From: pharrington@lowerchurchillproject.ca
To: gbennett@nalcorenergy.com
Subject: Decks used with IE/Canada this week - N Spur
Date: Thursday, July 24, 2014 10:26:32 AM
Attachments: _.png
_.png
North Spur- Site_description_Bidders 140224.pptx
North Spur Updated Ind Eng 140721.pptx

Paul Harrington
Project Director
PROJECT DELIVERY TEAM
Lower Churchill Project
t. **709 737-1907** c. **709 682-1460** f. **709 737-1985**
e. **PHarrington@lowerchurchillproject.ca**
w. **muskratfalls.nalcorenergy.com**

----- Forwarded by Paul Harrington/NLHydro on 07/24/2014 10:26 AM -----

From: Robert Woolgar/NLHydro

To: Lance Clarke/NLHydro@NLHydro,

Cc: "Krupski, Joseph" <Joseph.Krupski@NRCan-RNCan.gc.ca>, Nikolay.V.Argirov@mwhglobal.com, John.E.Young@mwhglobal.com, Paul Harrington/NLHydro@NLHydro

Date: 07/21/2014 10:05 AM

Subject: Re: Joe's Email for the decks

North Spur- Site_description_Bidders 140224.pptx

North Spur Updated Ind Eng 140721.pptx

Robert Woolgar, P.Eng.
Deputy Project Manager - MF Generation
PROJECT DELIVERY TEAM
Lower Churchill Project

t. **709-778-6677** c. **709 699-9684** f. **709-754-0787**
e. **RobertWoolgar@lowerchurchillproject.ca**
w. **muskratfalls.nalcorenergy.com**

You owe it to yourself, and your family, to make it home safely every day. What have you done today so that nobody gets hurt?

Lance Clarke---07/21/2014 10:03:07 AM--- Lance Clarke Business Services Manager

From: Lance Clarke/NLHydro

To: Robert Woolgar/NLHydro@NLHYDRO,

Cc: "Krupski, Joseph" <Joseph.Krupski@NRCan-RNCan.gc.ca>

Date: 07/21/2014 10:03 AM

Subject: Joe's Email for the decks

Lance Clarke
Business Services Manager
PROJECT DELIVERY TEAM
Lower Churchill Project
t. **709 737-1245** c. **709 699-5318**
e. **LanceClarke@lowerchurchillproject.ca**
w. **muskratfalls.nalcorenergy.com**

Lower Churchill Project

NORTH SPUR STABILIZATION WORKS

Site description, 10 and 11- Mar-2014

Boundless Energy

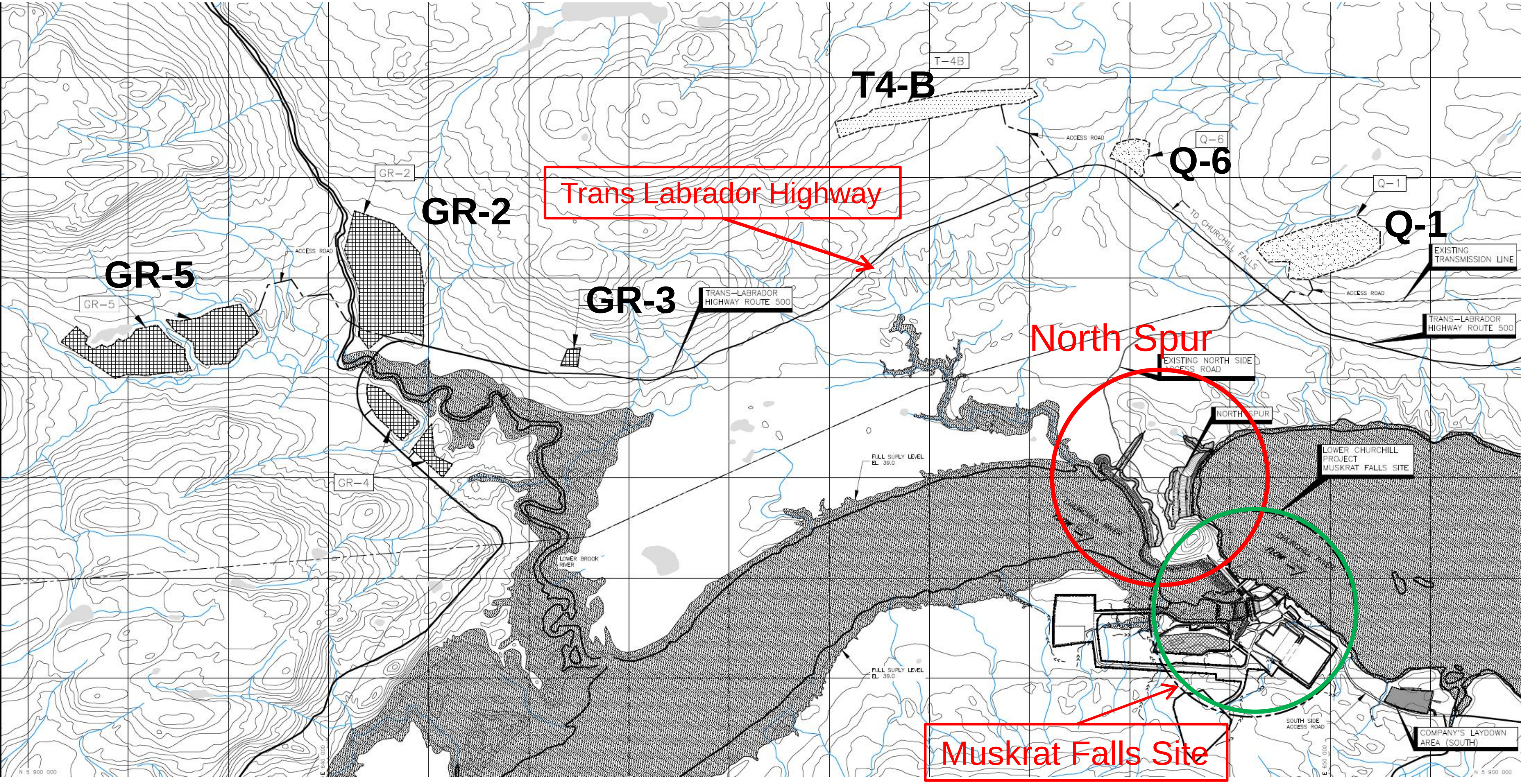
nalcor energy

SNC·LAVALIN EPCM consultant for Nalcor

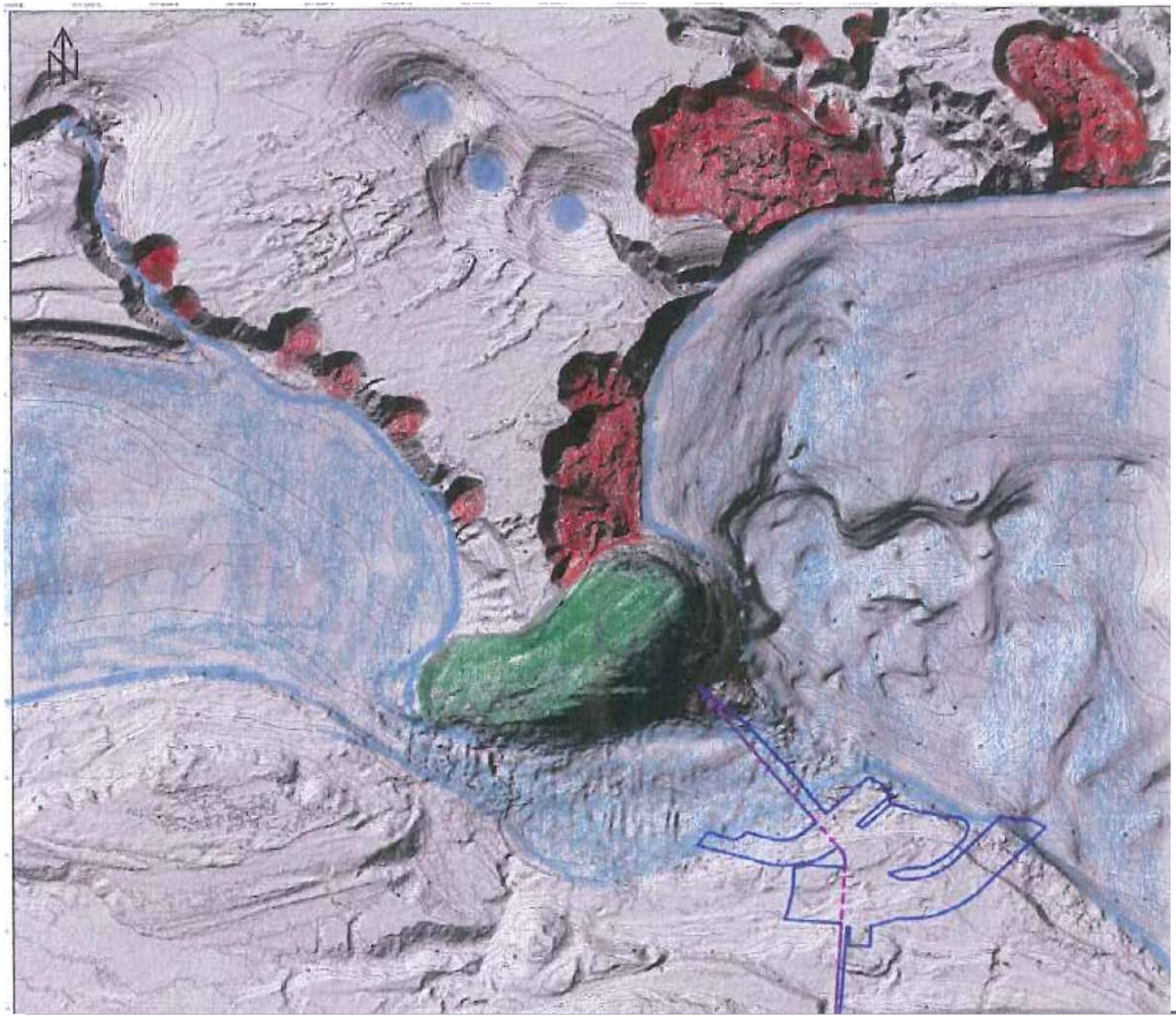
Site Visit Schedule

- Site and work description
- Site visit (North Spur)
  - 3 Kettle lakes and outlet
  - Downstream crest
  - Downstream shoreline
  - Upstream shoreline
  - Upstream crest
- Quarries and Borrow areas

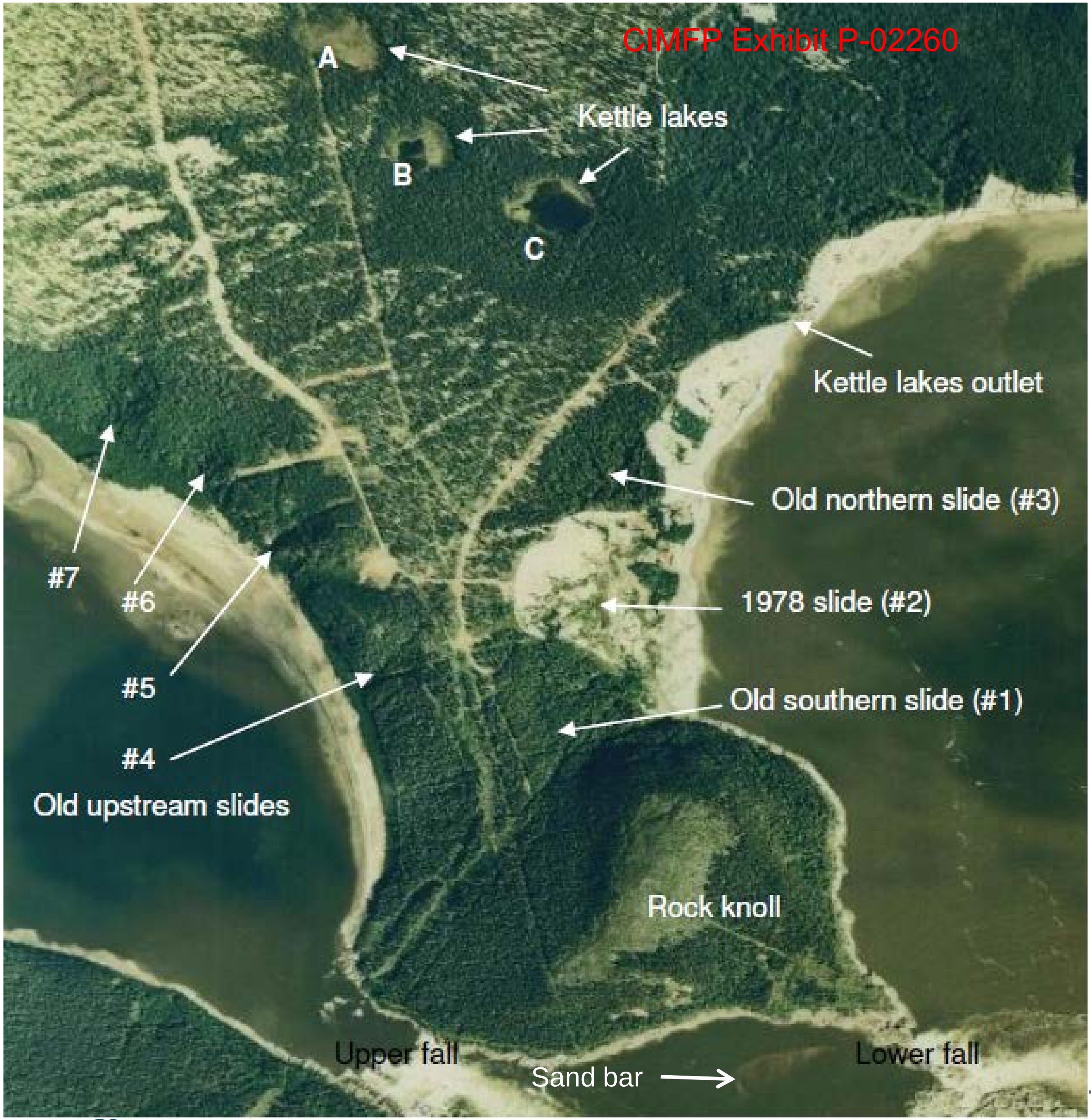
Site and Borrow Areas location



Lidar North Spur



-The Spur of land is a natural Dam on Churchill river
-South Knoll outcrop
-Soil deposit
- Sand dunes
- Up and downstream landslide scarps
- Kettle lakes



Aerial View of the North Spur (1988)

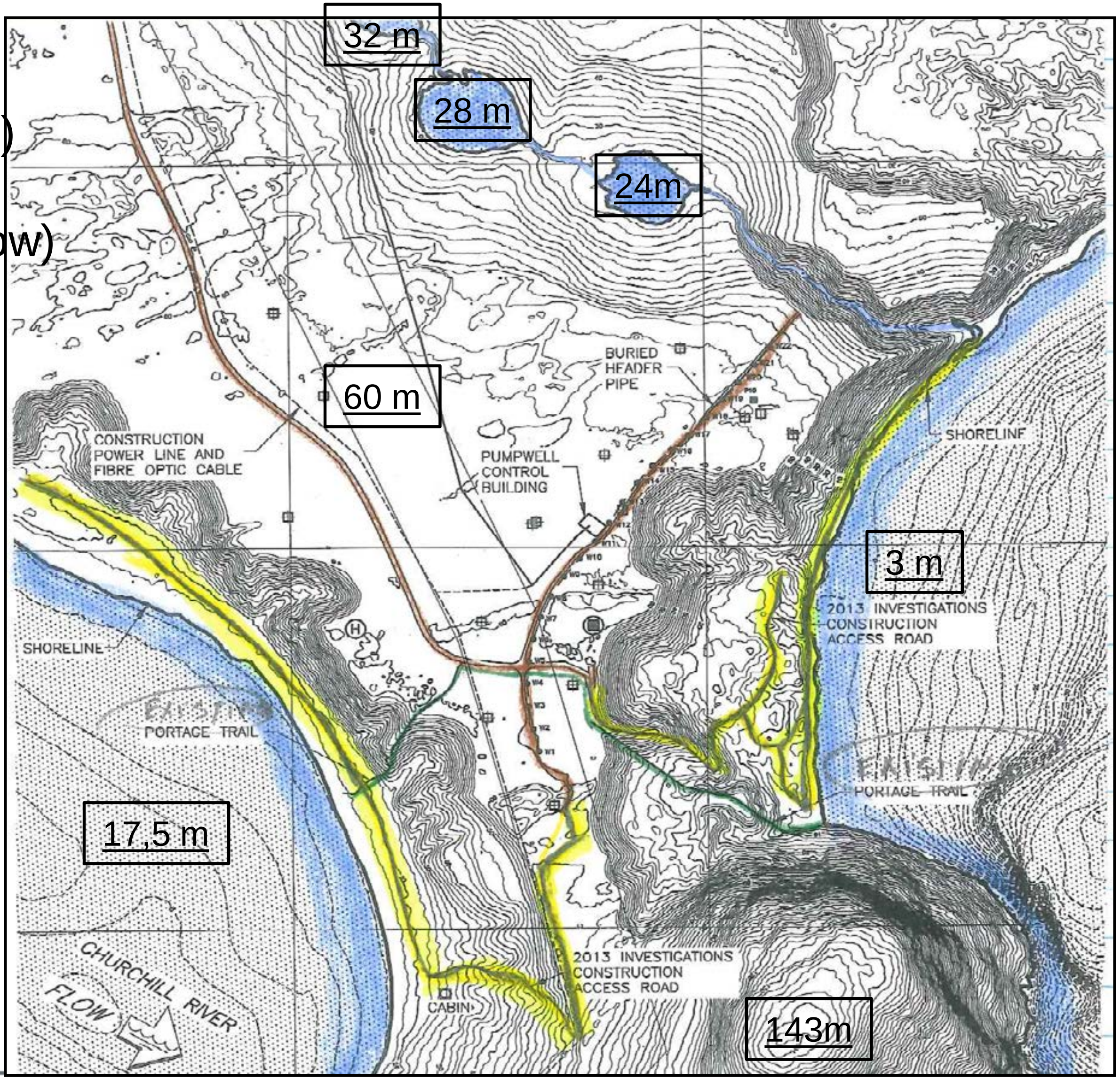
- 4 Upstream landslide scarps
-3 downstream landslide scarps
- 22 pump wells line

SNC·LAVALIN EPCM consultant for Nalcor

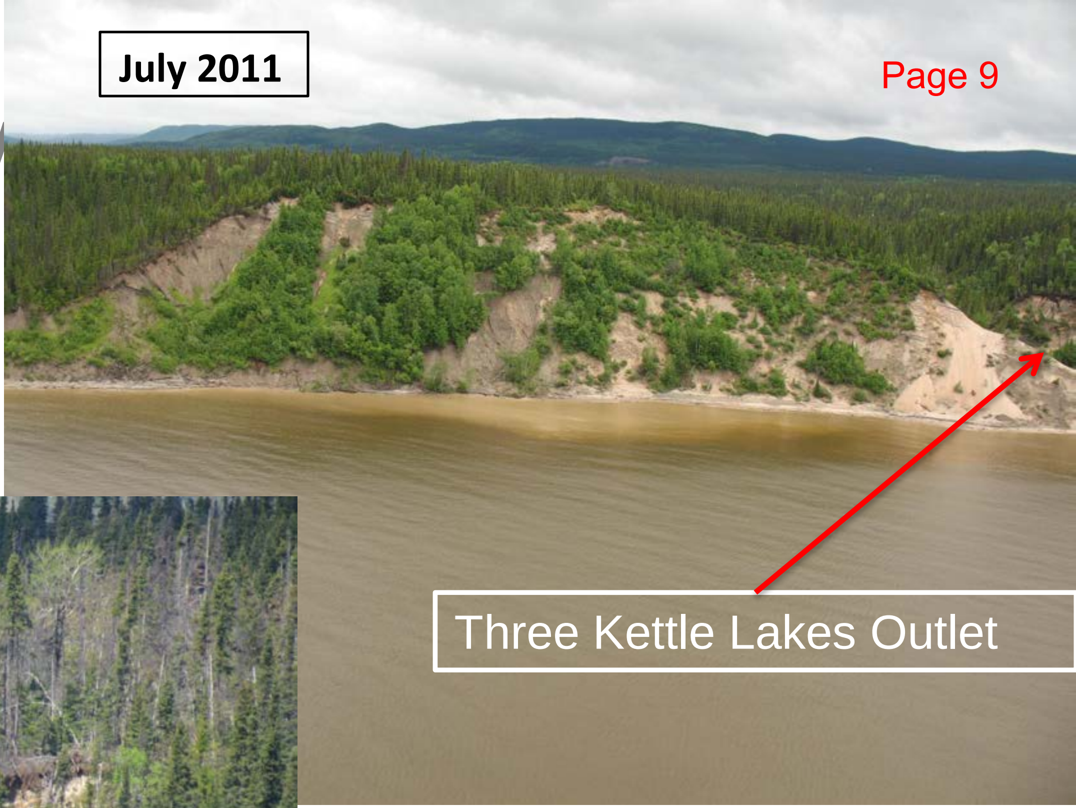
nalcor energy

Existing conditions

- Existing access road (brown)
- Portage trail (green)
- Shoreline access trails (yellow)
- elevation of main features



Recent slides activity



Upstream of Spur

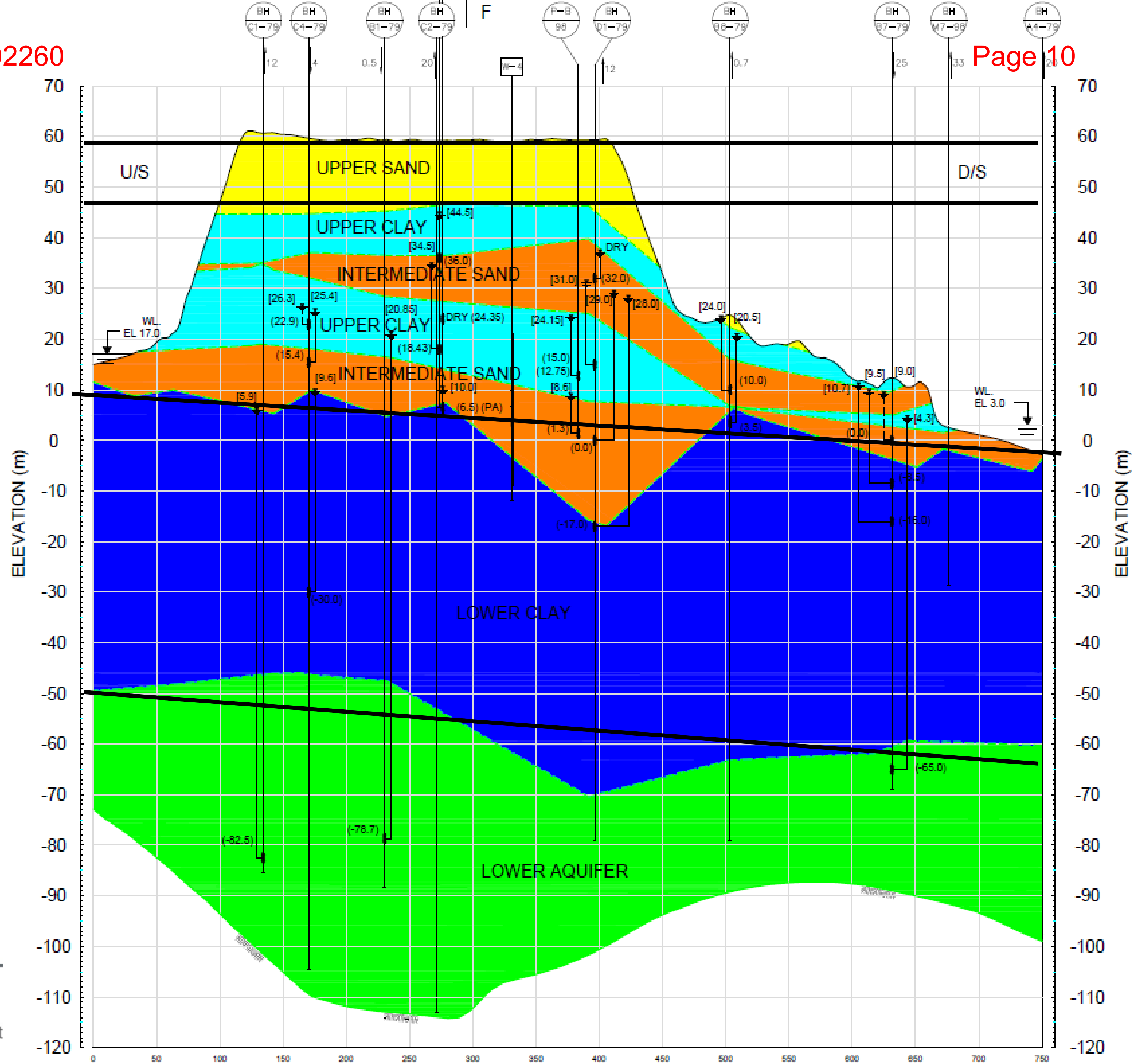
Downstream of Spur

Upper sand

Stratified drift
-Upper Clay
- Intermediate silty-sand

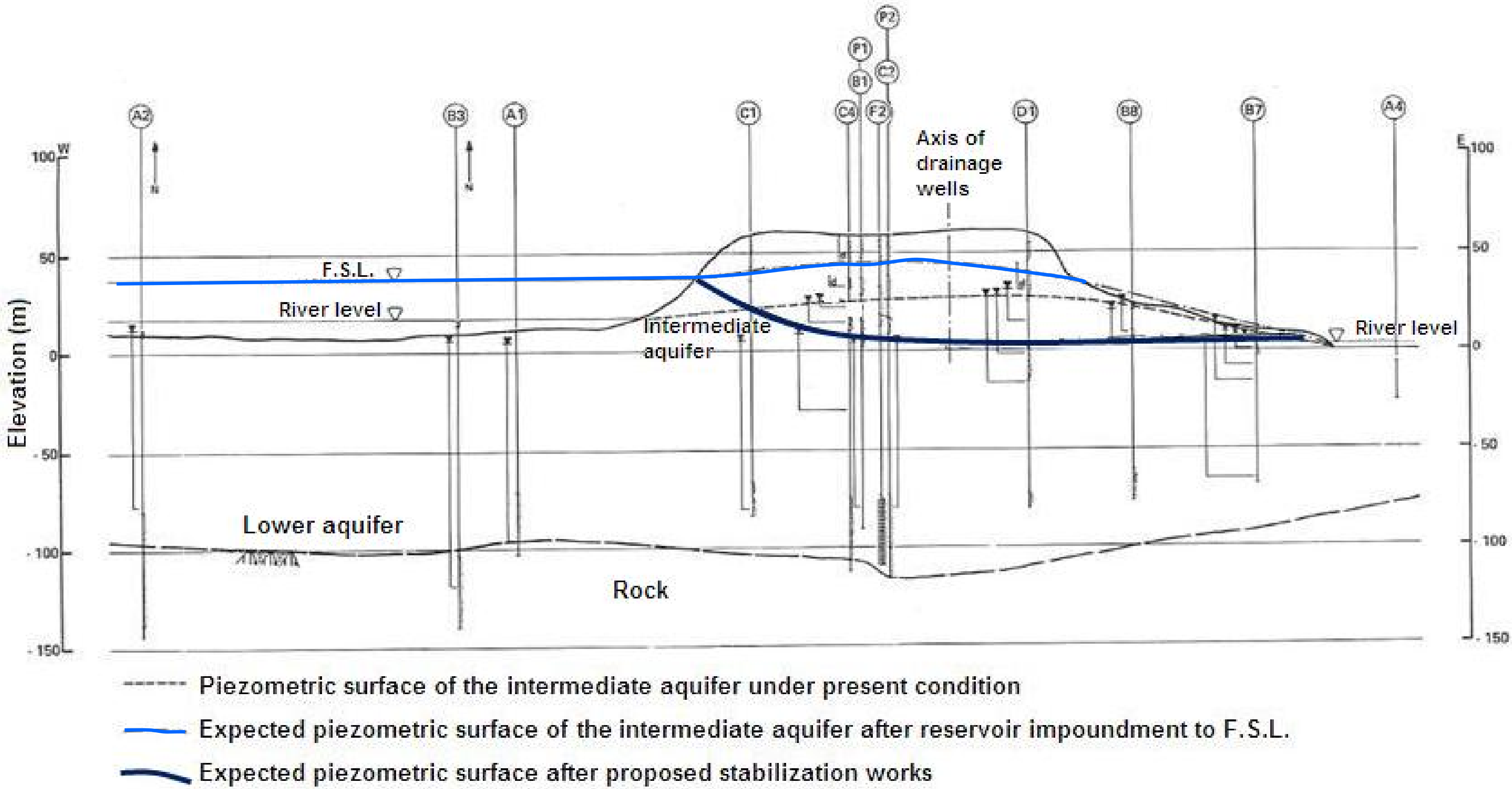
Lower clay

Lower aquifer



SNC·LAVALIN EPCM consult

Effect of reservoir impoundment



Objectives of the stabilization works

- Lowering the piezometric level
- Capturing and evacuating seepage water
- Improving slope stability (Geometry correction)
- Protecting against erosion at toe and on slopes
- Keep maintenance activities at minimum

Stabilization measures

Upstream Works

- Re-grading and granular fill
- Slurry cut-off wall
- Till blanket
- Erosion protection

Downstream Works

- Re-grading and granular fill
- Finger drains
- Relief wells (passive)
- Erosion protection

North side of the Spur

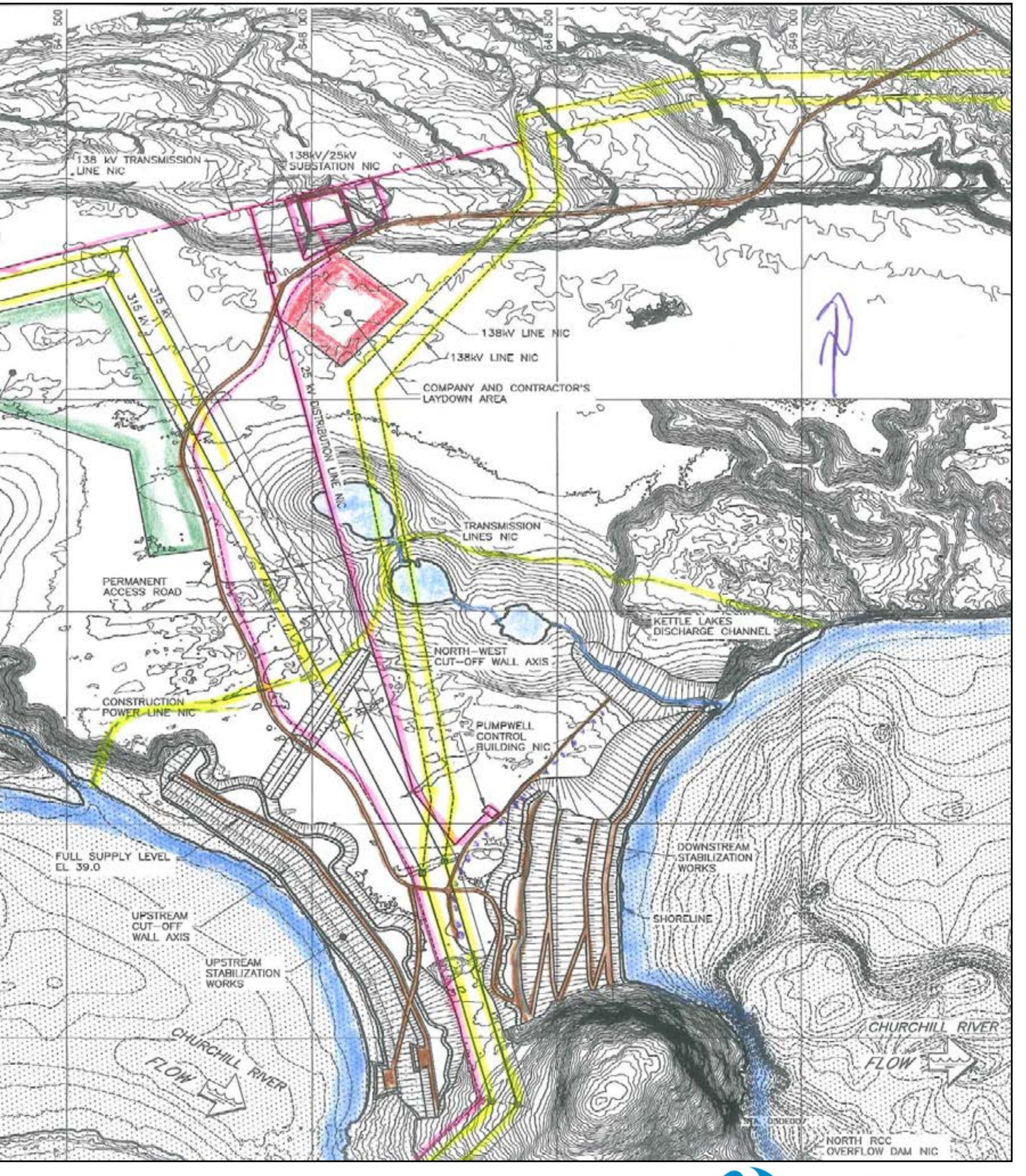
- Excavation
- Slurry cut-off wall
- Improving the three kettle lakes outlet channel

South end of the Spur

- Reduction in surface infiltration
- Drainage improvement (Water coming from the Rock Knoll)

Location of main features

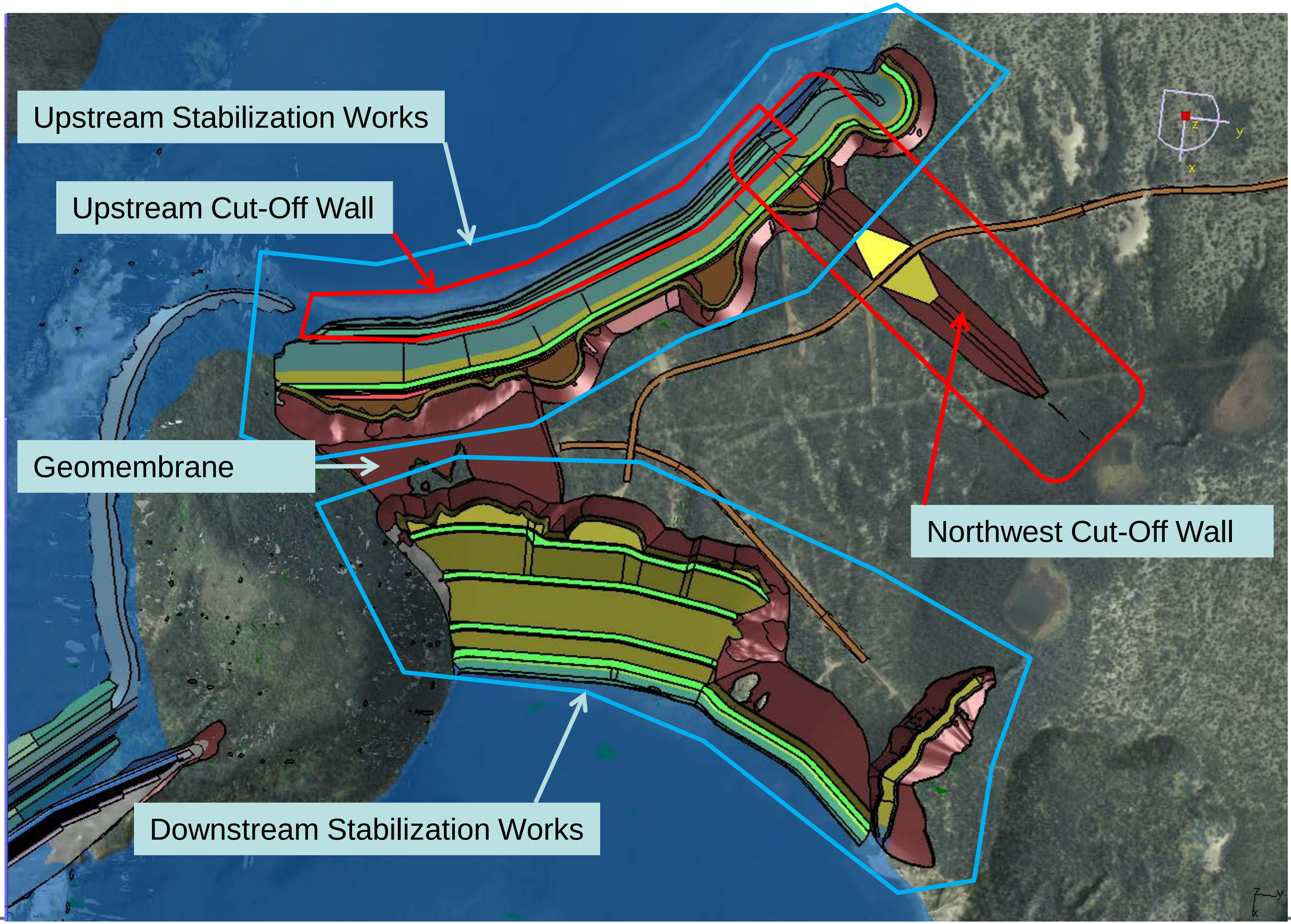
- Permanent roads
- Portage trail
-Transmission lines (NIC)
- Switchyard (NIC)
- Laydown
- Spoil disposal
- Upstream works
- Downstream works
- NW Cut-off wall
- 3 Kettle lakes outlet
- Log Boom platform and access
- Finger Drains
- Relief Wells
- Instrumentation



SNC·LAVALIN EPCM consultant for Nalcor

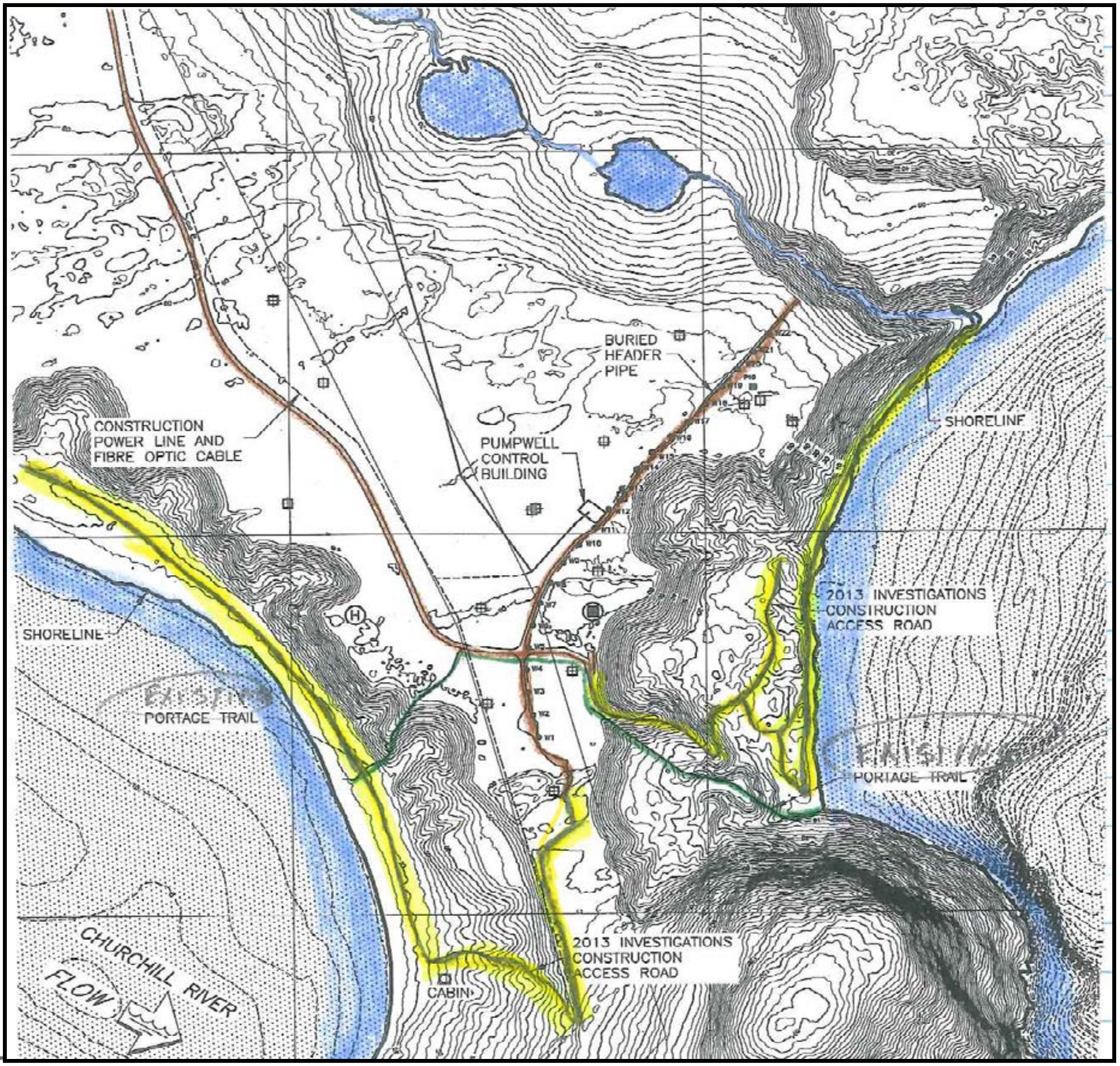
nalcor energy

Layout of Stabilization Works



Upstream and downstream shoreline access

- Existing access road
- Portage trail
- Shoreline access trails



SNC·LAVALIN EPCM consultant for Nalcor

nalcor energy

Upstream access looking up

Upstream access looking down

Upstream cut-off wall location

Downstream Shoreline (July 2013)

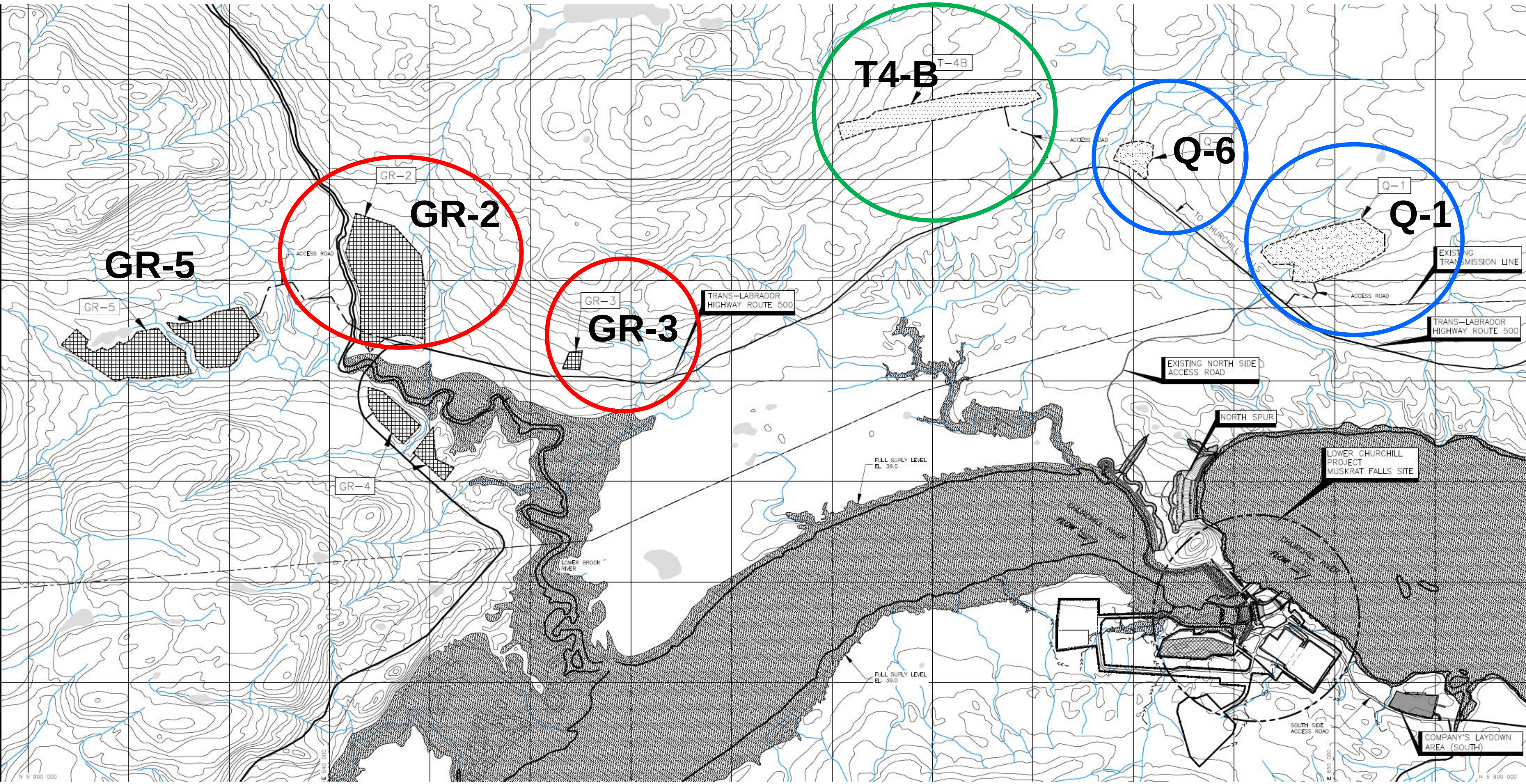
Downstream Ice Jam (May 2013)

3 Kettle Lakes Outlet

Clearing

Streams

Quarries and Borrow Areas location

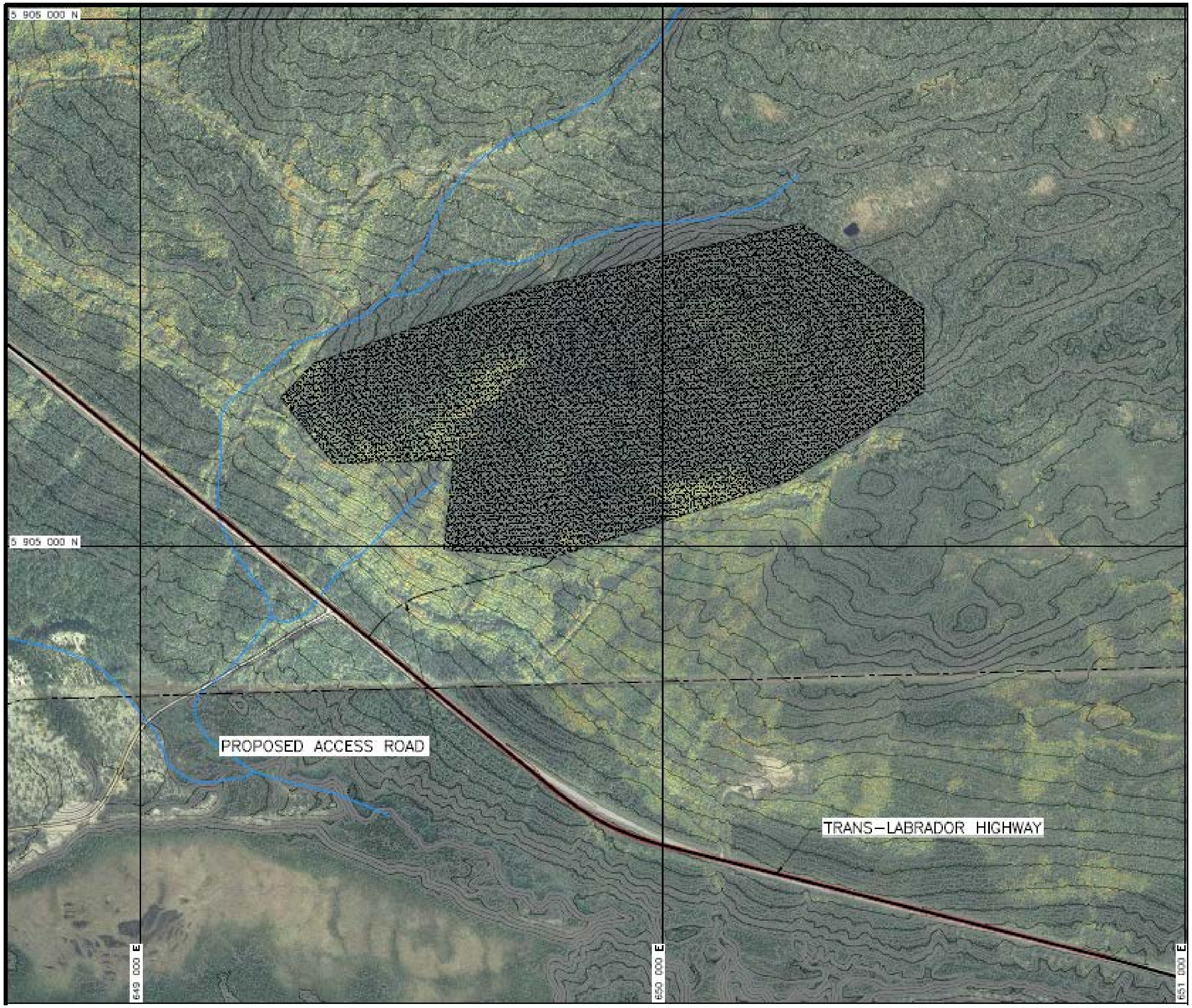


SNC·LAVALIN EPCM consultant for Nalcor

nalcor energy

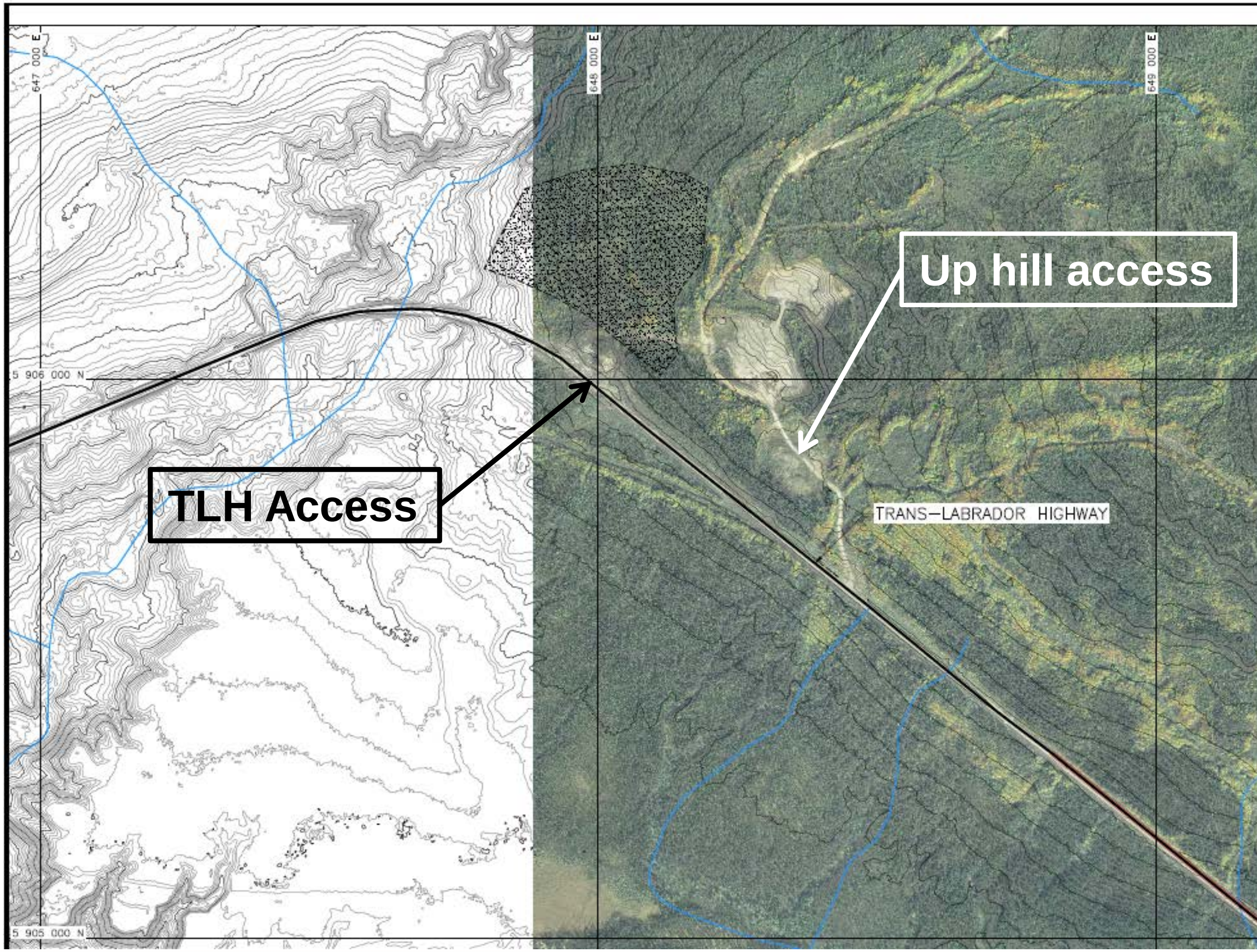
Quarry Q-1

No access

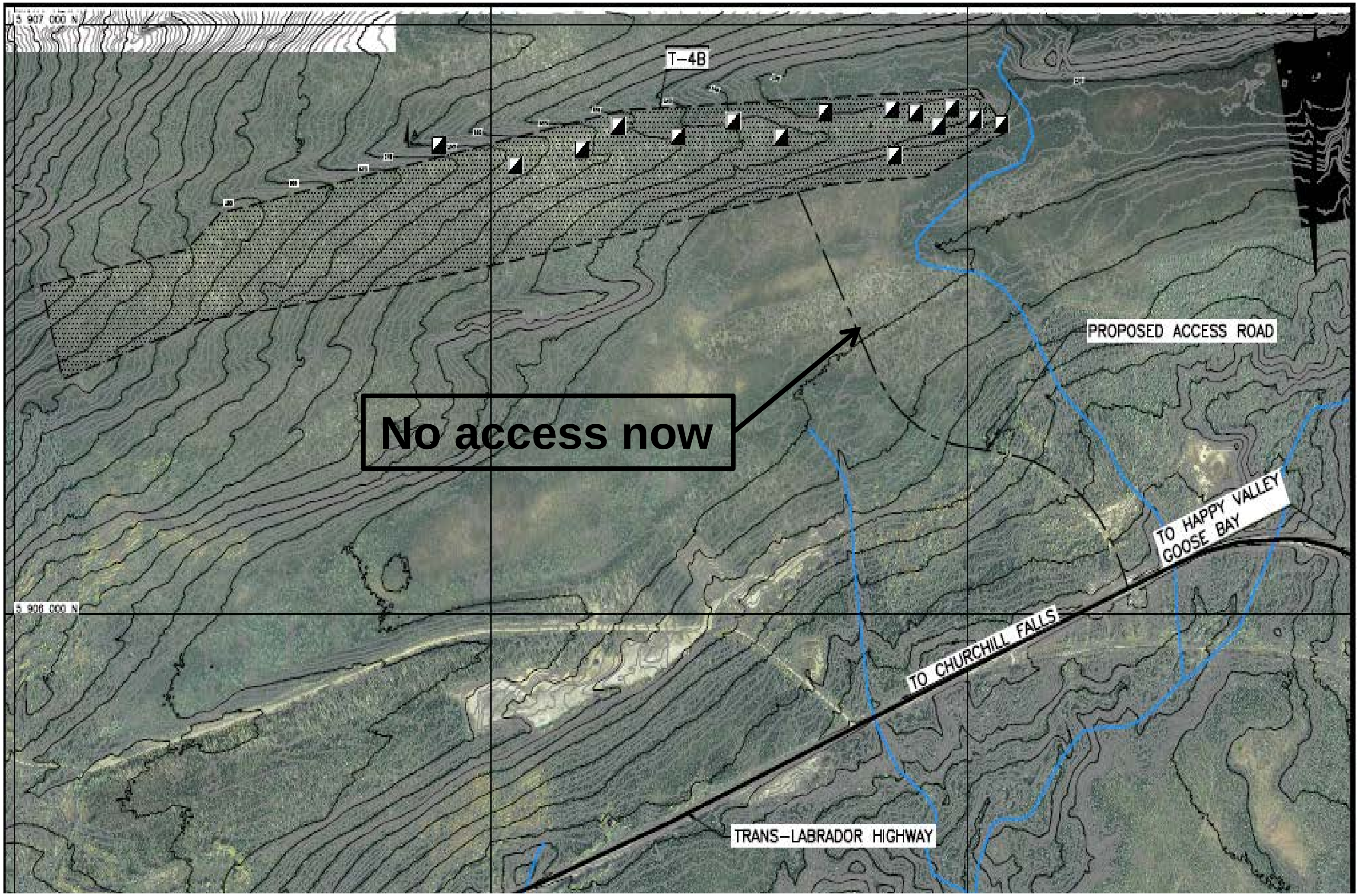


Quarry Q-6 (Existing quarry)

2 Access

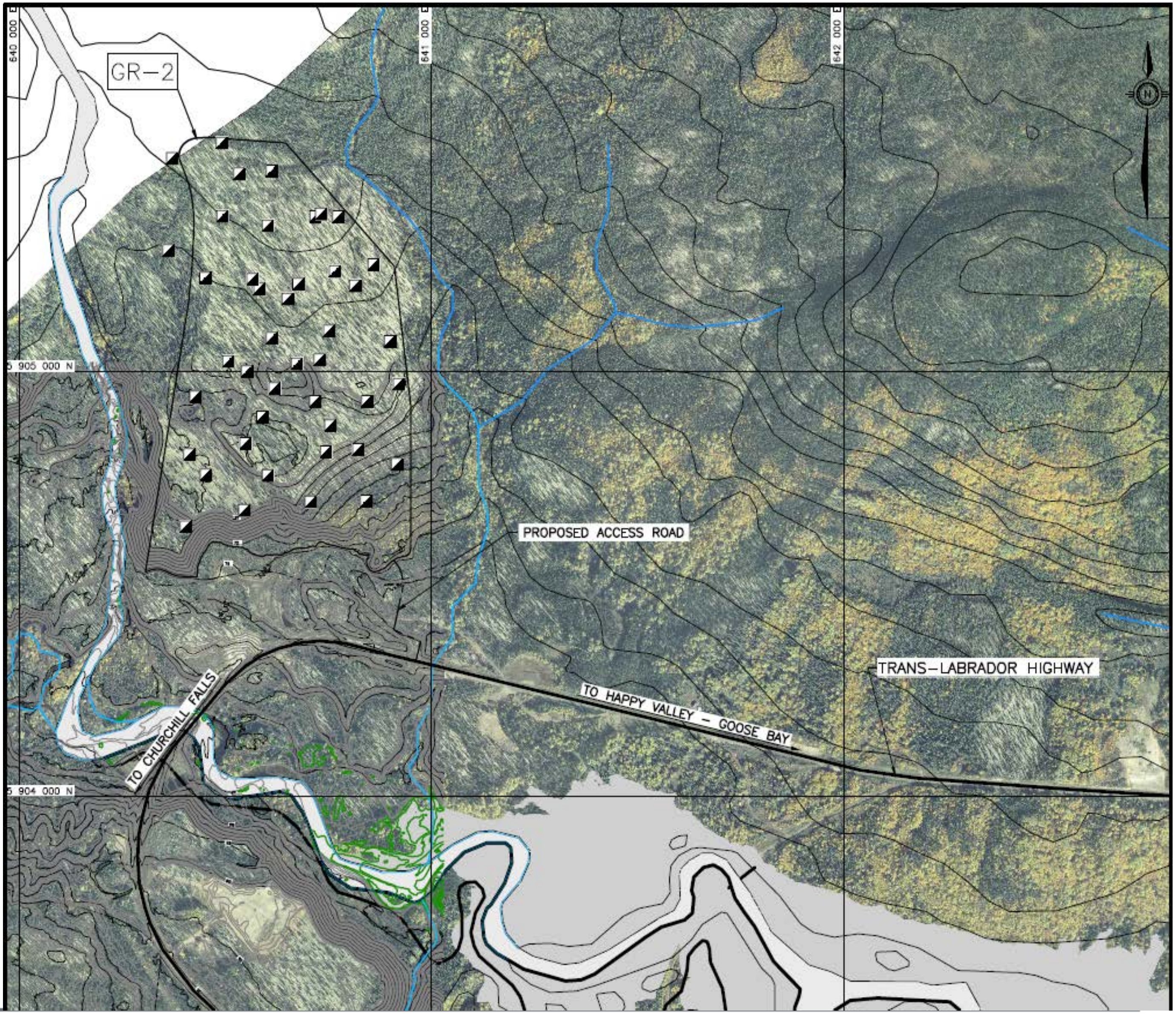


T4-B (Till deposit)



GR-2 (Granular deposit)

Excavator access built to do test pits in 2013



GR-3 (Granular deposit)

Near TLH

SNC·LAVALIN EPCM consultant for Nalcor

nalcor energy

Lower Churchill Project

NORTH SPUR UPDATED, Independent Engineer

21-JUL-2014

Boundless Energy

nalcor energy
LOWER CHURCHILL PROJECT

Outline

- From November report , Independent Engineer (IE) ask to receive more information on:
  - Progressive failure
  - New seepage analysis result (3D model)
  - Impact on piezometry in the lower aquifer by increasing the upstream water level (3D model)
  - Trigger to stop the pumpwell system (3D model)
  - Earthquake criteria (2014, Atkinson updated report)
  - Complementary dynamic study result (Dynamic analysis report)

General approach

- North Spur stability has to be maintain for Short and Long term
  - Evaluate parameters (Design based on Most Probable Conditions)
    - Soil properties (Clay sensitivity)
    - Groundwater conditions
    - External triggers, (wave, erosion, earthquake)
  - Controlling and acting on the triggers
    - Inclination of slope (Geometry)
    - Water pressure in the ground
    - Erosion (Wave effect)
    - Works impact on stability
      - Progressive failure (Downhill and Uphill)
  - Evaluate risk and impact of external uncontrolled triggers
    - Earthquake impact (Long term risk)
      - Liquefaction for sand
      - Strain softening for clays (Cyclic softening)
      - Human triggering
- **Observational Method (Peck, 1969)will be use during Construction works**

Complementary studies, Result presentation (Main Topics)

- Progressive Failure (review and evaluation)
- Three Dimensional (3D) Hydrogeological Study for the North Spur
  - Lower Aquifer
  - Intermediate Aquifer
- Dynamic study
  - Phase 1 and phase 2 studies
  - Gail Atkinson 2008 updated report
  - Input Motion Selection
  - Liquefaction and Cyclic Softening analysis and results

Observational Method (OM)

Step	Status
Exploration sufficient to establish the general nature, pattern and properties of the deposits	Done. Previous investigation results
Assessment of the most probable conditions	Done. Design Report
Creating the design based on the most probable conditions	Done. Technical specifications and drawings
Selection of quantities to be observed as construction proceeds	In progress
Calculation of values under the most unfavorable condition	In progress
Selection of a course of action for every foreseeable	In progress
Measurement of quantities and evaluation	During construction works
Design modification	During construction

Progressive Failure

Boundless Energy

nalcor energy
LOWER CHURCHILL PROJECT

Retrogressive landslide

Flowslide

Downhill progressive

Uphill progressive (Spread)

Flowslide at Edwards Island 2010

(Muskrat Falls reservoir, km 73)

Safety factor against progressive failure

- Calculations are based on slope geometry, soil properties, groundwater properties. **Calculations are calibrated locally with an existing slope.**
- Rotational, flowslide, spread stability is calculated with **a first movement at the toe.**
- There is **no** evidence of downhill progressive failure landslide along the Churchill river valley.
- **Counter measure will be in place to control "Human triggering"**

Conclusion on progressive failure risk

- North Spur Short and Long Term Stability is a major concern for LCP team
- Current design has evolved over many years and has been based on substantial geotechnical data.
- Canadian Dam Association guidelines requirements are followed and exceeded in Dam safety.
- Construction works will be followed to ensure that design objectives will be achieve. (Application of Observational Method)
- A special workshop was done with bidders to share our knowledge and concerns about stability concern.

Hydrogeological Study, 3D model

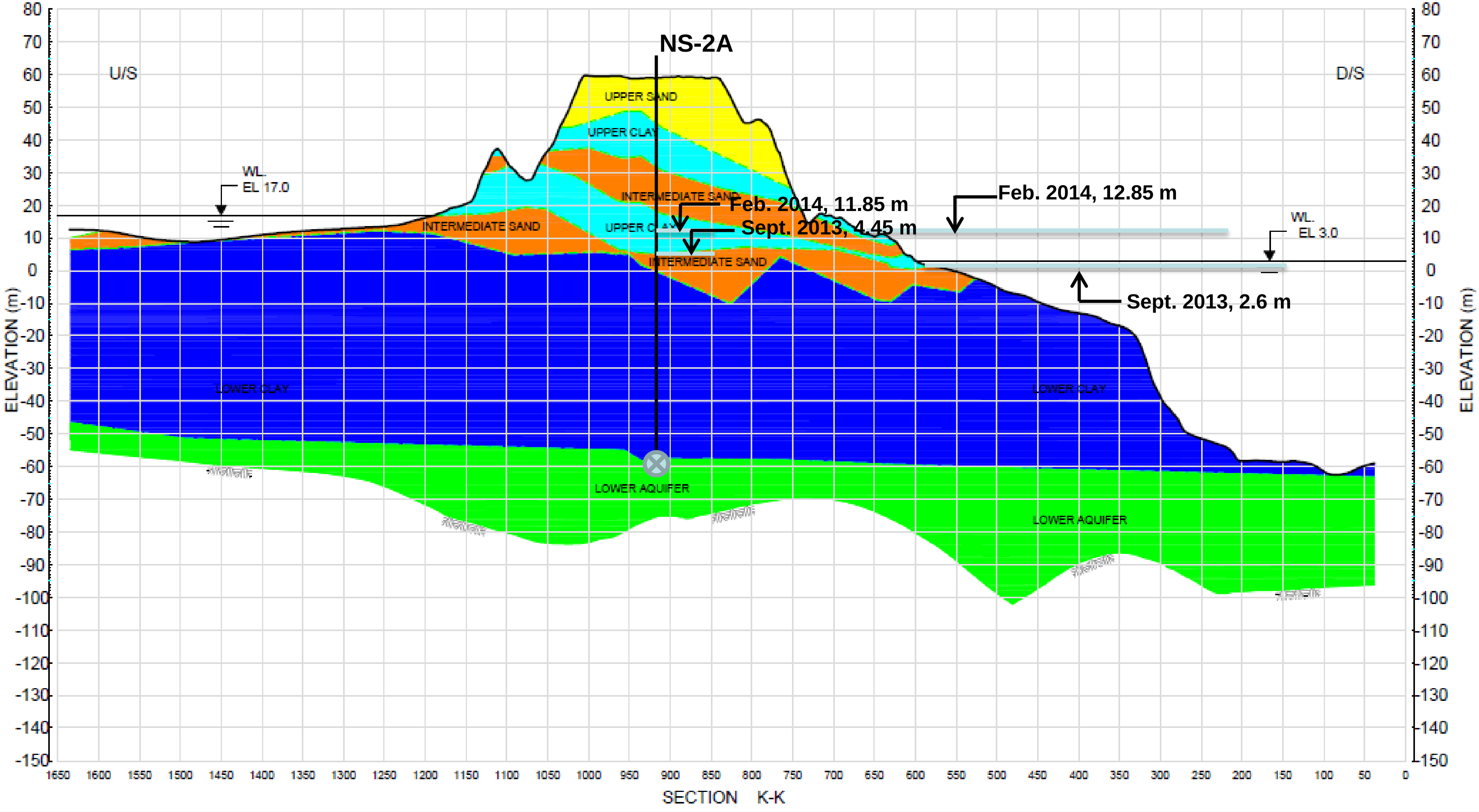
Boundless Energy

nalcor energy
LOWER CHURCHILL PROJECT

Purpose of the model(s)

- Develop a tool to define trigger in the Observational Method
- Simulate the behavior of both aquifers (Intermediate and Lower) during and after the two impoundments (25 and 39 m)
- Simulate the effect of the two cut off walls
- Simulate the global effect of the stabilization works
- Consider the effect of the existing pumpwell system operation

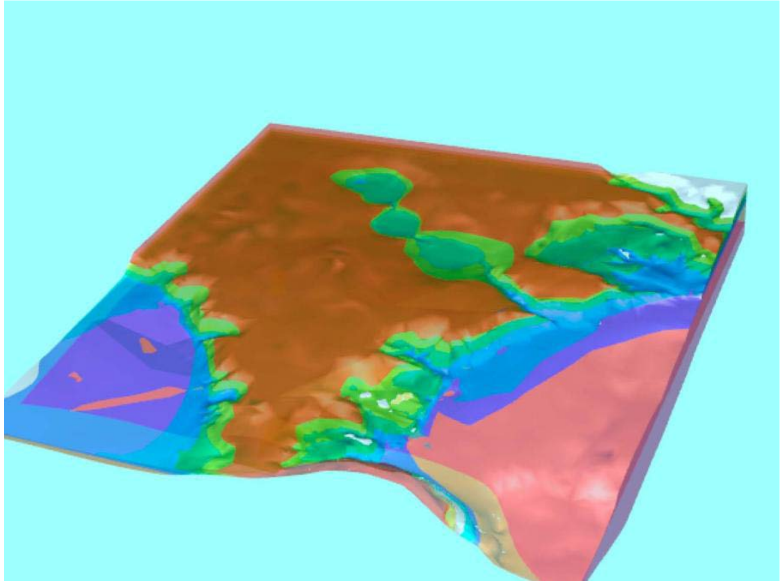
Lower aquifer connection to the River on the downstream side of the North Spur



North Spur3D model for Lower Aquifer

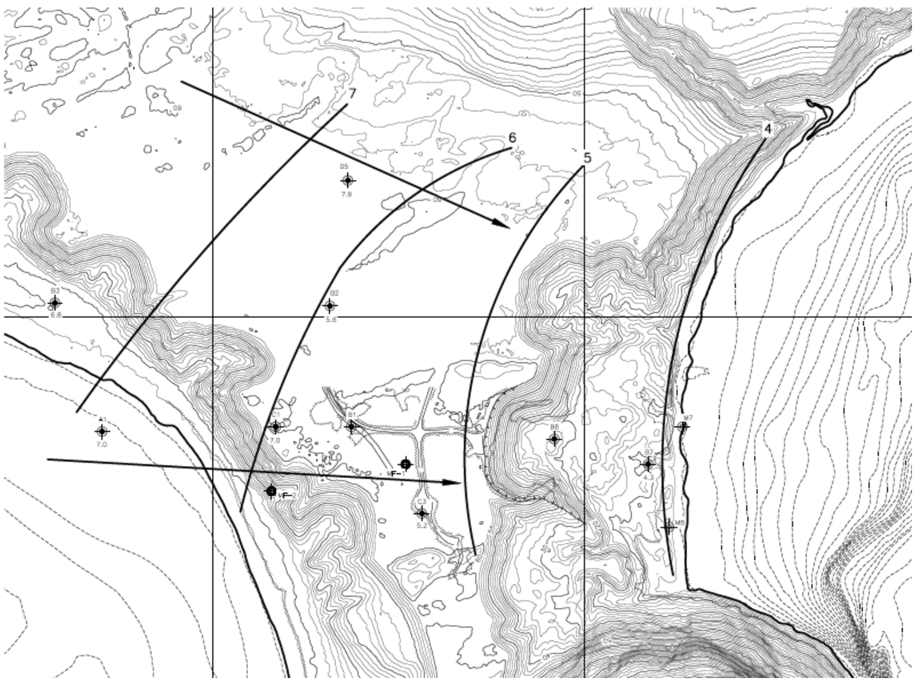
Model Area:
1.5 Km(W-E) X 1.65 km (N-S)

Soil layers:
Lower Clay and Lower Aquifer

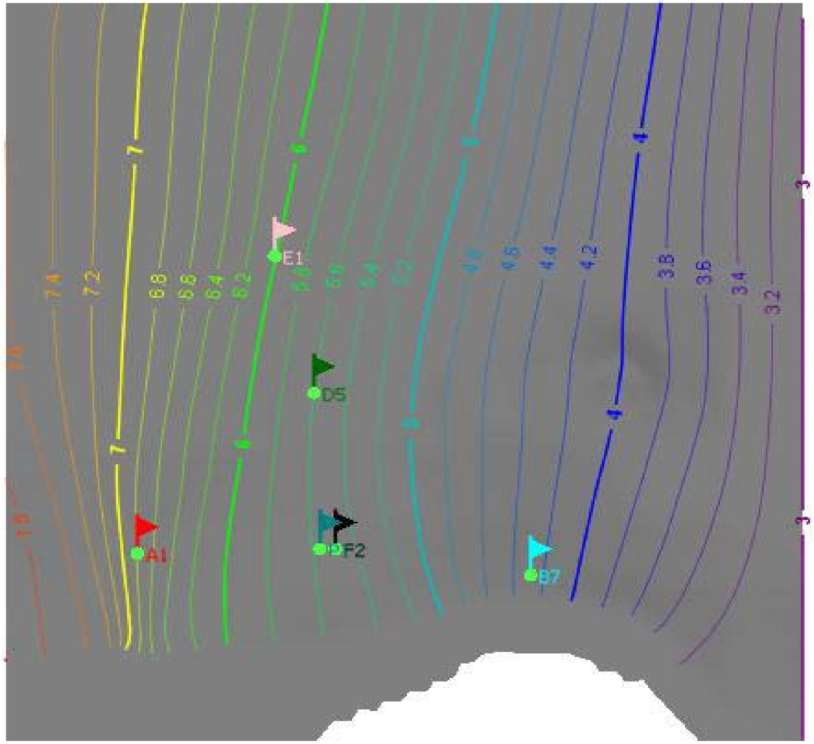


Lower aquifer model calibration

Existing Condition before Pump Testing in 1979

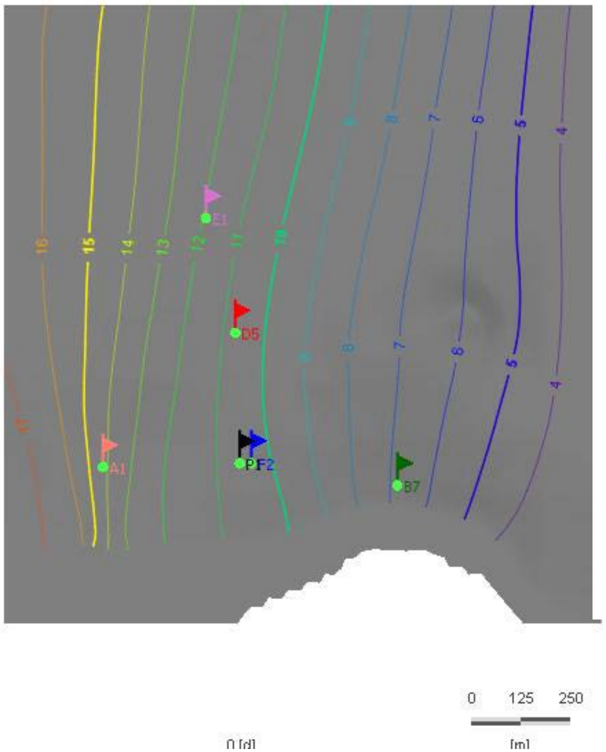


In-situ Measurement



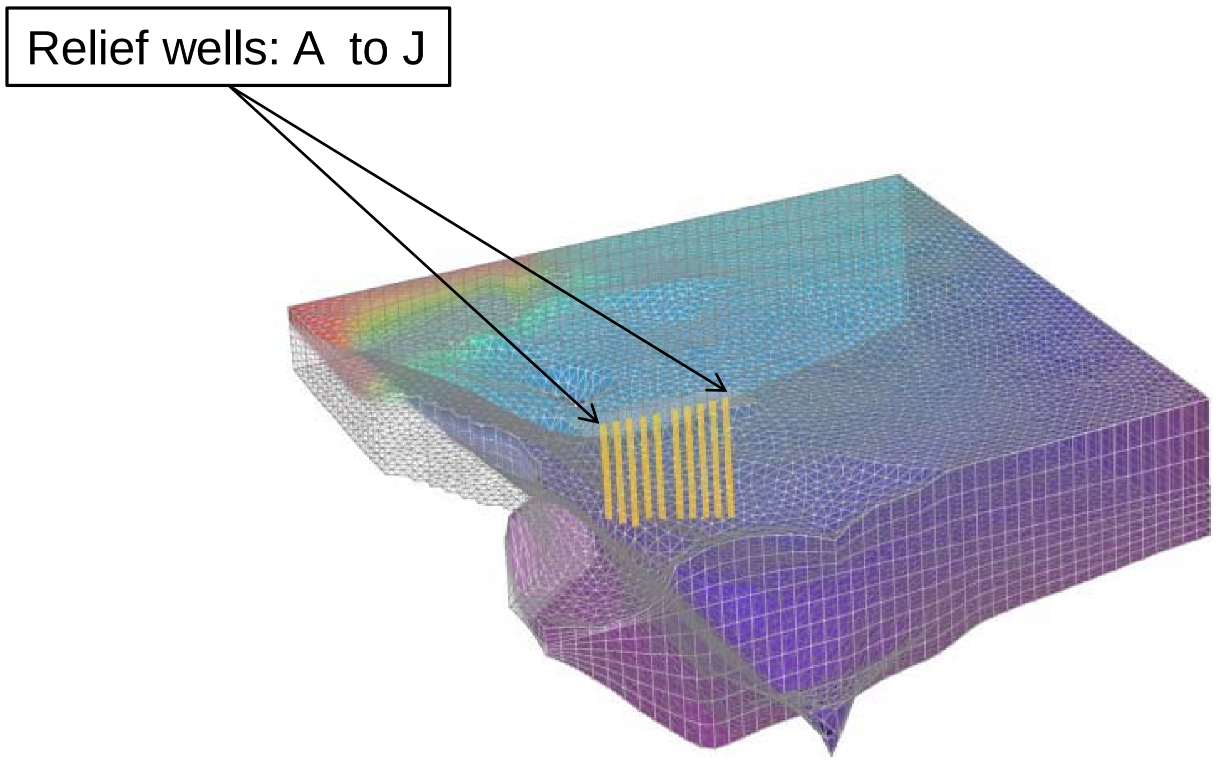
3D FEFLOW Model

Case Study-WL=25 and 39m, No Relief Wells



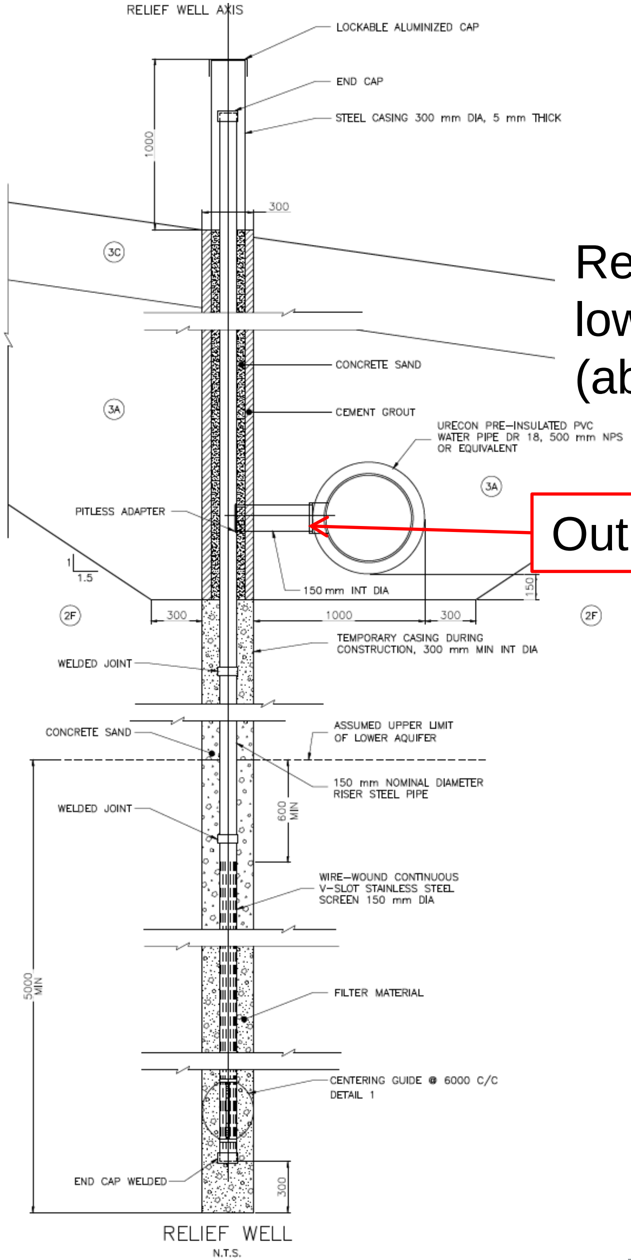
Piezometer/ Locations	Initial condition (U/S WL=17.5 m)	U/S WL= 25 m/no relief wells		U/S WL = 39 m/no relief wells	
		Head EL.	Raising	Head EL.	Raising
F2	5.5	7.6	2.1	10.3	4.8
P1	5.6	7.7	2.1	10.5	4.9
A1	6.9	10	3.1	14.4	7.5
B7	4.1	5.4	1.3	6.9	2.8
D5	5.6	7.7	2.1	10.8	5.2
E1	6	8.5	2.5	12	6
		Avg	2.2		5.2

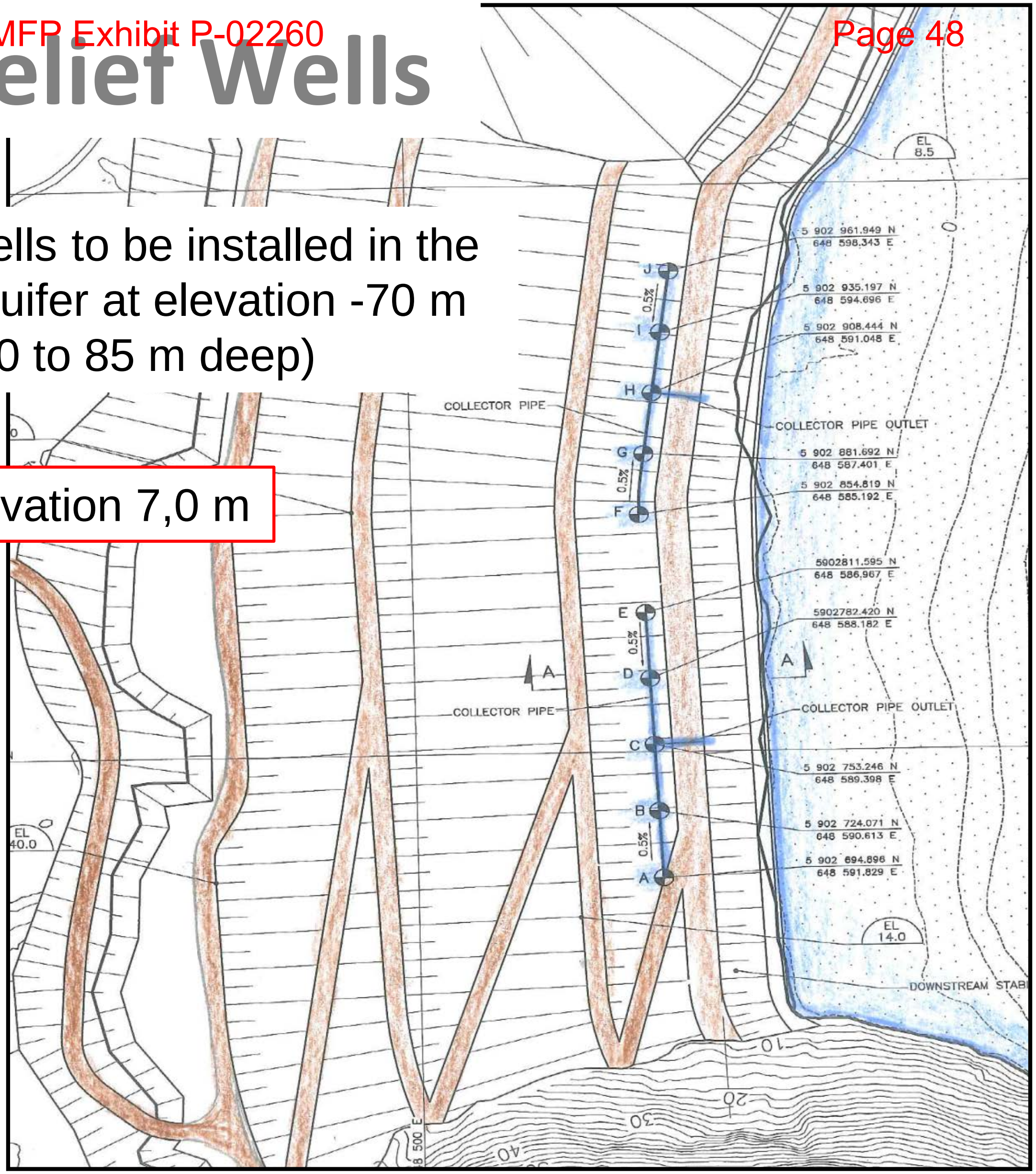
Case Study-Install Relief Wells in Lower Aquifer



10 Relief Wells, Φ30cm

Relief Wells

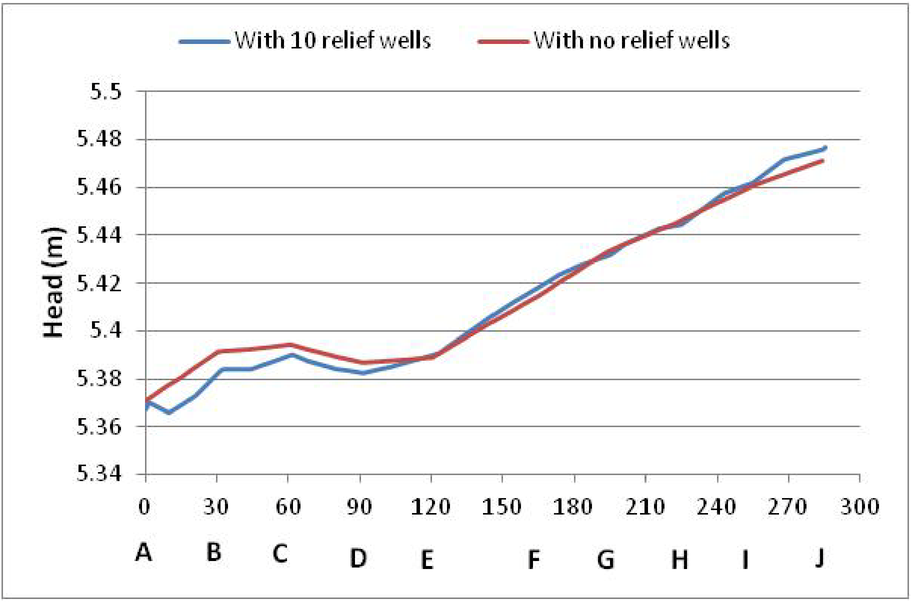




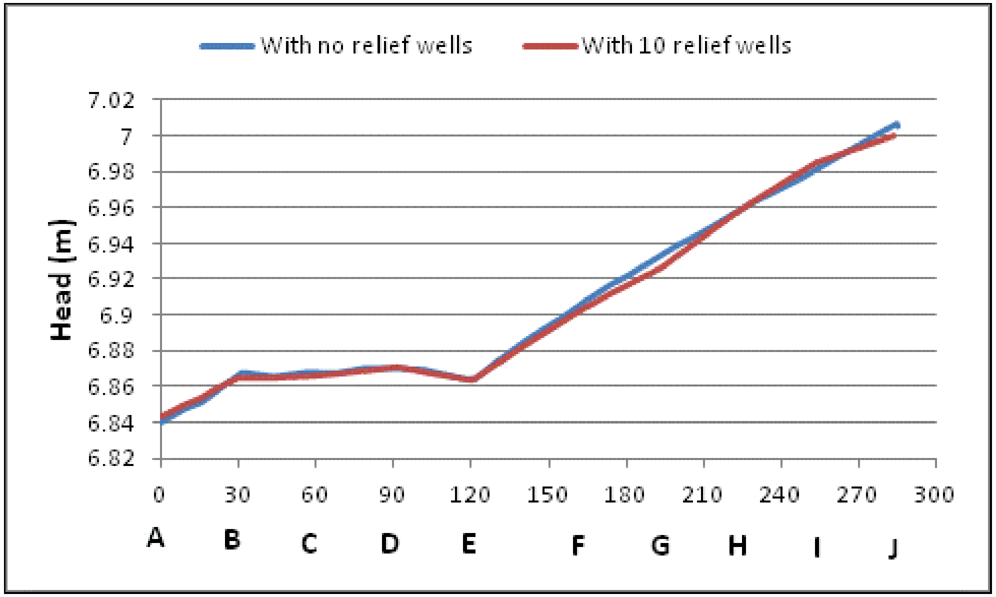
Relief wells to be installed in the lower aquifer at elevation -70 m (about 80 to 85 m deep)

Outlet elevation 7,0 m

Case Study-Install D/S Relief Wells



Hydraulic Head U/S, WL=25m

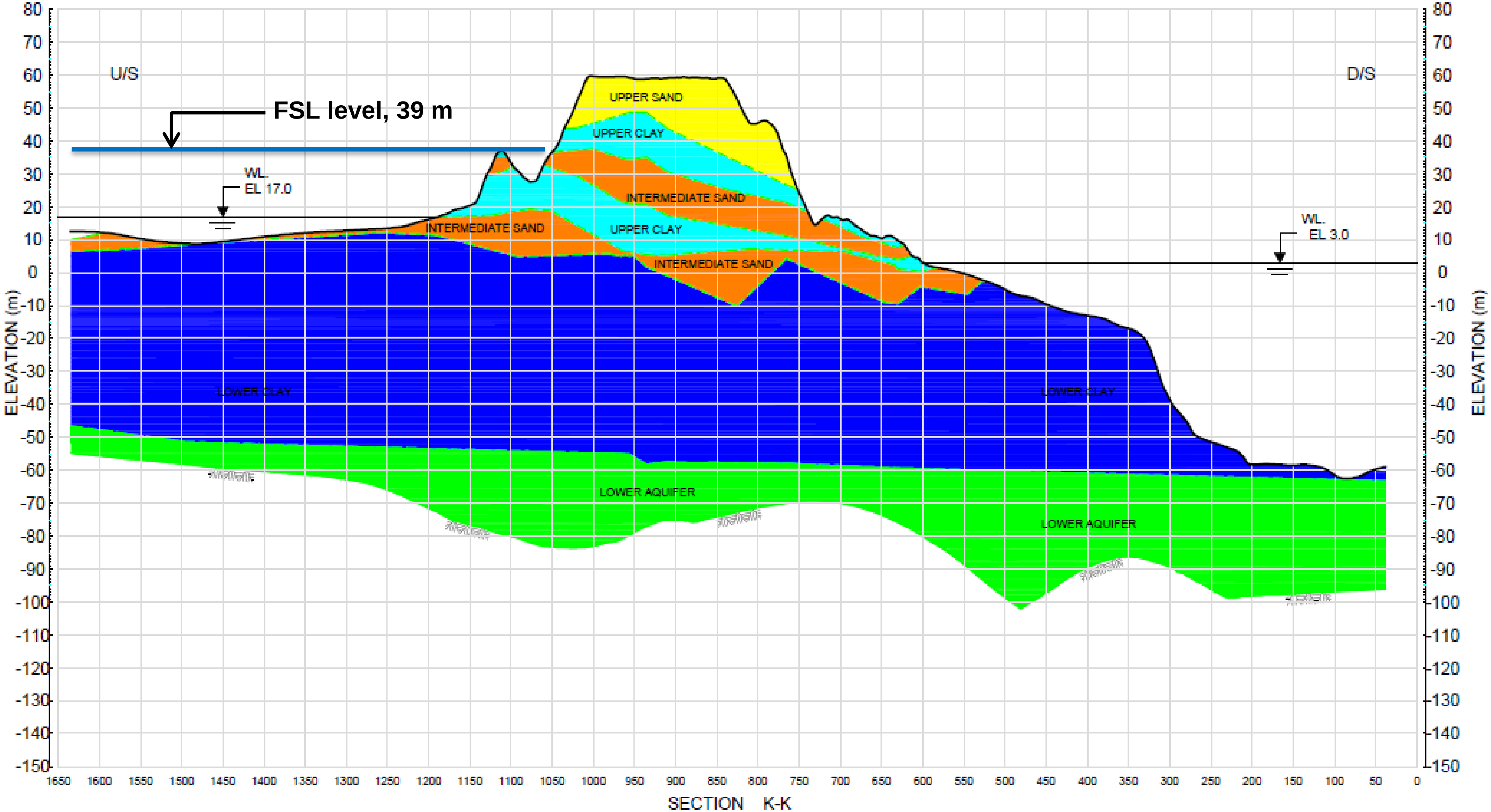


Hydraulic Head U/S, WL=39m

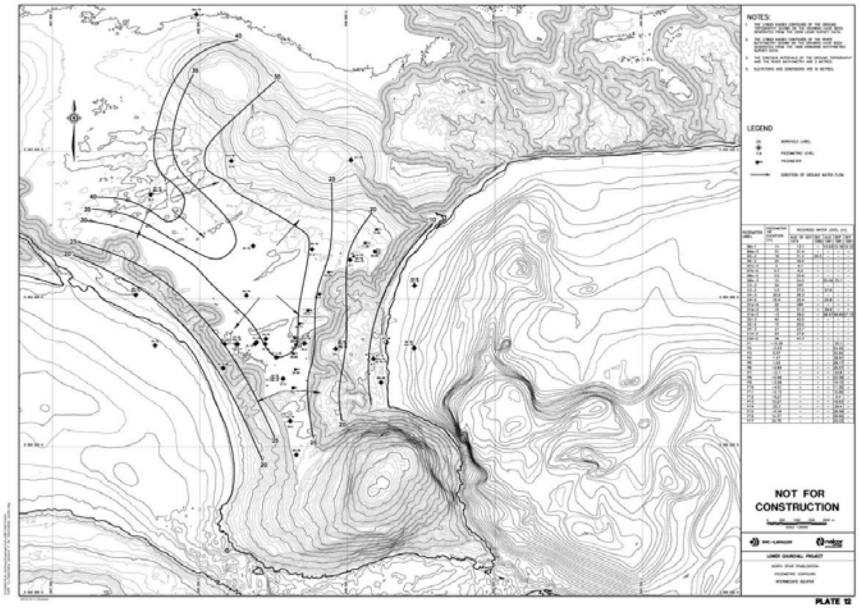
Hydrogeological model Conclusion

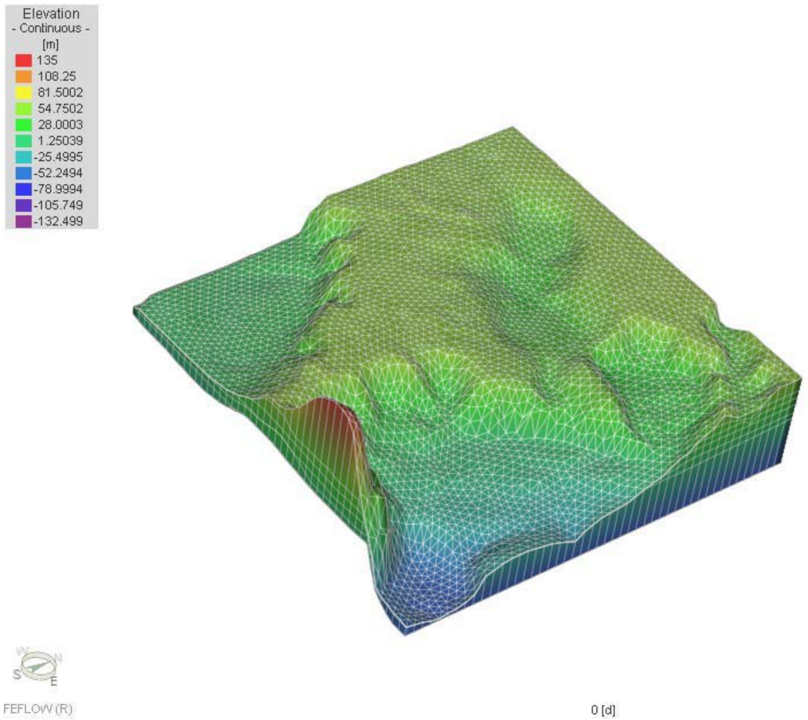
- **Lower Aquifer**
  - Model perform good to represent:
    - Actual condition
    - 1979 Pump Test
    - Churchill Falls event (river raising 2,82m)
  - After impoundment and installation of Relief wells
    - Model show no impact for 25m and 39m impoundments
- **Action**
  - We maintain the relief wells installation in the current CH0008 package.
  - Analysis of piezometric reaction of Lower Aquifer has to be done before making a final decision to install relief wells. (OM)
  - Installation will be done, if required, after 1st impoundment. (OM)

Intermediate Aquifer



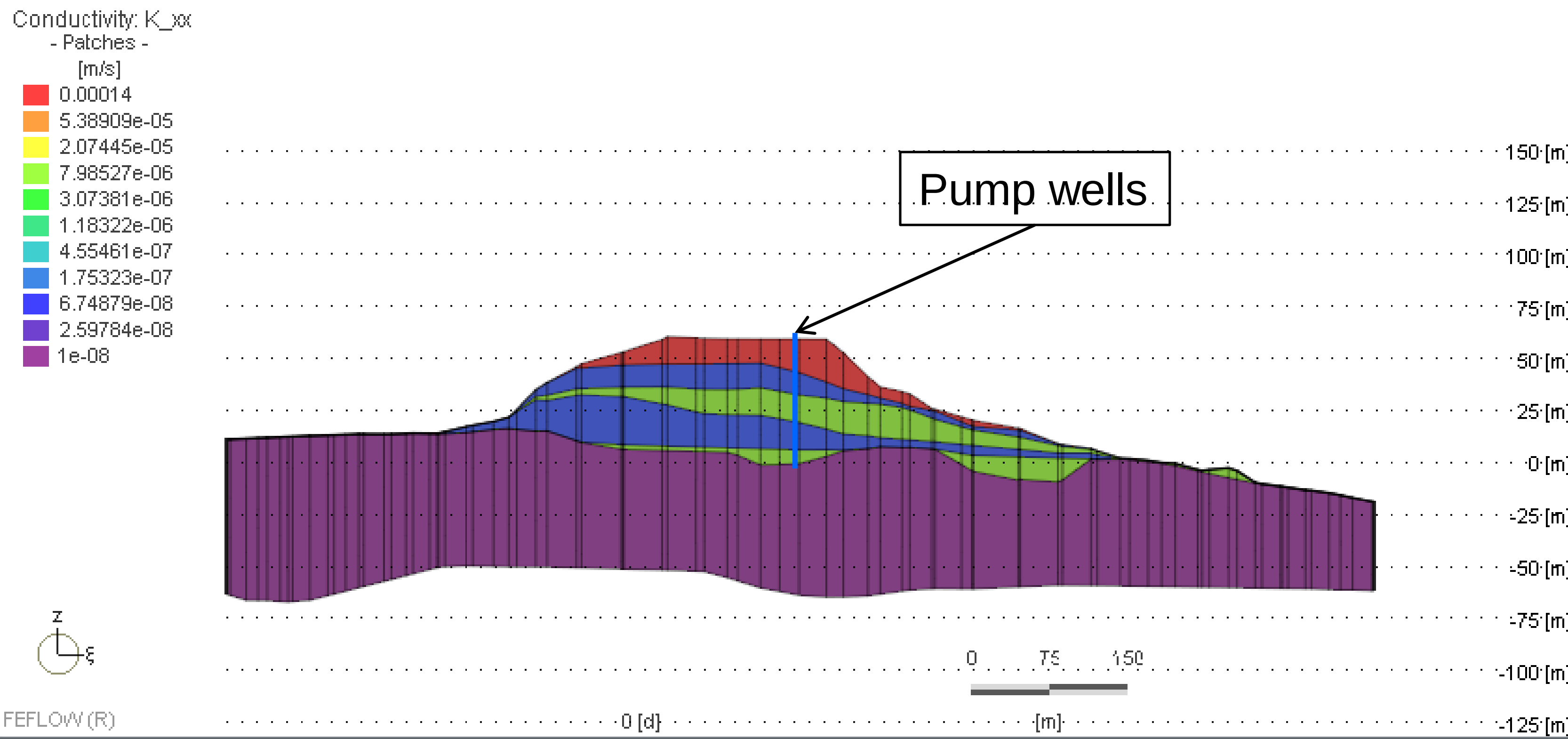
Intermediate Aquifer model



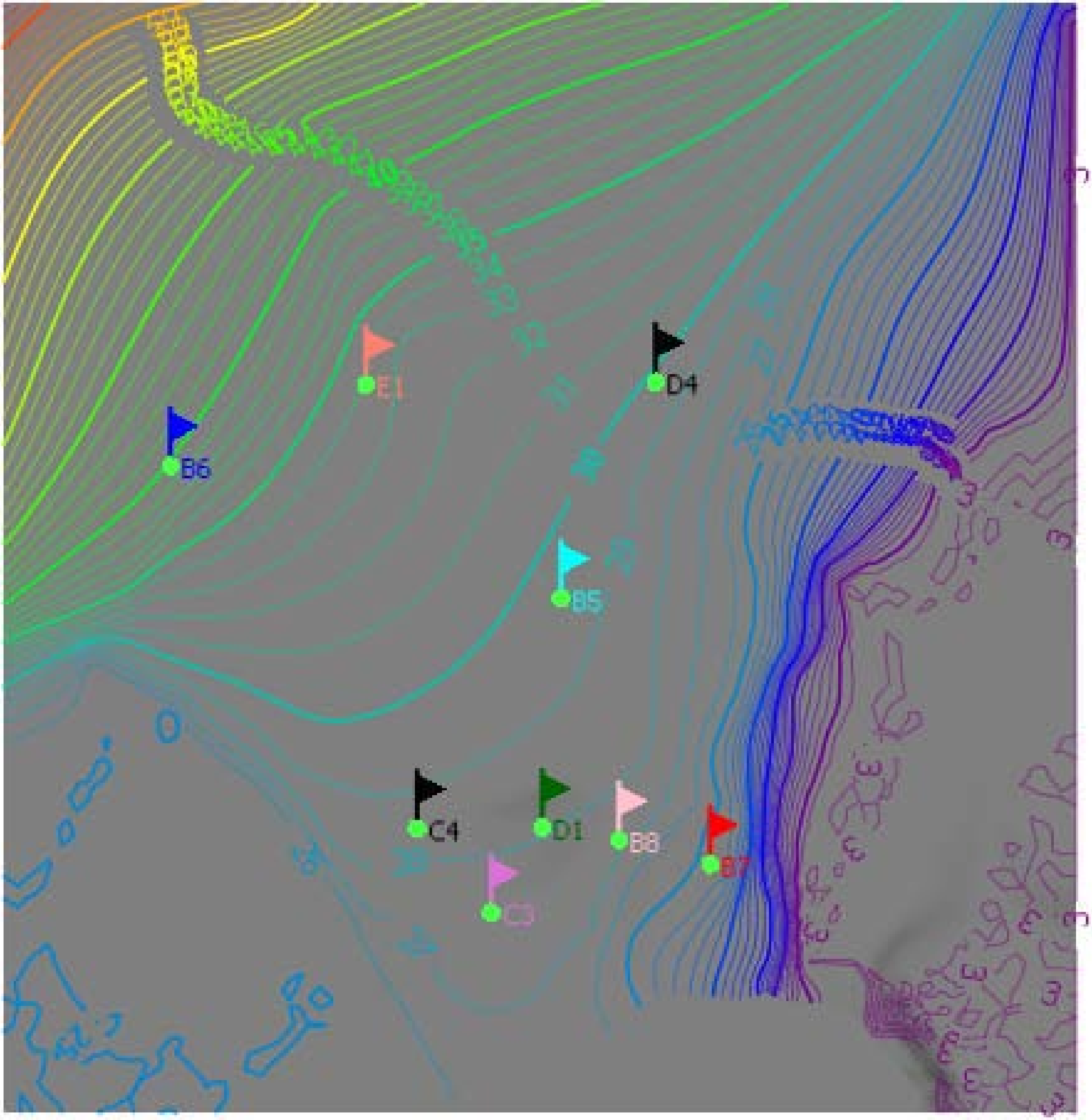


Soil properties, Permeability (K)

Layer 1 □ Upper Sand □ K= 1x10-4 m/s.
Layer 2 □ Silty Clay-1 □ k= 1x10-7 m/s.
Layer 3 □ Upper Intermediate Silty Sand Drift □ k= 8x10-6 m/s.
Layer 4 □ Silty Clay-2 □ k= 1x10-7 m/s.
Layer 5 □ Lower Intermediate Silty Sand Drift □ k= 8x10-6 m/s.
Layer 6 □ Clay □ k=1x10-8 m/s.



Piezometer location

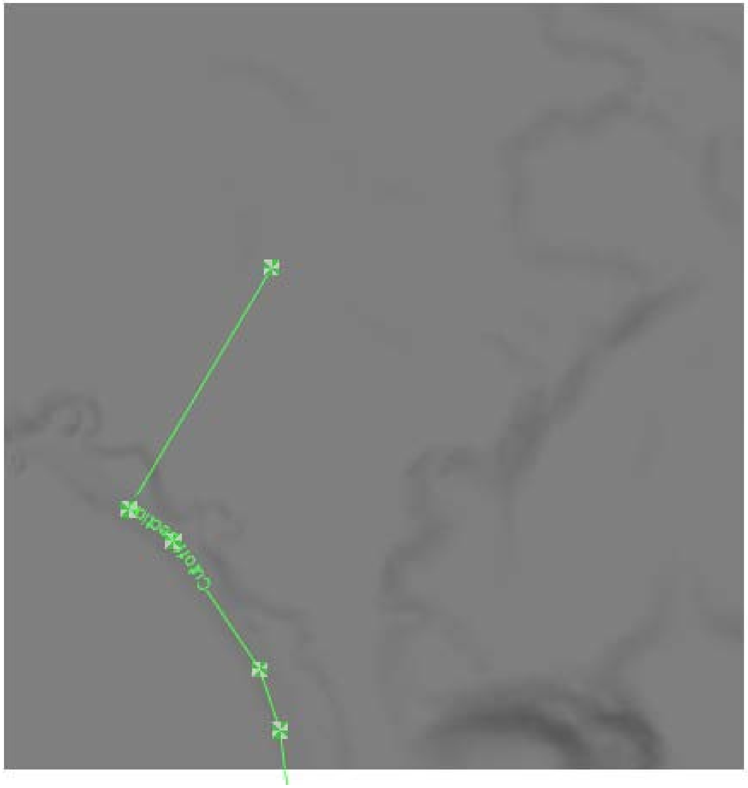


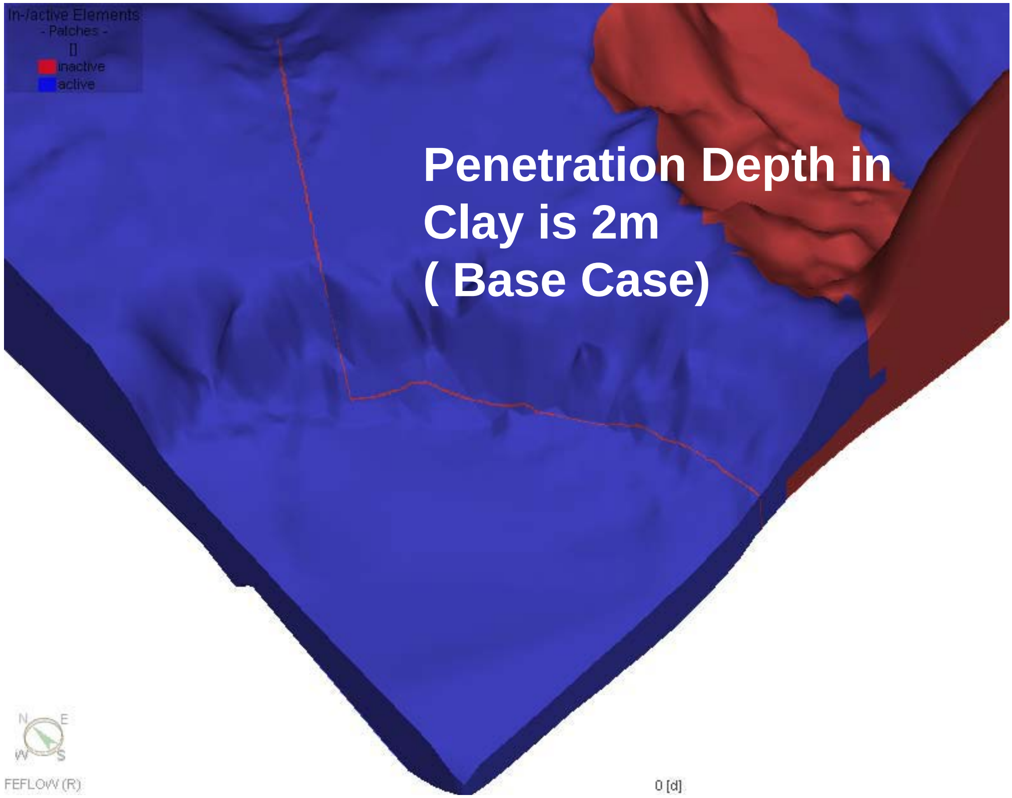
Response of Intermediate Aquifer to Impoundment (No Stabilization Works)

	IA-0	IA-1	IA-6
Piezometers	U/S @ WL 17.5 m	U/S @ WL= 25 m	U/S @WL= 39 m
B6	38.80	39.80	43.90
E1	33.50	34.10	36.30
D4	29.50	29.80	31.20
B5	28.90	29.50	33.80
C4	27.30	28.60	37.40
C3	26.30	27.60	36.90
D1	26.80	28.10	36.30
B8	26.00	27.30	35.10
		+1 m	+7 m

Installation of Cut off Walls (COWs)

Plan Section of COWs

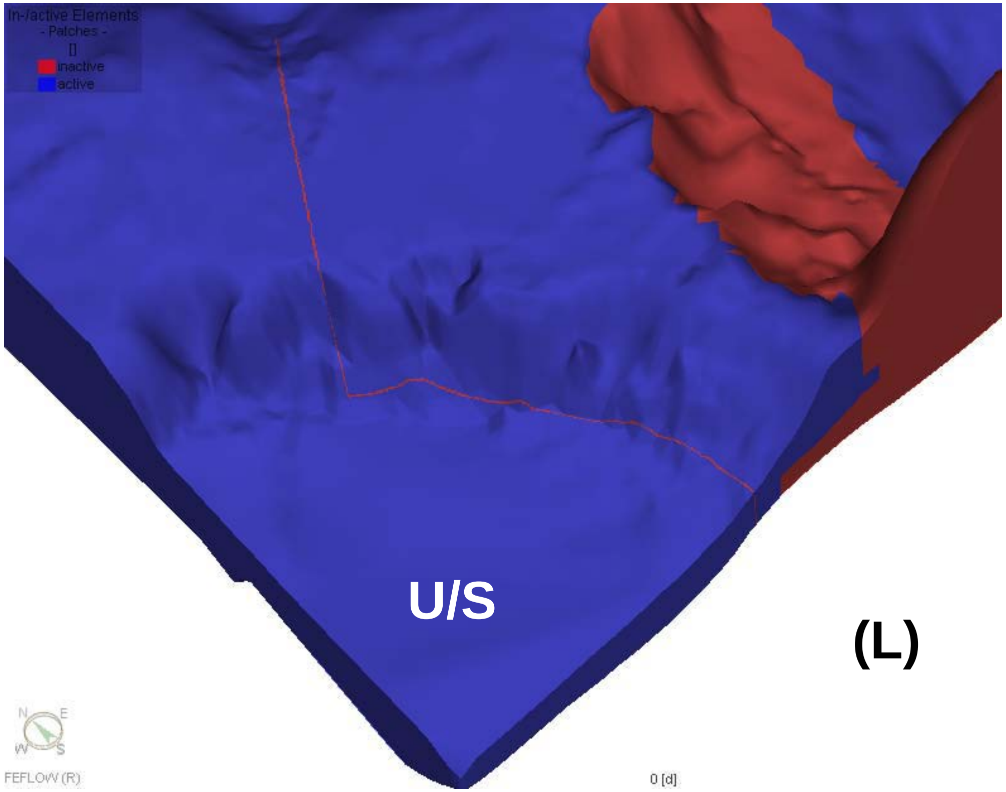




Sensitivity Study of COWs Penetration Depth (L) in Lower Clay

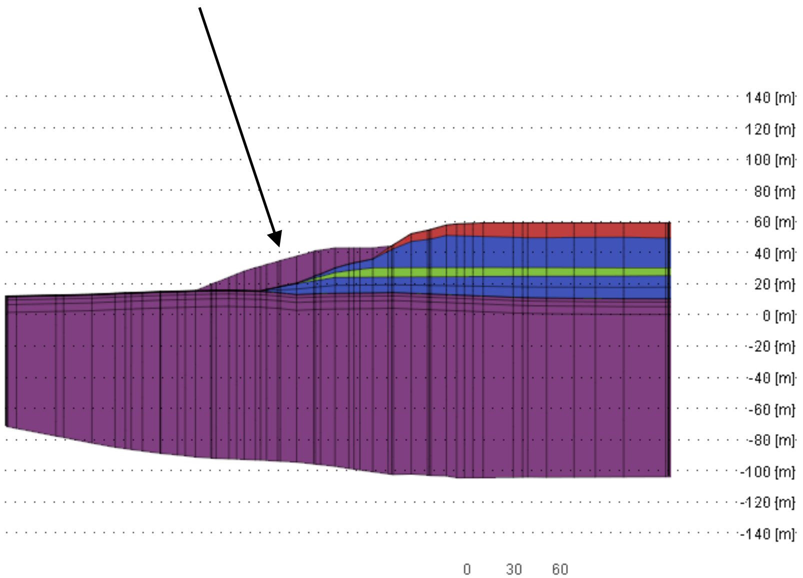
L = 2 m, 5 m, 10 m.

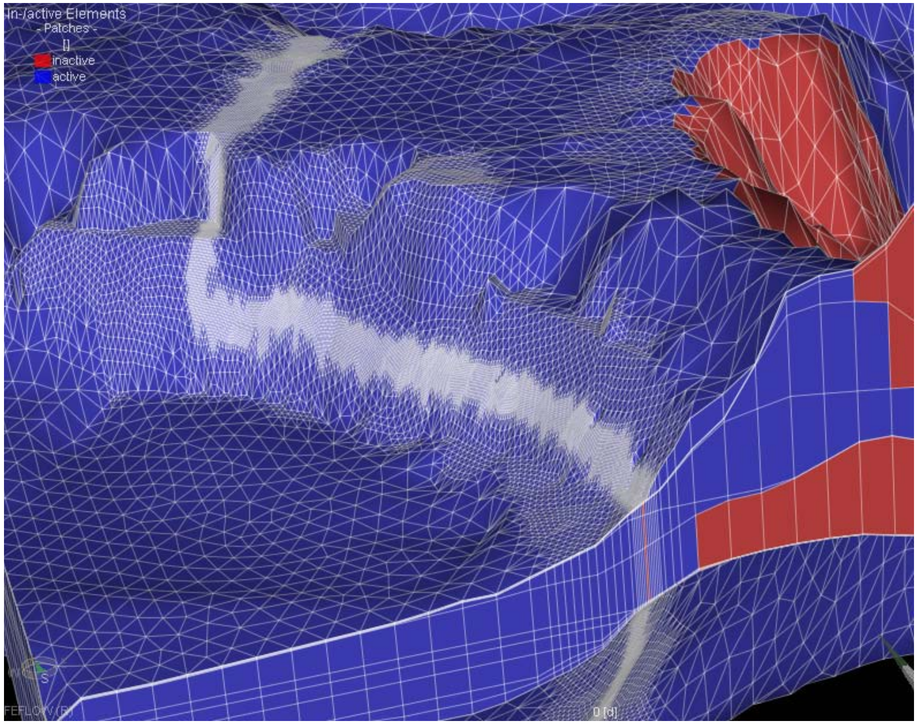
- **No impact on the response of hydraulic heads in Intermediate Aquifer**



Installation of U/S Till Blankets

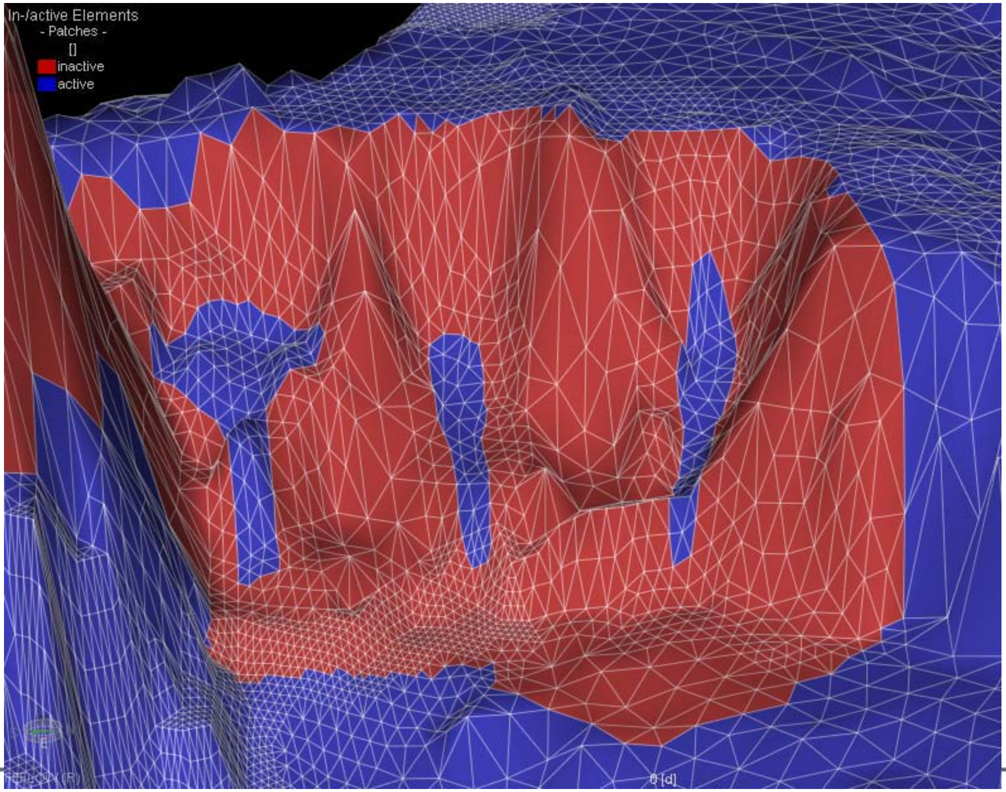
U/S Till Blanket (k=1x10-8 m/s)





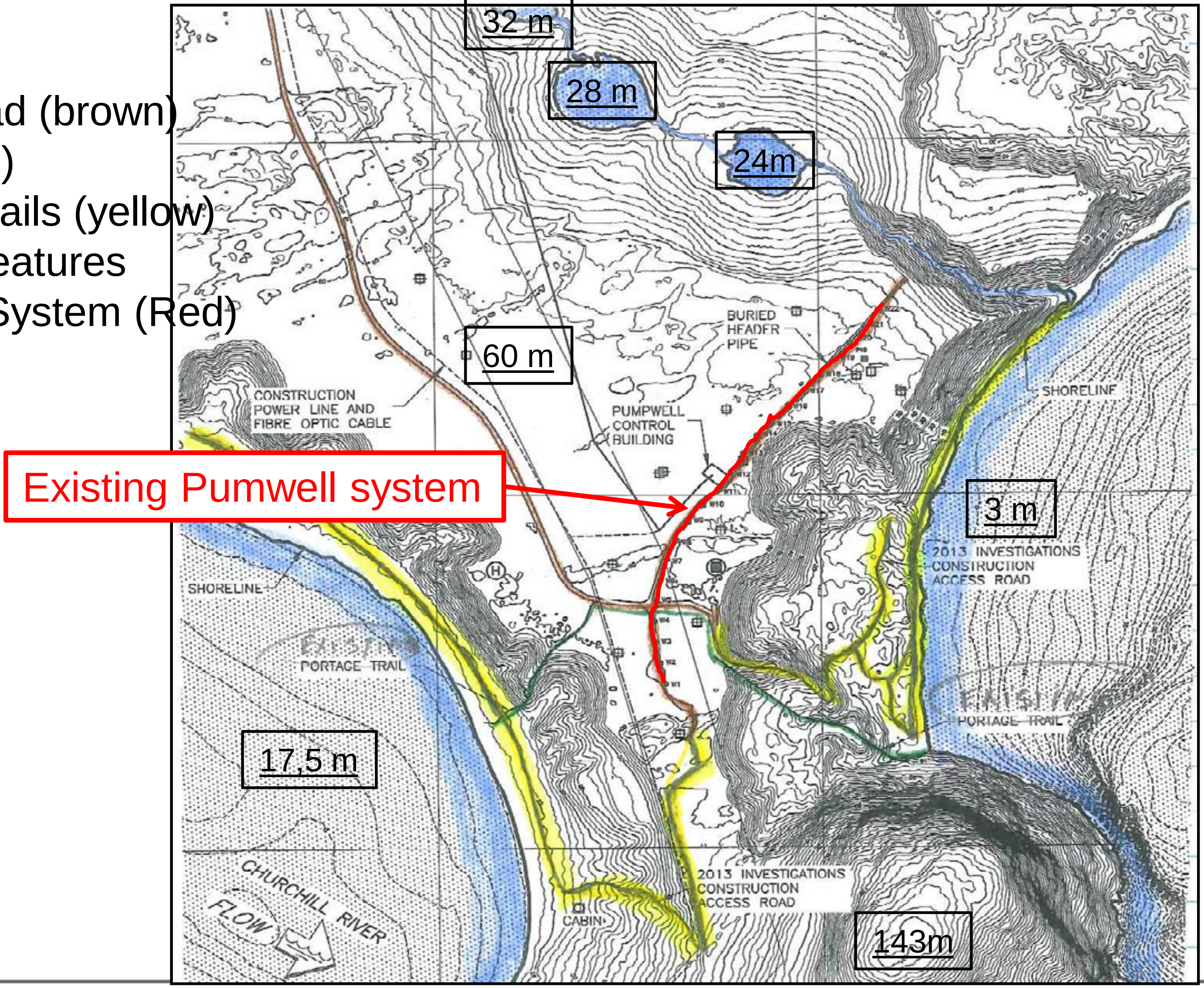
Installation of D/S Finger Drains

3 Finger Drains based on the current design

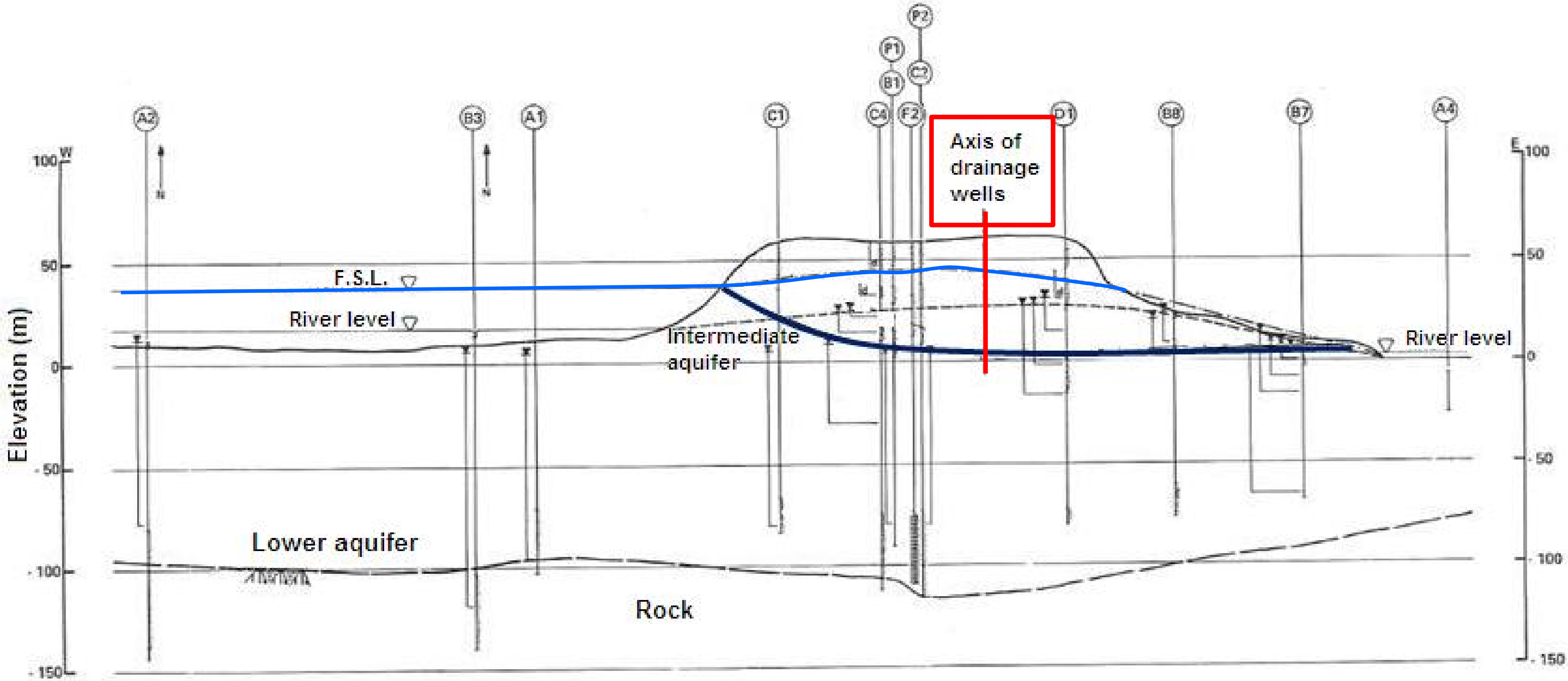


Existing Pumpwell System

- Existing access road (brown)
- Portage trail (green)
- Shoreline access trails (yellow)
- Elevation of main features
-Existing Pumpwell System (Red)



Axis of Pumwell System

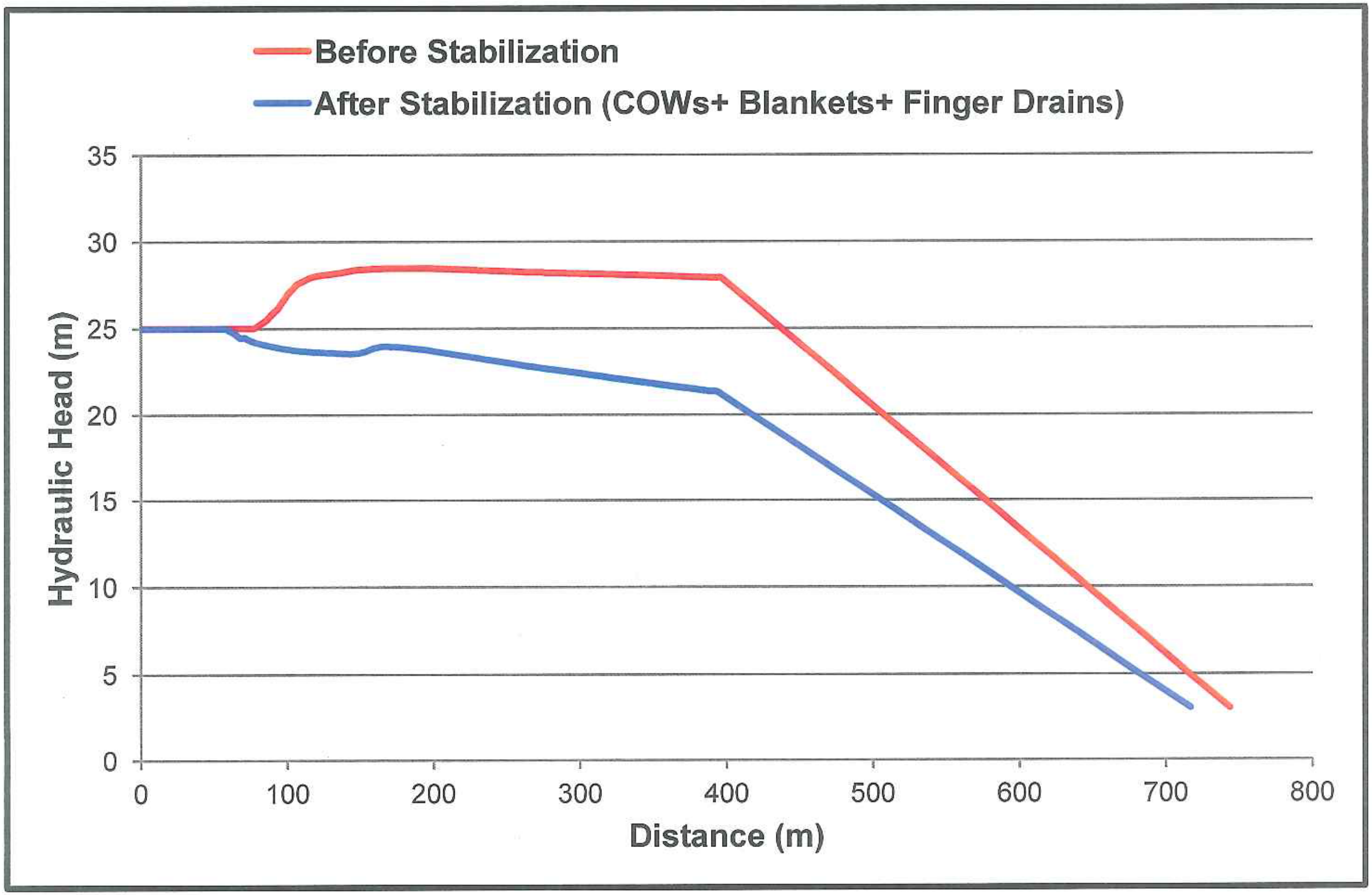


- - - - - Piezometric surface of the intermediate aquifer under present condition

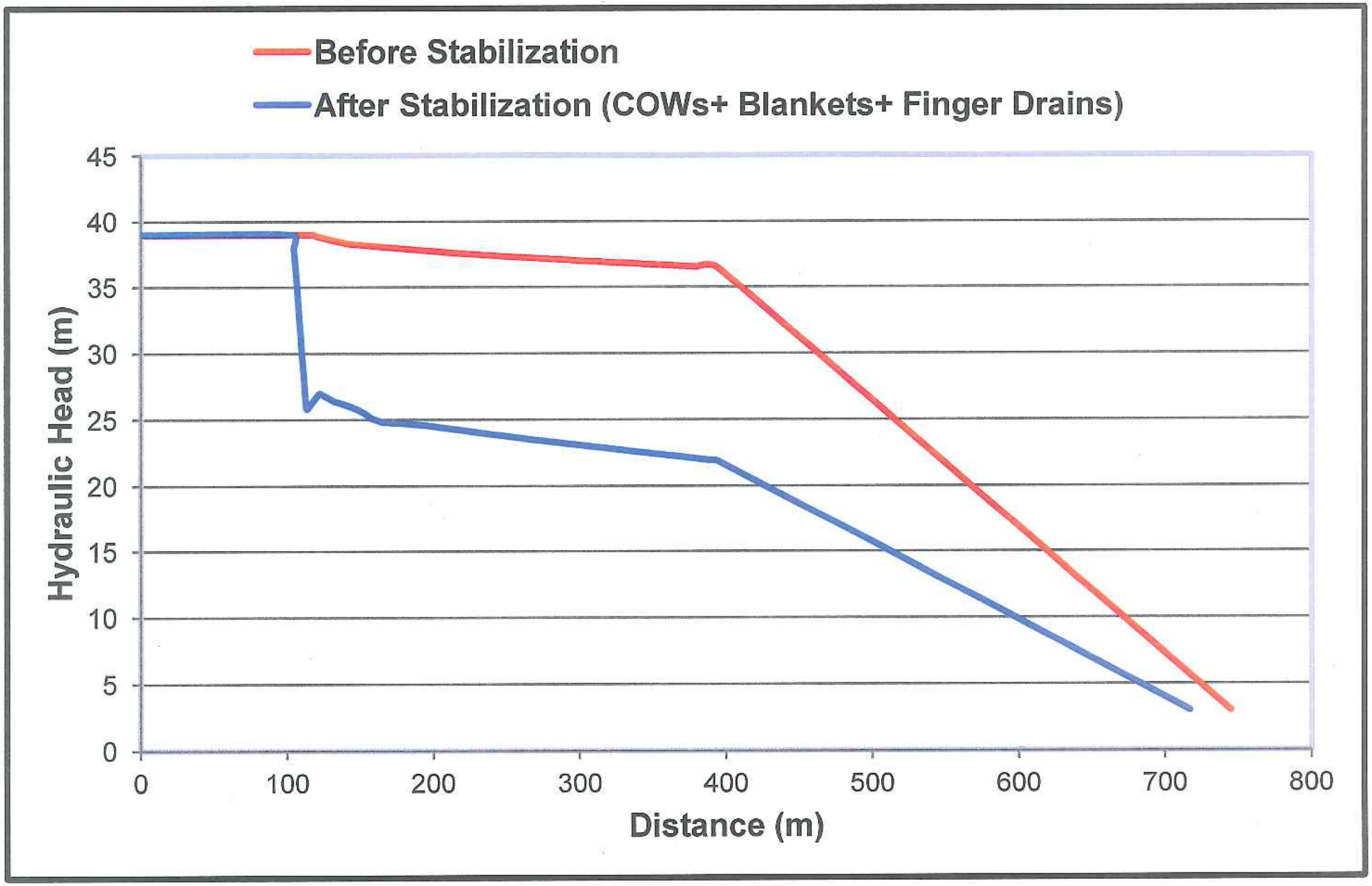
——— Expected piezometric surface of the intermediate aquifer after reservoir impoundment to F.S.L.

——— Expected piezometric surface after proposed stabilization works

Total Head Profiles in the Spur at U/S WL= El. 25 m



Total Head Profiles in the Spur at U/S WL= El. 39 m

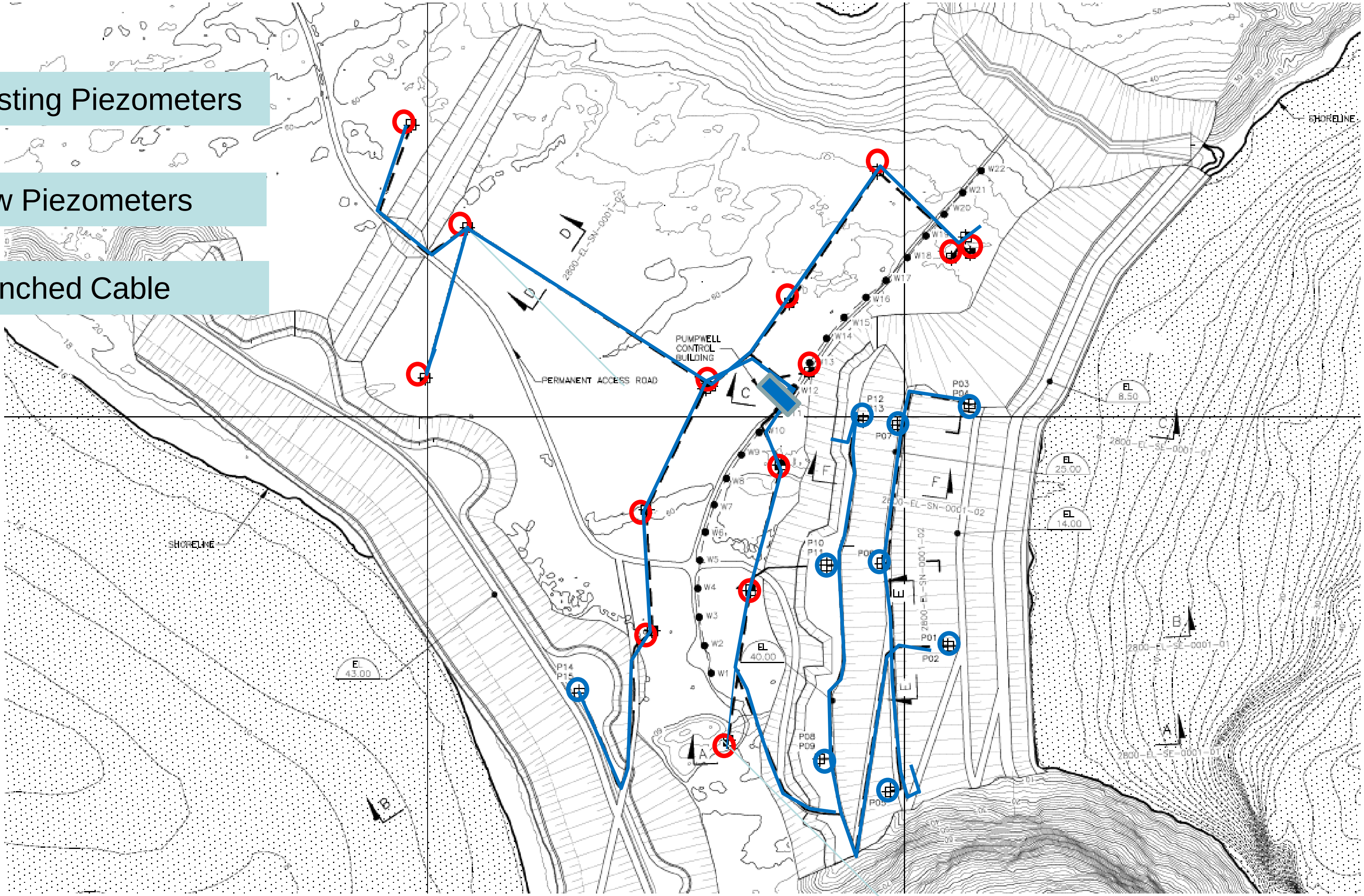


Instrumentation

Existing Piezometers

New Piezometers

Trenched Cable



Hydrogeological model Conclusion

- **Intermediate Aquifer**
  - Model calibration require more effort, (10 scenarios).
  - Blockage of D/S Surface has been selected to adjust the model.
  - A combination of multiple conditions can produce a realistic behavior. Observational Method has to be used during work progress.
  - Based on the model, stabilization works will control adequately groundwater pressure and expected safety factor will be satisfy.
  - Cut off wall penetration depth (2, 5, 10m) in lower clay deposit showed that there is no change in hydraulic head in the intermediate aquifer due to the penetration of the COW.

Dynamic study

Boundless Energy

nalcor energy
LOWER CHURCHILL PROJECT

Recommendations and Observations from Phase 1 Study (Prof. Leroueil, 2014)

- Slopes stability analysis seem to have a satisfactory factor of safety. Use existing slope to calibrate slope stability analysis evaluation. (done)
- Salinity profile changes with depth accordingly with physical properties of clayey deposit.
- Grain size analyses showed that there is no clean silt or sand material in the stratigraphy and there is no plasticity index smaller than 5%.
- Recommendation to prepare typical geotechnical profiles showing major properties of the soils. (done)

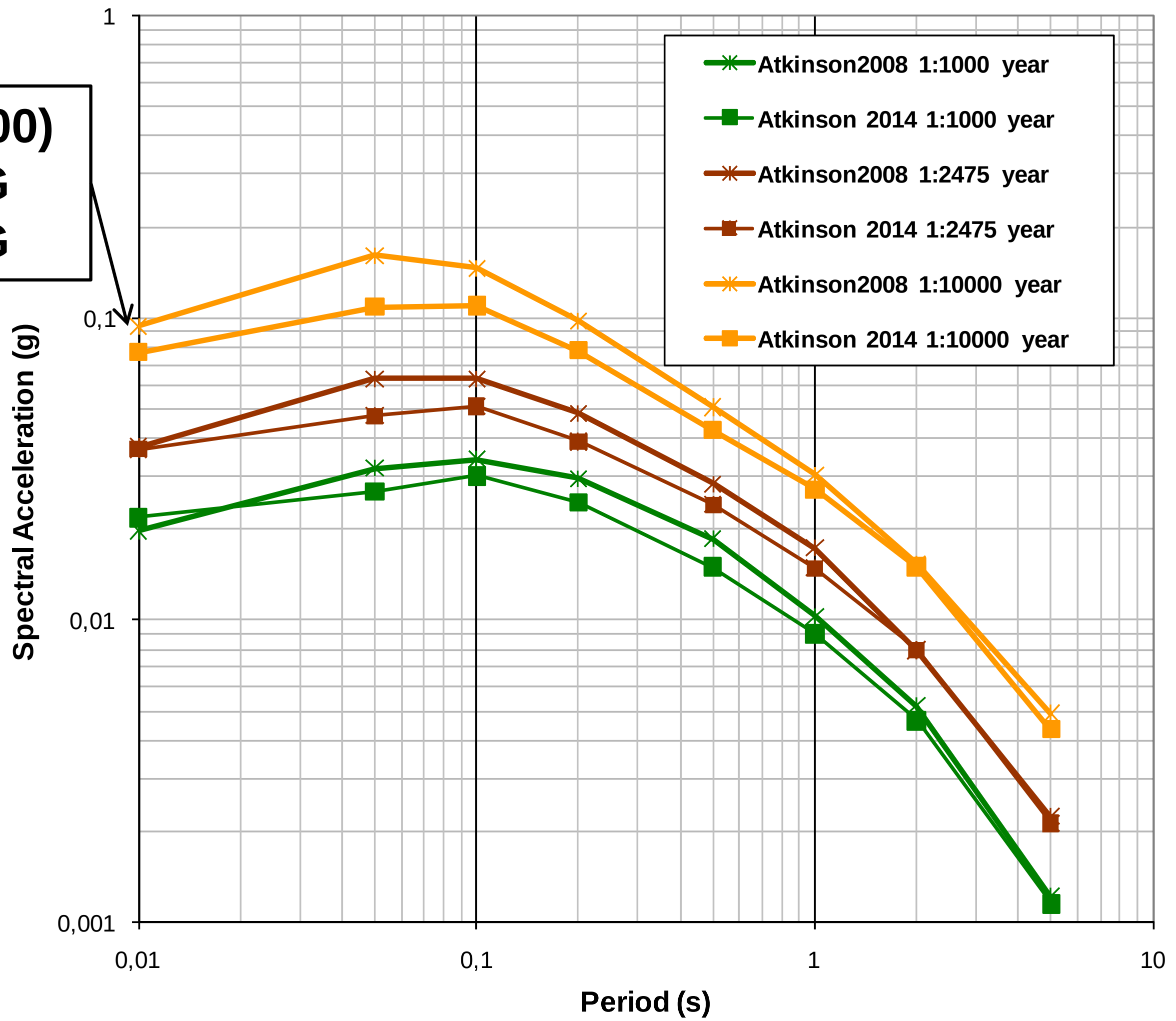
Recommendations and Observations from Phase 1 study (Prof. Idriss, 2014)

- The North Spur stabilization works, if constructed as currently designed, will have a satisfactory performance against earthquakes.
- Seismic Hazard Study (2008) from Mrs. Gail Atkinson has to be updated. (done)
- With the updated Seismic Hazard Study, Cyclic Stress Ratio (CSR) and Cyclic Resistance Ratio (CRR) should be recalculated including all Cone Penetration Test (CPT) results. (done)
- A dynamic nonlinear analysis (FLAC computer program) should be conducted to assess the induced pattern of deformations. (done)

SEISMICITY UPDATED REPORT (ATKINSON, 2014)

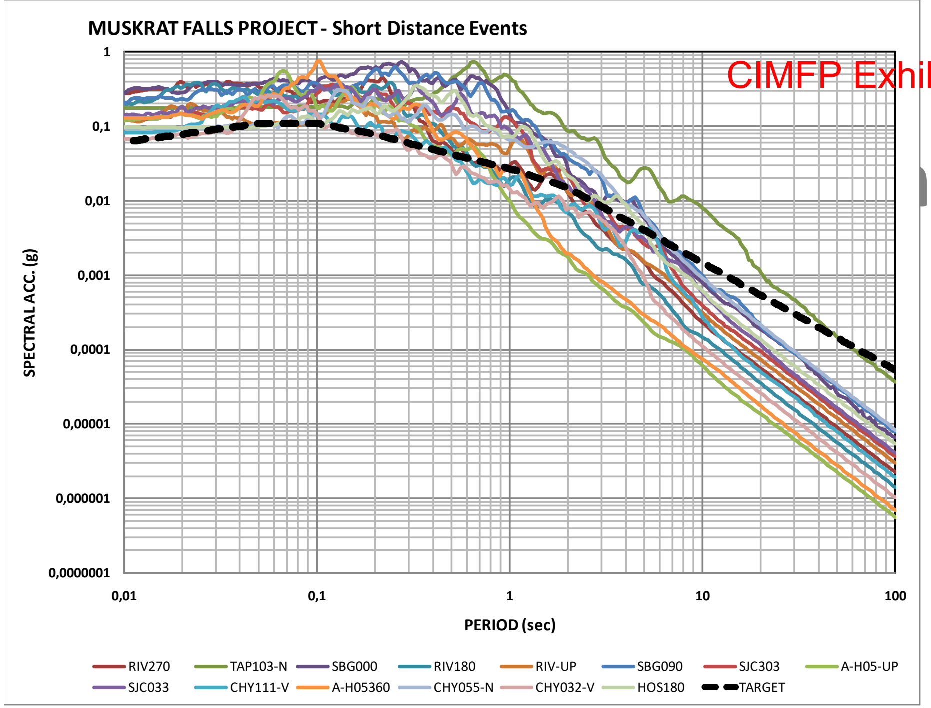
Update 2008 Earthquake Hazard Analysis (UHS)

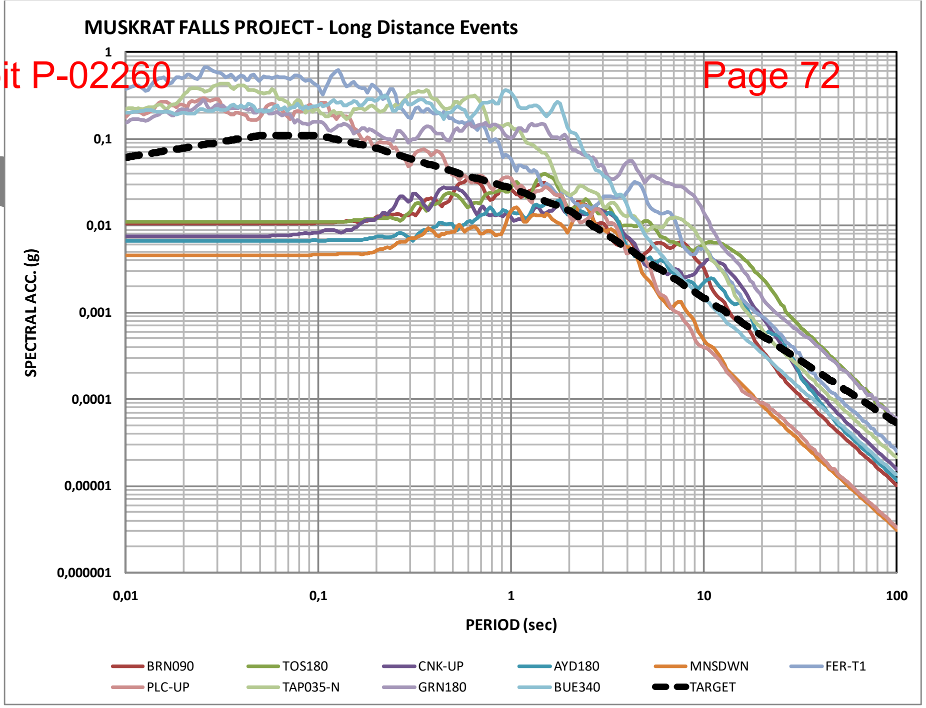
PGA (1:10000)
2008=0,09 G
2014=0,06 G

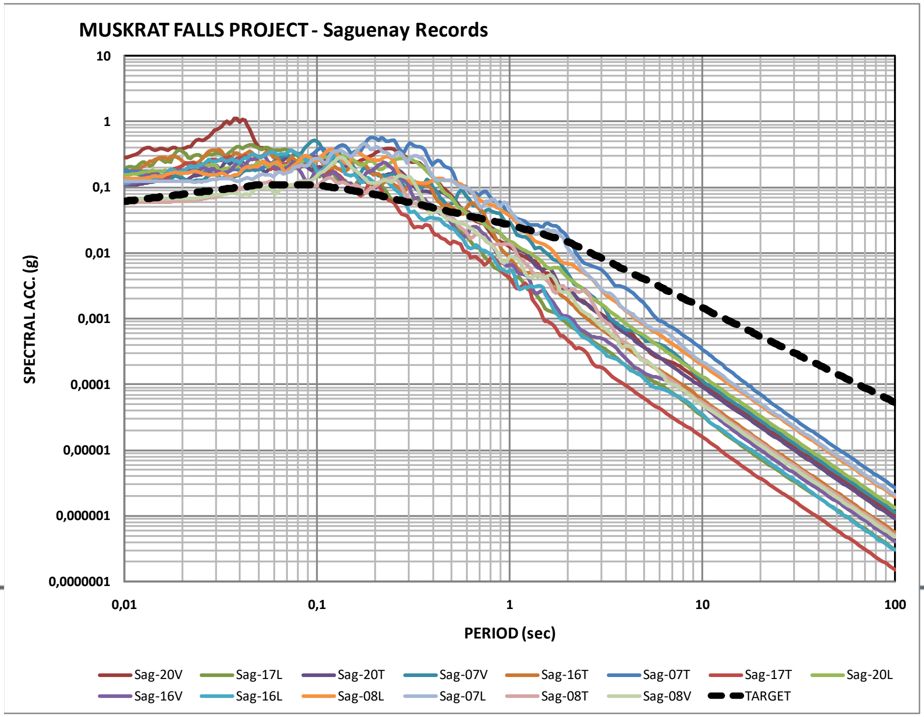


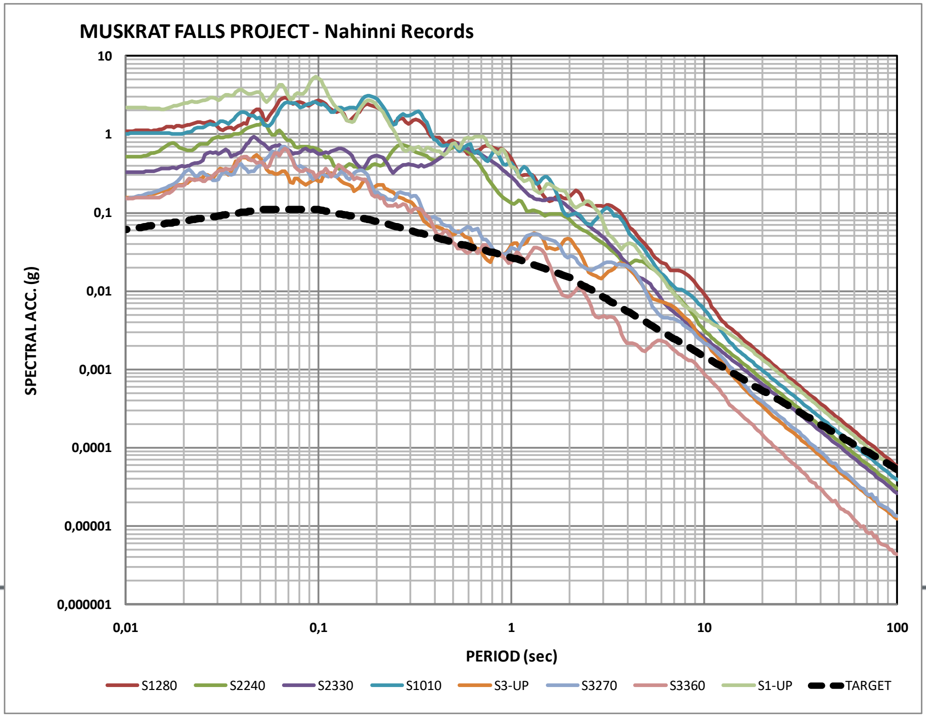
Input motion selection

- Representative accelerograms from databases for 2 scenarios:
  - Near event with M_w 6.5, R= 100 km and Aria duration of 10 s;
  - Far event with M_w 7.3, R= 400 km and Aria duration of 50 s;
  - Recording of the Saguenay 1988 earthquake from stations located in the Saguenay region;
  - Recording of the Nahanni 1985 earthquake;
  - Accelerograms used in the preliminary dynamic study.


MUSKRAT FALLS PROJECT - Short Distance Events
SPECTRAL ACC. (g)
1
0,1
0,01
0,001
0,0001
0,00001
0,000001
0,0000001
0,01
0,1
1
10
100
PERIOD (sec)
RIV270
TAP103-N
SBG000
RIV180
RIV-UP
SBG090
SJC303
A-H05-UP
SJC033
CHY111-V
A-H05360
CHY055-N
CHY032-V
HOS180
TARGET


MUSKRAT FALLS PROJECT - Long Distance Events
SPECTRAL ACC. (g)
1
0,1
0,01
0,001
0,0001
0,00001
0,000001
0,01
0,1
1
10
100
PERIOD (sec)
BRN090
TOS180
CNK-UP
AYD180
MNSDWN
FER-T1
PLC-UP
TAP035-N
GRN180
BUE340
TARGET


MUSKRAT FALLS PROJECT - Saguenay Records
SPECTRAL ACC. (g)
10
1
0,1
0,01
0,001
0,0001
0,00001
0,000001
0,0000001
0,01
0,1
1
10
100
PERIOD (sec)
Sag-20V
Sag-17L
Sag-20T
Sag-07V
Sag-16T
Sag-07T
Sag-17T
Sag-20L
Sag-16V
Sag-16L
Sag-08L
Sag-07L
Sag-08T
Sag-08V
TARGET

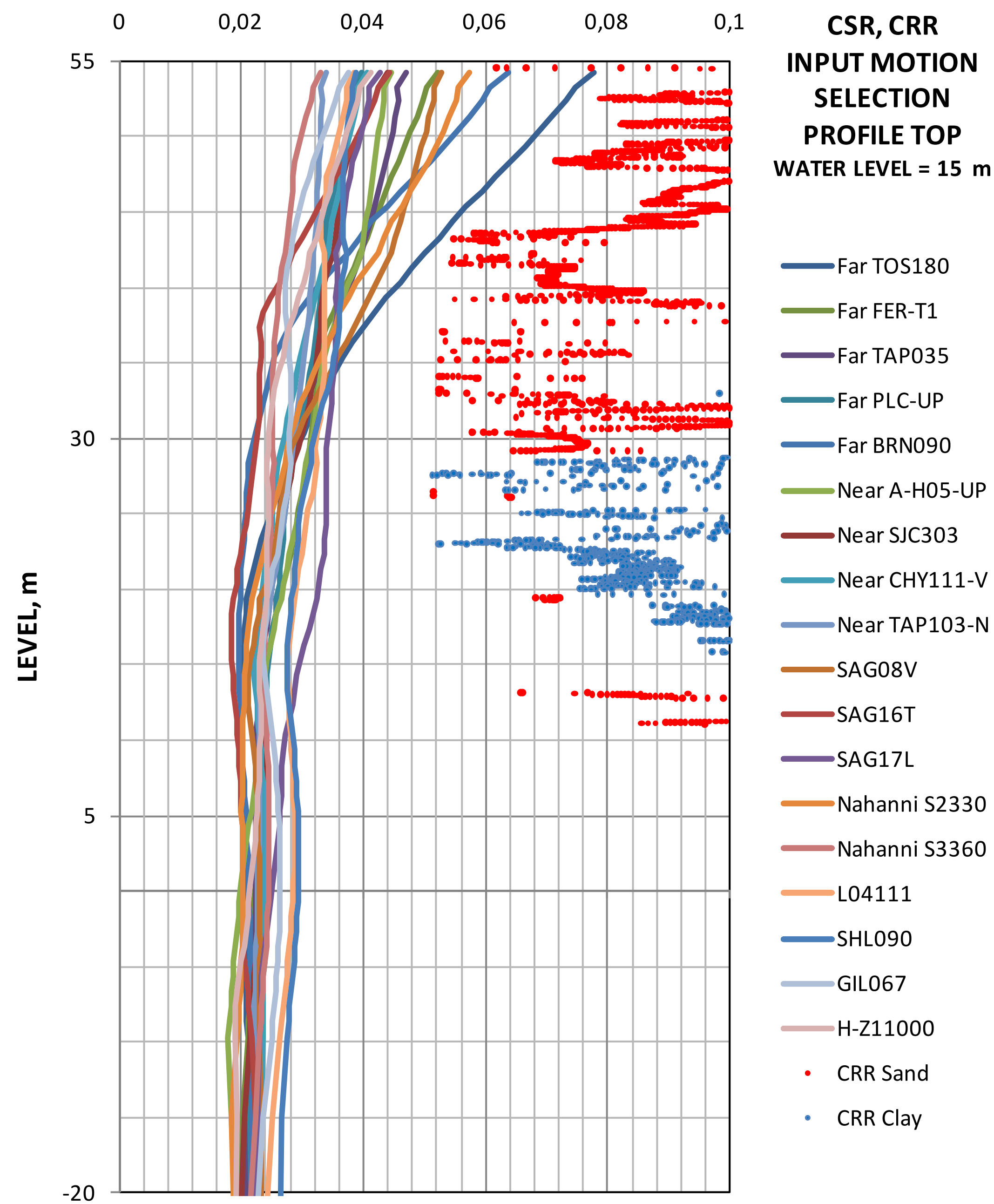

MUSKRAT FALLS PROJECT - Nahinni Records
SPECTRAL ACC. (g)
10
1
0,1
0,01
0,001
0,0001
0,00001
0,000001
0,01
0,1
1
10
100
PERIOD (sec)
S1280
S2240
S2330
S1010
S3-UP
S3270
S3360
S1-UP
TARGET

Site response analysis

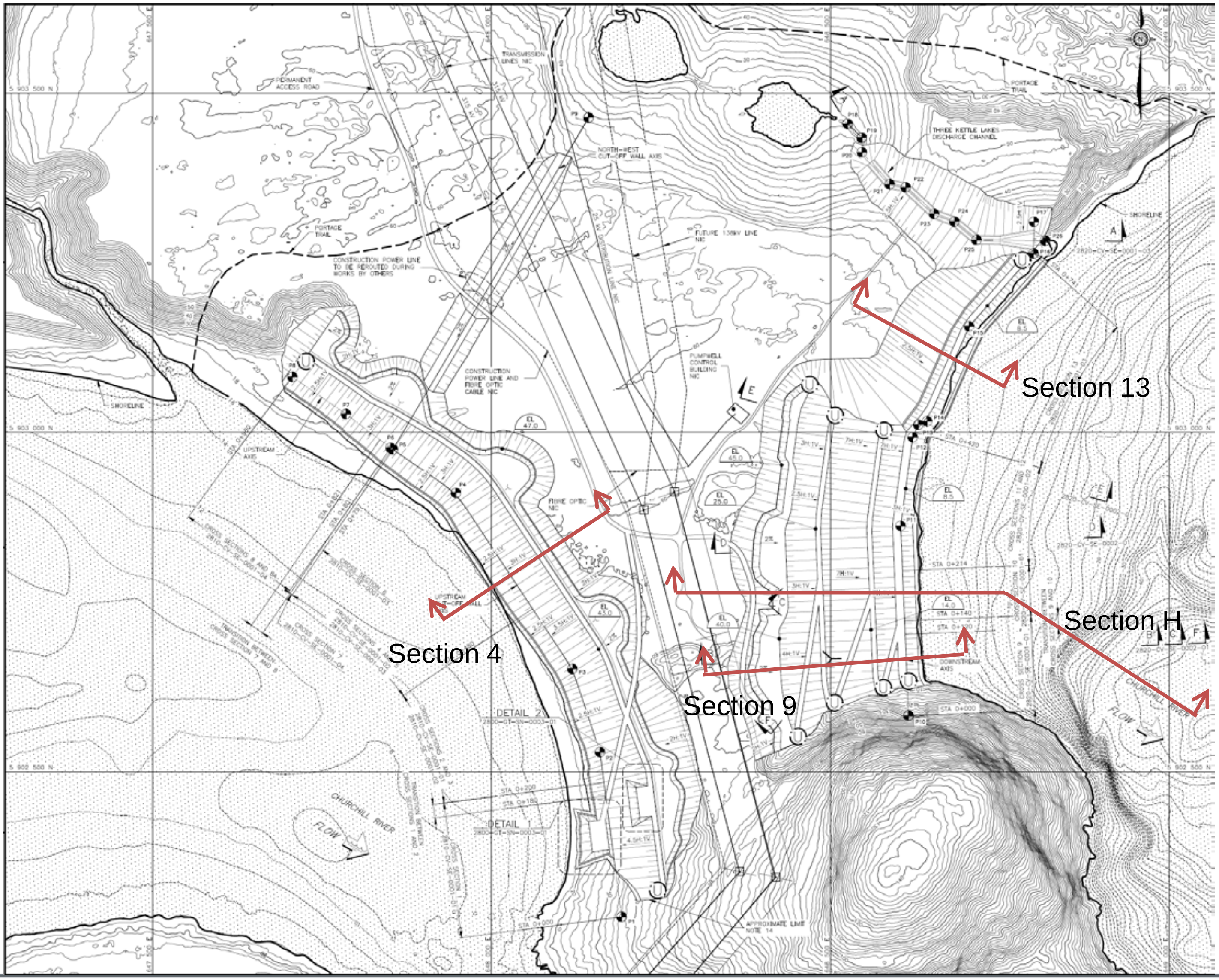
- Types of analysis
  - Empirical methods for liquefaction and cyclic mobility assessment
  - 1D Equivalent-linear method (Shake type analyses using EZ-Frisk)
    Site Reponse module of EZ-Frisk, version 7.62, Fugro, 2011
  - 2D Equivalent-linear method (Quake/W similar to Quad4Mu)
    Quake/W module of GeoStudio Suite, version 8.12.3.7901, Geo-Slope inc., 2013;
  - 2D non-linear method (Finite differences model using FLAC)
    FLAC 2D, version 7.0.411, Itasca, 2011.

Selection of Input Motions

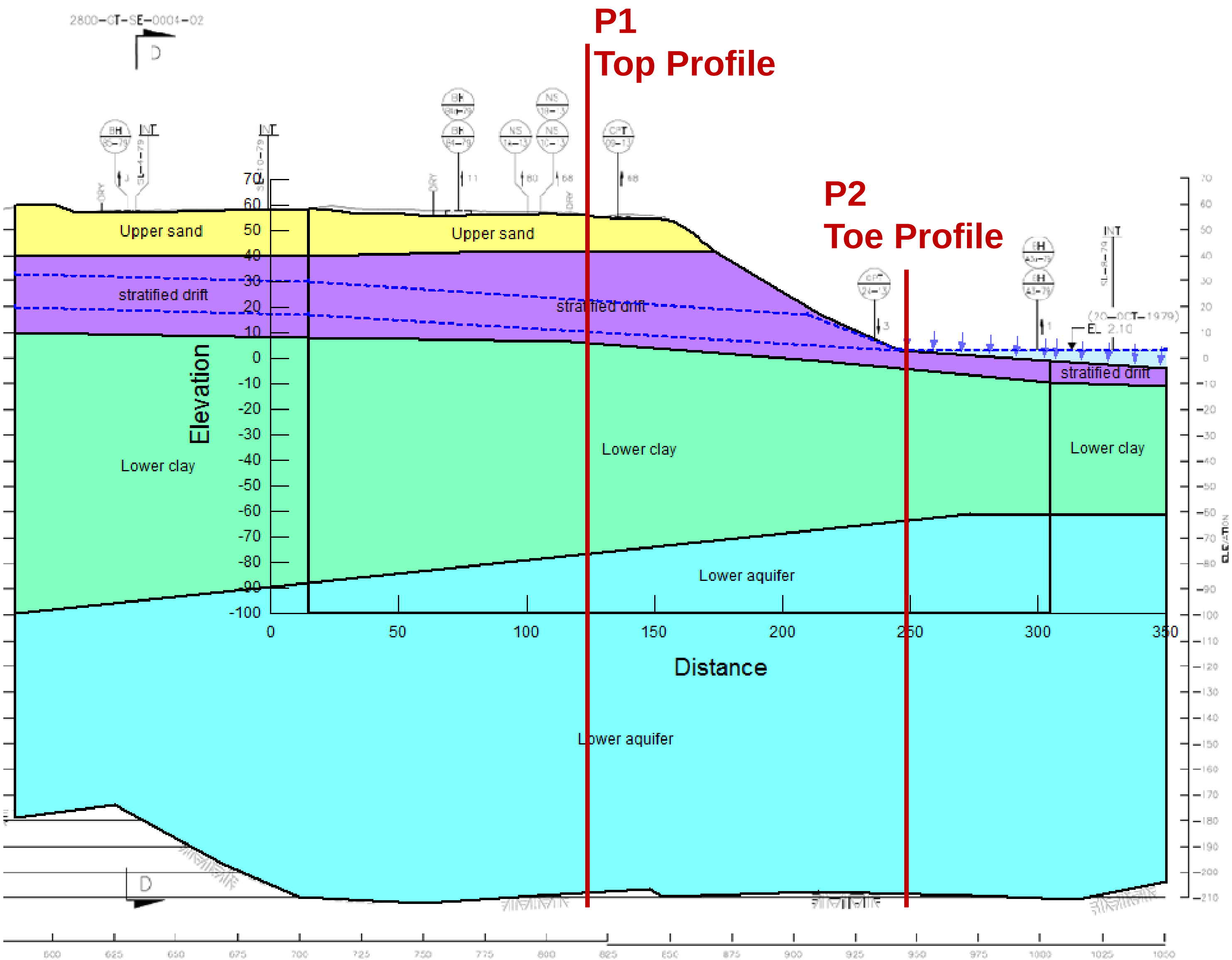
- Short list for 1D analyses of S1 (SCPT-11-13)
- Based on results a final selection 7 input motions for 2D Equivalent linear analyses



Sections location



1D Site Response Equivalent-linear analyses (section 13)



Sensitivity on bedrock depth

Shallow bedrock at El. -100 m

Deep bedrock at El. -210 m

Empirical Method

- The imposed seismic loading is represented by the Cyclic Stress Ratio (CSR) estimated using site specific dynamic response analyses.
- The Cyclic Resistance Ratio (CRR) is estimated based on SPT or CPT tests for granular material and plasticity and undrained shear strength for clay-like material.
- Magnitude Scaling Factor = 1
- Static shear stress correction factor, K_α (see Idriss and Boulanger, 2008)
  - For sand-like material, K_α = 1.0;
  - For clay-like material, K_α = neglected for 1D analysis and = 0,9 for 2D;

1D equivalent-linear analysis

A soil or soft-rock column is defined by specifying soil properties such as maximum shear wave velocity and density. Then, an input motion applied to the bedrock (or any other layer) is propagated through the soil or soft-rock column to produce a site-specific ground motion time history. The analyses are performed in the frequency domain using the total density of each sub-layer.

An equivalent-linear procedure is used to account for the non-linearity of the soil using an iterative procedure to obtain values of modulus and damping that are compatible with the equivalent uniform strain induced in each sub-layer (of the vertical profile) (Idriss and Sun, 1992).

Modulus Degradation and Damping

- For Sand - Seed & Idriss 1970:
  - G/Gmax and Damping Average curves
- For Clay - Sun et al 1988:
  - G/GMax proposed for IP of 10-20%
  - Damping average curve

2D EQUIVALENT-LINEAR DYNAMIC ANALYSES

- A similar equivalent-linear iterative procedure is used then in 1D equivalent analyses. However, the software is a finite element model solving in the time domain
- The same degradation curves as for 1D analyses were used in the 2D Equivalent-linear analyses

2D NON-LINEAR DYNAMIC ANALYSES

- The main characteristics of this model are:
  - Solving in the time domain;
  - Damping and shear modulus reduction are function of the shear strain in each element.
  - Excess porewater pressure generation modeled and considered in analysis.
  - Deformation and stresses induced by earthquake shaking considered in the dynamic response.
- the Mohr-Coulomb model has implemented for the materials not susceptible to liquefaction and the UBC Sand model (Beaty and Byrne , 2011) for potentially liquefiable materials. For the other materials, hysteretic damping is added and adjusted to fit the modulus reduction and damping curves used in the 1D and 2D Equivalent-linear Analyses.

1D EQUIVALENT-LINEAR ANALYSES
ANALYSES RESULT

- The 1D equivalent-linear analyses indicate adequate provision against liquefaction for granular material and cyclic softening for clay material.

2D EQUIVALENT-LINEAR ANALYSES

- The analyses indicate that CSR for all the input motions are lower than the selected CRR profiles for liquefaction of sand-like material and for cyclic softening of clay-like material . This indicates that liquefaction and cyclic softening should not be an issue for Section 13 and Section 9.

2D NON-LINEAR DYNAMIC RESPONSE ANALYSES

- Even if the 1D and 2D equivalent-linear analyses indicated no potential for liquefaction of the granular materials or potential for cyclic softening for the clay, Section 13 was submitted to 2D non-linear dynamic response analyses *to assess the pattern of deformations that may be induced by the postulated earthquake ground motions* as proposed by Prof. Idriss.
- The results show displacements of the crest of less than 3 cm both horizontally and vertically, very little pore water increase and conditions at the end of shaking very similar to those at the end of the static equilibrium.

Dynamic study highlights

- From 2014 Atkinson updated report, the design earthquake (1:10 000) is lower than previously expected.
- 1D equivalent-linear analysis with revised time history earthquake confirm previous result for up and down hill location.
- 2D equivalent-linear analysis confirm the same results.
- 2D non-linear analysis show deformation less then 3 cm, small pore pressure generation and no permanent deformation after the design earthquake.
- External experts will provide comments on study results

Conclusion

- The results indicate no potential for liquefaction of the granular materials nor potential for cyclic softening for the clay. A cross-section was submitted to indicative 2D non-linear dynamic response analyses. These analyses confirmed the findings of the equivalent-linear analyses.
- Based on the findings of this complementary dynamic study, the North Spur integrity is not expected to be affected by the occurrence of the design seismic event .

General comments on complementary studies

- Complimentary studies conclusion (up to now) confirm design choices
- Construction works will be followed (Observational Method) to ensure that design objectives will be achieved.

Sharing our ideas in an open and supportive manner to achieve excellence.

Teamwork

Open Communication

Fostering an environment where information moves freely in a timely manner.

Honesty and Trust

Being sincere in everything we say and do.

Relentless commitment to protecting ourselves, our colleagues, and our community.

Safety

Respect and Dignity

Appreciating the individuality of others by our words and actions.

Leadership

Empowering individuals to help, guide and inspire others.

Holding ourselves responsible for our actions and performance.

Accountability