Nipigon River Landslide, Ontario, Canada

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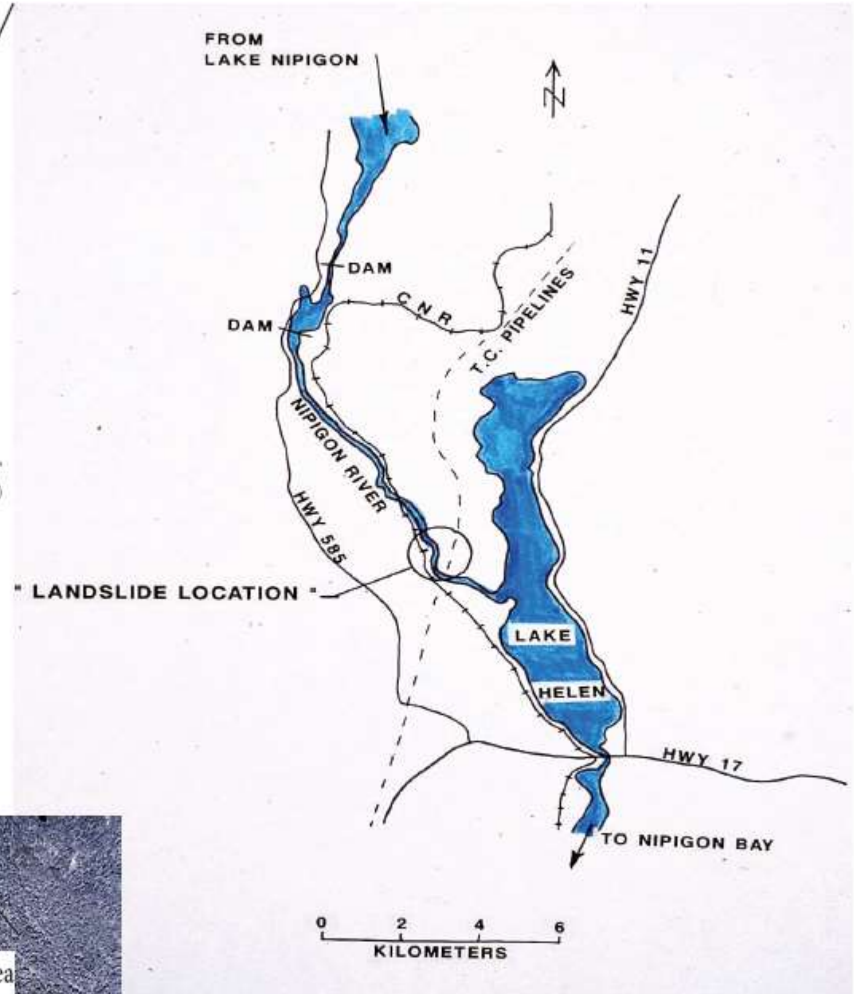
Contents

Nipigon River

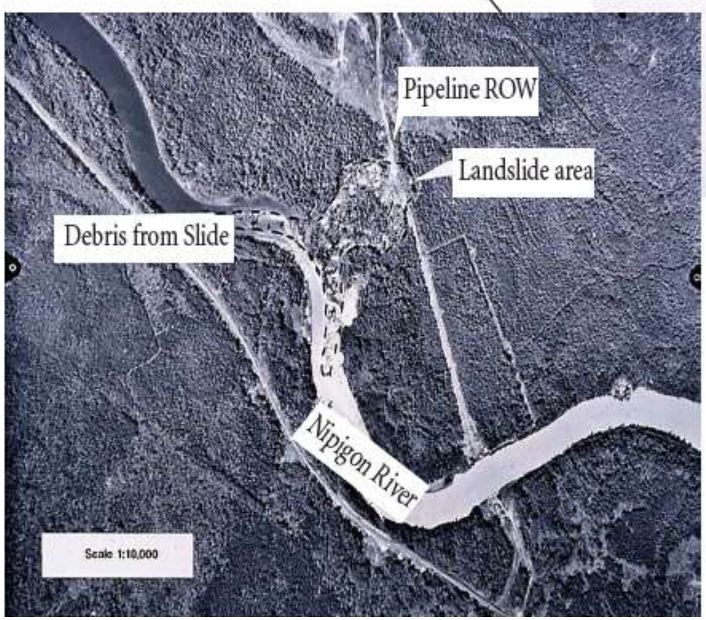
- Nipigon River is located on North shore of Lake Superior, Great Lakes in North America
- Soils along the Nipigon River are products of glaciolacustrine and delta deposits consisting of sands and silts
- Frequent small failures of natural and man-made slopes

Alaska (US)
Brooks Range
Alaska Range
Mount McKinley 6194 m
Beaufort Sea
Banks Island
Victoria Island
Baffin Bay
Baffin Island
Gulf of Boothia
Davis Strait
EUROPE
Great Bear Lake
Mackenzie Mts.
Foxe Basin
Hudson Strait
Gulf of Alaska
Great Slave Lake
Lake Athabasca
Labrador Sea
Peninsule d'Ungava
Hudson Bay
CANADA
Reindeer Lake
Smallwood Reservoir
Laurentian Plateau
Newfoundland
Queen Charlotte Islands
Edmonton
Lake Manitoba
Lake Winnipeg
Canadian Shield
Coast Mts.
Rocky Mountains
Vancouver
Calgary
Seattle
Mt. Baker 3286 m
Winnipeg
Lake Nipigon
Québec City
Mt. Katahdin 1606 m
Portland
Great Plains
Montréal
OTTAWA
Mt. Hood 3426 m
Mt. Washington 1917 m
Toronto
Grand Teton 4199 m
Boston
PACIFIC OCEAN
Mt. Shasta 4322 m
UNITED STATES
Great Salt Lake
New York
ATLANTIC OCEAN
San Francisco
Great Basin
Wheeler Peak 3982 m
Chicago
Detroit
Philadelphia
Indianapolis
San Jose
Denver
WASHINGTON, D.C.
Mt. Whitney 4421 m
Las Vegas
Mt. Elbert 4402 m
Ozark Plateau
Appalachian Mountains
Mt. Mitchell 2037 m
Colorado Plateau
Los Angeles
Bermuda (UK)
Oklahoma City
Atlanta
San Diego
Phoenix
Memphis
Dallas
Tucson
El Paso
Edwards Plateau
Jacksonville
Coastal Plains
Houston
San Antonio
THE BAHAMAS
Miami

(a) Map of Canada



(b) Local map



(c) Satellite image of landslide area

Outside sections of the river meanders

Nipigon River Landslide

- ✓ A massive landslide occurred on April 23, 1990
- ✓ Involved 300,000 cubic meters of soil
- ✓ Extended almost 350 m inshore with a maximum width of approximately 290 m
- ✓ Caused soil to be pushed into the Nipigon River 300 m upstream and about the same distance downstream.
- ✓ The islands, formed by the soils pushed into the river, redirected the current and caused subsequent erosion on the west bank and further landslides on the south.
- ✓ A section of Trans Canada Pipeline was left unsupported
- ✓ Difficulties for water supply for Nipigon and Red Rock
- ✓ Adverse Economic and Environmental effects (fish habitat, etc.)

Affected Parties

- Ministry of Natural Resources
- Ontario Hydro
- TransCanada Pipelines
- Bell Canada
- Canadian National Railway
- City of Nipigon
- Town of Red Rock
- Red Rock Indian Band
- Domtar Mill at Red Rock
- Ministry of Environment
- The public

Water Intakes

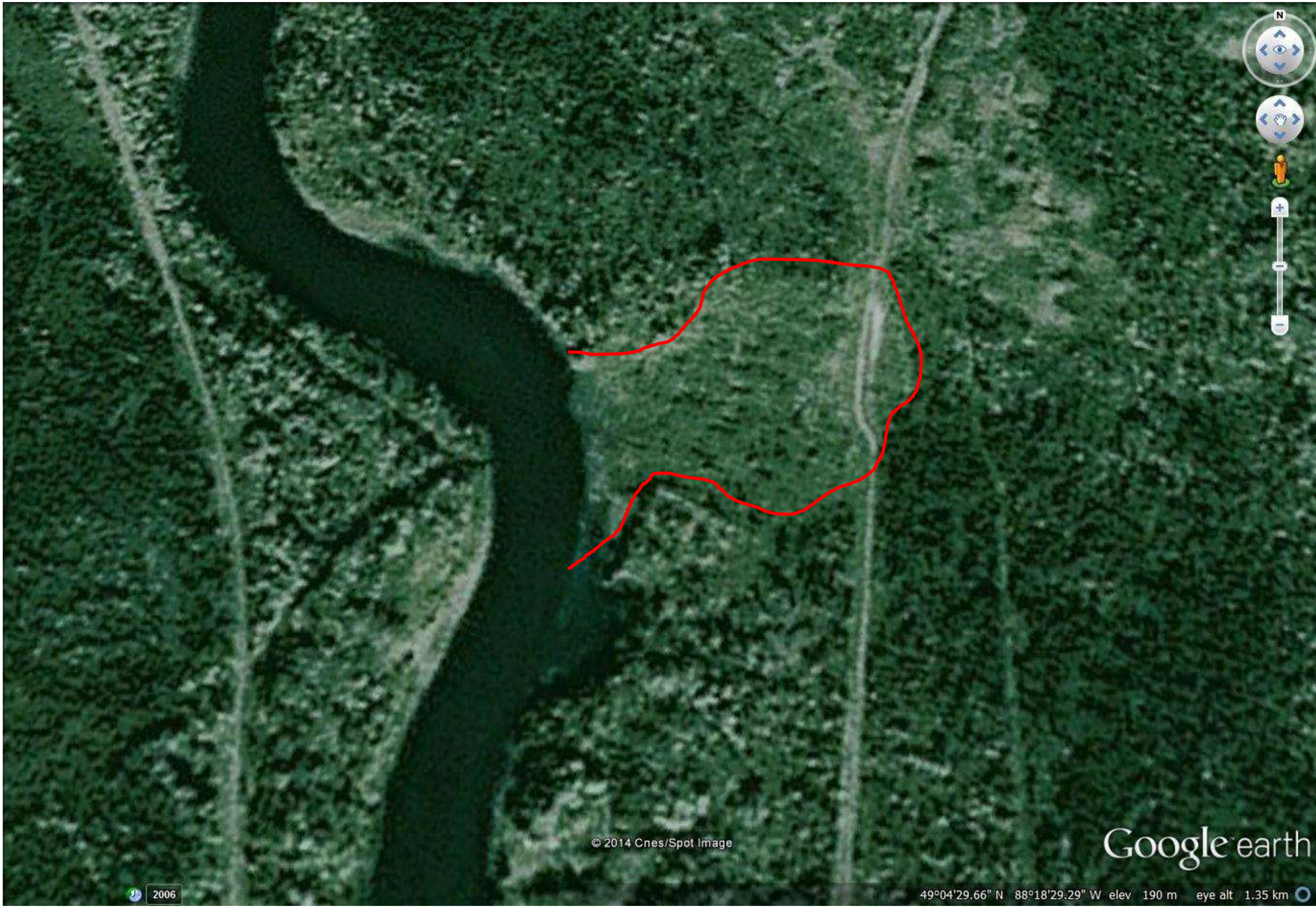

N
© 2014 Cnes/Spot Image
Google earth
2006
49°04'29.66" N 88°18'29.29" W elev 190 m eye alt 1.35 km

Figure 3: A day after the landslide (Adamson, 2015)


'90 4 24

Figure 4: A day after the landslide (Adamson, 2015)

Figure 5: A day after the landslide (Adamson, 2015)


LUND
'90 6 6

Objectives of Soils Investigation and Analysis

- Establish the causes of the slide;
- Assess the risk of further slides taking place in the vicinity;
- Assess the feasibility of relocating the gas pipeline or rehabilitating the slide area;
- Advise on the operational procedures of the hydro-electric dam located upstream 8 km of the landslide site.
- Stabilization measures for a country road

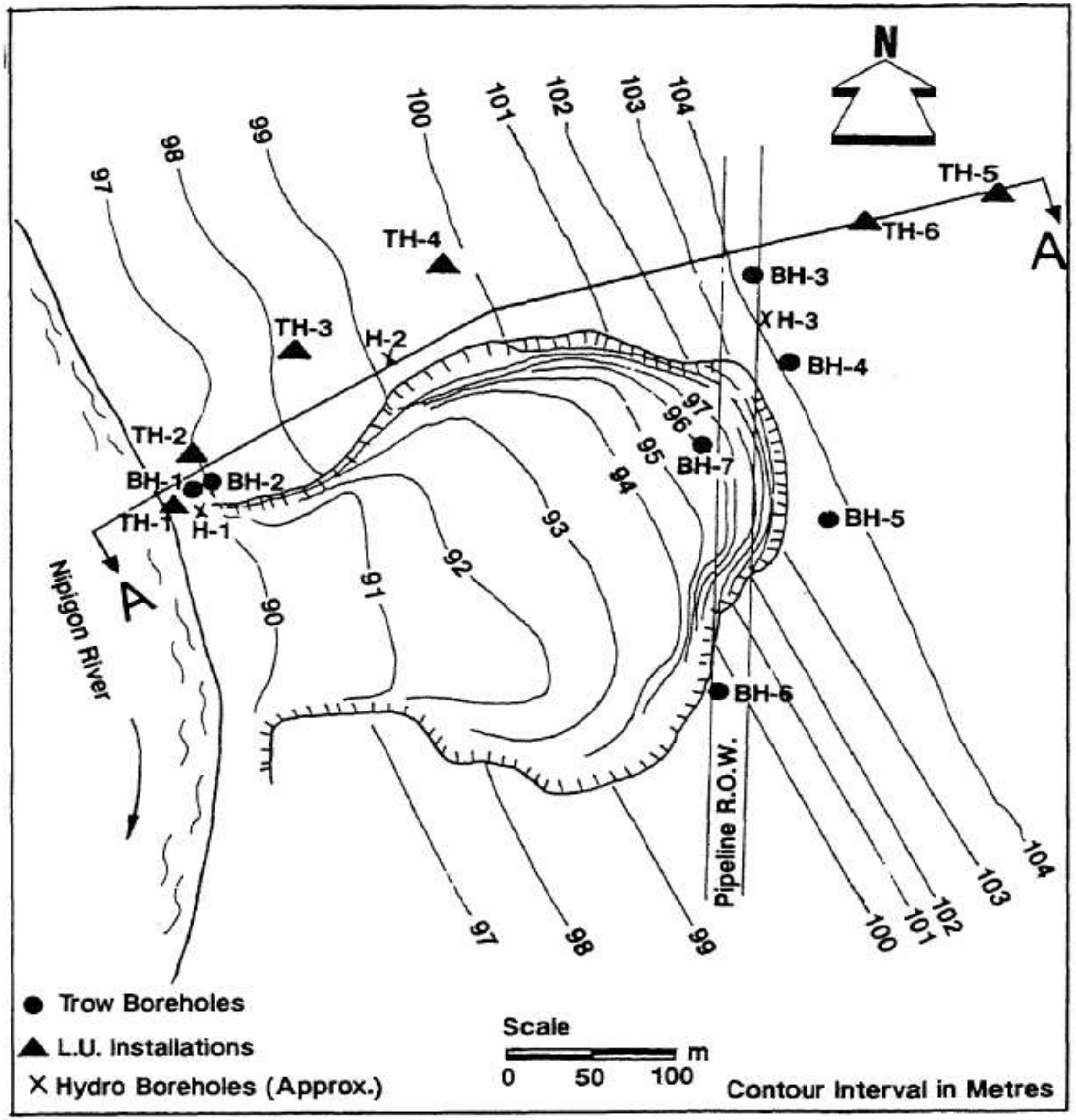


Figure 3 Site Plan

Field investigations

Electric piezocone,
Geonor shear vane test,
Piezometers,
Slope indictor casing in borehole…

By Trow Consulting Engineers,
Ontario Hydro,
And Lakehead University

General Geology and Slope Soil Stratigraphy

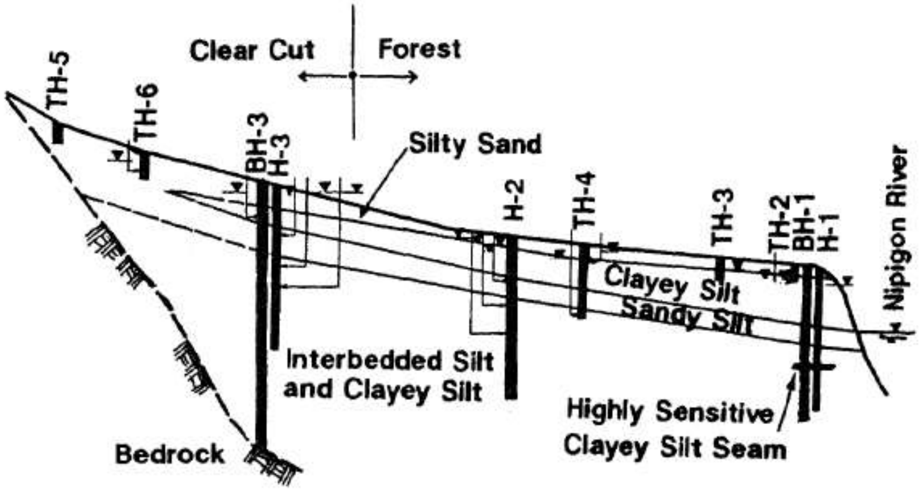
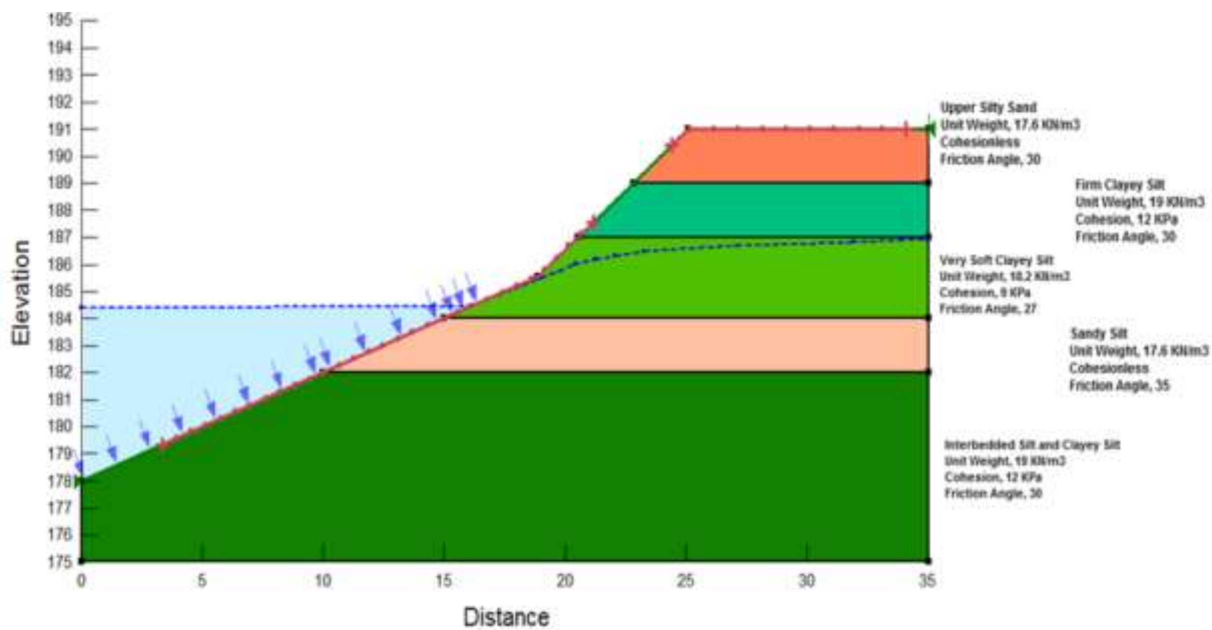


Figure 4 Stratigraphic Section



Soil properties

Soil Layer	Unit Weight (kN/m^3)	Cohesion (kPa)	Friction Angle (°)	Hydraulic Conductivity, K (cm/s)	Characteristics (Thickness)
Upper Silty Sand	17.6	0	30	1.0×10^{-5}	Loose silty sand, 1m-3m
Clayey Silt Firm Clayey Silt Soft Clayey Silt	 19.0 19.0	 12 9	 30 27	 5.0×10^{-7} 5.0×10^{-7}	Clay fraction (20-30%) Very soft, high moisture(22-39%, easy liquefaction), high sensitivity (failure upon disturbance)
Sandy Silt	17.6	0	35	1.0×10^{-4}	Sand fraction (14-30%) Moisture(18-22%), 3m-5m
Interbedded Silt and Clayey Silt	19.0	12	30	5.0×10^{-7}	Stiffer, darker

Sensitivity analysis

- To identify which factors/variables have more influence on the slope stability.
- In each analysis, only one input parameter changed while other parameters unchanged at their mean value.

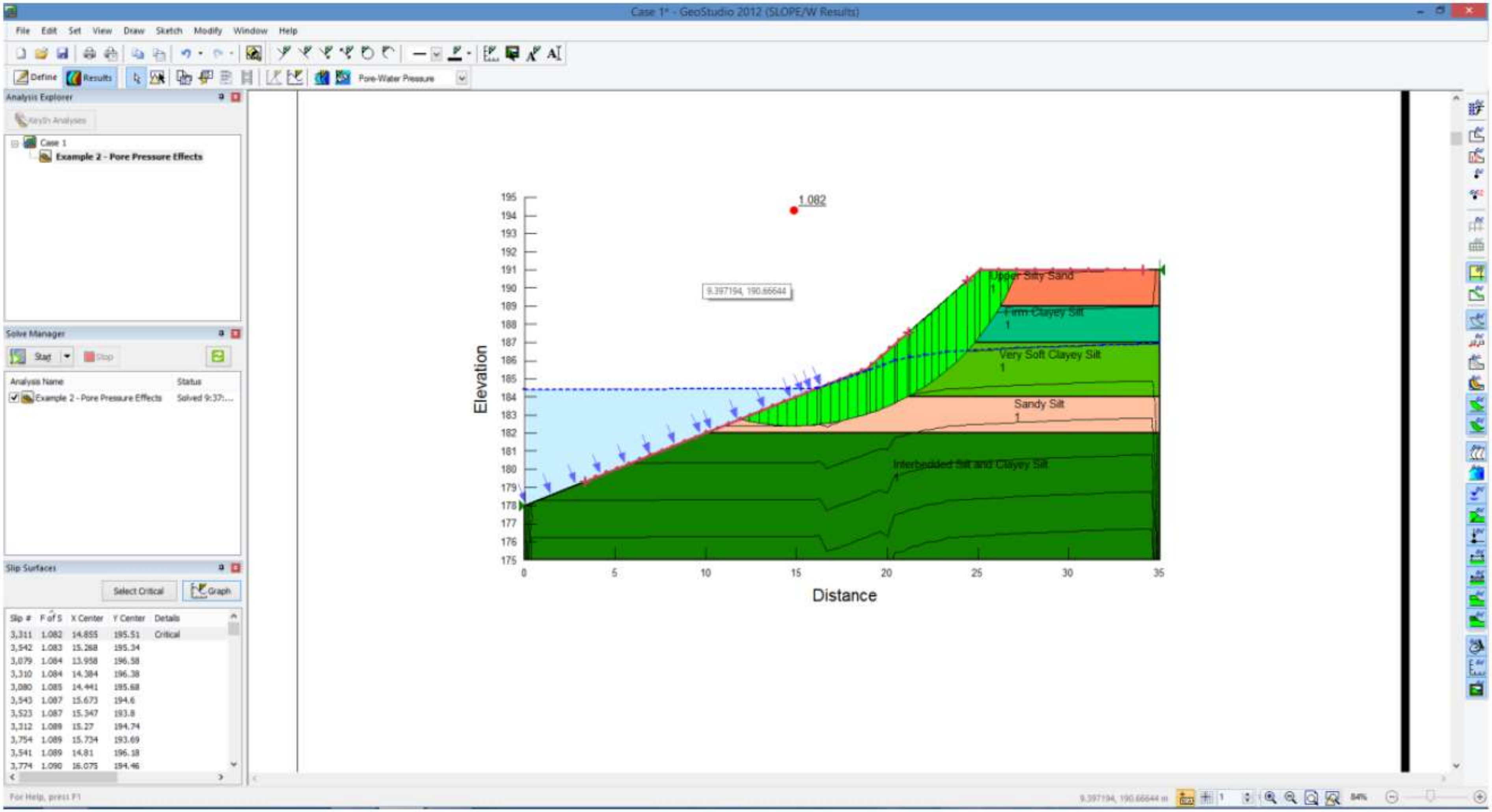


Figure A-1 : Case 1: Benchmark Case – average values, moderate ground water and river levels

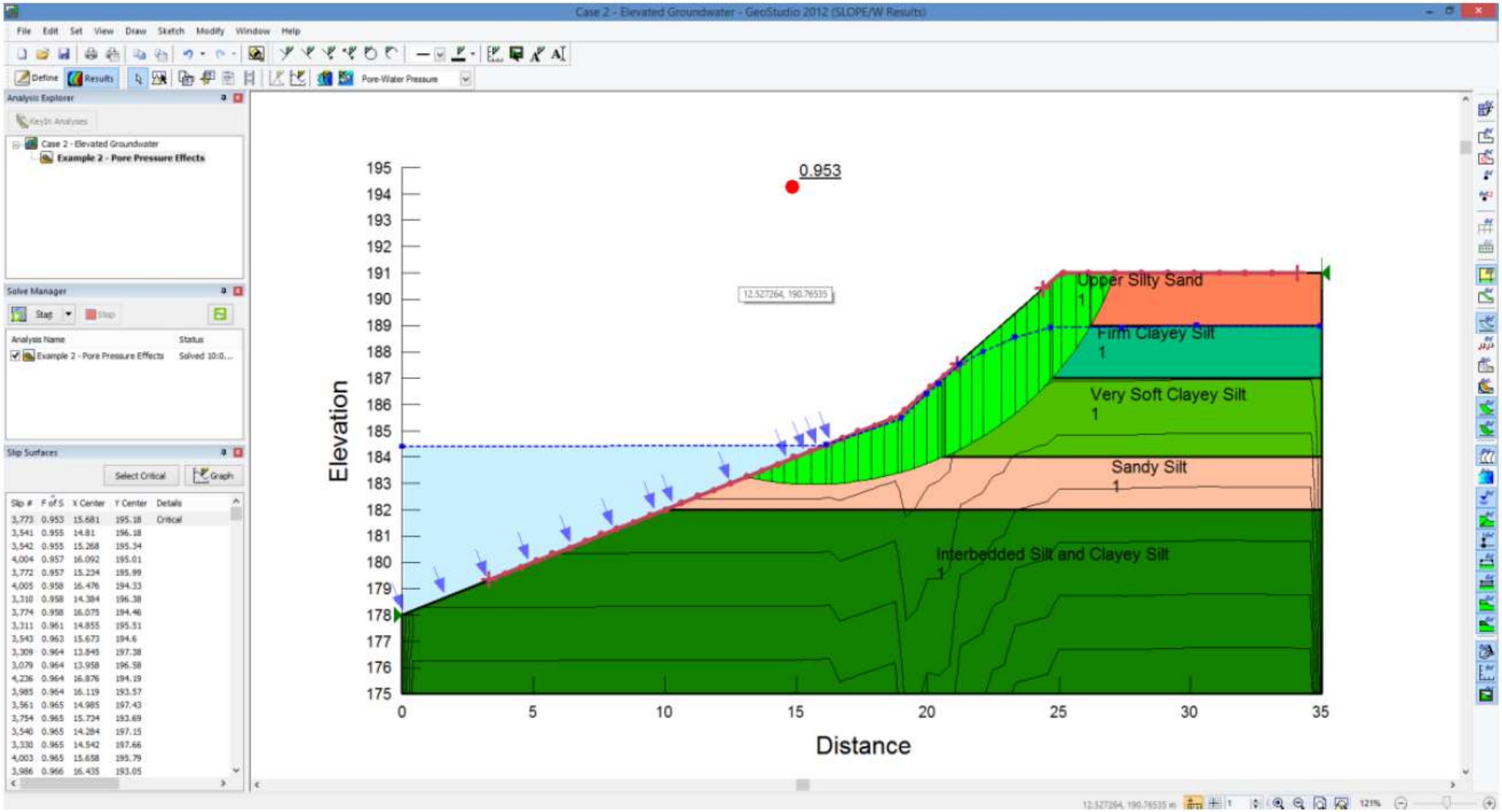


Figure A-2 : Case 2: Elevated Groundwater by 2 meters Figure

Table 4-2 : Case analysis for factor of safety

Case #	Parameter Changed	Change	Factor of Safety	Effect on FS
Case 1	N/A	N/A	1.082	N/A
Case 2	Ground water	Elevated by 2 meters	0.953	- 0.129
Case 3		Lowered by 2 meters	1.165	+ 0.083
Case 4	River Level	Elevated to 185.7m	1.179	+ 0.097
Case 5		Lowered to 183.4m	1.033	- 0.049
Case 6	Ground Water and River Level	Low river level with high GW	0.943	- 0.139
Case 7		Low river with low GW	1.219	+ 0.137
Case 8	Friction angle of Sandy Silt Layer	Decrease From 35 to 25	0.900	- 0.182
Case 9		Increase From 35 to 45	1.208	+ 0.126
Case 10	Cohesion of upper clay layers	Decrease C' By 3 KPa	1.002	- 0.080
Case 11		Increase C' By 3 KPa	1.148	+ 0.066
Case 12	Changes in unit weights	Increase Top two layers by 2KN/m^3	1.052	- 0.030
Case 13		Decrease Top two layers by 2KN/m^3	1.116	+ 0.034
Case 14	Changes in unit weights	Increase 3rd and 4th layers by 2KN/m^3	1.131	+ 0.049
Case 15		Decrease 3rd and 4th layers by 2KN/m^3	1.019	- 0.063
Case 16	Changes in the toe slope by erosion	Scouring Erosion of Toe Slope	0.946	- 0.136
Case 17		Deposition Erosion of Toe Slope	1.226	+ 0.144

Factors contributing significantly to Nipigon River landslide

- Change of river level and ground water level;
- Internal friction angle of sandy silt layer;
- Change in the slope toe by erosion.

Erosion Control

2.5m Sloped Gabion Wall, Slope Geometry 3:2

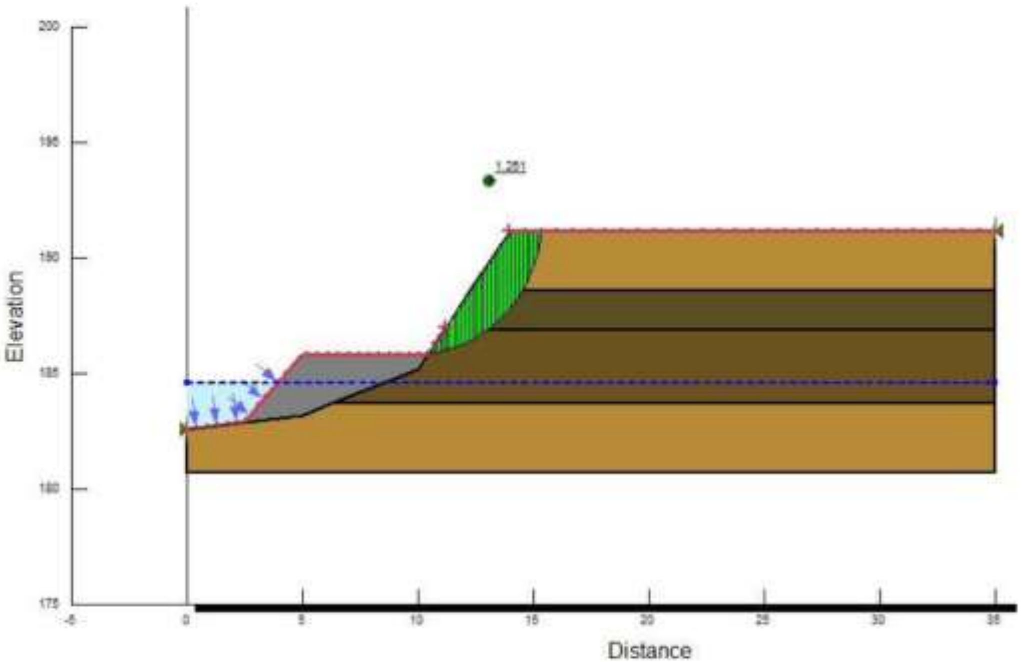


Figure A-16: Bishop's Simplified Nipigon River Slope Stability Analysis Case 16

Eroded Toe, Slope Geometry 3:2

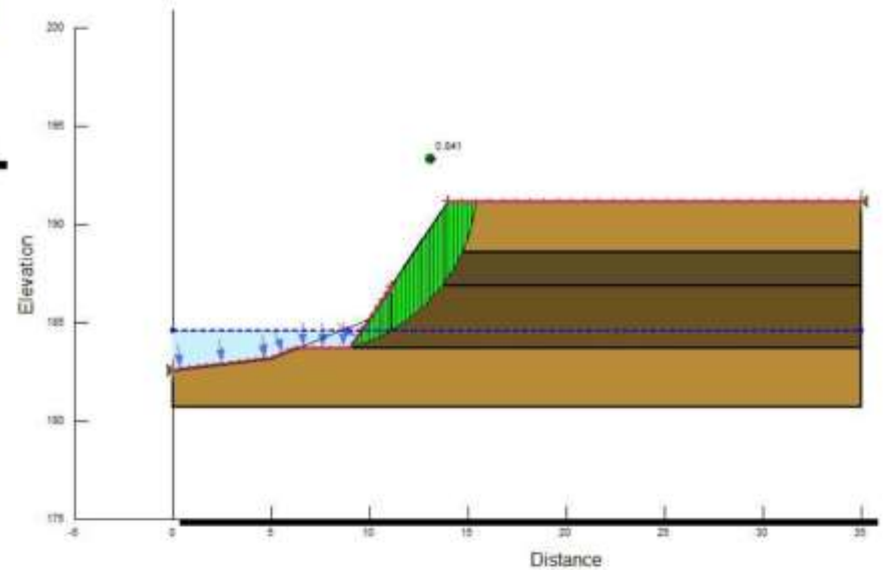
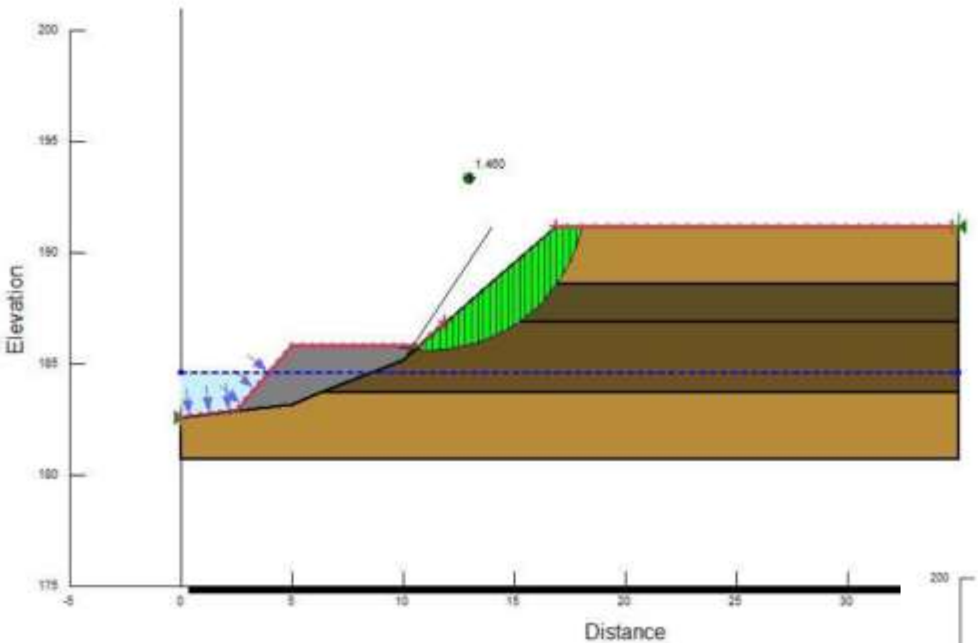


Figure A-4: Bishop's Simplified Nipigon River Slope Stability Analysis Case 4

2.5m Sloped Gabion Wall, Slope Geometry 1:1.15



Eroded Toe, Slope Geometry 1:1.15

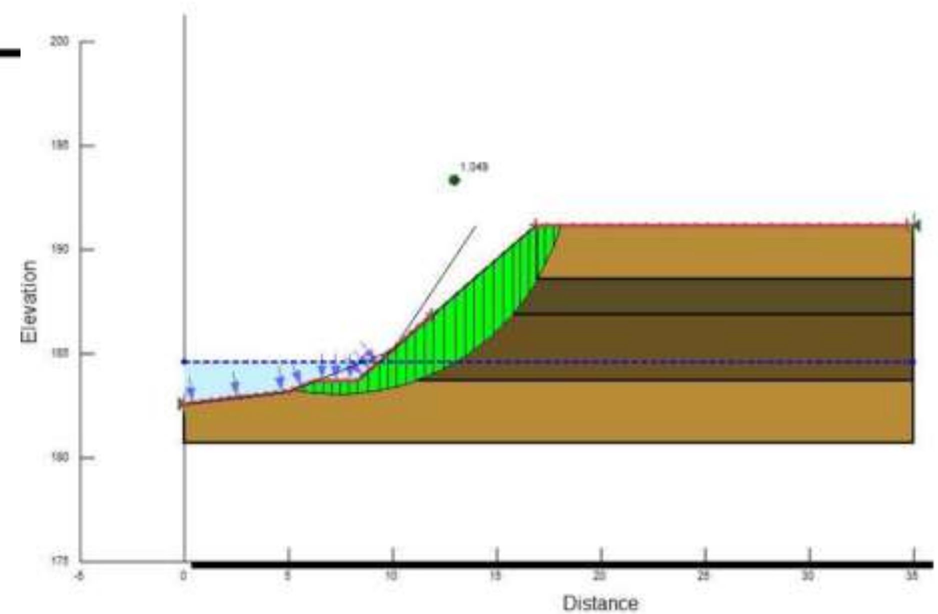


Figure A-5: Bishop's Simplified Nipigon River Slope Stability Analysis Case 5

2.5m Sloped Gabion Wall, Slope Geometry 1:2

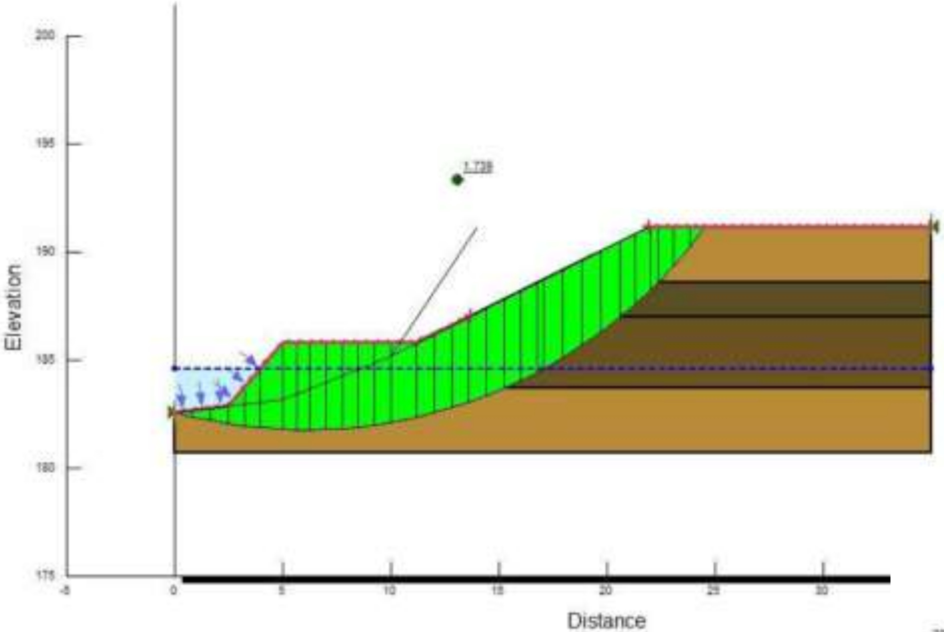


Figure A-18: Bishop's Simplified Nipigon River Slope Stability Analysis Case

Eroded Toe, Slope Geometry 1:2

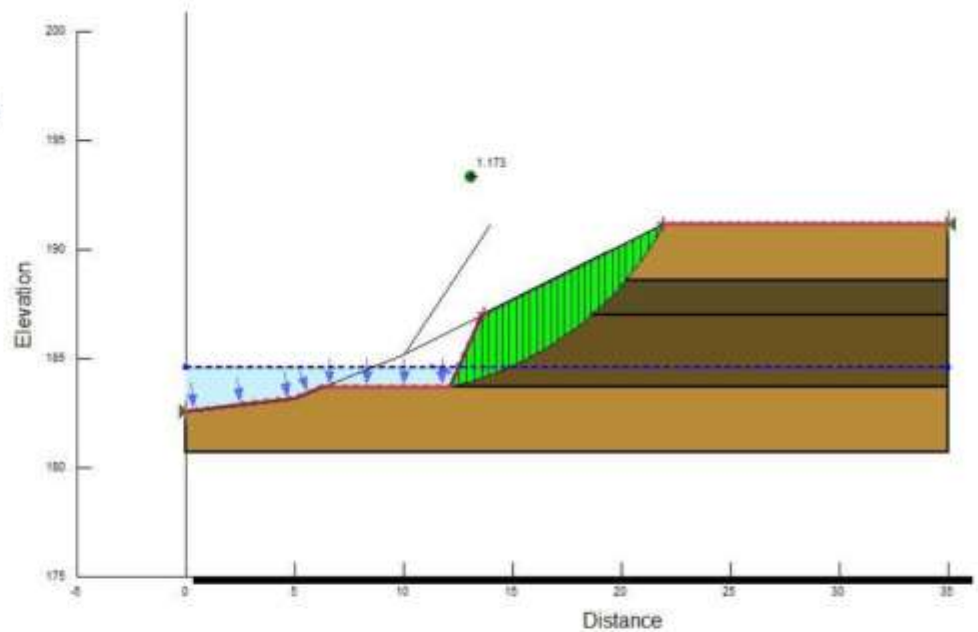


Figure A-6: Bishop's Simplified Nipigon River Slope Stability Analysis Case 6

High Groundwater, Slope Geometry 3:2

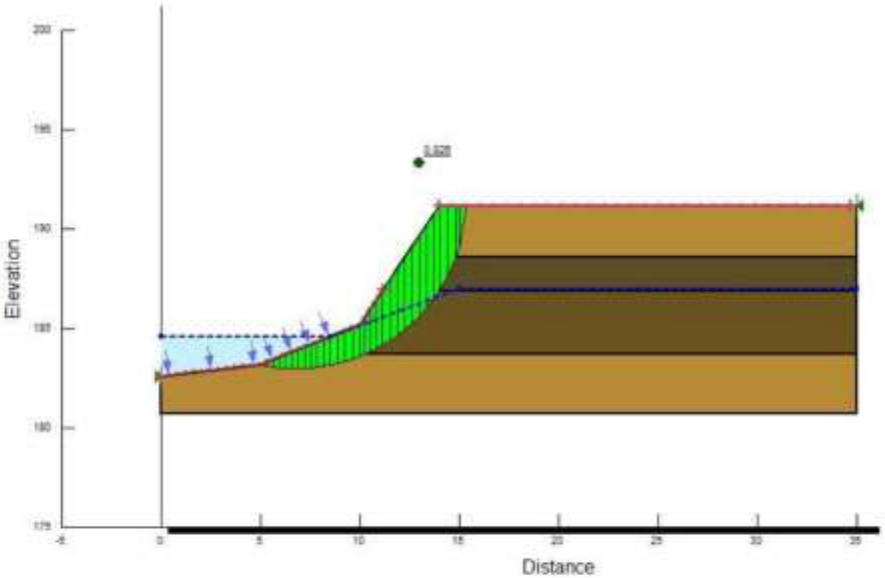


Figure A-7: Bishop's Simplified Nipigon River Slope Stability Analysis Case 7

Rapid Draw Down, Slope Geometry 3:2

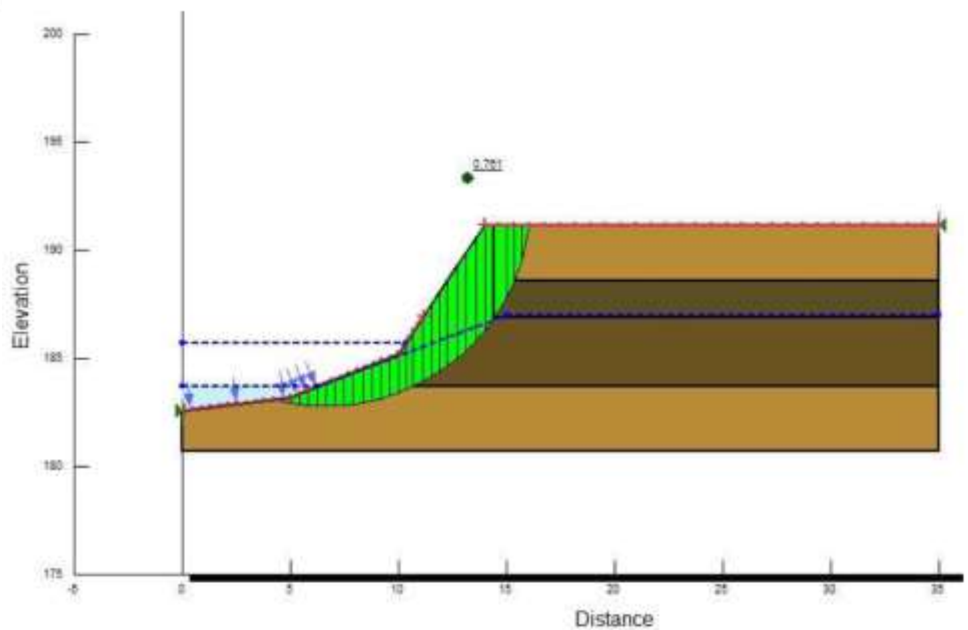


Figure A-10: Bishop's Simplified Nipigon River Slope Stability Analysis Case 10

High Groundwater, Slope Geometry 1:1.15

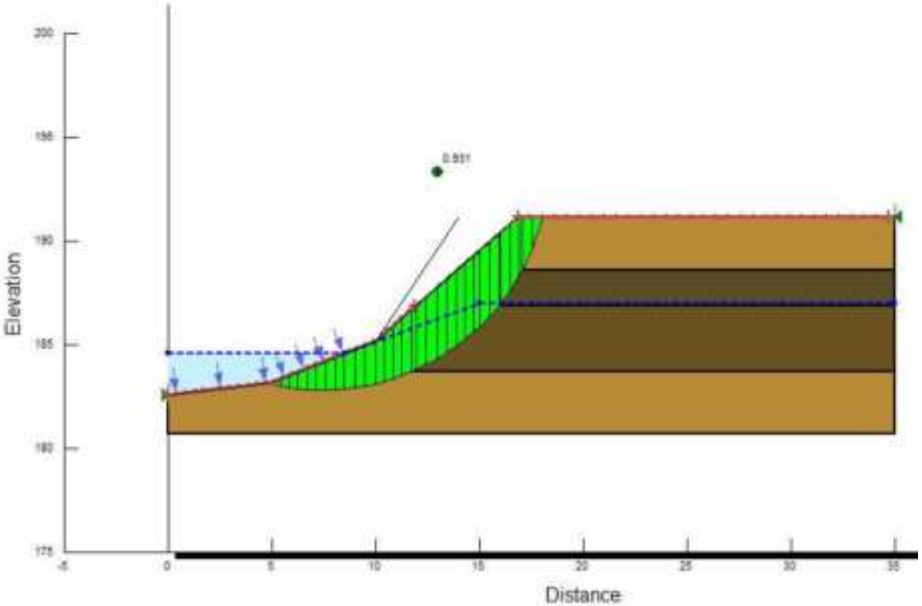


Figure A-8: Bishop's Simplified Nipigon River Slope Stability Analysis Case 8

Rapid Draw Down, Slope Geometry 1:1.15

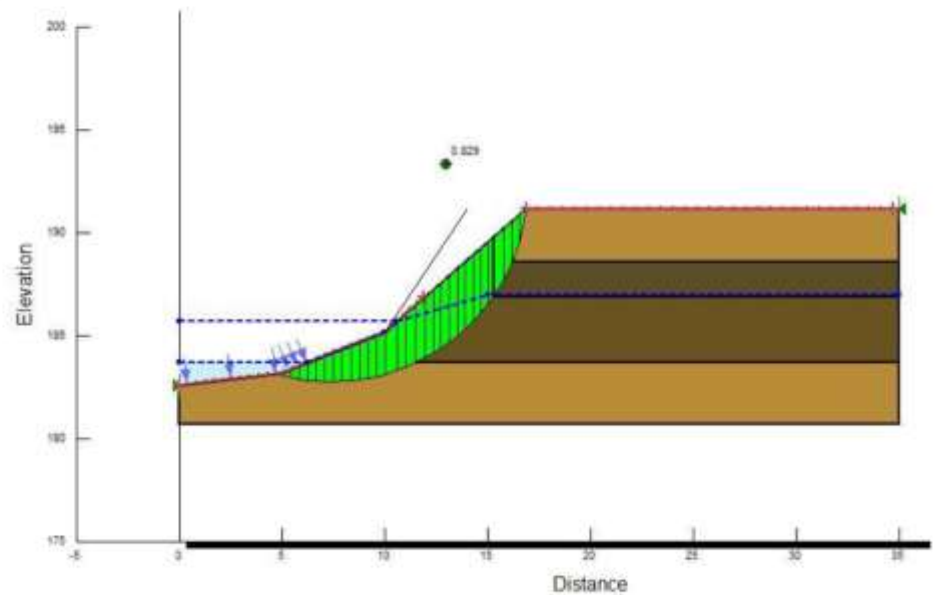


Figure A-11: Bishop's Simplified Nipigon River Slope Stability Analysis Case 11

High Groundwater, Slope Geometry 1:2

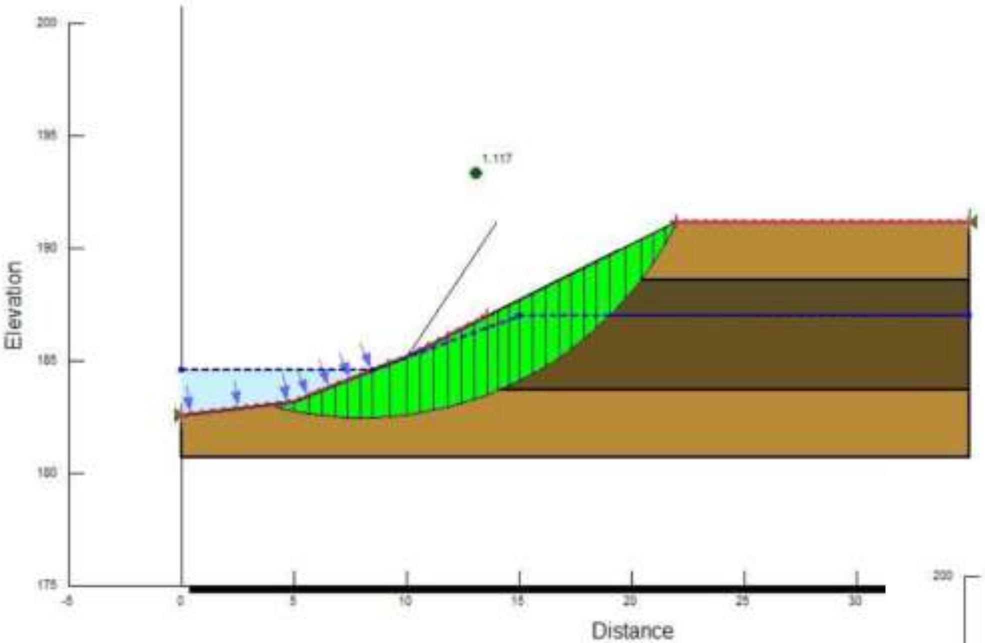


Figure A-9: Bishop's Simplified Nipigon River Slope Stability Analysis

Rapid Draw Down, Slope Geometry 1:2

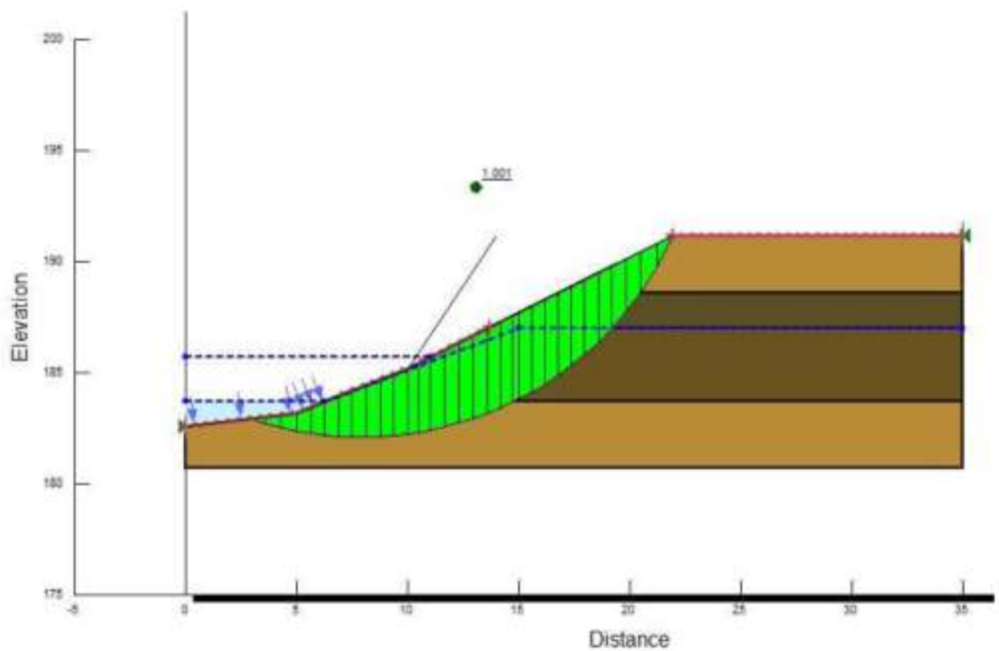
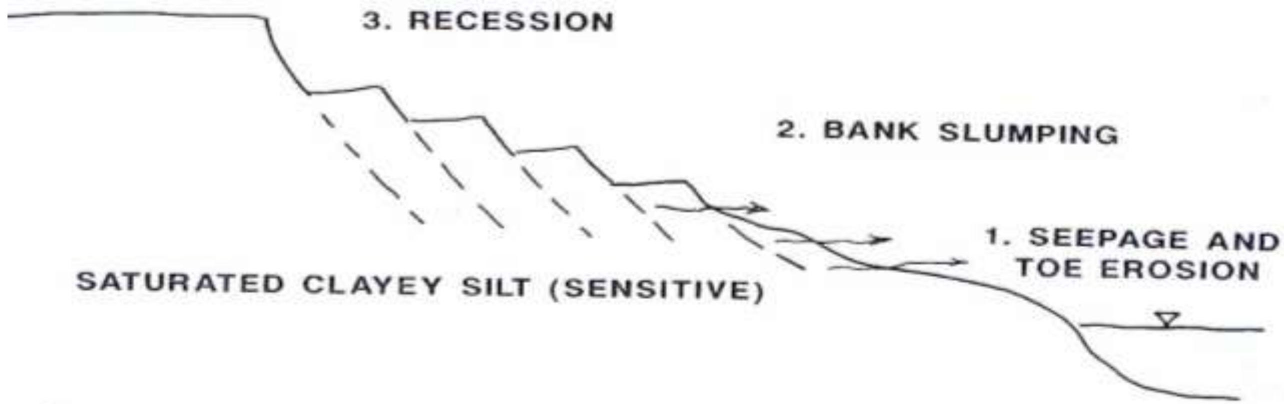


Figure A-12: Bishop's Simplified Nipigon River Slope Stability Analysis Case 12

Significant effect of groundwater and river level

Case No.	Groundwater	River level	Factor of Safety
1	Low	Low	1.08
2	Same as river	High	1.01
3	High	High	0.93
4	high	low	0.86

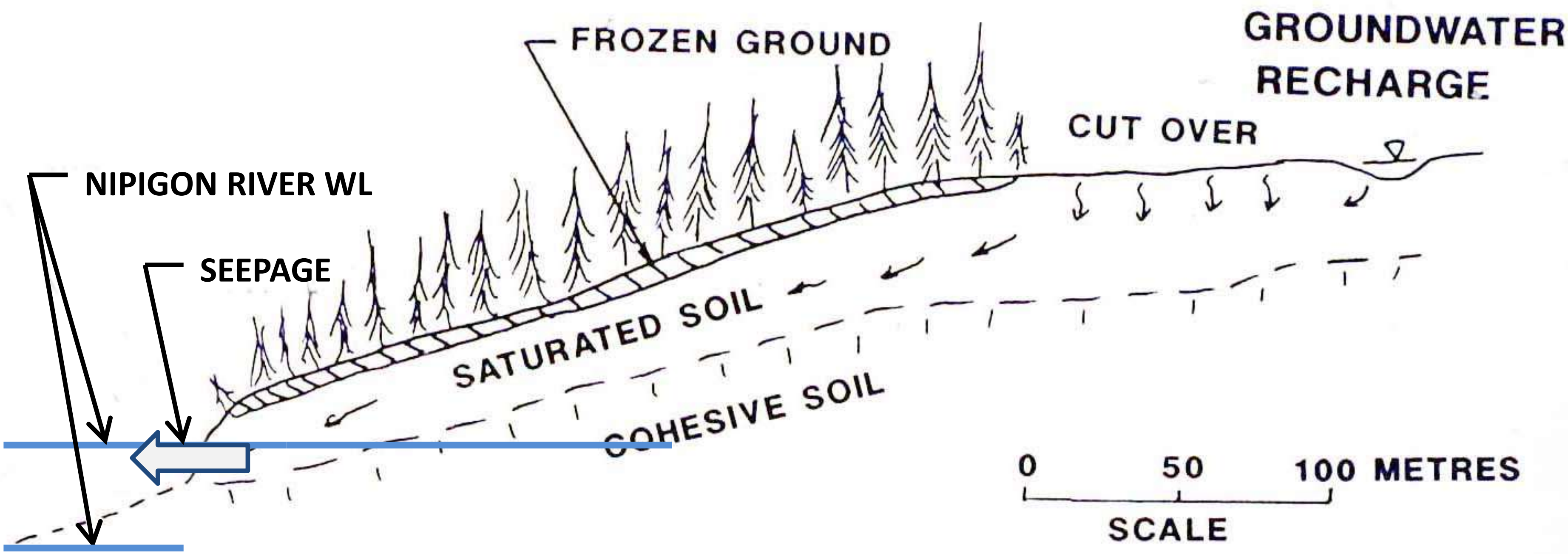
Retrogressive Failure



PROCESS OF FAILURE
EROSION, LANDSLIDING AND SLOPE RECESSION
(FROM TROW REPORT)

- The most critical slip circles are near the toe of the slope.
- The slide started as a small slip at the river bank and did not fail as a whole entity, but retrogressed uphill after initial failure occurred.
- The retrogression was due to high ground water level and sensitive soil deposits.
- The high ground water was due to warm weather, heavy rainfall, and timber harvesting operations.

Factor of Safety with rapid drawdown = 0.83



POSSIBLE MODEL FOR SOIL SATURATION

(SOURCE TROW REPORT)

Probabilistic Risk Assessment of Further Slides

- Uncertainties in soil properties
- Probability of Failure supplement to Factor of safety
- Monte Carlo Simulation in GEO-SLOPE
- 2000 simulations were performed for each individual analysis

Table 3 Soil Parameters Used in Monte Carlos Simulation Method

	Upper Silty Sand	Firm Clayey Silt	Soft Clayey Silt	Sandy Silt	Interbedded Silt and Clayey Silt
Unit Weight (kN/m^3)					
Min	16	16	16	16	16
Mean	17.6	19	19	17.6	19
Max	21	21	21	21	21
Cohesion (kPa)					
Min	0	5	0	0	0
Mean	0	12	9	0	12
Max	5	20	20	5	20
Φ (degree)					
Min	20	15	19	20	20
Mean	30	30	27	35	30
Max	40	45	35	45	40

Table 4 Summary of Risk Analysis Results

Case	Slope (V:H)	FS	Probability of Failure (%)	Increase in FS (%)	Increase in FS from Base Case(%)
1 (Base)	1:0.68	0.901	45.55	-	-
2	1:1	1	32.25	11.0	11.0
3	1:2	1.244	5	24.4	38.1
4	1:3	1.426	0	14.6	58.3

Conclusions

Probable contributing factors to river bank failures

- Toe erosion & soil loss due to river flow
- Higher than normal groundwater pressure in the soil as evidenced by seepage out of the bank
- Rapid drawdown of Nipigon River water levels, more quickly than the river bank soils could drain, thus reducing the factor of safety

Reasons for retrogression

- Glaciolacustrine soil deposits are weak and rather sensitive to disturbance (significant reductions in strength when disturbed)
- High groundwater upslope from river decreased the shear strength and stability, due to the weather conditions and high groundwater recharge.

Possible man-caused factors

- Frequent rapid changes in river level controlled by Ontario Hydro's dam operations
- Timber harvesting upslope contributed to high soil moisture content by infiltration and thus high groundwater pressures in soil downslope
- Pipeline right-of-way could increase soil moisture and impede drainage

Recommendations

- No tree harvesting in this landform without engineering study
- Flow reductions at the hydro dams should be timed to avoid rapid drawdown in river bank soils
- TransCanada Pipelines should drain water ponding on right of way
- A gabion baskets wall could prevent toe erosion and soil loss economically and environmentally

THANK YOU !

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