Manitoba Clean Environment Commission Public Hearing

Sio Silica Corporation
Vivian Silica Sand Extraction Project

Geotechnical Additional Clarifications

February 28, 2023

Stantec

Analysis

Winnipeg Shale Strength

- To respond to a question asked regarding the strength of the Winnipeg Shale, we informally assessed 5 boreholes Rock Mass Ratings and 3 boreholes Point Load Test Results.
- RMRs in the Winnipeg Shale were typically 50% of the competent Limestone values.
- Point Load Testing rock strengths for Winnipeg Shale were 20 to 30% of the strengths of competent Limestone.
- Most importantly the Winnipeg Shale was observed to be friable, and susceptible to disturbance during the sand extraction process.
- As a result, the Winnipeg Shale strength was not relied upon to provide any support when assessing the cavern stability.

Carman Sand Strength

- Collecting Intact Samples of Carman Sand to Measure Strength:
  - Sonic drilling, use of Shelby tubes and other typical less invasive approaches are not expected to collect intact samples because of the disturbance caused by drilling (rotation, vibration).
  - The use of ground freezing also is not expected to provide undisturbed samples as freezing saturated sand will produce expansion of the sand which releases cohesion (breaks the glue between sand particles). Upon thawing to test the sample strength, the sample is expected to fail with very low strengths (slump).

Analysis

Carman Sand Strength

- Initial numerical analysis used an angle of repose of 31^{o} (based on a measurement of a disturbed sample).
- Side scan sonar shows vertical/overhanging sand side walls.
- Standard Penetration Testing (a field measure of strength) returned refusal (they couldn't advance because the material was so hard) which demonstrates high strength in the sand deposit.
- Therefore, the sand is stronger than the 31^{o} disturbed sand angle of repose.
- This higher strength is understood to be the result of weak cementation.
- Shallow sea cemented sand deposits (similar to Carmen Sand environment) have peak (undisturbed) friction angles of 38^{o} to 45^{o}.
- We assumed a conservative value of 35^{o} for friction angle of the Carman Sand.

Standard Penetration Test Results - Carman Sand			
Bru 92 Property	Starting Depth** (ft)	Number of blows	Driving Distance (in)
SPT Well 1	166	105	6
SPT Well 1	171	118	10
SPT Well 1	175	75*	10
SPT Well 1	197.66	100	2
SPT Well 2	166	102	6
SPT Well 2	170.3	100	8
SPT Well 2	175.5	101	6
SPT Well 2	198	130	2.5

*Was called at 75 due to inability advance

**Starting Depth is depth below ground surface

Carman Sand Strength

- The side scan survey data which showed vertical to overhanging sand was used in the FLAC model to back calculate the cohesion of the undisturbed sand. The cohesion was calculated to be 220 kPa.
- The strength of the Carman Sand changes from the undisturbed condition to the disturbed condition with deformation which occurs during extraction. This behavior is captured in the FLAC model using a shear weakening model.

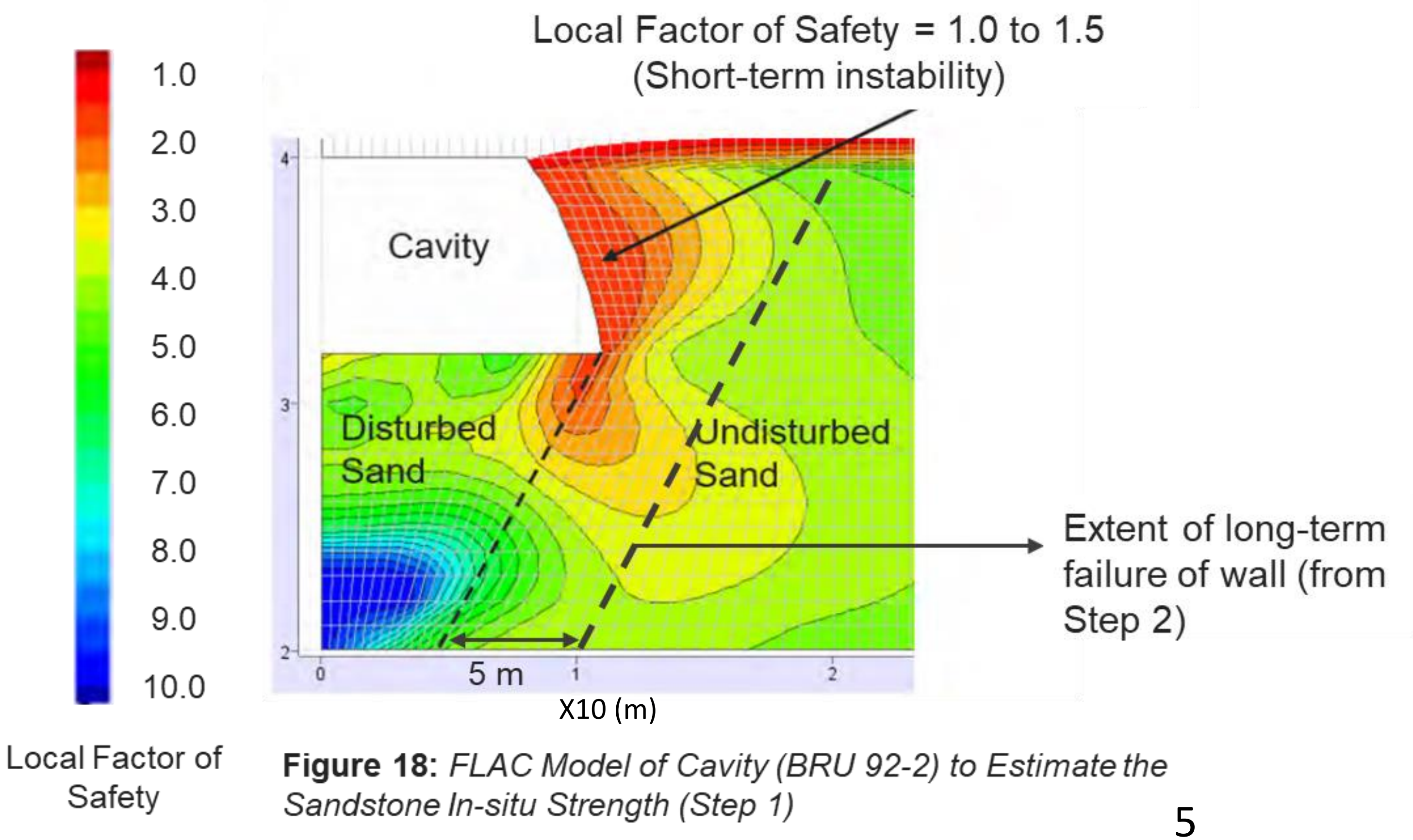


Figure 18: *FLAC Model of Cavity (BRU 92-2) to Estimate the Sandstone In-situ Strength (Step 1)*

Analysis

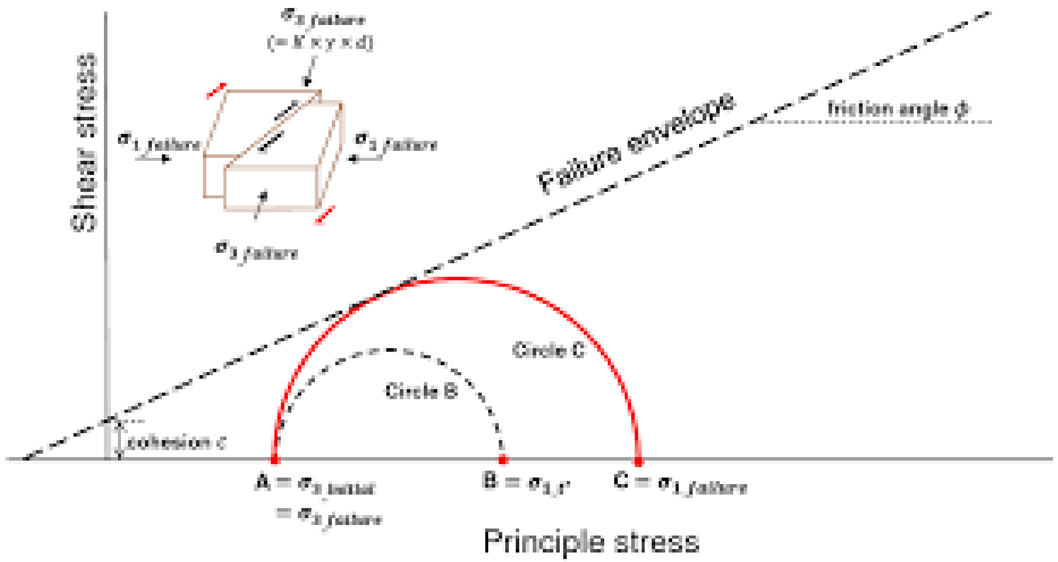
Carman Sand Strength

Material	Material Model	Density (kg/m3)	Bulk Modulus (MPa)	Shear Modulus (MPa)	Young's Modulus (GPa)	Poisson's Ratio	Soil Strength Parameters
Undisturbed Carman Sand	Strain Softening	2,000	600	200	0.54	0.35	C=220 to 0 (kPa) φ= 35° to 31°

- The cavity side wall slope of 65^o is the result of the friction angle (35^o) and cohesion (220 kPa).
- The approach used to determine the friction angle and cohesion is reliable. In particular, the use of a full-scale test (sonar scan and back analyses) to identify properties is accurate.
- A typical shortcoming of the engineering process is the lack of full-scale test data which considers the complexity of the combination of material properties.
- The accuracy of rock and soil behavior depends on the scale of the tests. If you want to know if your roof will hold a snow load, it isn't helpful to check the strength of a single 2x8 board.
- The side scan sonar results and FLAC modelling tool allowed us to complete a full-scale test of the entire system and identify reliable strengths.

Why Cohesion is Important

- Description of Mohr Coulomb Failure Criterion



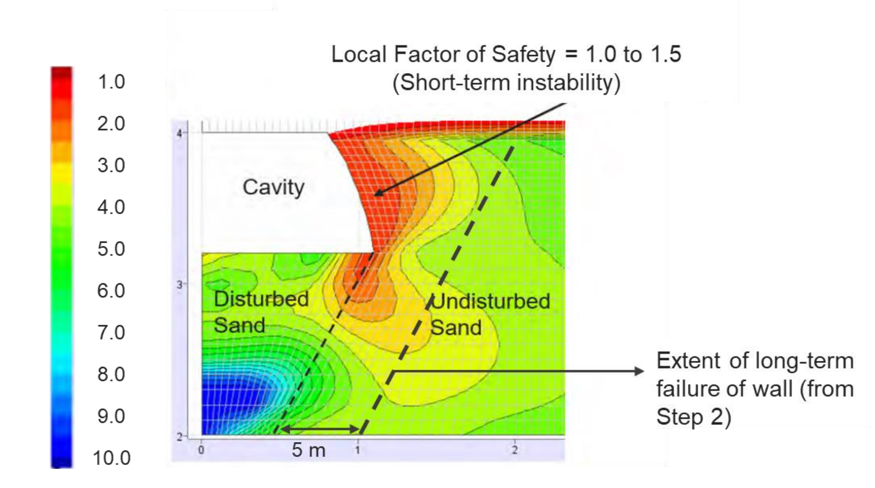
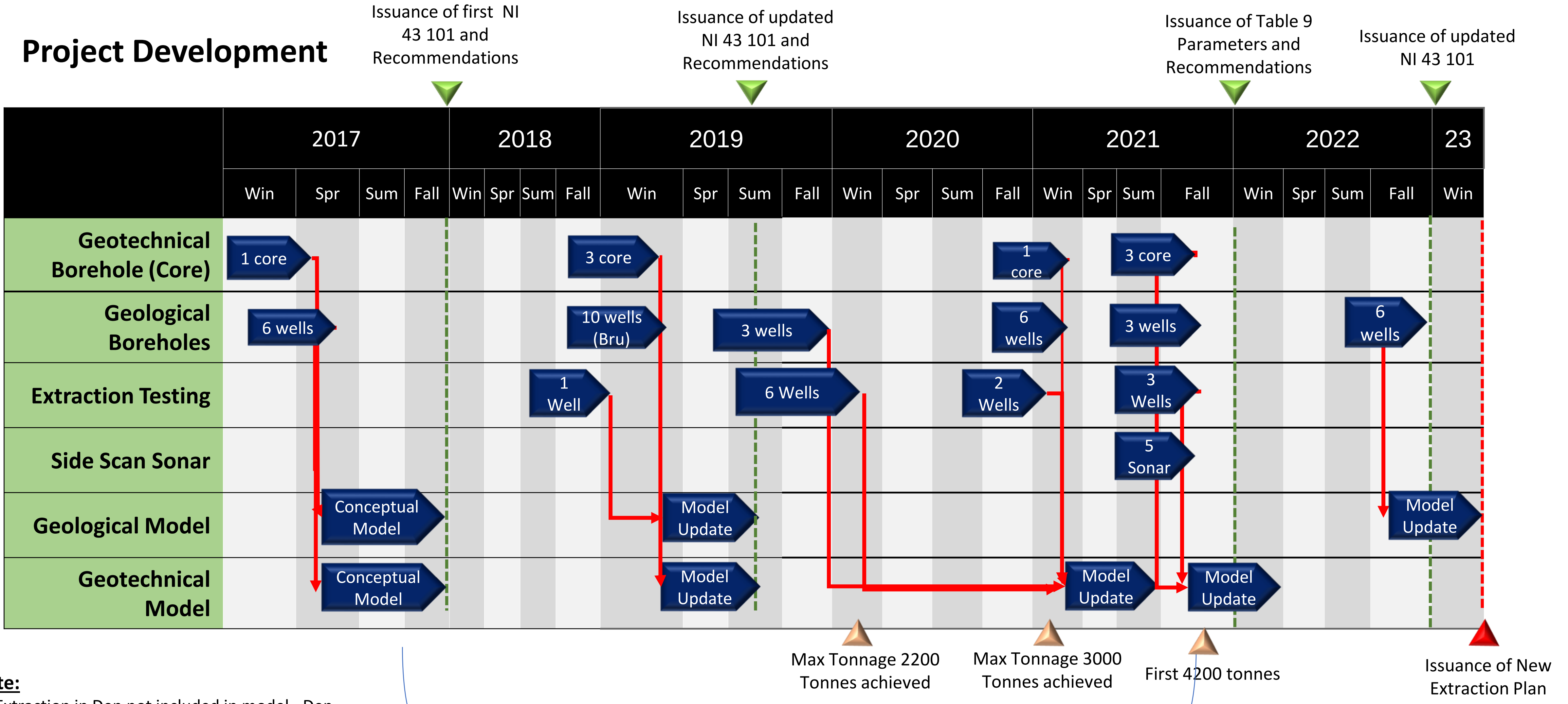


Figure 18: *FLAC Model of Cavity (BRU 92-2) to Estimate the Sandstone In-situ Strength (Step 1)*

Post-Extraction Conditions

- The duration of the extraction is very short (matter of days).
- After extraction and sealing the extraction well, groundwater conditions equilibrate.
- All the forces associated with sand extraction are absent, and groundwater flow returns to pre-extraction velocities (to be discussed during water panel).
- The sand ‘pillars’ are under the confining pressure of overlying rock and soil greater than 50 metres (160 feet) below ground surface.
- The undisturbed Carman comprising the pillars is very dense and weakly cemented (less than 1% by weight kaolinite).
- Based on the observed properties of the Carman Sand (overhanging and vertical side-walls) the geotechnical modelling recommended an additional 5m radius (10m diameter) offset between extraction areas in Table 9.

Project Development



Design Basis 31 degree angle of repose

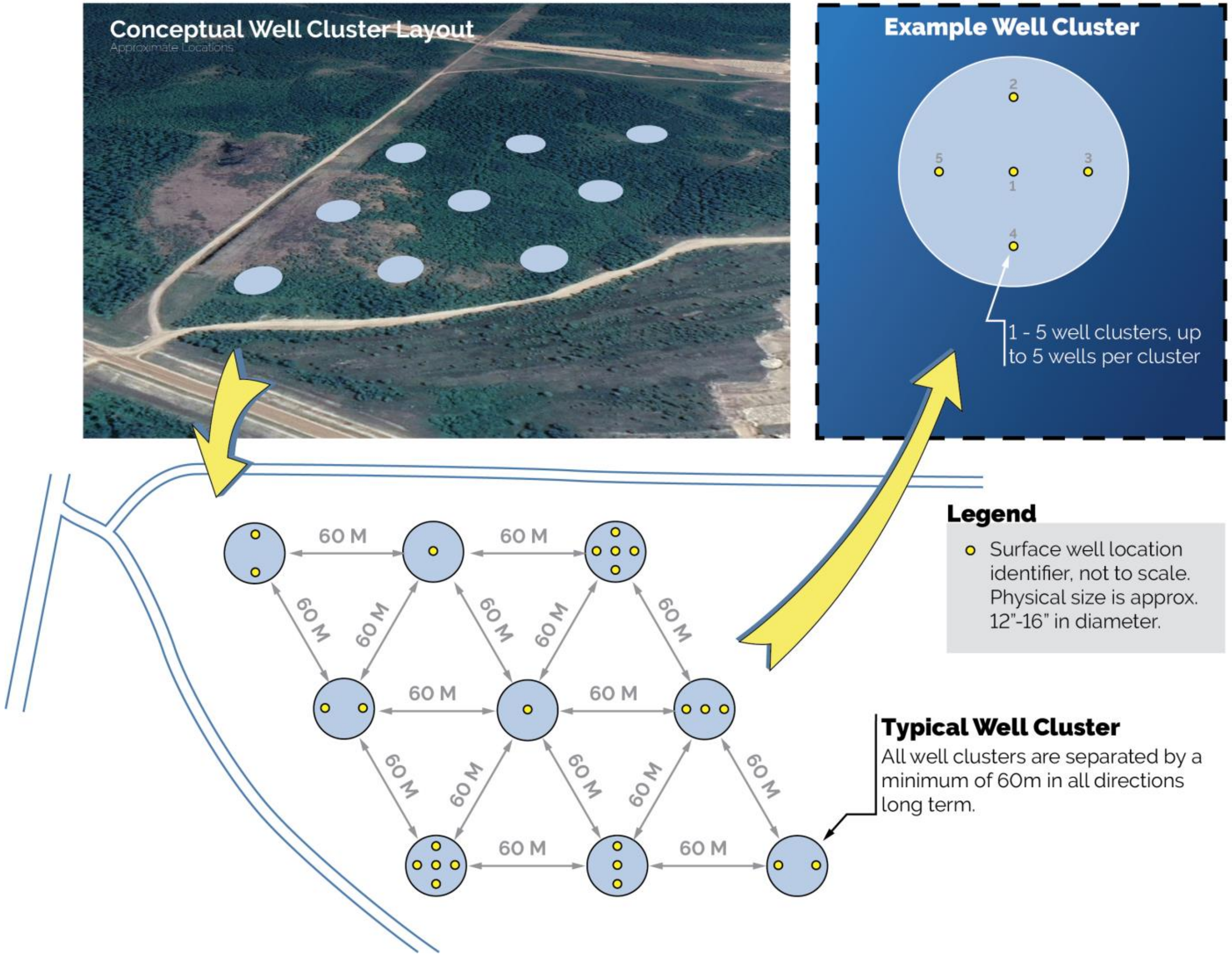
Note:

- 1 Extraction in Den not included in model - Den 304- Summer 2020 (but utilized in Extraction Development)

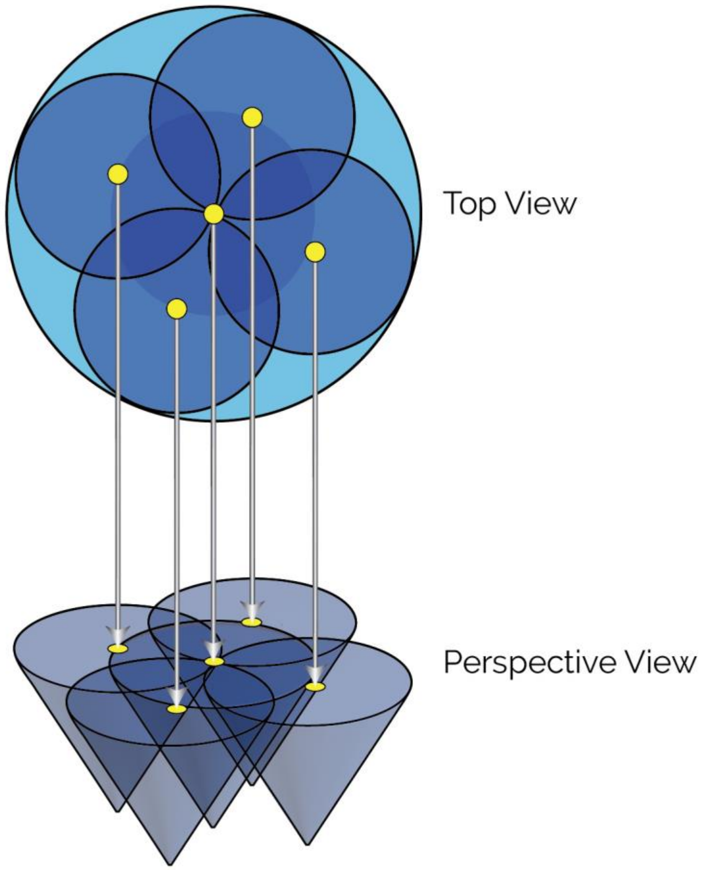
Sonar Imaging:

- Bru 92-2 – 3000 tonnes
- Bru 92-8 – Specific milestones 3000 tonnes, 4200 tonnes, 1 month and 4 month after

Extraction Operations Example



Extraction Operations Example



Subject Matter Experts

List of Contributors / Reviewers

Table 1: *List of Contributors*

Name	Consulting Firm	Role	Specialty
Wilhelm Greuer, Ph.D., P.E.	Stantec	Technical Reviewer	Underground rock mechanics specialist
Karl Xiao, Ph.D., P.Eng.	Stantec	Geotechnical Designer	Geotechnical numerical modeling specialist
Jack Yu Guo, Ph.D., P.Eng.	AECOM	Independent Reviewer	Geotechnical & rock mechanics specialist
Taesang Ahn, Ph.D., P.Eng.	AECOM	Independent Reviewer	Geotechnical & rock mechanics specialist

Table 2: *List of Clean Environment Commission (CEC) Reviewers*

Name	Consulting Firm	Role	Specialty
Gerd M. Wiatzka, P.Eng.	Arcadis	CEC Reviewer	Environmental specialist
Tony Brown, M.Sc., P.Eng.	Arcadis	CEC Reviewer	Environmental specialist
Charles Gravelle, M.Sc., P.Eng.	Arcadis	CEC Reviewer	Geotechnical & environmental specialist

Summary

- The Project was designed from the beginning for no subsidence.
- Stability Factors of Safety: A factor of safety of 2.0 was selected to be reasonably conservative for stability analysis such that subsidence will not occur.
- Level of data collection and assessment exceeds where a project would typically be at the stage of an Environmental Assessment regulatory phase.
- Monitoring plans such as the TARP are not required to apply for an Environment Act Licence and are typically developed after the issuance of a Licence.
- Subsidence monitoring will occur before, during and after extraction activities and will continue long term.
- Carman Sand strength is based upon full scale measurement of behavior and is well understood for this level of design.
- Winnipeg Shale, which was assumed to provide no support for overlying rock has been tested and confirmed as having low strength.
- Underground Room and Pillar mines often include groundwater that must be managed throughout the mine life.