



Manitoba Clean Environment Commission Public Hearing

Sio Silica Corporation
Vivian Silica Sand Extraction Project

Geotechnical Assessment Summary

February 27, 2023





Agenda

1. Introduction
2. Design Basis
3. Analysis
4. Results
5. Summary & Recommendations

Introduction

Geotechnical Specialists

Introduction

- **Douglas McLachlin, P.Eng.**
 - 38 years of experience
 - Manitoba and Ontario professional engineer
 - AECOM geotechnical practice lead for Ontario
 - Subject matter expert for geotechnical and hydrogeological site investigation and assessment
 - Geotechnical lead for mining, tunneling, road and rails, buildings and bridges projects
- **Steve Bundrock, P.Eng.**
 - 22 years of experience
 - Manitoba, Alberta, British Columbia, Yukon, and Northwest Territories professional engineer
 - Stantec senior principal geotechnical engineer
 - Subject matter expert for site investigation, analysis, design, construction, operation, and surveillance of underground and open pit mines
 - Geotechnical lead for underground and open pit mine projects with experience working on more than 100 projects
- **Arash Eshraghian, Ph.D., P.Eng., P.E.**
 - 22 years of experience
 - Alberta, British Columbia, and Idaho professional engineer
 - Stantec senior principal geotechnical engineer
 - Subject matter expert for analysis, design, construction, operation, surveillance, and mitigation of underground and open pit mines
 - Geotechnical lead for underground and open pit mine projects

Other Contributors

Introduction

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

Design Basis

Extraction Process

Design Basis

Extraction leaves a cavity that acts as a "Room"

Undisturbed sandstone remains that acts as a "Pillar" to support the cavity

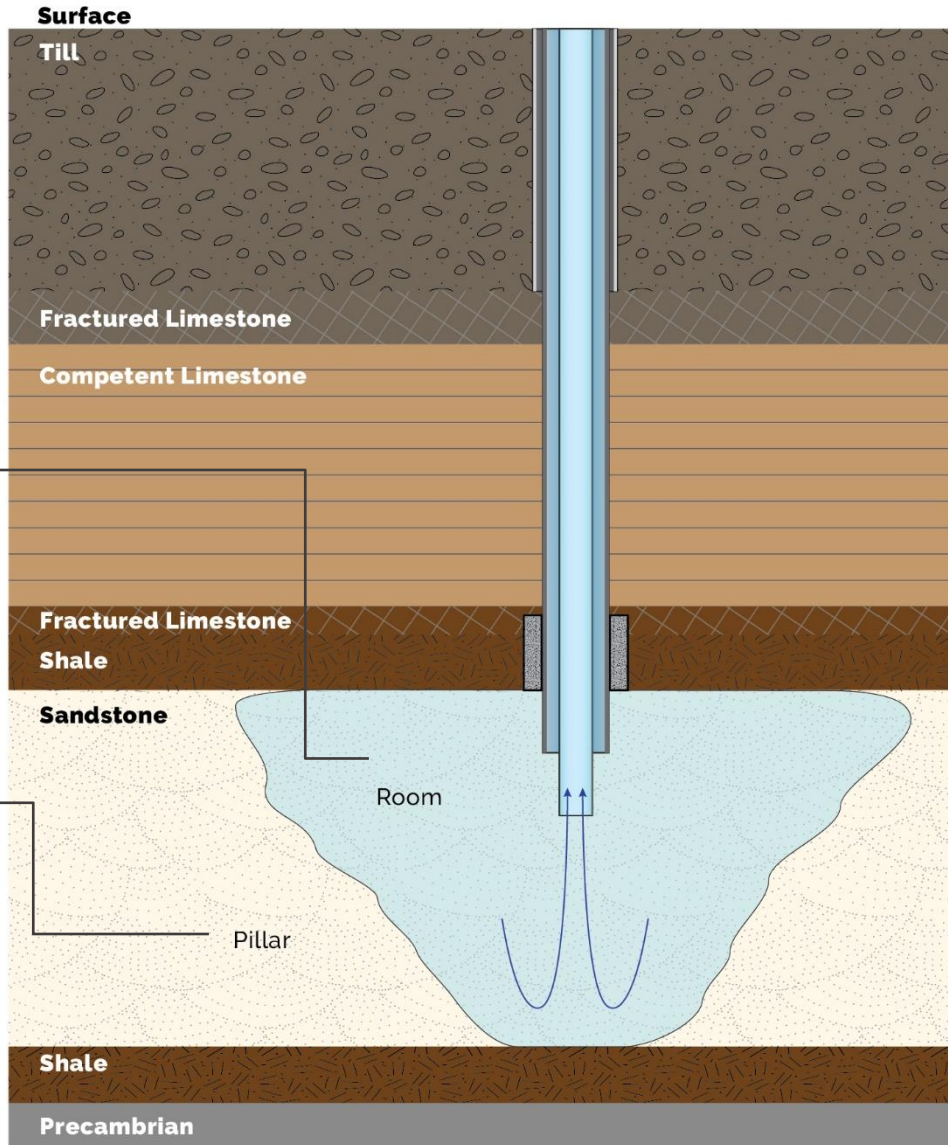


Table 3: Canada's Underground Room and Pillar Mines that Stantec has Contributed to

#	Mine	Province
1	Jansen Mine	Saskatchewan
2	Snap Lake Mine	Yellowknife
3	Lamaque Mine	Quebec
4	Esterhazy Mine	Saskatchewan
5	Lanigan Mine	Saskatchewan

Figure 1: Drilling Section of Extraction Process

Site Investigations

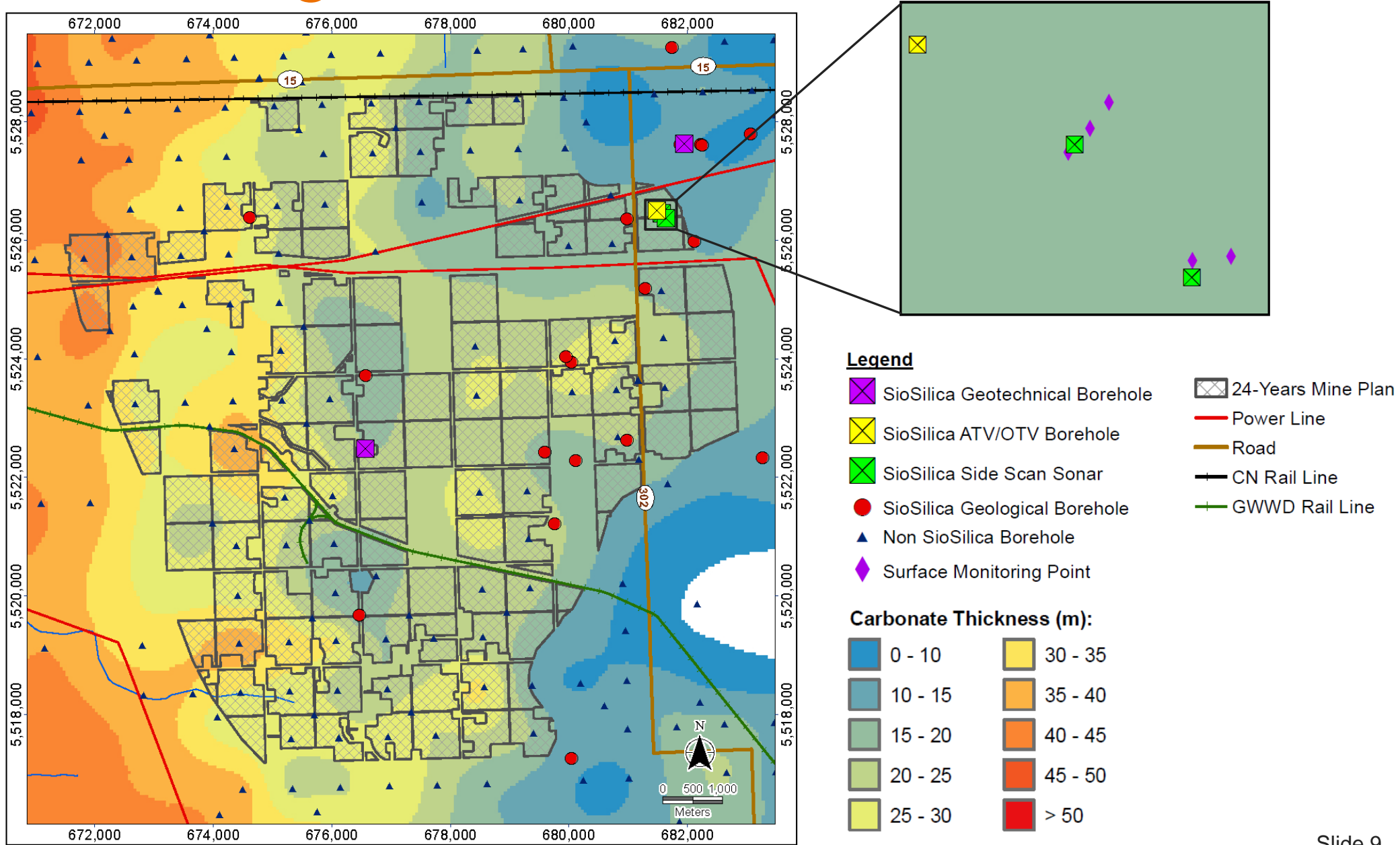
Design Basis

Table 4: *Site Investigation Data*

Site Investigation	# of Boreholes	Used to Develop
Sio Silica Geological Boreholes	46	Geological core logging (to build geological model and identify the continuity & location of geological layers)
Non-Sio Silica Boreholes (Groundwater Information Network/GW Drill)	1425	
Sio Silica Geotechnical Boreholes	8	<ul style="list-style-type: none"> - Geotechnical core logging - Point Load Testing (PLT) - Rock Mass Rating (RMR) - Geological Strength Index (GSI) - Sampling and testing (Tensile Strength and Unconfined Compression)
Sio Silica ATV/OTV Borehole	1	Acoustic and visual scan of borehole (to identify structures)
Sio Silica Side Scan Sonar of Extraction Boreholes	2	4 scans (to identify cavity shape)
Note: ATV/OTV - Acoustic Televiewer/Optical Televiewer		

Site Investigations Plan View

Design Basis



Geology – Simplified Stratigraphy

Design Basis

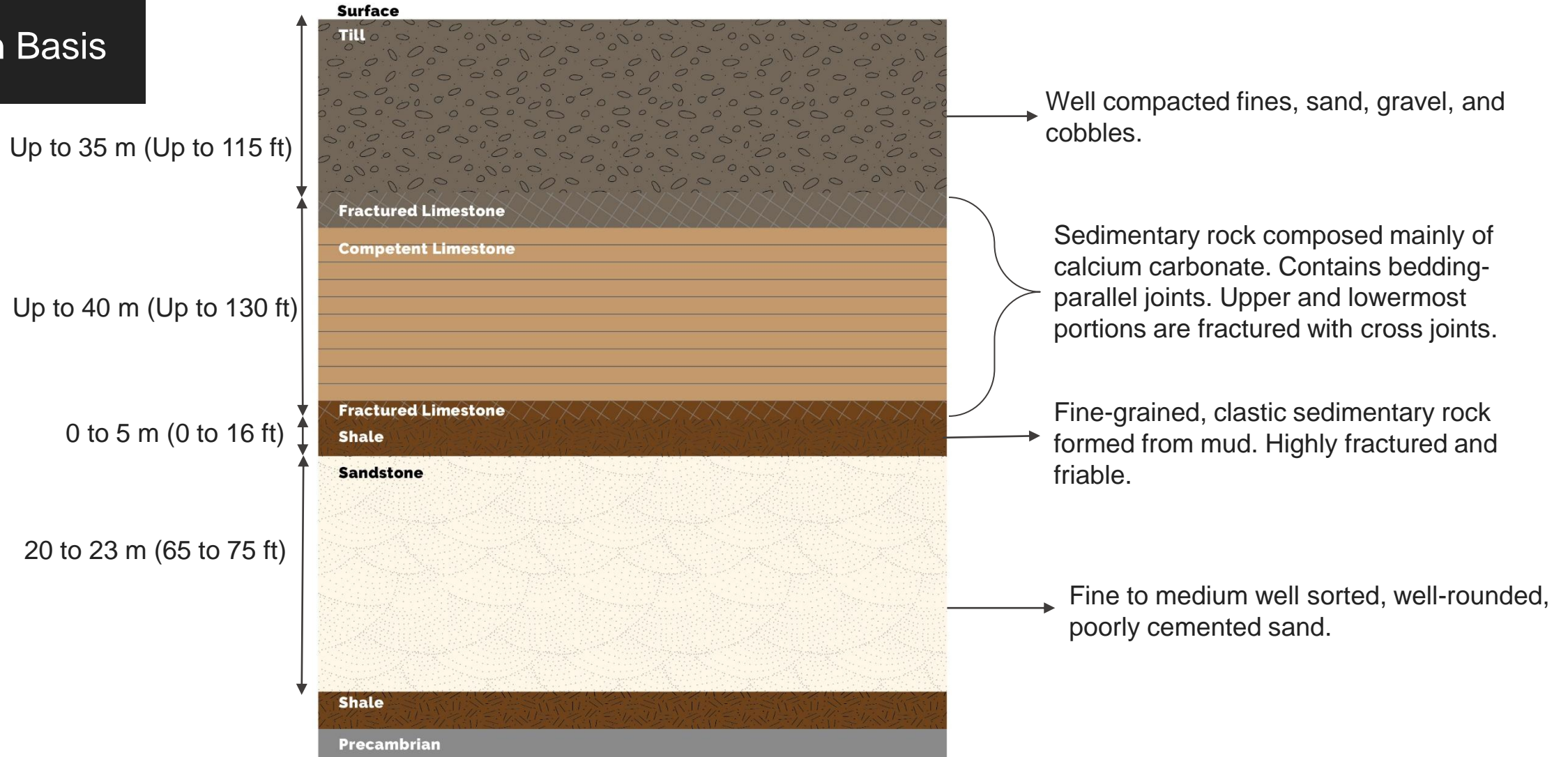


Figure 3: Site Stratigraphy

Geology – Structure

- Image of limestone and shale structure zones (in a vertical borehole).
- Potentially fractured portions of limestone and shale have been conservatively excluded from geology. The simplified geology used for stability analysis is as below:

Design Basis

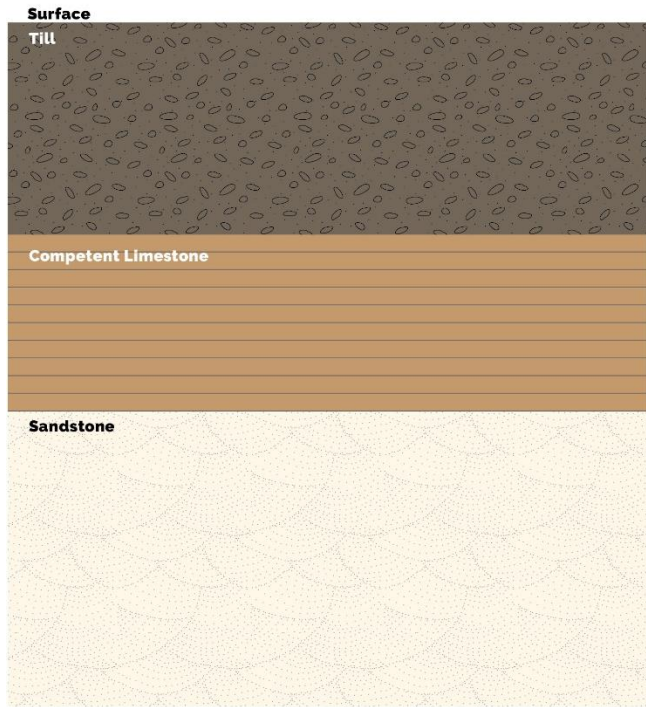


Figure 5: Geotechnical Stability Model

← Conservative

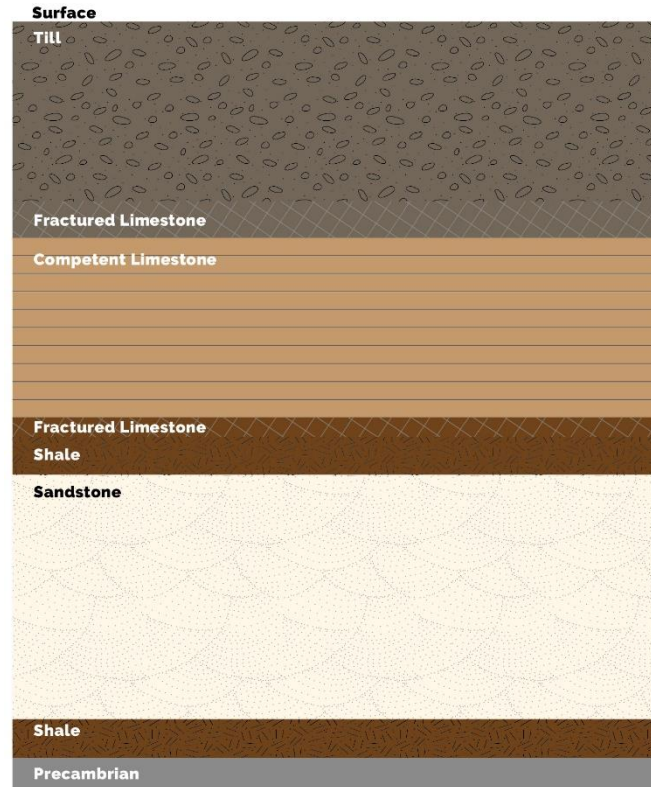
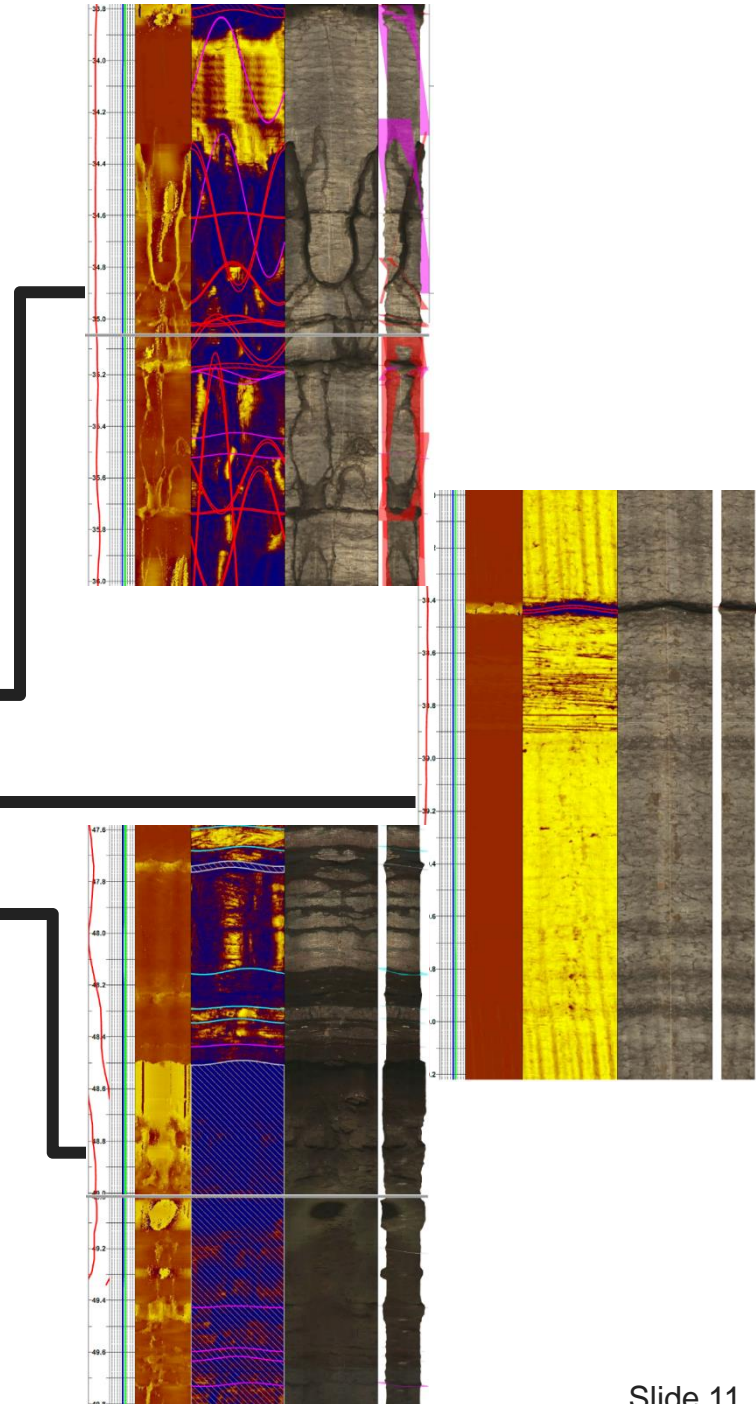


Figure 4: Geology



Geotechnical Logging

Design Basis

Table 5: Rock Mass Classification vs. GSI

Rock Mass Classification	GSI (Note)
Very Poor	0 - 15
Poor	16 - 35
Fair	36 - 55
Good	56 - 75
Very Good	76 - 100

Competent Limestone Quality

Note: $GSI = RMR_{89} - 5$

1.5 m



Table 6: Competent Limestone Equivalent GSI and Geotechnical Logging Summary

Borehole	Number of Geotechnical Intervals	Length of Core Logged (m)/(ft)	Competent Limestone GSI (Note 1&2)
BH 10-17 (BRU)	25	26.2 (86)	65.0
BRU 121-1	19	15.9 (52)	57.5
BRU 146-1	14	14.3 (47)	60.0
BRU 95-8	46	15.9 (52)	60.3
DEN 216-1	16	23.1 (76)	61.3
DEN 117-1	45	40.9 (134)	-
DEN 120-1	26	23.0 (75)	-
DEN 204-1	15	15.2 (50)	-
Stantec Selected Value			60

Note 1: GSI - Geological Strength Index
 Note 2: GSI was estimated based on Rock Mass Rating (RMR) method

Figure 6: Image of collected cores for logging borehole DEN 117-1

Geotechnical Field and Lab Test Results

Design Basis

Table 7: Rock Strength vs. UCS

Rock Strength	UCS (MPa)
Very Weak	1 - 5
Weak	5 - 25
Medium Strong	25 - 50
Strong	50 - 100
Very Strong	100 - 250
Extremely Strong	>250

Competent Limestone Strength



Figure 7: Point Load Test

Table 8: Field Competent Limestone Point Load Test Results – UCS estimation

Borehole	Number of Point Load Tests	Average UCS (MPa) (Note 1 & 2)
BH 10-17 (BRU)	15	71
BRU 121-1	38	68
BRU 146-1	42	89
BRU 95-8	28	94
DEN 216-1	64	98

Note 1: UCS - Unconfined Compressive Strength

Note 2: UCS was calculated based on point load test results

Note 3: Total of 224 point load tests completed

Table 9: Laboratory Tensile Strength and UCS Tests for Limestone

	Tensile Strength (MPa)	UCS (MPa) (Note 1 & 2)
Total Number of Tests	71	12
Average	5.3	68
Lower Quartile	3.8	45
Minimum	1.5	34
Selected Value by Stantec	1.5	50

Note 1: UCS - Unconfined Compressive Strength

Note 2: Samples were tested at Stantec Laboratory & Geomechanica Inc.



Figure 8: Tensile Strength Test

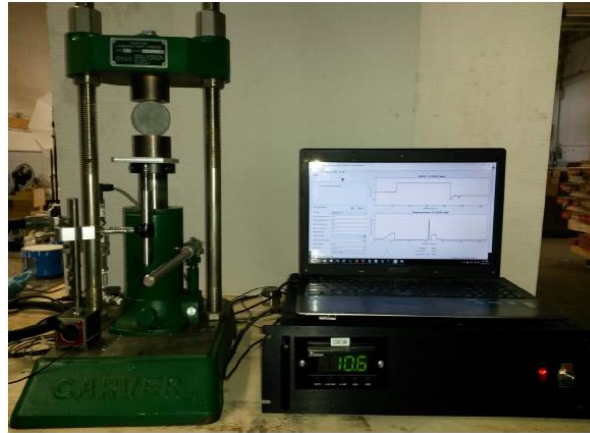


Figure 9: Unconfined Compressive Strength (UCS) Test

Seismicity

Design Basis

- Low seismic hazard area based on Geological Survey of Canada Seismic Hazard Map and National Building Code of Canada PGA

Table 10: Peak Ground Acceleration for a 100-year return period (project design life span)

Location	PGA (g)
Project Site	0.002
Vancouver	0.081
Toronto	0.011

Note: National Building Code 2020 PGA value for the project site is unchanged from 2015 value

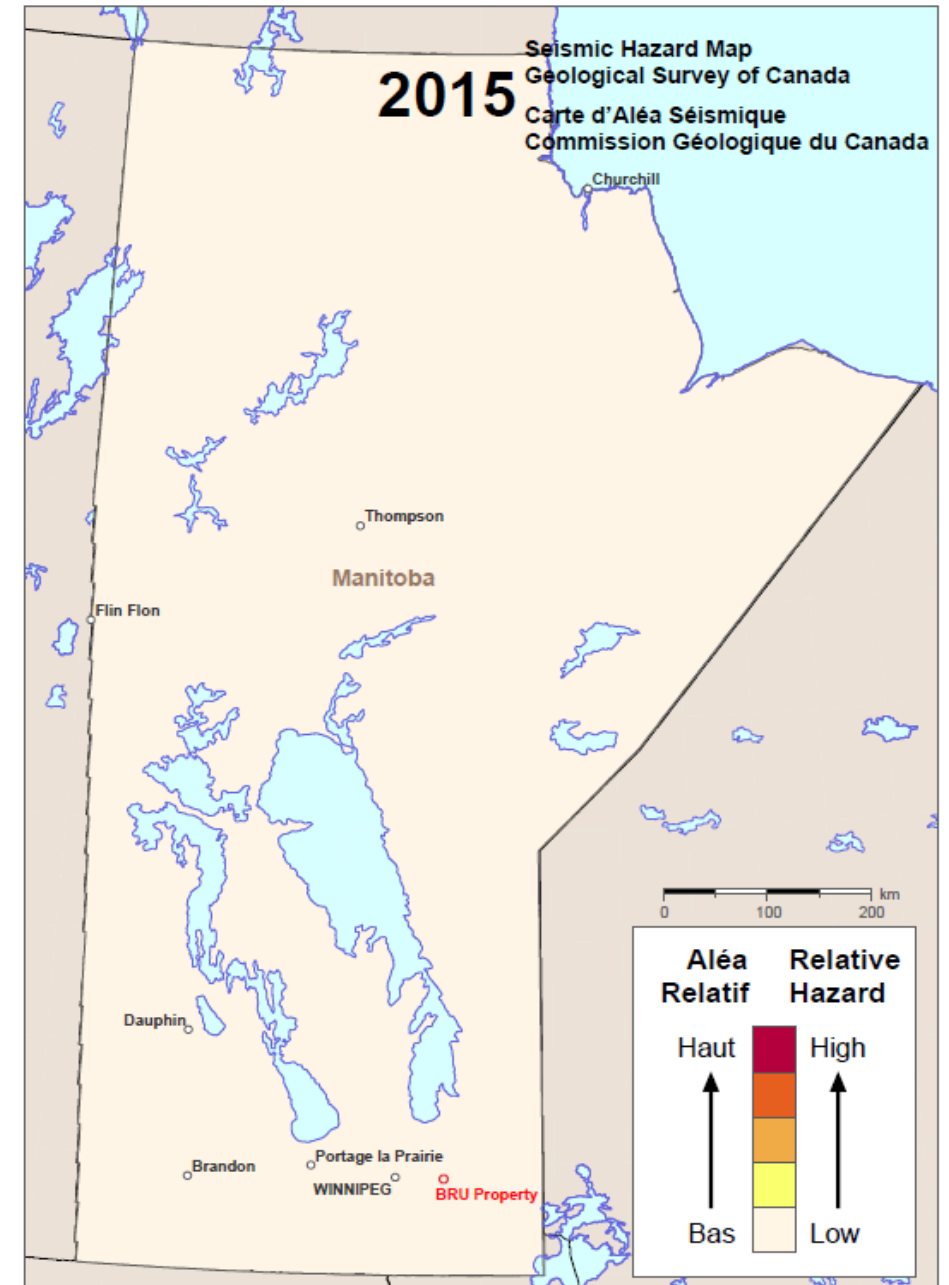


Figure 10: Seismic Hazard Map of Manitoba

Side Scan Sonar

Design Basis

- Cavity shape measured using side scan sonar.
- Side Scan Sonar is an accurate snapshot of cavity in time.
- Currently we use axisymmetric cavity for stability analysis (potential variations in cavity shape will be managed by adapting borehole location).

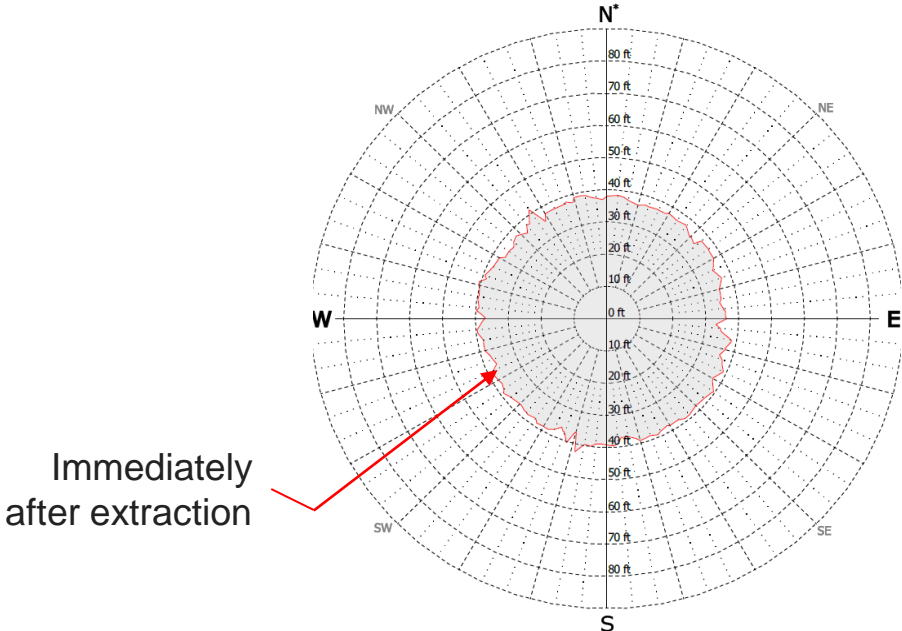
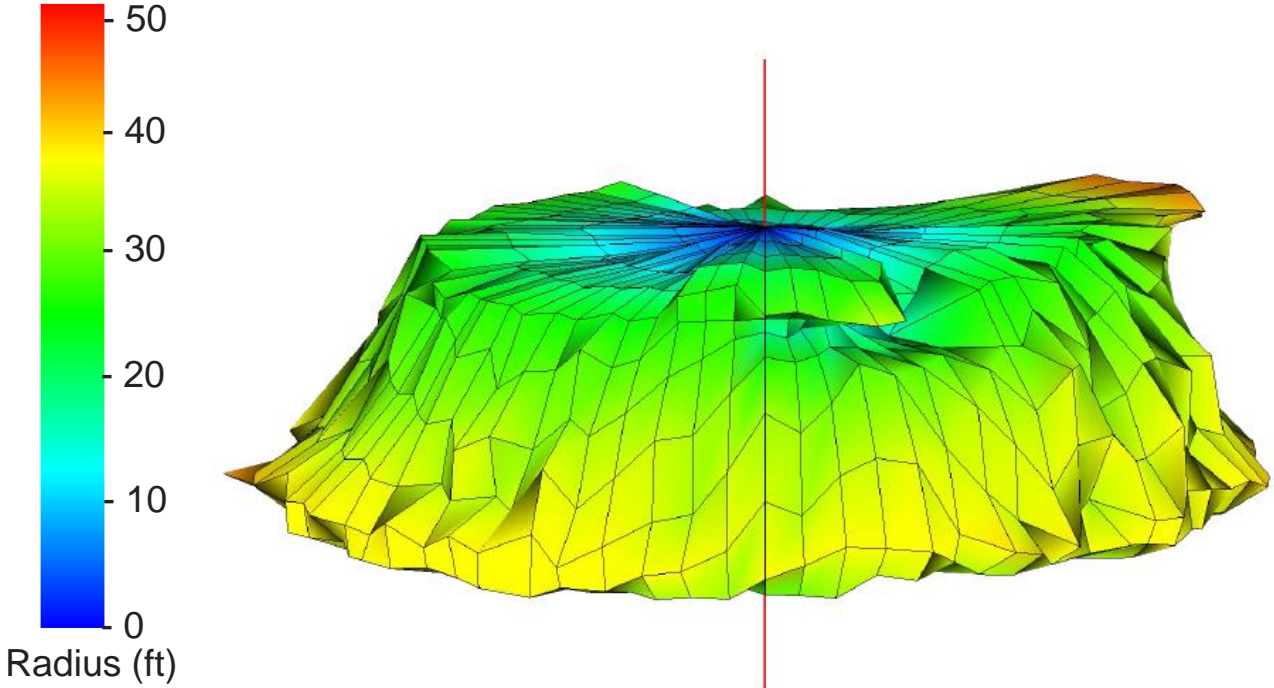


Figure 12: BRU 92-2 Plan View

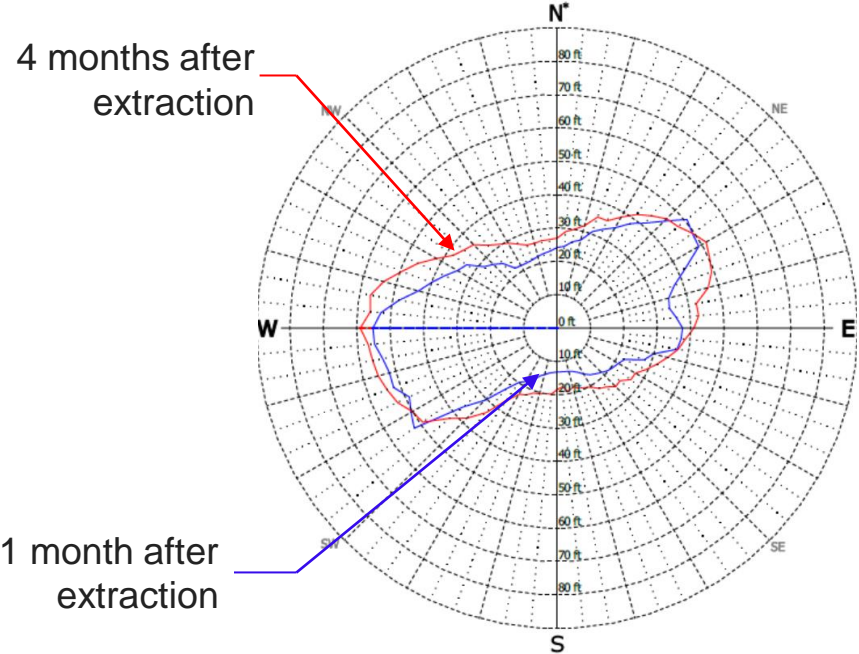


Figure 13: BRU 92-8 Plan View

Surface Monitoring

Design Basis

- Potential surface deformation was monitored at three boreholes (BRU 92-2, BRU 92-3, and BRU 92-8) from April to December 2021 using five settlement gauges surrounding the extraction wells.
- Survey points located 4 to 20 m (13 to 65 ft) from extraction centers.
- Measured deformations range from 0 to 2 mm (1 mm accuracy – No significant deformation).

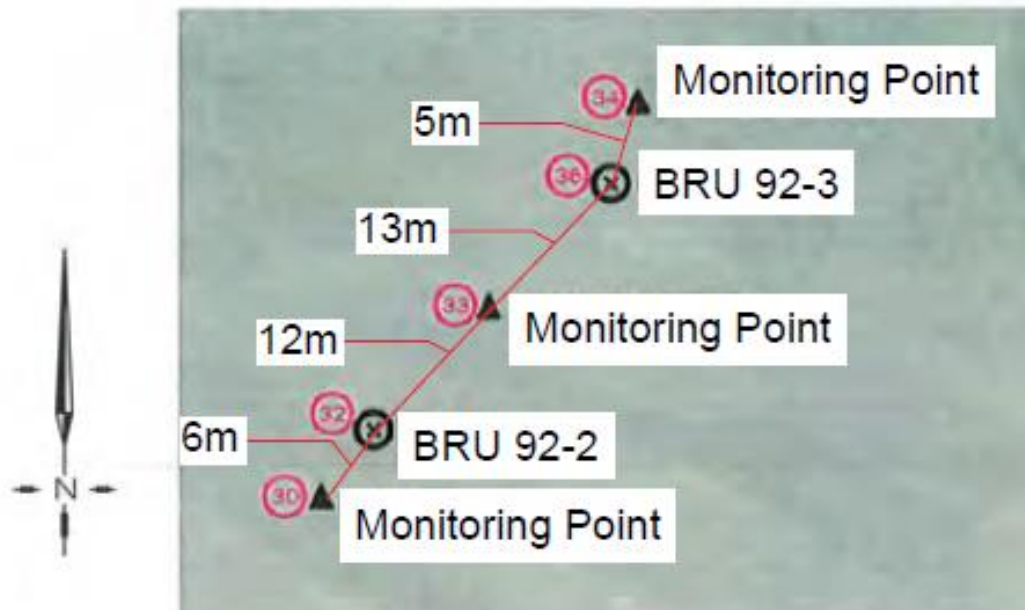


Figure 14: Monitoring Points (BRU 92-2 & 92-3)

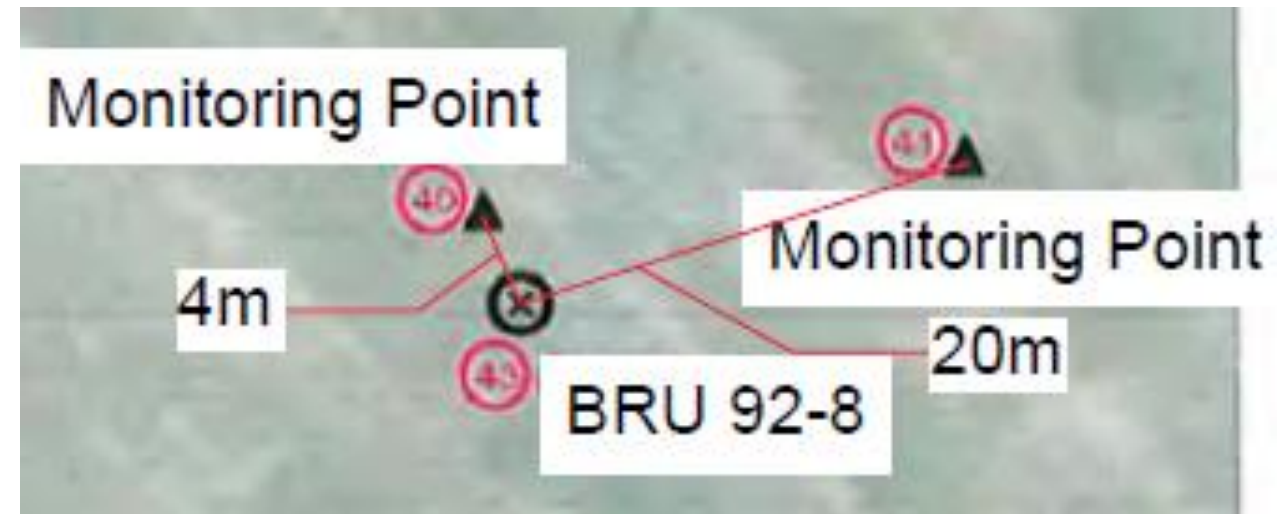


Figure 15: Monitoring Points (BRU 92-8)

Analysis

Geotechnical Design Basis/Criteria

Analysis

Table 11: *List of Geotechnical Design Basis/Criteria*

Items	Criteria
Cavity Lifespan	100 years after extraction
Stability Factors for Cavity Expansion	Minimum factor of safety 2.0 against horizontal expansion of cavity
Extraction Cavity	<ul style="list-style-type: none">• Axisymmetric development of cavity• Depth of extraction in sand: 20 m (65 ft) maximum
Stratification	<ul style="list-style-type: none">• Stratigraphy based on geological model• Caprock strength based on competent limestone
Carbonate/ Limestone GSI	Caprock GSI of 60
Seismicity	Low

Shear Failure Mode - Analysis

Analysis

- In shear failure mode, the load on a block of competent limestone directly above the cavity roof overcomes the competent limestone shearing resistance, resulting in downward movement of the block.
- Advanced geotechnical numerical modeling, using FLAC software, was completed to estimate the safe cavity size to provide stability against shearing failure into the cavity.
- Extensive sensitivity analyses were completed to evaluate the design range of cavity size using shear deformation models.

Note:

Fast Lagrangian Analysis of Continua (FLAC) is a numerical modeling software for advanced geotechnical analysis of soil, rock, groundwater, and ground support.

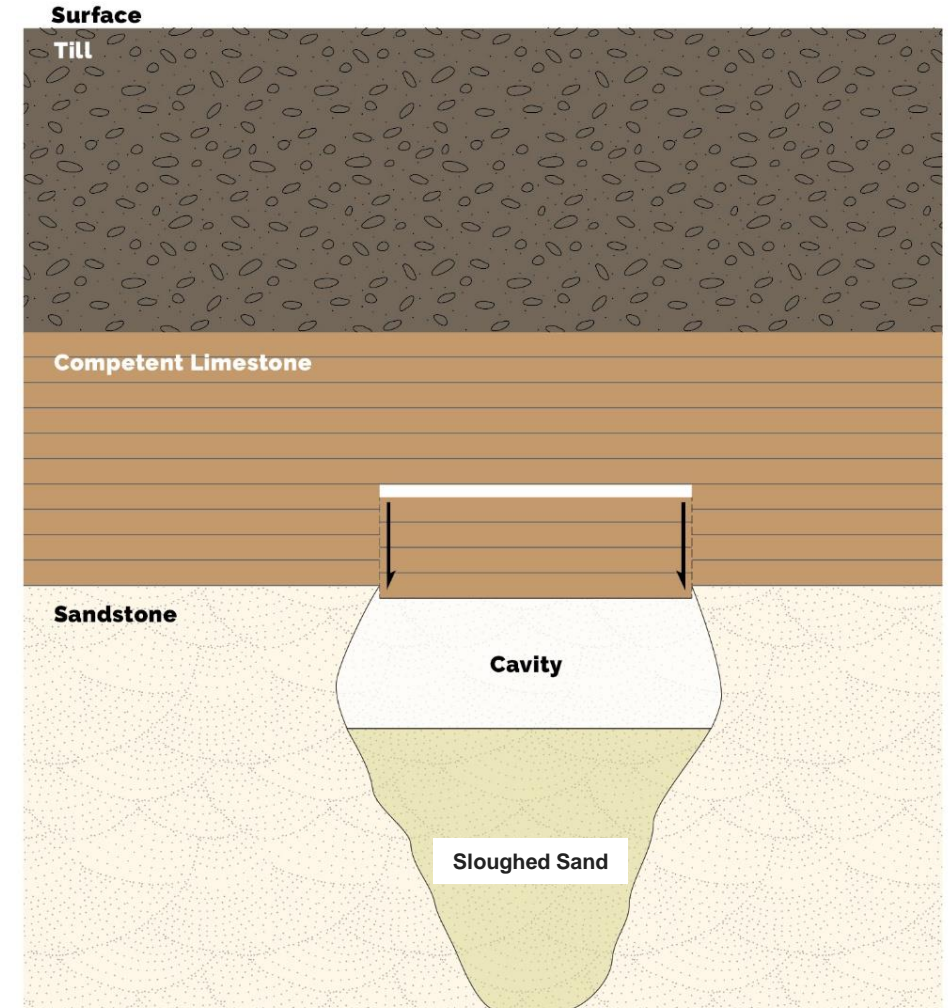


Figure 16: Shear Failure Mode

Advanced Modelling of Cavity

Analysis

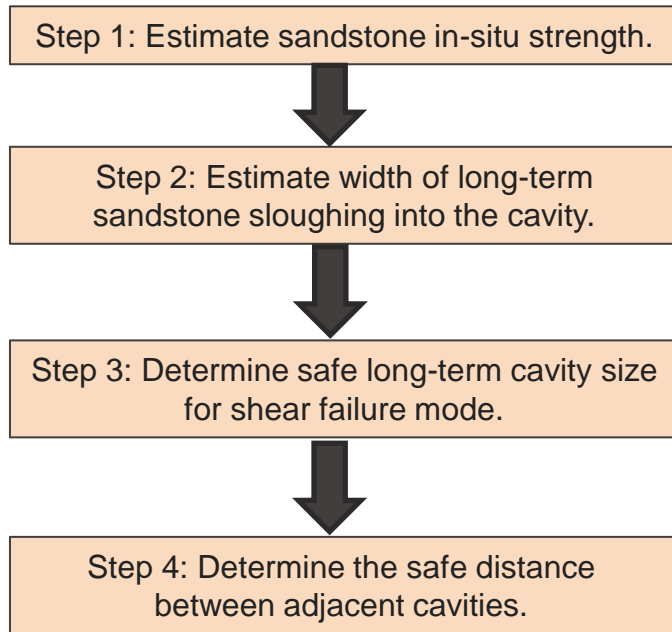
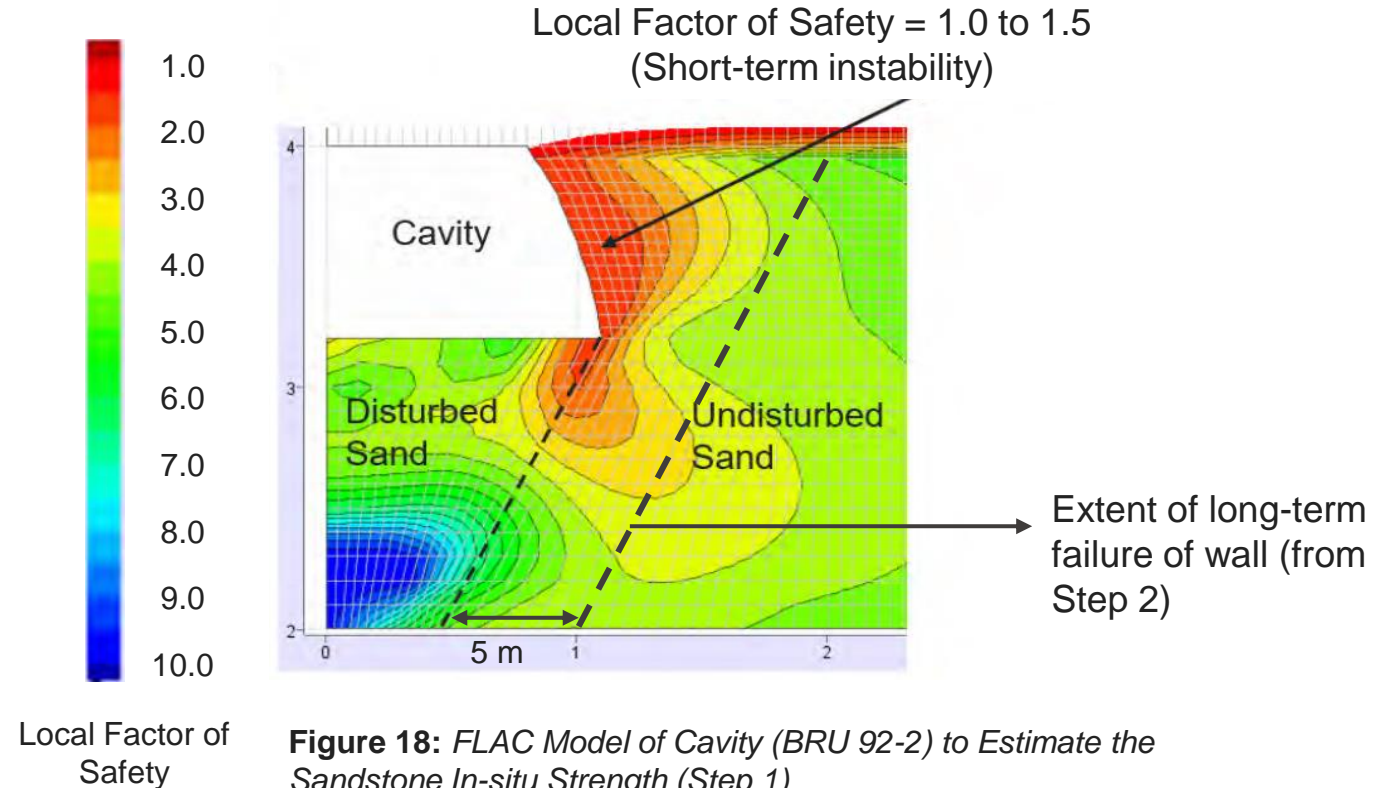


Figure 17: FLAC Modeling Steps



Bending Failure Mode - Analysis

Analysis

- With a large unsupported cavity, the layers of limestone on the roof of the cavity may detach downwards. The collapse of the lower layers leaves cantilevers that progressively provide support for the upper beams.
- Allowable long-term span includes a span that has enough thickness of competent limestone at the top and several stable cantilevers to span the long-term cavity.

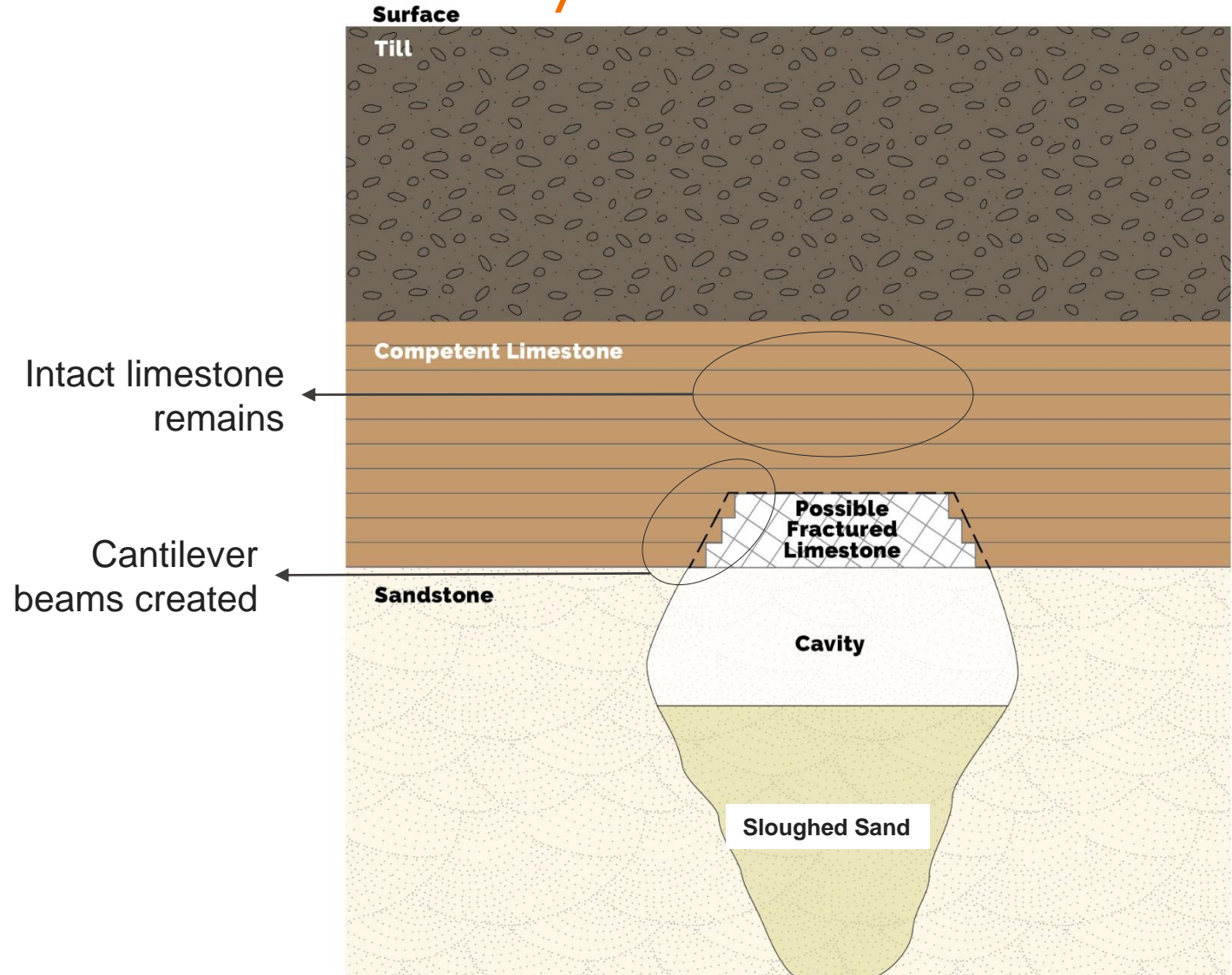


Figure 19: Graphical Representation of Bending Failure Mode

Results

Allowable Extraction Zone

Results

Table 12: Extraction Disturbance Zone Size Based on Thickness of Competent Limestone

Limestone Thickness (m)/(ft)	Overburden Thickness (m)/(ft)	Long-term Allowable Limestone Unsupported Span (Diameter) (m)/(ft)	Extraction Disturbance Zone Dimensions	
			Top Diameter (m)/(ft)	Bottom Diameter (m)/(ft)
15 (49)	25 (82)	35 (114)	25 (82)	6 (20)
	35 (114)	32 (105)	22 (72)	3 (10)
20 (65)	25 (82)	43 (141)	33 (108)	14 (46)
	35 (114)	40 (131)	30 (98)	11 (36)
25 (82)	25 (82)	50 (164)	40 (131)	21 (69)
	35 (114)	47 (154)	37 (121)	18 (59)

Note 1: Bending (Tensile) is the controlling failure mechanism to determine the long-term allowable span.

Note 2: Extraction zone side wall slope is 65°.

Note 3: Extraction depth is 20 m (65 ft).

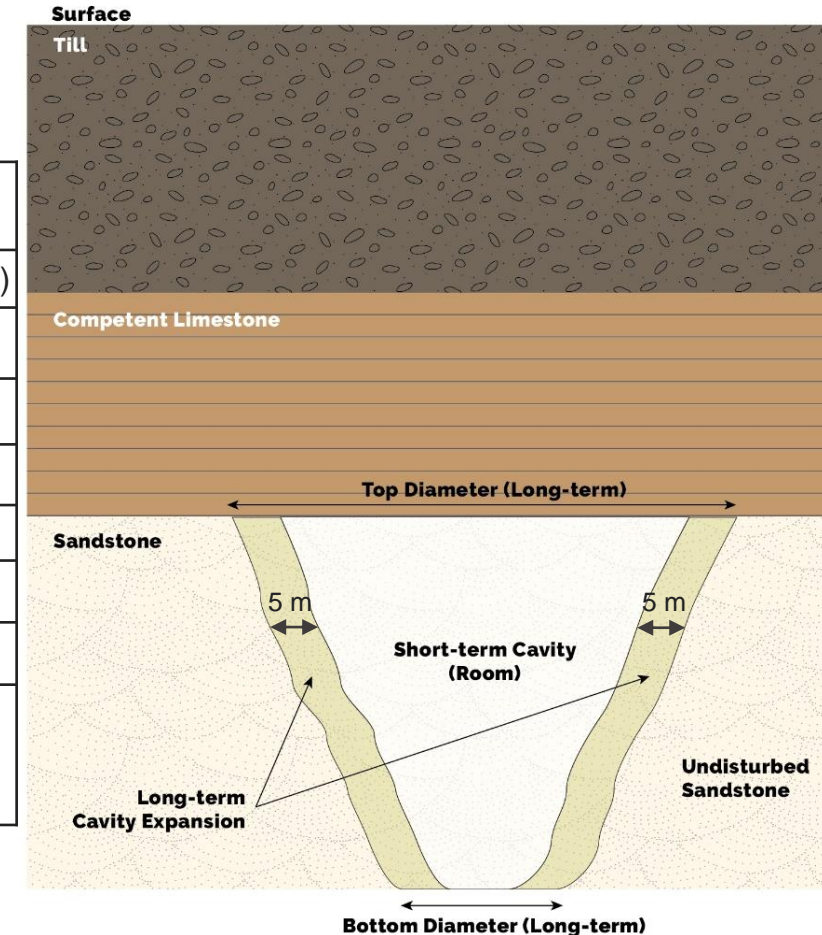


Figure 20: Allowable Cavity Extraction Zone

Effect of Adjacent Extraction Areas on Stability

Results

- The possible range of influence of a cavity on the ground surface was estimated using a FLAC model to be 60 m (196 ft).
- The pillar (distance from outside long-term diameter of one cavity to next one) must be at least 60 m (196 ft) wide.

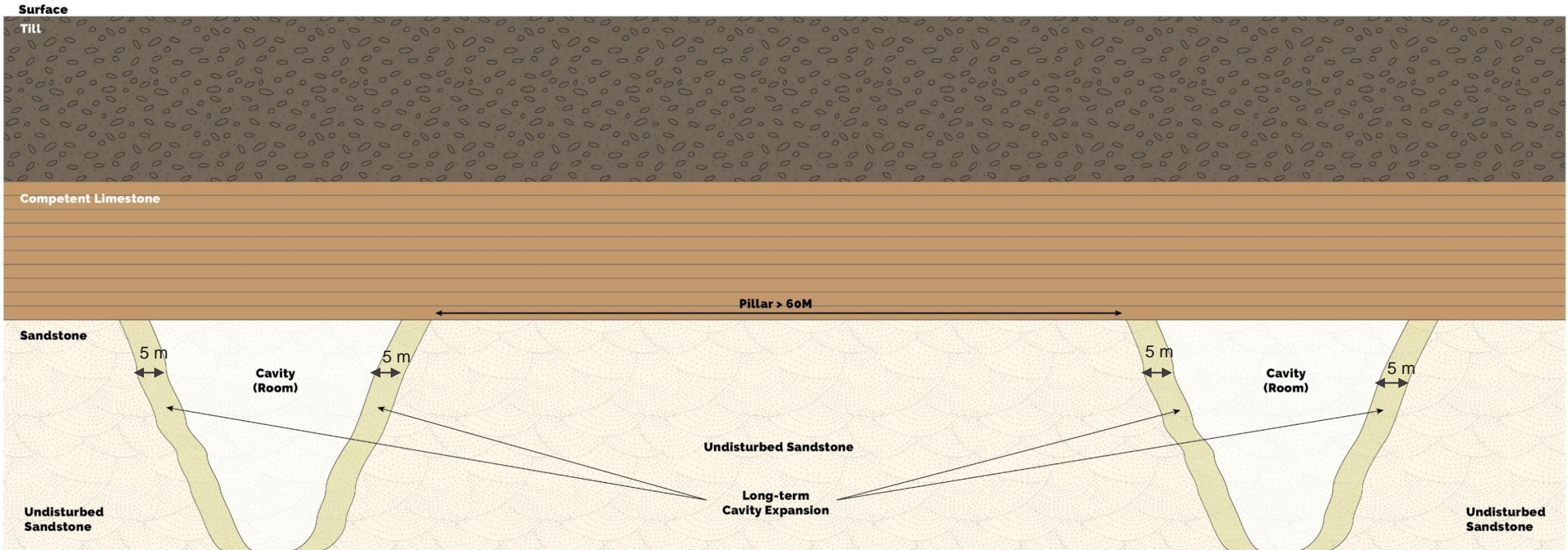


Figure 21: Distance Between Adjacent Extractions

Summary & Recommendations

Summary of Results

Summary & Recommendations

- Shear and Bending Failure modes were analyzed to identify the allowable short- and long-term cavity size. The bending failure mode controls stability. Other failure modes were also considered.
- The extraction cavity may expand due to wall sloughing with time. This possibility is considered in the geotechnical design.
- Based upon the results of site investigations and geotechnical analyses completed to date, the caprock remains intact (i.e., no surface breakthrough after extraction). Limited to no surface subsidence is expected to occur when Sio Silica follows the guidance provided by Stantec including continual assessment of geotechnical characteristics and performance of the sand deposit and overlying materials during the project life, and to adjust design accordingly.

Summary of Monitoring Plan

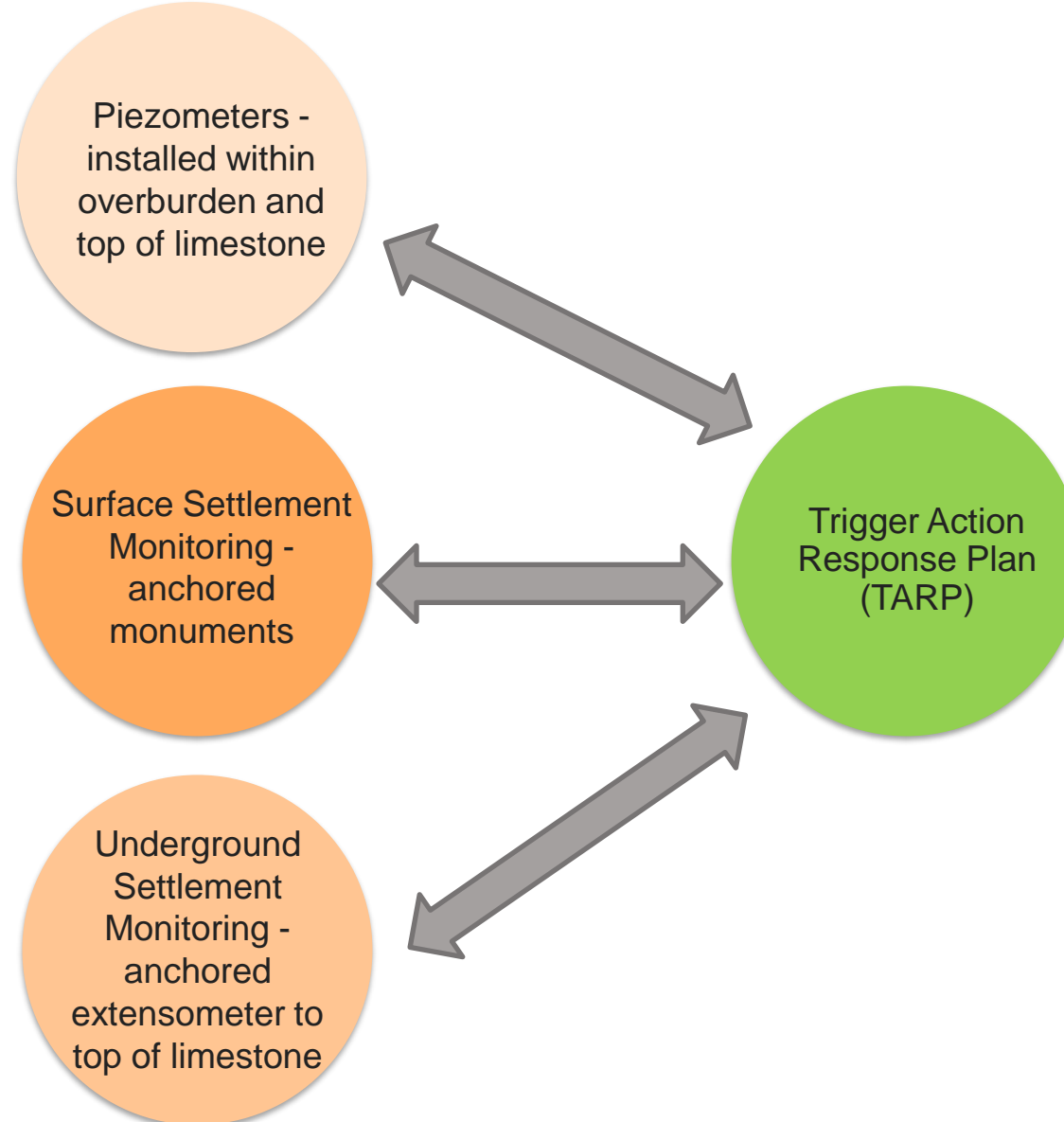


Figure 22: Monitoring Plan

Recommendations

- Limit the disturbance zone to the allowable dimensions designed by Stantec.
- Limit extraction to areas with competent limestone thicker than 15 m (49 ft).
- Locate extraction wells in each group to allow at least 70 m (230 ft) distance between short-term cavity edges.
- Complete multi-well extraction testing to confirm conditions.
- Confirm thickness of the overburden, competent limestone, shale and sandstone at each location before extraction.
- Drill inclined boreholes and complete ATV/OTV surveys to further assess the competent limestone.
- Install geotechnical instruments and monitor data.
- Develop a Trigger Action Response Plan (TARP) with defined triggers, actions, and responses.



Communities are fundamental. Whether around the corner or across the globe, they provide a foundation, a sense of place and of belonging. That's why at Stantec, we always **design with community in mind.**

