE PRESSURE r_u' OBTAINED FROM SITE-SPECIFIC STUDIES IN THE OTTAWA AND SOUTH NATION RIVER AREA.**

Slope	Critical Strength Parameters c' (kN/m²)	Ø' (deg)	r_u	Remarks	Source
Lemieux	8.2	39°	0.62	Assumed hydrostatic saturation.	Fondex Ltd. 1974.
South Nation Slide	9.0	36°	0.60	Assumed hydrostatic saturation.	Eden, Fletcher, Mitchell 1971.
Cumberland	12.4	25°	0.62	Assumed hydrostatic saturation.	Ontario Ministry of Transportation & Communications 1973.
Bearbrook	8.9	27°	0.62	Assumed hydrostatic saturation.	Golder Assoc. 1974.
Queenswood	11.1	33°	0.62	Assumed hydrostatic saturation.	Golder Assoc. 1974.
Castor River	11.4	34°	0.62	Assumed hydrostatic saturation.	D. Goodings 1976.
Bearbrook	7.3	34°	0.62	Assumed hydrostatic saturation.	D. Goodings 1976.
St. Bernadin Slide (in slide)	3.6	34°	0.62	Assumed hydrostatic saturation.	D. Goodings 1976.

has been done to take into account the fact that c' and ϕ' are averaged values and not entirely accurate numerical representations of strength at a specific location.

SLOPE STABILITY CLASSIFICATIONS (after Klugman and Chung 1976)

Factor of Safety — Guidelines

<0.8 Unsuitable for construction, or will require extreme remedial measures in order to safely utilize the site. These measures would need to be based upon extensive detailed geotechnical studies. The proportion of necessary investment to make the property usable for construction probably would out-weigh the cost of the completed structures. It is therefore not economically feasible.

0.8-1.2 Will require extensive remedial measures as dictated by detailed geotechnical studies. The necessary investment to prepare and stabilize the site will be great and probably would make normal development uneconomical.

1.2-1.5 Detailed geotechnical investigation necessary, with concomitant remedial works. This class, under undisturbed conditions, is considered marginal. Stabilization works or restrictive physical conditions would be necessary. Their type and extent would depend on the type of development.

1.5-2.0 Routine geotechnical investigation necessary. Developer would have to know soil conditions. Stabilization works would depend on type and size of planned structures.

2.0-2.5 Routine inspection necessary to determine the need and extent of geotechnical investigation.

>2.5 Should be inspected, but no remedial action likely to be required. This class also includes slopes that were inspected, but because of their nature, no detailed recordings were deemed necessary.

SUMMARY

As indicated on the northern and southern map sheets, the South Nation River and the portion of the Ottawa River that was studied illustrate variable slope characteristics. Areas with high Factor of Safety values can be directly adjacent to locations with lower Factors of Safety. Different Factors of Safety also occur on opposite banks of the river.

The portion of the South Nation River between Bear Brook and the Castor River is exceptionally prone to landsliding. Examples of areas with low Factors of Safety can be found around Fournier, St-Bernadin, and a section along the Ottawa River northwest of Orleans. Areas with high Factor of Safety values are found in the vicinity of Winchester and Spencerville. In general, rivers and streams south of Chesterville have higher Factors of Safety than the water courses in the northern part of the South Nation River watershed. It should be stressed that there are exceptions in each case.

ACKNOWLEDGMENTS

The writers would like to acknowledge the assistance and invaluable advice during the course of this study and the preparation of the manuscript of the following: staff members of the South Nation Conservation Authority; Professor R.J. Mitchell, Queen's University; Dr. N.R. Gadd, Geological Survey of Canada; and associates in the Ontario Ministry of Natural Resources and the Ontario Ministry of Transportation and Communications.

APPENDIX 1

COMPUTER PROGRAM

The computer program used for calculating the factors of safety was developed at the National Research Council by J. G. Arseneault (1967), and was adapted for the first report (Klugman and Chung 1976) by Professor R. J. Mitchell of Queen's University, Kingston, Ontario. The program solves for Factors of Safety by an iterative process using the Standard Bishop's equation for analysing slopes.

Each slope was approximated with three or more line segments resolved into a co-ordinate system. The toe of the slope was chosen as the point through which all slip circles in the failing slope would pass. The Factor of Safety was calculated by dividing each slip circle into 100 equal width slices through the slope over which the forces are calculated. One hundred such circles, each with a centre point located inside a designated search area, are solved to find the minimum factor of safety and the critical centre.

The slopes were assumed homogeneous in soil and ground water conditions. Given input data used were:

- c′ —effective cohesion in kN/m^2 = $10 kN/m^2$
- Ø′ —effective angle of internal friction in degrees = 33°
- γ —unit weight of soil in kN/m^3 = $16.45 kN/m^3$
- r_u —pore pressure ratio = 0.62

The input data cards were arranged as follows:

Card 1	04	—slope number
Card 2	03	—number of line segments of slope (N)
Card 3	x y	—co-ordinates of nodes of line
Card 4	x y	—segments in consecutive order
Card 5	x y	—(to a maximum of 20)
Card 6	x y	
Card 7	1.00	—10-FS and c′
Card 8	10	—constant, other than 10 means variable
Card 9	16.45	
Card 10	10	—for constant r_u
Card 11	0.62	—r_u
Card 12	33	—Ø′ (in degrees)
Card 13	27 30	—other trial values of Ø′ for minimum F.S.
Card 14	X_sS_f	—X co-ordinates for search area for critical centres.
Card 15	Y_sY_f	—Y co-ordinates for search area for critical centres.
Card 16	X Y	—X, Y co-ordinates of chosen failure point.
Card 17	Blank	—terminates readings and directs program to next slope number

On the basis of the given input data, it is possible to show the relationship between slope inclinations and slope heights to the calculated Factor of Safety. The plot shown in Figure 5, can offer an approximate guide for determining the Factor of Safety of simple slopes in the South Nation River watershed.

Each site surveyed in the South Nation River watershed is shown on the accompanying maps. The sites have been assigned a symbol and a site number. Symbols without numbers are locations of slope failures only. In places, it was not possible to take readings at these failures or alternatively, at the discretion of the senior author, measurements were deemed unnecessary.

Appendix 2 gives the computed Factors of Safety for all the surveyed sites. It must be stressed that the computed Factors of Safety are based on a profile measured at a point on the slope and illustrate the slope conditions only at the time it was surveyed. The Factors of Safety are time dependent values that should not be used for detailed site design. The Factors of Safety are presented solely as a guide to further work.

APPENDIX 2

COMPUTED FACTORS OF SAFETY FOR SURVEYED SITES IN THE AREA OF THE SOUTH NATION RIVER WATERSHED AND THE OTTAWA RIVER, FROM TREADWELL TO OTTAWA.

Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS
1	>2.50	36	2.50	71	2.20	106	1.39	141	1.10
2	1.82	37	1.45	72	1.60	107	1.38	142	0.96
3	1.69	38	1.58	73	1.57	108	1.52	143	1.25
4	1.36	39	2.50	74	1.31	109	1.45	144	1.50
5	1.40	40	1.23	75	0.94	110	1.80	145	0.77
6	1.48	41	2.40	76	1.33	111	1.35	146	1.05
7	1.52	42	1.22	77	0.98	112	1.64	147	0.97
8	1.68	43	1.54	78	1.33	113	1.29	148	1.05
9	2.00	44	1.87	79	1.55	114	1.38	149	0.97
10	1.31	45	0.78	80	1.58	115	1.15	150	1.22
11	1.04	46	>2.50	81	1.25	116	1.60	151	1.22
12	0.80	47	2.40	82	1.54	117	1.36	152	0.96
13	1.00	48	1.87	83	1.25	118	1.20	153	1.31
14	Bedrock	49	1.42	84	1.62	119	1.92	154	1.06
15	1.50	50	1.29	85	1.85	120	1.71	155	1.59
16	2.30	51	1.66	86	1.98	121	1.53	156	0.96
17	0.84	52	1.43	87	1.40	122	1.39	157	1.50
18	2.20	53	1.78	88	1.43	123	1.35	158	1.92
19	>2.50	54	1.42	89	1.42	124	1.35	159	1.43
20	>2.50	55	1.39	90	1.74	125	1.60	160	1.45
21	1.20	56	1.39	91	1.42	126	1.67	161	1.30
22	1.40	57	1.39	92	1.24	127	2.04	162	1.65
23	0.87	58	1.31	93	1.39	128	1.18	163	1.35
24	2.40	59	1.48	94	1.48	129	1.88	164	1.50
25	1.86	60	1.49	95	1.40	130	1.18	165	1.80
26	2.38	61	1.44	96	1.53	131	1.45	166	1.30
27	1.90	62	1.49	97	1.45	132	1.28	167	1.69
28	0.85	63	1.21	98	1.53	133	1.16	168	2.04
29	2.40	64	1.26	99	1.35	134	1.50	169	1.65
30	>2.50	65	1.30	100	1.52	135	1.40	170	1.51
31	0.98	66	1.40	101	1.75	136	1.03	171	0.92
32	1.59	67	1.76	102	2.07	137	1.19	172	0.90
33	1.83	68	1.60	103	1.03	138	0.85	173	1.56
34	1.70	69	1.50	104	2.00	139	1.24	174	1.39
35	1.86	70	1.40	105	1.28	140	1.31	175	1.42

APPENDIX 2 — Continued

Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS
176	1.55	214	1.52	252	1.53	290	>2.50	328	2.29
177	1.27	215	2.34	253	2.36	291	1.10	329	1.25
178	1.89	216	1.82	254	1.76	292	>2.50	330	1.77
179	0.81	217	1.60	255	1.26	293	2.15	331	>2.50
180	1.23	218	2.40	256	1.60	294	1.55	332	>2.50
181	1.30	219	1.55	257	1.11	295	2.02	333	1.34
182	1.25	220	1.95	258	1.38	296	1.64	334	1.49
183	1.30	221	1.54	259	0.90	297	0.71	335	1.94
184	1.23	222	2.06	260	1.13	298	1.42	336	2.42
185	1.41	223	>2.50	261	1.36	299	0.75	337	2.33
186	1.02	224	1.55	262	2.02	300	0.76	338	1.70
187	0.88	225	1.67	263	1.64	301	1.42	339	2.45
188	0.85	226	1.23	264	1.64	302	0.92	340	2.16
189	0.71	227	1.60	265	1.15	303	1.57	341	2.20
190	>2.50	228	1.58	266	1.37	304	0.97	342	1.63
191	2.35	229	1.48	267	1.15	305	1.50	343	1.67
192	2.17	230	2.03	268	1.37	306	1.45	344	1.51
193	2.35	231	1.47	269	1.20	307	0.87	345	1.93
194	>2.50	232	1.50	270	2.10	308	1.77	346	1.86
195	2.02	233	>2.50	271	1.70	309	0.80	347	1.83
196	>2.50	234	2.22	272	1.71	310	1.43	348	1.28
197	1.44	235	1.10	273	1.51	311	1.20	349	1.50
198	>2.50	236	2.25	274	1.34	312	2.10	350	1.49
199	>2.50	237	2.40	275	1.56	313	1.50	351	1.59
200	1.57	238	2.45	276	1.67	314	1.16	352	1.83
201	1.34	239	1.40	277	1.25	315	1.21	353	1.34
202	1.26	240	2.10	278	0.81	316	1.24	354	>2.50
203	1.88	241	1.73	279	1.44	317	1.08	355	1.38
204	2.44	242	1.28	280	1.28	318	1.57	356	1.43
205	2.20	243	1.27	281	2.13	319	2.19	357	1.75
206	1.33	244	1.95	282	2.16	320	1.08	358	1.59
207	>2.50	245	1.95	283	2.08	321	1.34	359	1.34
208	2.08	246	1.54	284	>2.50	322	0.80	360	1.36
209	2.03	247	2.10	285	1.79	323	2.03	361	2.39
210	2.16	248	1.54	286	1.39	324	1.41	362	1.61
211	1.70	249	1.65	287	1.82	325	2.42	363	0.68
212	1.72	250	2.45	288	1.23	326	>2.50	364	2.34
213	2.16	251	1.35	289	1.76	327	1.44	365	1.53

APPENDIX 2 — Continued

Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS
366	1.79	404	1.50	442	2.00	480	Ø	609	1.53
367	1.84	405	1.78	443	1.63	481	Ø	610	1.24
368	1.60	406	1.05	444	1.15	482	Ø	611	1.18
369	1.68	407	1.12	445	2.43	483	Ø	612	1.38
370	1.74	408	1.49	446	1.63	484	Ø	613	1.19
371	1.59	409	1.84	447	1.42	485	Ø	614	1.24
372	1.73	410	1.68	448	1.33	486	Ø	615	1.75
373	Ø	411	1.62	449	1.33	487	1.73	616	1.19
374	1.76	412	1.86	450	1.31	488	2.30	617	1.53
375	1.95	413	1.62	451	1.83	489	2.30	618	1.34
376	2.00	414	1.58	452	1.25	490	1.65	619	1.45
377	1.40	415	1.57	453	1.93	—	—	620	1.03
378	1.95	416	1.52	454	1.88	—	—	621	1.05
379	2.07	417	Ø	455	0.89	—	—	622	1.04
380	1.77	418	2.00	456	2.35	—	—	623	1.73
381	1.59	419	2.02	457	0.83	586	1.84	624	2.10
382	Ø	420	Ø	458	1.07	587	1.49	625	1.14
383	1.24	421	1.34	459	2.45	588	1.50	626	1.14
384	1.43	422	1.69	460	1.45	589	1.40	627	1.67
385	1.59	423	1.27	461	Ø	590	0.82	628	1.56
386	1.55	424	1.45	462	1.30	591	1.03	629	1.18
387	1.40	425	2.40	463	1.50	592	Ø	630	Ø
388	2.16	426	Ø	464	1.28	593	1.35	631	1.43
389	1.98	427	1.40	465	1.40	594	1.26	632	0.99
390	1.50	428	0.98	466	1.51	595	1.15	633	1.00
391	2.08	429	1.81	467	1.15	596	1.10	634	1.17
392	2.07	430	0.88	468	1.15	597	0.71	635	1.07
393	1.95	431	2.15	469	0.96	598	0.82	636	1.71
394	2.03	432	1.57	470	2.23	599	1.65	637	1.26
395	1.85	433	1.65	471	2.26	600	0.89	638	2.34
396	1.89	434	1.33	472	2.24	601	0.76	639	1.34
397	1.54	435	0.83	473	2.13	602	1.72	640	1.39
398	Ø	436	1.08	474	1.24	603	1.17	641	2.25
399	1.59	437	1.77	475	1.71	604	1.81	642	1.22
400	1.68	438	1.68	476	1.72	605	0.83	643	1.35
401	1.09	439	1.18	477	1.71	606	1.30	644	1.36
402	2.08	440	1.18	478	1.67	607	Ø	645	1.21
403	1.76	441	1.32	479	Ø	608	1.53	646	1.73

APPENDIX 2 — Continued

Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS
647	1.33	685	2.25	723	Ø	761	0.86	799	0.81
648	1.49	686	Ø	724	2.35	762	1.49	800	1.31
649	1.69	687	1.93	725	Ø	763	0.68	801	0.79
650	1.91	688	Ø	726	1.69	764	0.67	802	1.52
651	Ø	689	1.70	727	0.86	765	0.91	803	1.20
652	1.29	690	2.08	728	0.86	766	0.79	804	0.90
653	1.30	691	Ø	729	2.52	767	0.75	805	0.98
654	1.28	692	1.32	730	1.70	768	0.75	806	0.81
655	1.38	693	1.98	731	1.56	769	0.75	807	0.96
656	1.31	694	Ø	732	1.52	770	Ø	808	1.08
657	1.91	695	2.42	733	Ø	771	0.80	809	0.78
658	1.25	696	1.86	734	1.88	772	0.89	810	1.20
659	1.82	697	1.98	735	1.03	773	0.55	811	1.15
660	1.59	698	2.31	736	1.53	774	1.33	812	0.88
661	1.50	699	1.51	737	2.10	775	Ø	813	Ø
662	1.21	700	2.08	738	1.29	776	1.16	814	1.17
663	1.41	701	2.28	739	1.20	777	0.87	815	1.38
664	1.39	702	Ø	740	2.30	778	1.20	816	1.18
665	1.45	703	Ø	741	1.34	779	Ø	817	0.90
666	1.73	704	1.70	742	1.16	780	1.57	818	1.15
667	1.73	705	Ø	743	1.24	781	Ø	819	1.05
668	2.05	706	2.21	744	1.19	782	2.11	820	Ø
669	1.43	707	2.21	745	1.42	783	1.25	821	2.45
670	1.24	708	Ø	746	Ø	784	1.35	822	1.37
671	1.13	709	1.66	747	0.91	785	2.04	823	1.32
672	1.39	710	Ø	748	0.93	786	Ø	824	1.56
673	2.09	711	Ø	749	1.37	787	0.82	825	1.24
674	1.83	712	1.45	750	2.02	788	1.14	826	1.22
675	Ø	713	1.32	751	1.44	789	0.92	827	1.00
676	1.07	714	1.22	752	1.16	790	1.02	828	1.31
677	Ø	715	1.25	753	Ø	791	1.10	829	1.19
678	1.42	716	1.43	754	2.21	792	Ø	830	1.28
679	1.98	717	1.42	755	2.12	793	0.62	831	1.44
680	1.36	718	0.95	756	1.33	794	1.87	832	1.08
681	2.09	719	1.05	757	1.50	795	0.70	833	Ø
682	1.92	720	1.54	758	2.09	796	0.66	834	1.64
683	Ø	721	Ø	759	Ø	797	Ø	835	0.86
684	1.66	722	1.06	760	2.04	798	0.88	836	1.79

APPENDIX 2 — Continued

Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS
837	1.03	875	2.14	913	0.84	951	Ø	989	—
838	0.52	876	2.12	914	1.07	952	Ø	990	1.50
839	1.01	877	Ø	915	1.24	953	1.78	991	1.40
840	0.79	878	1.95	916	1.29	954	Ø	992	1.00
841	0.83	879	1.55	917	Ø	955	1.04	993	1.40
842	Ø	880	1.40	918	1.49	956	0.77	994	1.40
843	1.78	881	1.31	919	Ø	957	Ø	995	1.10
844	Ø	882	1.05	920	Ø	958	0.98	996	1.30
845	1.39	883	1.17	921	Ø	959	1.18	997	2.20
846	Ø	884	1.19	922	Ø	960	1.53	998	1.10
847	1.58	885	1.24	923	0.87	961	1.00	999	1.90
848	1.30	886	1.31	924	1.02	962	0.55	1000	1.90
849	Ø	887	1.03	925	Ø	963	Ø	1001	1.50
850	1.19	888	2.01	926	1.24	964	0.79	1002	2.10
851	1.16	889	1.53	927	0.83	965	1.10	1003	0.70
852	Ø	890	1.16	928	0.78	966	1.38	1004	—
853	1.09	891	1.66	929	1.24	967	1.90	1005	0.90
854	1.29	892	1.58	930	1.16	968	1.80	1006	1.30
855	Ø	893	1.27	931	Ø	969	1.40	1007	0.80
856	1.89	894	2.29	932	Ø	970	1.30	1008	1.10
857	1.30	895	1.02	933	1.31	971	1.30	1009	0.50
858	0.93	896	1.75	934	Ø	972	—	1010	1.10
859	Ø	897	1.01	935	Ø	973	1.00	1011	1.10
860	1.21	898	1.74	936	Ø	974	0.70	1012	1.40
861	1.15	899	1.24	937	Ø	975	Ø	1013	0.70
862	1.09	900	0.84	938	Ø	976	1.30	1014	0.90
863	1.84	901	Ø	939	1.29	977	0.80	1015	1.30
864	1.54	902	0.95	940	0.97	978	0.70	1016	1.10
865	1.49	903	Ø	941	0.90	979	1.70	1017	0.80
866	1.64	904	0.86	942	Ø	980	0.80	1018	0.80
867	Ø	905	Ø	943	1.20	981	—	1019	1.50
868	1.28	906	0.70	944	0.97	982	—	1020	1.70
869	1.39	907	Ø	945	1.20	983	0.70	1021	2.40
870	Ø	908	0.73	946	1.33	984	0.70	1022	—
871	1.97	909	0.61	947	1.35	985	0.70	1023	0.90
872	1.66	910	0.82	948	1.50	986	1.30	1024	0.90
873	1.67	911	Ø	949	1.11	987	1.10	1025	1.00
874	Ø	912	0.84	950	Ø	988	1.50	1026	2.10

APPENDIX 2 — Continued

Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS
1027	1.80	1063	2.00-2.50	1099	1.40	1135	2.30
1028	1.30	1064	Bedrock	1100	1.40	1136	2.30
1029	Ø	1065	Ø	1101	1.40	1137	2.10
1030	Ø	1066	2.10	1102	1.40	1138	2.10
1031	0.90	1067	0.90	1103	—	1139	0.90
1032	0.70	1068	Bedrock	1104	2.30	1140	1.20
1033	1.10	1069	1.60	1105	1.50	1141	1.00
1034	1.90	1070	0.80	1106	0.70	1142	0.80
1035	1.10	1071	1.20	1107	0.80	1143	1.90
1036	1.40	1072	1.60	1108	1.40	1144	2.45
1037	1.10	1073	Bedrock	1109	1.30	1145	2.07
1038	Bedrock	1074	Bedrock	1110	1.90	1146	1.75
1039	—	1075	—	1111	1.20	1147	2.27
1040	—	1076	1.30	1112	2.30	1148	2.08
1041	2.40	1077	1.10	1113	1.70	1149	Ø
1042	1.30	1078	1.90	1114	1.40	1150	1.22
1043	1.10	1079	0.90	1115	Ø	1151	2.00
1044	—	1080	1.20	1116	1.70	1152	2.15
1045	—	1081	Ø	1117	0.80	1153	1.22
1046	—	1082	2.50	1118	2.30	1154	2.30
1047	—	1083	—	1119	2.30	1155	0.97
1048	—	1084	—	1120	Ø	1156	1.78
1049	1.70	1085	Ø	1121	0.80	1157	1.46
1050	1.60	1086	—	1122	2.10	1158	1.78
1051	1.20	1087	—	1123	1.90	1159	1.71
1052	1.60	1088	—	1124	Ø	1160	1.18
1053	1.10	1089	—	1125	1.30	1161	1.25
1054	2.50	1090	0.90	1126	2.30	1162	1.60
1055	2.00	1091	0.90	1127	1.30	1163	2.18
1056	1.20	1092	—	1128	1.30	1164	1.70
1057	1.70	1093	—	1129	Ø	1165	1.70
1058	Bedrock	1094	1.10	1130	Ø	1166	2.18
1059	Bedrock	1095	1.30	1131	1.80	1167	1.60
1060	Ø	1096	—	1132	Ø	—	—
1061	Ø	1097	—	1133	Ø	—	—
1062	Ø	1098	—	1134	2.30	—	—

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Geotechnical Series Maps

Map 2486 (coloured)— Slope Stability Study of the South Nation River and Portions of the Ottawa River, Northern Sheet, Southern Ontario, Scale 1:50 000.

Map 2487 (coloured)— Slope Stability Study of the South Nation River and Portions of the Ottawa River, Southern Sheet, Southern Ontario, Scale 1:50 000.