Manitoba Clean Environment Commission

Technical Review of Sio Silica Corporation's Environment Act Project Proposal

Vivian Sand Extraction Project

13 September 2022

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Executive Summary

Arcadis Canada Inc. (Arcadis) was retained to provide technical advisory services to support the Manitoba Clean Environment Commission (CEC) in its evaluation of Sio Silica Corporation's Environment Act Proposal for the Vivian Sand Extraction Project. This project is for the sequential installation, operation and decommissioning of silica sand extraction wells to remove silica sand from the Winnipeg Formation at various locations within the Rural Municipality of Springfield.

The objective of Arcadis' review was to assess the information on the proposed extraction process, geotechnical principles and modeling and identification of potential adverse environmental effects of the sand extraction. Specific areas of review included the silica sand extraction process, geotechnical principles and modeling, and identification of potential adverse environmental effects of the sand extraction.

Consistent with the overall objective of environmental assessment (EA) processes, Arcadis evaluated whether the proposed undertaking is likely to result in significant adverse impacts that cannot be mitigated. In this regard, the review was intended to identify potential "fatal flaws" related to the environmental performance of the project. For clarity, the review is not intended to resolve potential operational environmental management issues that are better addressed through future regulatory approval processes.

In Chapter 4 of this document, Arcadis provides a synthesis of the proposed project description based on the information provided by Sio Silica along with observations, comments, and conclusions related to the completeness of the description within the context of the environmental review. In Chapters 5 and 6, Arcadis provides a summary of the Proponent's Environmental Impact assessment for the various environmental components along with Arcadis' assessment and conclusion of the appropriateness of the Proponent's Proposal with respect to each environmental component related to Arcadis' scope of work. Chapter 7 provides Arcadis' review summary and conclusions.

Based on our review, Arcadis reached a series of conclusions which, in broad terms, relate to technical issues or the EA process. The most notable technical conclusion deals with the potential geotechnical failure of the Winnipeg Shale, which separates the Red River Carbonate Aquifer from the Winnipeg Sandstone Aquifer. The Project Proposal presents no information related to the potential failure of the Winnipeg Shale. With regard to the EA process, Arcadis concluded that the abbreviated temporal scope, substantively smaller spatial scope and exclusion of critical project components constitutes "project splitting". Arcadis considers this to be a material deficiency with the Project Proposal.

Arcadis' assessment and comments as provided to CEC in the 27 July 2022 report were based on information contained in the Project Proposal and its associated supporting documents. With regard to the potential failure of the Winnipeg Shale aquitard, Arcadis also considered comments from Sio Silica's technical advisors provided during a technical meeting (as per the recommendation in Section 7.2) held on 6 September 2022. No technical changes were made to the 27 July 2022 document as a result of the meeting.

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Version Control Record

A draft of this report dated 27 July 2022 was provided to the Manitoba Clean Environment Commission for review. As per Section 7.2, Arcadis recommended that a technical meeting be held with the proponent to discuss various technical aspects of the proposal. CEC agreed with this recommendation and a meeting was arranged with Sio Silica and its technical consultants for 6 September 2022.

The agenda topics for the meeting included:

- Shale aquitard integrity
- Validity of field investigations (hydrogeology and geochemistry)
- Conceptual and numerical models (hydrogeology and geochemistry)
- Water treatment (optional, time permitting)

Based on the 6 September 2022 technical discussions, Arcadis finalized the report as provided in this document with no technical changes to the original 27 July 2022 draft submission.

1 Clean Environment Commission Technical Review

The Manitoba Clean Environment Commission (CEC) was asked by the Manitoba Minister of Environment, Climate and Parks (formerly Conservation and Climate) to undertake a technical review and public hearing of Sio Silica Corporation's (formerly CanWhite Sands Corp.) Environment Act Project Proposal for the sequential installation, operation and decommissioning of silica sand extraction wells to remove silica sand from the Winnipeg Formation at various locations within the Rural Municipality of Springfield. The scope of the CEC review is as defined in a Terms of Reference (TOR) from the Minister to the CEC (dated November 15, 2021). The CEC subsequently established a Panel to undertake the review.

2 Scope of Technical Advisory Services

To support its evaluation of the proponent's Environment Act Proposal, the CEC retained Arcadis Canada Inc. (Arcadis) to provide technical advisory services. In providing such services, the CEC requested that Arcadis' scope consider the proposed extraction process, geotechnical principles and modeling and identification of potential adverse environmental effects of the sand extraction. CEC's requirements included the following elements:

i. Undertake an independent technical review of the Environment Act Project Proposal, taking into consideration existing materials and information available from Sio Silica Corporation (technical information on the extraction process and land subsidence) and those available on Manitoba's environmental public registry.

ii. In consideration of the Panel's requirement to provide advice to the minister on the potential environmental and health effects of the Project, provide the Panel with a written evaluation of the adequacy and completeness of the Project Proposal for this purpose.

Specific requirements of Arcadis' Scope of Work were as follows:

a. Read, review and provide advice regarding technical documents provided by Sio Silica Corporation, Manitoba Environment, Climate and Parks and other information supplied during the hearing process.

b. Assist the Panel in understanding the engineering design specifications and proposed extraction technologies, and advise the Panel regarding alternatives or modifications of those technologies.

c. Assist the Panel in understanding the specific health and environmental effects of the proposed Project including short- and long-term land subsidence and potential mitigation measures.

d. Provide advice on the proposed Project in comparison to similar existing sand extraction methods, their health and environmental effects and documented impacts on groundwater and aquifers.

e. Prepare and use briefing documents, issue papers, reports, presentations or any other suitable methods of information dissemination to facilitate the Panel's full understanding of the issues.

f. Act as liaison between Sio Silica Corporation and the Panel on the clarification of technical issues.

g. Attend hearing sessions, as required, to provide technical advice to the Panel (estimated 2-3 days).

h. Abide by the Commission's Code of Conduct

Consistent with the overall objective of environmental assessment (EA) processes, Arcadis evaluated whether the proposed undertaking is likely to result in significant adverse impacts that cannot be mitigated. In this regard, the review was intended to identify potential "fatal flaws" related to the environmental performance of the project. For clarity, the review is not intended to resolve potential operational environmental management issues that are better addressed through future regulatory approval processes.

The scope of technical support provided by Arcadis includes all environmental aspects associated with the proposed mining activities, with the exception of hydrogeology, the biological environment and socio-economic impacts.

The CEC required that Arcadis' assessment report be in a form suitable for public release. The current document is provided in fulfillment of that requirement.

In addition to performing a technical review of the Environment Act Project Proposal, Arcadis will assist with the Panel's understanding of the technical descriptions and details and assist in interpretation of technical materials throughout the full hearing process.

3 Documents Reviewed

Table 1 Documents Reviewed

Report Title	Author / Date
Vivian Sand Extraction Project – Environment Act Proposal	AECOM, 23 July 2021
Geotechnical Analysis for SioSilica Extraction Project	Stantec, 14 Jan. 2022
Appendix A – Hydrogeological Assessment Final Report	AECOM, July 2021
Appendix B – Expert Peer Review of Draft Hydrogeological Assessment Report	Friesen Drillers Limited; Dr. Grant Ferguson, 2021
Appendix C - Project Mining Claims and Legal Description Information	AECOM, 3 Dec. 2021
Appendix D – Soil Characteristics in the Project Site Area	AECOM, 2021
Appendix E – Species of Conservation Concern in the Interlake Plain Ecoregion	AECOM, 2021
Appendix F – Historic Resources Branch Communications	Manitoba Sport, Culture & Heritage, 11 March 2021
Appendix G – Heritage Resources Impact Assessment of the CanWhite Sands Corp. Vivian Sand Extraction Project	Western Heritage, 4 June 2021
Update to Geotechnical Parameters for Operations (Letter to Manitoba Conservation and Climate)	SioSilica, 21 Jan. 2022
Process Wastewater Treatment Options (Draft)	AECOM, June 2022
SioSilica Supplemental Information Document #1 - Silica Extraction Method	SioSilica, 2 June 2022
SioSilica Supplemental Files #2 – Erosion and Sediment Control Plan (Example Only)	AECOM
SioSilica Supplemental Files #2 – Groundwater Monitoring and Impact Management Plan (Draft Example)	AECOM
SioSilica Supplemental Files #2 – Waste Characterization and Management Plan (Draft Example)	AECOM
SioSilica Supplemental Files #2 – Water Management Plan (Draft Example)	AECOM
SioSilica Supplemental Information Document #3 - Progressive Well Abandonment and Site Closure Additional Information	SioSilica, 29 June 2022
Patent 3080017 Summary	Canadian Patents Database (accessed 11 July 2022)

4 Project Description and Scope

The current section is provided as a synopsis of the proposed Project. For brevity, the descriptions are limited to the key aspects of the undertaking and readers are encouraged to review the full Project Proposal and supporting documents if further details are required.

4.1 Project Purpose

The Proponent is planning to extract high purity silica sand from the Winnipeg Sandstone aquifer (approximately 61 m, or 200 ft below ground) within the Winnipeg Sandstone geological formation southwest of the hamlet of Vivian, Manitoba and approximately 26 km east of the City of Winnipeg. The purpose of the Vivian Sand Extraction Project (the 'Project') is to obtain high purity silica sand for use in a variety of markets such as the renewable energy industry (e.g., solar panel production), metallurgical silicon (lithium ion batteries), telecommunications (e.g., fibre optics), smart glass, precipitated silica (e.g., tires, medical and dental), silica carbides (e.g., electronics, cellphones, computer chips), silicon enhanced alloys (e.g., aluminum components for aerospace and automobile), low iron glass (architectural envelopes) and ceramics.

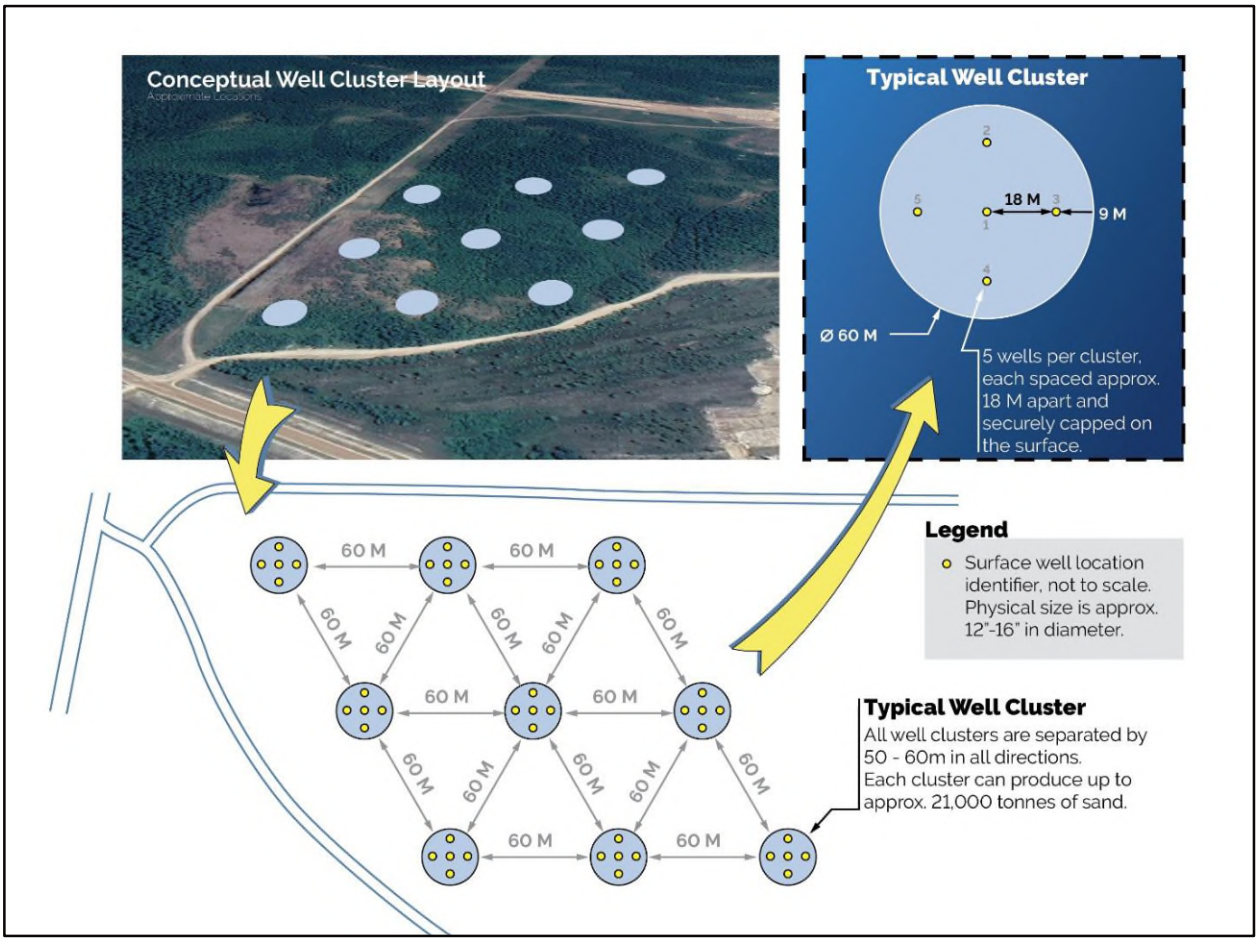
4.2 Project Synopsis

Extraction of sand and other unconsolidated granular materials is typically achieved through the development of open pits. Under that approach, granular materials are excavated from the pits and transported to surface, usually via truck. In the case of the Vivian Sand Project, the Proponent concluded that the target sand deposit is too deep (60 plus metres below surface) to use an open pit extraction method. Instead, extraction wells will be drilled into the Winnipeg Sandstone aquifer and unconsolidated sand will be removed using an air lift extraction method. The technique involves pumping air into the sandstone formation to mobilize sand and transport it to the surface within the well. Following is a summary of the extraction process:

1. Drilling of extraction wells will occur year-round. Clusters of one to five extraction wells will be installed in advance of extraction using standard water well drilling techniques. The clusters will have a maximum diameter of 60 m and each well will be located a minimum of 18 m from other wells. A hypothetical layout of extraction well clusters is presented in Figure 1.
2. When each well is drilled, a casing will be installed and grouted in place to isolate between the various formation layers to prevent vertical mixing of the different aquifers present. Once a well is drilled and the casing is in place, the well will be securely capped until sand extraction activities begin.
3. A production pipe will be inserted into the extraction well with an air line installed inside the production pipe for air to circulate and facilitate movement of sand and groundwater to the surface. This activity is a standard water well production method. A schematic of the sand extraction method is provided in Figure 2.
4. The sand and groundwater slurry brought to surface will pass through vibrating screens installed over a sump pit at the extraction site that will capture oversized materials such as concretions (calcified sand), which are commonly encountered.
5. The sand and groundwater slurry will then move to a dewatering station at the extraction site where the sand will be separated from the groundwater.

6. This groundwater will then be returned to the aquifer via the sand producing extraction well after being treated with ultraviolet (UV) light, which is a water treatment technique commonly used in municipal water treatment facilities. In this case, the purpose of the UV treatment is to ensure micro-organisms present at surface are not introduced into the groundwater aquifers when the water is reinjected.
7. The extracted sand will enter a movable slurry transport pipeline system that will transport the sand to the Processing Facility located south of the hamlet of Vivian. This slurry transport system will contain recycled water from the facility that is traveling in a continuous loop. The sand enters the loop at the extraction site, travels in the slurry line to the facility and is removed from the slurry line for washing and drying. Once the water no longer contains sand and has been through the treatment process, the water returns back to the extraction site via a dedicated water return line. This water then feeds back into the sand slurry line to move more sand back to the facility in a continuous loop process. The slurry transport concept is presented in Figure 3.
8. Up to seven extraction wells will be operating simultaneously with active wells in up to two adjacent clusters operating at any time. The sand extraction process within each well will continue for five to seven days before the well is capped and equipment is moved to the next well. When a well is no longer producing sand, the production piping will be removed, the slurry line will be disconnected, and the well will be capped. All equipment will then be moved to the next well in the cluster and re-connected. While this is occurring, the other wells (up to seven) will continue to operate so that the slurry loop system continues to supply sand to the facility for processing.
9. Once the production piping is removed from the extraction well, the well will be sealed as per *The Groundwater and Water Well Act* requirements to prevent movement of water vertically between the aquifers.
10. The Project will operate 24 hours per day, seven days/week (24/7) on a year-round basis. The Proponent anticipates extracting sand from up to 324 wells per year (i.e., approximately 1,300 wells over the first four-year extraction period).

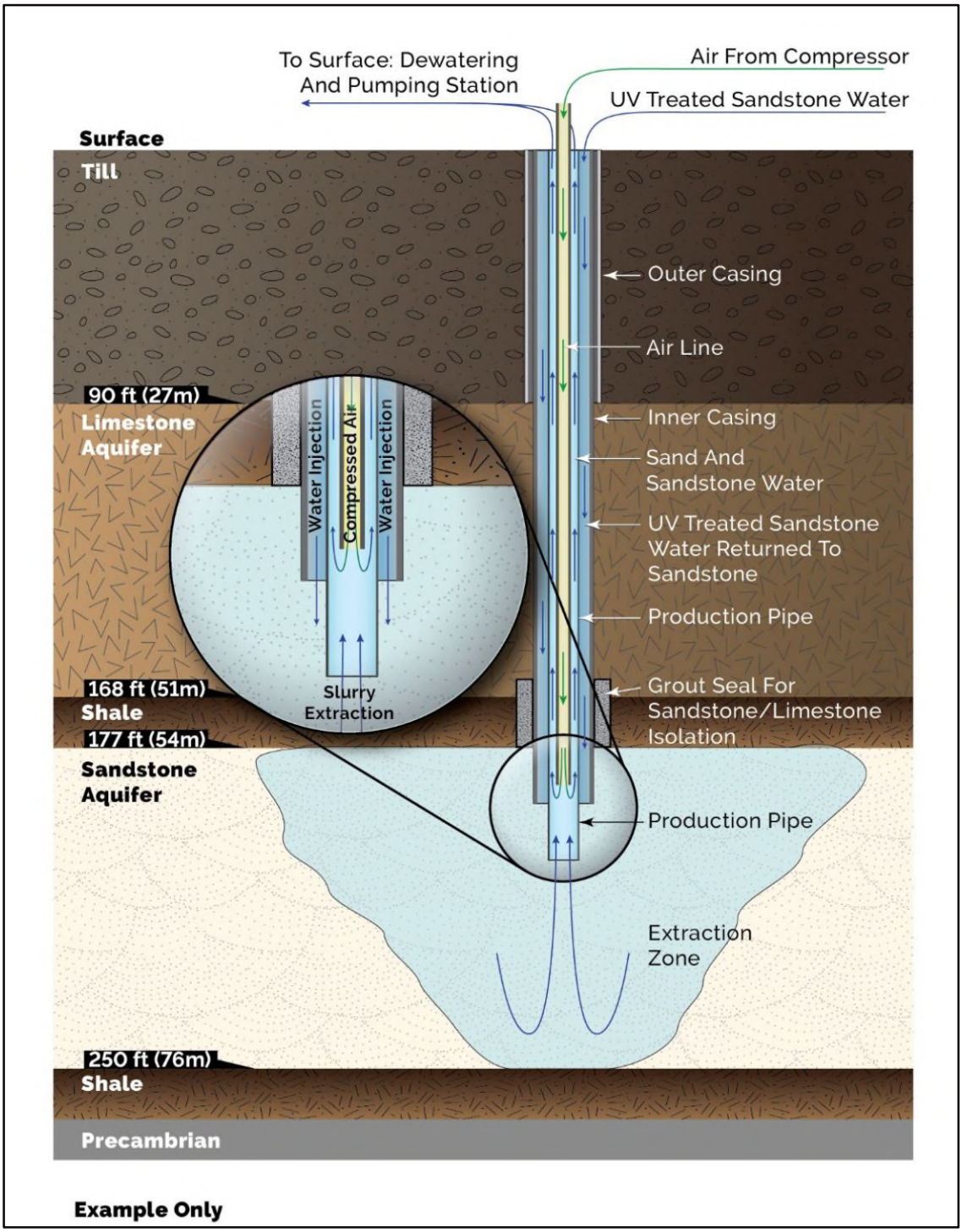
Figure 1 Conceptual Extraction Well and Well Cluster Layout



Note: The well/cluster configuration described in the Project Proposal was based on seven wells per cluster. A revised configuration based on up to five wells per cluster, as presented above, was provided in supplemental information submitted by the Proponent in June 2022 (see following source).

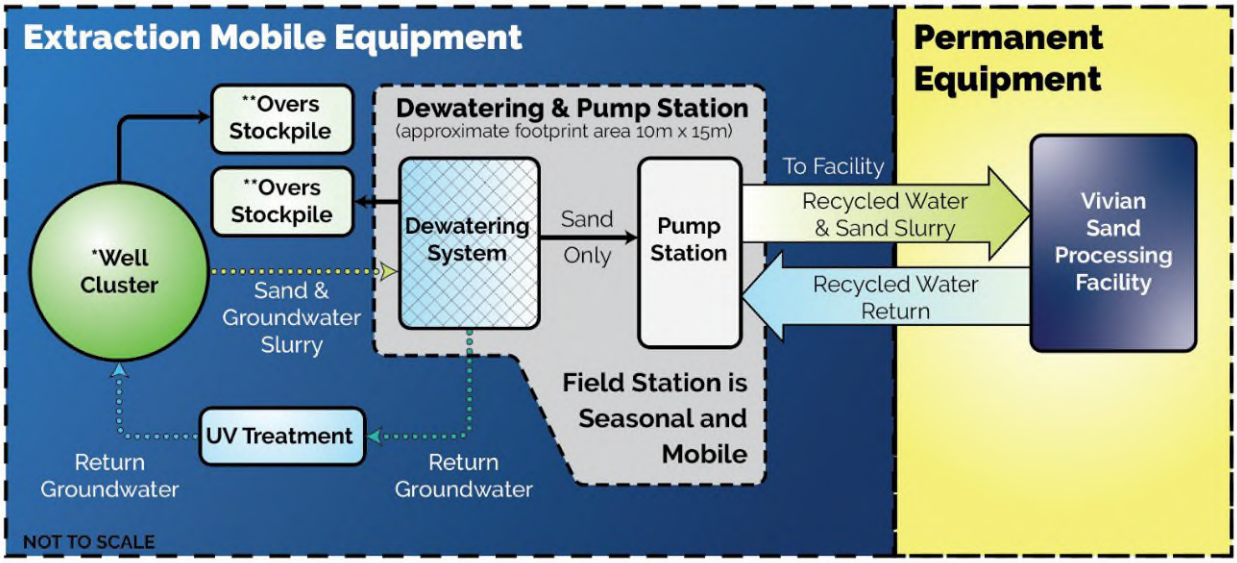
Source: Supplemental Information: Document #1 – Silica Extraction Method Vivian Sand Extraction Project, Sio Silica (June 2022).

Figure 2 Well and Sand Extraction Schematic



Source: Supplemental Information: Document #1 – Silica Extraction Method Vivian Sand Extraction Project, Sio Silica (June 2022).

Figure 3 Slurry Transport Concept



Source: Vivian Sand Extraction Project Environment Act Proposal, AECOM (July 2021).

Arcadis Assessment

When compared to other conventional aggregate extraction techniques (i.e., open pit excavation), the proposed extraction method is less invasive and has the potential to result in lower environmental impacts. Compared to such alternatives, the proposed extraction method would result in relatively minor surface disturbances and the extracted material would remain within a "closed loop", thereby limiting the potential for interactions with the environment (e.g., dispersion of silica dust). In qualitative terms, we anticipate that the proposed method would result in fewer impacts to the atmospheric and surface water environments when compared to open pit methods. The extraction method would also have different and potentially less significant groundwater impacts relative to open pit mining. This does not, however, imply that reduced impacts would necessarily be acceptable; it is simply an acknowledgment that the Proponent selected an extraction method that appears to have important advantages over conventional alternatives.

When considering the selected extraction method, Arcadis notes that the "air lift" method has been used primarily for the development of wells and that there are no examples of the technique being used as a full-scale mining method. This introduces a degree of uncertainty regarding the performance of the method at full scale and under a range of geological and environmental conditions. Relative to other proven techniques, this uncertainty justifies adopting a more precautionary approach when developing and implementing project designs. This is particularly important given the need to protect local and regional groundwater resources.

Arcadis Conclusion #1: Extraction Method

When compared to other conventional aggregate extraction techniques (i.e., open pit excavation), the proposed extraction method is less invasive and has the potential to result in lower environmental impacts. This does not, however, imply that reduced impacts would necessarily be acceptable; it is simply an acknowledgment that the Proponent selected an extraction method that appears to have important advantages over conventional alternatives.

The "air lift" method has not been used as a full-scale mining method. This introduces a degree of uncertainty regarding which justifies adopting a more precautionary approach when developing and implementing project designs. This is particularly important given the need to protect local and regional groundwater resources.

4.3 Project Scope Boundaries

The Project Proposal scope does not include the following activities that are integral to the Vivian Sand Project. By extension, the Project Proposal does not assess or consider the environmental impacts associated with these activities.

Future Sand Extraction

The scope of the Proponent's Environment Act Project Proposal is limited to four years of sand extraction within the immediate vicinity of the Processing Facility. After the first four-year phase of extraction, the Proponent intends to gradually progress further from the Processing Facility each year within blocks of land adjacent to previous extraction wells over the anticipated 24-year life of the Project. This will reportedly be explained in subsequent Notices of Alteration for the future extraction years, with the information and review process for Notices of Alteration of an Environment Act Licence for the Project being as required under Section 14 of The Environment Act. Sio Silica's rationale for using a phased approach is based on their expectation that advancements in extraction methods and operations will increase efficiency and reduce the overall footprint after the first phase of extraction.

The conceptual progression of well development and extraction during the initial four-year phase and subsequent years of operation are illustrated in Figures 4 and 5. Based on those figures, it is evident that the spatial scope of development assessed by the Proponent in the current Project Proposal represents a small portion of the area that will ultimately be impacted during the 24-year mine life. In this regard, the Proponent's decision to substantively limit the temporal scope of the Project Proposal has also resulted in the spatial scope of the assessment being limited.

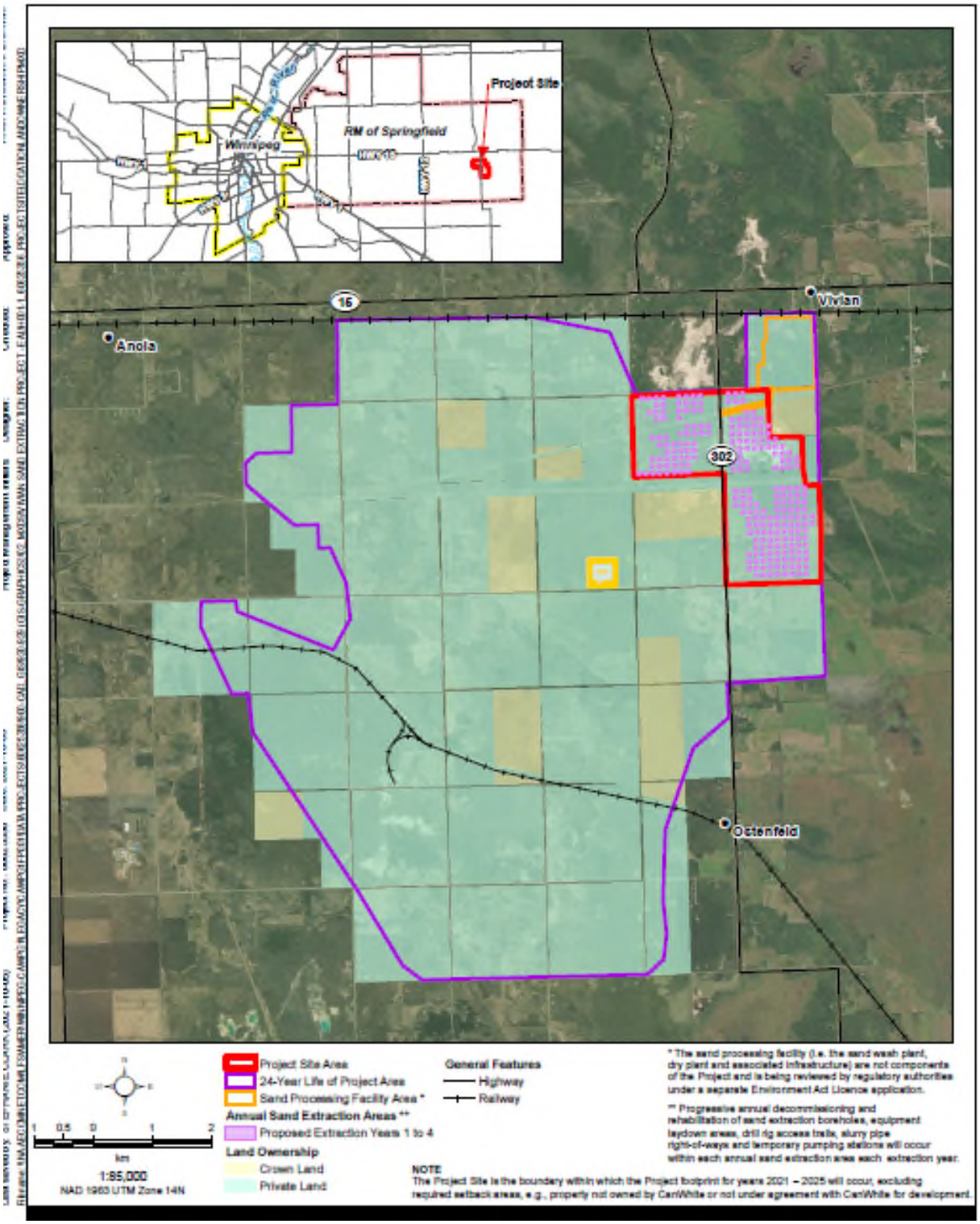
Sand Processing and Supporting Infrastructure

Sio Silica's sand Processing Facility and associated infrastructure, including a rail loop and interconnection with the existing Canadian National Railway, are being reviewed by Manitoba Conservation and Climate (MBCC) as a separate project requiring a separate Environment Act Licence to proceed. Therefore, the Processing Facility and associated infrastructure components are not assessed within the Environment Act Proposal for the sand extraction project, nor are they being reviewed by Arcadis.

Arcadis Assessment

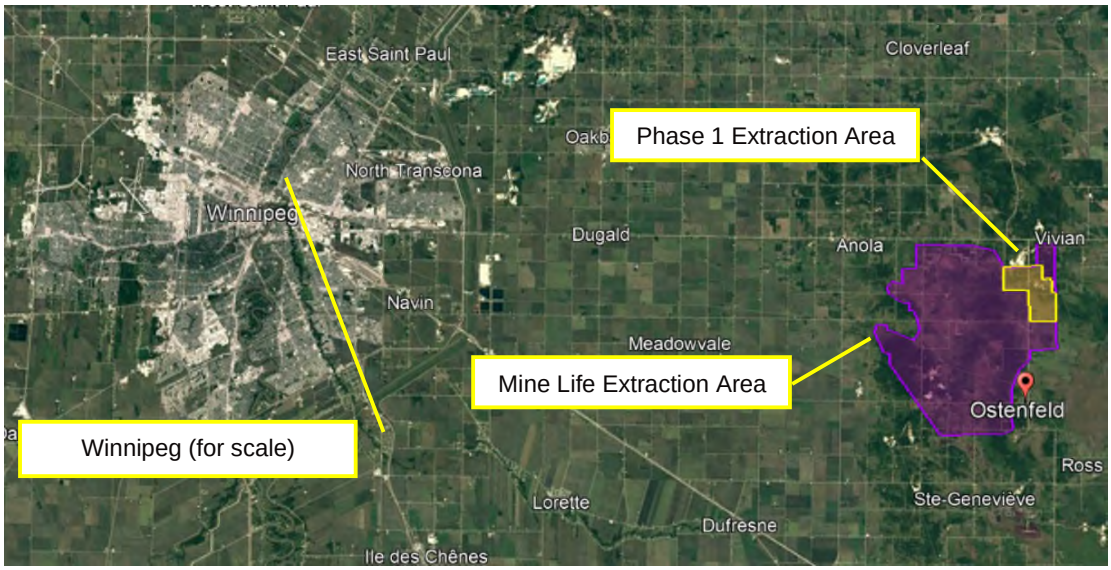
The mine has an expected life of 24 years but only 4 years of mining activity have been assessed in the Project Proposal. While breaking projects into phases is a common approach when issuing regulatory authorizations, it is

Figure 4 Project Spatial Scope (1 of 2)



Source: Updated Figure 1 from Vivian Sand Extraction Project Environment Act Proposal, AECOM (July 2021)

Figure 5 Project Spatial Scope (2 of 2)



inappropriate in the context of Environmental Assessment because it has the potential to underestimate the spatial extent, duration and therefore significance of project impacts.

Similarly, the exclusion of Sio Silica's sand processing facility and other supporting infrastructure from the scope of the current Environmental Assessment is inappropriate. The potential impacts of the entire mining project throughout its life cycle including extraction, processing and transport should be evaluated by a single, comprehensive assessment that considers the Vivian Sand Project as one undertaking, not a series of independent and unrelated projects.

Arcadis Conclusion #2: Project Scope

In the opinion of Arcadis, the abbreviated temporal scope, substantively smaller spatial scope and exclusion of critical project components constitutes "project splitting". In simple terms, this involves breaking a project into smaller pieces that individually fall below EA impact thresholds that might otherwise result in significant impacts.

Arcadis considers this to be a material deficiency with the Project Proposal and recommends that the CEC explore options to evaluate the potential environmental impacts of the entire Vivian Sand Project, not just sand extraction.

5 Environmental Assessment

The Project Proposal evaluates the potential environmental impacts associated with the following environmental components:

1. Geology/Topography
2. Soils
3. Groundwater
4. Air Quality
5. Climate/Greenhouse Gases
6. Noise
7. Surface Water
8. Fish and Fish Habitat
9. Vegetation
10. Wildlife
11. Species of Conservation Concern

In the following sections Arcadis has indicated whether it agrees with the Proponent's conclusions and/or whether any substantive technical concerns have been identified.

5.1 Geology/Topography Impact Assessment

Proponent's Impact Assessment

Proposed Activity

The Proponent's Environment Act Project Proposal indicates that the geology and topography of the Project Site will be affected by Project activities including:

- Clearing and levelling as needed at the sand extraction well locations;
- Clearing for temporary laydown areas in well cluster areas;
- Development of temporary access trails for drilling equipment access;
- Development of Temporary trails for the sand slurry line to the Process Plant and return water line to the wells, and associated pumping stations; and
- Drilling of sand extraction wells and sand/water separation at the well cluster.

Extraction of the silica sand resource will result in a permanent change to the underground geology in the form of horizontal arrays of rooms and pillars in the sandstone geological layer (between 52 m to 76 m), in the Winnipeg Formation aquifer within the Project Site.

Results of a geotechnical assessment based on preliminary exploratory drilling associated with this Project from 2017 to 2021 indicated that the overlying carbonate (limestone) geological layer needs to be at least 15 m thick to minimize the possibility of surface subsidence as a result of sand extraction activities. Additionally, the preliminary analysis indicated that:

- The diameter of extraction voids (i.e., areas where sand is extracted at each cluster of wells) should not extend beyond 60 m in any circumstance, and should be reduced to 50 m as the overlying limestone layer thins to 15 m.
- The distance from the edge of one extraction void to the edge of the next extraction void should not be less than 60 m in any direction.[1]

Based on these cluster extraction void diameters and distances between sand extraction centers, each extraction void would contain approximately 25,000 tonnes of sand resource, and a total estimated sand recovery of 1.06% targeted over the 24-year life of the Project compared to the total volume of sand identified as a resource in the Winnipeg Sandstone Formation.

Mitigation Measures

The Proponent has committed to implementing the following measures to avoid or minimize adverse impacts on geology and topography, including potential for underground and surface subsidence due to the sand and groundwater extraction activities:

- Where applicable, existing roads and trails and other previously disturbed areas will be utilized to minimize disturbance to the natural topography.
- The locations of annual extraction wells will be determined based on the results of preliminary geotechnical modeling used to predict thresholds of extraction amounts to mitigate adverse effects related to the potential for underground and surface subsidence.
- Additional testing will be conducted to further assess and confirm the limestone and overburden thickness and structure as the Project progresses and expands geographically.
- Progressive annual decommissioning of extraction wells will be done using a concrete cap, bentonite and permeable backfill in accordance with applicable guidance documents such as 'Constructing and Sealing Wells in Manitoba'.
- Levelling and grading will occur during progressive annual decommissioning of extraction wells to return the landscape to elevations typical to the surrounding area.

While measurable disturbances will be imposed on natural geologic and topographic features, disturbances will be limited to the Project Site. With the application of the above-described mitigation measures, the Proponent concluded that impacts on topography will be minor because disturbed land will be leveled, graded and progressively rehabilitated. Impacts to geology were assessed as being minor due to the abundance of remaining silica sand resource with approximately 1.06% removed throughout the 24-year life of the project in the target regional aquifer geological layer within the Project Site. The extracted silica sand will not be replaced; therefore, impacts to the geology will be irreversible/permanent.

Overall, the Proponent concluded that the Project Impacts to Geology and Topography will be "Minor" based on the following considerations:

[1] Note: As described in Stantec (2022) more conservative design parameters have subsequently been recommended. These more conservative design parameters are discussed in the following pages.

Magnitude of Effect:	Minor (Topography and Geology)
Direction of Effect:	Adverse
Duration of Effect:	Long-term
Frequency:	Intermittent
Scope of Effect:	Project Site
Reversibility:	Reversible (Topography); Irreversible (Geology)

Arcadis Impact Assessment

Arcadis' assessment of potential impacts to geology and topography is based on the Proponent's Environment Act Proposal and the following technical supporting document:

- Stantec Consulting Limited (Stantec). 2022. *Geotechnical Analysis for Sio Silica Extraction Project.*

In simple terms, the Stantec (2022) report assessed the likelihood that sand extraction would result in geotechnical failures of overlying geological strata, thereby creating subsidence of surficial topography. Prior to evaluating potential failure modes, the report defines the geological stratigraphy (i.e., layers) that are present at the Project site. Those layers, which are shown in Figure 6, include:

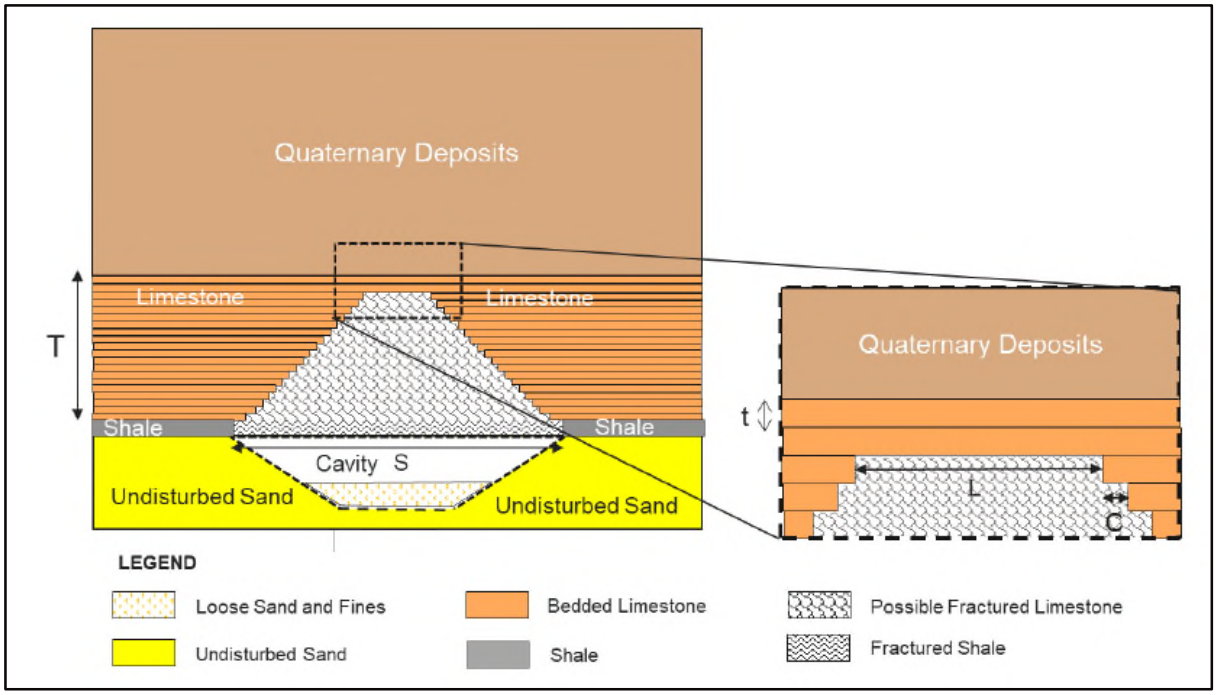
1. **Quaternary Deposits** – This is overburden that, for the purpose of Stantec's assessment, has limited structural strength.
2. **Limestone** – Referred to as the Red River Carbonate, the limestone serves as a "cap rock" that supports the overlying quaternary deposits. If the cap rock fails, the quaternary deposits will "cave" into the void, thereby creating subsidence at surface. In addition to supporting the quaternary deposits, the limestone layer is a freshwater aquifer that is used extensively throughout the local and regional areas surrounding the Project site.
3. **Shale** – Referred to as the Red River or Winnipeg Shale, this layer has limited structural strength and, similar to the quaternary deposits, will collapse downward if it is not supported. The shale also serves as an important aquitard (i.e., water barrier) that limits the flow of water between the Red River Carbonate Limestone aquifer and the underlying Winnipeg Sandstone aquifer.
4. **Sand** – This layer, referred to as the Winnipeg Sandstone aquifer, is the layer from which silica sand will be extracted. Similar to the Red River Carbonate aquifer (see above), the Winnipeg Sandstone is a locally and regionally significant freshwater aquifer.

The Stantec (2022) geotechnical assessment evaluated five potential failure modes that could result in environmental impacts. Following a qualitative evaluation, two of the five failure modes (Shear Failure and Bending Failure) were advanced for a detailed quantitative assessment to evaluate the likelihood and consequences of geotechnical failure. Of the two modes, Bending Failure was determined to be the controlling mode because it would occur prior to Shear Failure. Bending failure was therefore subjected to a more detailed analysis. Bending Failure is illustrated conceptually in Figure 6.

Stantec (2022) evaluated the strength and other properties of the limestone and determined that it is present in multiple horizontal layers. The subsequent analysis concluded that the lowest limestone layer was at risk of failing (i.e., breaking) and collapsing into the void if the diameter of the void became too large for the layer to "span" the opening. Following the collapse of the lowest limestone layer, the overlying layer would no longer be supported from below and would also be at risk of collapsing into the void. This failure mode would continue in an upward direction until a limestone layer has sufficient strength to span the underlying void. In the event that all of the

limestone layers failed, the overlying quaternary deposits would no longer be supported, and they would also be at risk of collapsing into the void. Such a collapse would have the potential to result in subsidence at surface (e.g., sink holes).

Figure 6 Bending Failure Mode in Bedded Limestone



Source: Stantec (2022)

Based on their analysis, Stantec (2022) concluded that the sand extraction process could occur without resulting in the full failure of the limestone cap rock, thereby preventing subsidence at surface. However, this would require the application of recommended design parameters to limit the risk of failure. Examples of the design parameters recommended by Stantec include:

- Limiting the horizontal extent of sand extraction voids;
- Limiting sand extraction to locations that have a competent limestone thickness greater than 15 m;
- Locating clusters of extraction wells at least 60 m apart;
- Completing full scale extraction tests to confirm performance prior to advancing the full Project;
- Preparing and following site-specific extraction designs, taking into consideration the geological properties at each location.

Overall, Stantec (2022) reached the following conclusion:

> *Based upon the results of geotechnical assessment and with the understanding that Sio Silica will follow guidance provided by Stantec including continuing to assess the geotechnical characteristics and performance of the sand deposit and overlying materials during the project life and to adjust design accordingly, no large scale surface subsidence is expected to occur as a result of sand extraction.*

Based on our review, Arcadis agrees with the assessments, recommendations and conclusions provided by Stantec (2022). The report presents a technical analysis of potential geotechnical failure modes that, in the opinion of Arcadis, is generally appropriate for a project that is undergoing Environmental Assessment. While the report appears to be well done and we generally agree with the analytical approach used by Stantec, we have identified a number of areas where additional evaluations and/or refinements to the study assumptions are justified.

Detailed findings and recommendations of Arcadis' review are presented in Appendix A to the current document.

Arcadis Conclusion #3: Geotechnical and Topographic Impacts

If the Project implements the design parameters recommended by Stantec (2022), Arcadis supports the Proponent's conclusion that the undertaking will not result in significant adverse impacts to the geotechnical/topographic environment. This conclusion applies exclusively to impacts at surface and does not address potential hydrogeological impacts that may occur as a result of sub-surface geotechnical failures. The conclusion does not apply to areas outside of the spatial scope assessed by Stantec (2022) and is subject to change as additional information becomes available.

In addition to the conclusion noted above, Arcadis has provided a series of Geotechnical Findings and Recommendations in Appendix A.

5.2 Soils Impact Assessment

Proponent's Impact Assessment

Proposed Activity

The Proponent's Environment Act Project Proposal indicates that construction/operation activities including clearing, levelling, and construction of temporary access trails, well clusters and slurry line and water return line routes, and the progressive annual decommissioning of extraction wells and disturbed areas have the potential to cause soil erosion. Soil erosion can potentially increase during high wind and precipitation events, which are expected to be most frequent during the extraction activities when soils are exposed and not frozen/snow covered (i.e., April through November).

Mitigation Measures

Soil erosion may affect other environmental components, such as air quality (e.g., dust from soil disturbance), water quality and vegetation. To mitigate the effects of soil erosion, the following measures will be incorporated:

- An Erosion and Sediment Control Plan will be implemented for all phases of the Project.
- During the progressive annual decommissioning activities, after Project components have been removed, the landscape will be leveled and graded, and disturbed areas will be revegetated as quickly as feasible to stabilize the soil and minimize soil erosion.

With the application of the above mitigation measures, the Proponent concluded that the potential for soil erosion and associated adverse impacts to the surrounding environment are anticipated to be "Minor" based on the following considerations:

Magnitude of Effect:	Minor
Direction of Effect:	Adverse
Duration of Effect:	Long-term
Frequency:	Intermittent
Scope of Effect:	Project Site
Reversibility:	Reversible

Arcadis Impact Assessment

For the purposes of Environmental Assessment decision-making, Arcadis agrees that the Project is unlikely to result in significant adverse impacts to soils. This conclusion is based on the expectation that:

1. Regulatory authorizations will require the Project to implement best-practice environmental management controls. This includes but is not limited to Erosion and Sediment Control Plans, Spill Management Plans, etc.;
2. Any releases on surface, including spills of silica sand, hydrocarbons and other potential environmental contaminants are appropriately mitigated; and
3. The sand extraction process does not result in any subsidence at surface (see Section 5.1).

Arcadis Conclusion #4: Soil Impacts

If the Project is subjected to standard regulatory requirements and implements appropriate environmental controls and mitigation measures, Arcadis supports the Proponent's conclusion that the undertaking will not result in significant adverse impacts to soils.

5.3 Groundwater Impact Assessment

Potential impacts to groundwater are being evaluated by CEC's hydrogeological advisors (Dr. Hartmut Holländer and Dr. Allan Woodbury). As a result, Arcadis has not performed a detailed evaluation of potential hydrogeological impacts; instead, we defer to Drs. Holländer and Woodbury to determine whether there are any substantive groundwater impact concerns related to the undertaking.

Nonetheless, in the course of performing our review of the Project, we have identified several topics that, in our opinion, are relevant to the assessment of groundwater impacts. The following sections present summaries of those topics for the consideration of the CEC.

a) Arcadis Comment regarding Shale Aquitard Vulnerability

As described in Section 5.1, Sio Silica's geotechnical engineers (Stantec 2022) predict that the lower layers of the limestone carbonate cap rock may collapse into the void that is left after sand extraction. The geotechnical design concept considers this collapse to be acceptable, provided that some of the limestone carbonate layers remain intact to support the overlying quaternary deposits, thereby preventing surface subsidence.

Notwithstanding the conclusions presented above with respect to potential surface impacts, Arcadis notes that the failure modes evaluated by Stantec (2022) do not assess the geotechnical fate of the shale aquitard between the limestone carbonate and sandstone aquifers (see Figure 6). The Stantec report does, however, indicate that the

shale is "*highly fractured and friable,"* and "*is a weak member not considered to be providing support to resist failure for stability analysis*", and that "*the Shale below the Limestone is excluded from the model because of its cross-bedded joints and therefore low GSI*".

Based on the geotechnical information presented, as well as technical discussions with Sio Silica (6 September 2022) it is understood by Arcadis that the shale aquitard has the potential to collapse into the sand extraction void if: a) the overlying limestone carbonate layers collapse; and/or b) the shale collapses independent of the limestone carbonate layers.

The geotechnical failure of the shale aquitard has potentially significant hydrogeological implications. Specifically, given the anticipated diameter of the void at each well cluster (i.e., up to 40 m), significant breaches in the shale aquitard will occur when the shale collapses into the underlying void. Conceptually, this will create a hydraulic connection between the Red River Carbonate Aquifer (i.e., limestone carbonate) and the Winnipeg Sandstone Aquifer.

It is Arcadis' understanding that continued separation of the two aquifers is a fundamental design requirement of the proposed project. This is supported by the following statement from Sio Silica:

> *The Red River Shale Aquitard (or the Winnipeg Shale) is a protective layer below the Red River Carbonate Formation and is a critical divide between the two freshwater aquifers: the Carbonate aquifer and the Sandstone aquifer.* [2]

The goal of preventing mixing between the two aquifers is also incorporated into key design elements of the Project. For example, the Proponent has committed to preventing exchanges between the aquifers by placing impermeable plugs prior to, and after, the sand extraction takes place. However, following the geotechnical collapse of the shale and limestone into the underlying voids, these measures will likely no longer serve to isolate the aquifers from one another.

In addition, it is noted that the geotechnical assessment (Stantec 2022) was not available at the time of the Proponent's hydrogeological assessment (AECOM 2021). Further, it is Arcadis' understanding that the environmental and regulatory implications of shale collapse were not explicitly considered in the hydrogeological assessment.

Based on information available to Arcadis, the collapse of the shale aquitard represents a potentially significant failure mode for the Project. In this regard, the Project Proposal's silence on the matter represents a material deficiency in the Project Proposal. It should be noted, however, that Arcadis has not undertaken a hydrogeological evaluation to determine the environmental implications associated with the collapse of the shale. We trust that CEC's hydrogeological advisors will evaluate this potentially significant issue.

Arcadis Conclusion #5: Hydrogeology – Shale Aquitard

The Project Proposal does not identify the collapse of the shale aquitard as a critical failure mode, nor does it explicitly evaluate the hydrogeological or regulatory implications of such a failure. While Arcadis considers this to be a material deficiency in the Project Proposal, we defer to the CEC's hydrogeological advisors on the topic.

[2] Sio Silica Website (Accessed 21 July 2022): https://www.viviansandproject.com/facts-matter/blog-post-title-three-d8e3a-5cp5a-24683-ph99n-zfafy-sedh8-hlbnc

b) Arcadis Comment regarding Water Treatment Efficacy

In addition to sand, groundwater present in the Winnipeg Sandstone Aquifer will be brought to surface during the extraction process. This groundwater will be re-injected back into the aquifer at the well head. To address concerns related to the potential introduction of micro-organisms into the aquifer, the Proponent committed to "sterilize" the extracted groundwater with Ultra-Violet (UV) treatment prior to re-injection.

As indicated in previous discussions with the CEC, Arcadis is skeptical that UV treatment will be effective in reducing microbial contamination in the high turbidity water that will be extracted from and re-injected into the Winnipeg Sandstone Aquifer.

While the Project Proposal does not address turbidity as a concern for UV treatment, a water treatment technical supporting document prepared by AECOM (2022) identifies turbidity as a key water treatment challenge. The document indicates that multi-stage treatment trains will be necessary to remove suspended solids prior to UV treatment. It also describes a series of treatment requirements that have environmental implications. To illustrate, the removal of suspended solids will produce large quantities of sludge that will require management. The Project Proposal does not evaluate this, or other environmental implications associated with water treatment. Overall, AECOM (2022) indicates that UV treatment of water slated for re-injection into the Winnipeg Sandstone aquifer will be significantly more challenging than inferred in the Project Proposal.

Arcadis Conclusion #6: Hydrogeology – Water Treatment

The design of water treatment systems to sterilize extracted groundwater prior to re-injection into the Winnipeg Sandstone aquifer remains at an early conceptual stage. As a result, there is currently insufficient information regarding the treatment requirements and process to confirm whether there are any potentially significant impacts associated with the reinjection of treated water. The topic should be pursued further during the course of the Environmental Assessment.

c) Arcadis Comment regarding Air Injection

As described in Section 4.2, the extraction method will involve injecting large quantities of air into the Winnipeg formation. While the vast majority of the air will be released from the aquifer, partitioning of oxygen into groundwater will occur throughout the multi-day extraction process (similar to a bubbler in an aquarium). The presence of dissolved oxygen in the otherwise oxygen-free environment of the Winnipeg Sandstone Aquifer has the potential to affect the geochemistry of the aquifer. While some of these aspects are addressed in the Project Proposal (e.g., acid rock drainage/metal leaching), it is unclear to Arcadis whether the potential geochemical impacts of aquifer oxygenation have been adequately assessed.

In addition to oxygen, the large volume of air injected during the extraction process has a theoretical potential to introduce microbial contamination into the aquifer. While the Proponent intends to avoid microbial contamination in re-injected water by using UV treatment, the Project Proposal does not address the risks associated with any microbial populations present in the air that will be injected into the aquifer during sand extraction. At minimum, Arcadis expected the Project Proposal would include a qualitative discussion of this risk but none was provided.

Given that these topics are directly related to hydrogeology, Arcadis has not evaluated the associated environmental consequences. We trust that CEC's hydrogeological advisors will evaluate these topics and determine whether they are potentially significant.

Arcadis Conclusion #7: Hydrogeology – Air Injection

In the opinion of Arcadis, further quantitative assessment and modelling may be necessary to support the Proponent's conclusions that oxygen introduced by the extraction process will not have an adverse impact on groundwater geochemistry. Consideration should also be given to potential microbial contamination of groundwater aquifers from the injection of large volumes of air during the sand extraction process. Arcadis defers to the CEC's hydrogeological advisors on these topics.

5.4 Air Quality Impact Assessment

Proponent's Impact Assessment

Proposed Activity

The Project Proposal concludes that Project activities are expected to affect air quality due to dust generated by movement of drilling rigs and other mobile equipment, and due to exhaust emissions including nitrogen dioxide (NO_2), carbon monoxide (CO) and sulfur dioxide (SO_2). The exhaust emissions and dust generated from mobile equipment can have adverse effects on human health, wildlife and vegetation.

The number of vehicles and equipment used for Project activities listed in Section 2.8 would not all be operating simultaneously. Therefore, adverse effects on air quality beyond Manitoba's air quality guidelines at nearest residences from vehicles and mobile equipment use are not anticipated. In addition, at no time will dry silica sand be left exposed at the Project Site. Sand will be wet and will either be contained within the extraction well lines or the slurry lines, or material that is too large will be stored in appropriate containment prior to removal from site or use in well sealing activities. Therefore, the risk of silica sand dust dispersal is eliminated.

Mitigation Measures

Measures that will be applied to minimize potential Project effects to air quality include the following:

- Idling of motorized equipment will be minimized to the extent feasible;
- Water will be applied on gravel roads to control dust, as required; and
- Equipment and vehicles will be properly maintained.

With the application of the above mitigation measures, the Proponent concluded that the potential for soil erosion and associated adverse impacts to the surrounding environment are anticipated to be "Minor" to "Negligible" and sufficiently mitigated based on the following considerations:

Magnitude of Effect:	Minor to Negligible
Direction of Effect:	Adverse
Duration of Effect:	Long-term
Frequency:	Intermittent
Scope of Effect:	Project Regional Area
Reversibility:	Reversible

Arcadis Impact Assessment

Based on the overall approach to silica sand extraction and transportation, Arcadis agrees with the Proponent that the Project is unlikely to result in atmospheric emissions of silica sand that would have a significant negative impact on the environment. That conclusion is based on normal operating conditions and may not apply to situations involving the inadvertent release of large quantities of silica sand to the environment (e.g., from a large release of sand from the slurry line). However, impacts from such releases would be partially mitigated by the fact the sand would be wet, thereby limiting the potential for atmospheric dispersion. In addition to environmental considerations, Arcadis notes that industrial hygiene practices will be in place to limit silica dust exposure risks to workers. Collectively, these factors suggest that significant air quality impacts from silica dust are unlikely.

With regard to other sources of air quality impacts, combustion emissions from stationary and mobile equipment require consideration. Emissions of potential concern from combustion sources typically include nitrogen dioxide, carbon monoxide, sulfur dioxide and fine particulate matter. Although the Project Proposal identifies the potential sources of combustion emissions (drill rigs, compressors, trucks, etc.) it does not include an estimate of those emissions. Further, the Proposal does not include atmospheric dispersion modelling to verify that the concentrations of air quality contaminants will remain below applicable regulatory criteria in the vicinity of potentially sensitive receptors (e.g., off-site residential properties). Such emissions inventories and atmospheric dispersion modelling are commonly performed for mining sector and other industrial developments to verify that significant air quality impacts will not occur. In the absence of this information, the conclusions presented in the Project Proposal are based solely on a qualitative assessment of emissions and potential impacts. Further, the Proposal lacks a commitment to perform air quality monitoring during operations.

Arcadis Conclusion #8: Air Quality Impacts

Quantitative analyses are required to confirm the Proponent's conclusions that the Project will not result in significant air quality impacts. These analyses should include baseline air quality assessments, the preparation of emissions inventories, atmospheric dispersion modelling and air quality monitoring.

5.5 Climate/Greenhouse Gases Impact Assessment

Proponent's Impact Assessment

Proposed Activity

To estimate the annual emissions of greenhouse gases (GHG), emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) were estimated from onsite activities associated with the Project operation. Overall, the Project is estimated to generate 0.006797411 tonnes (Mt) of CO2e annually, which is 0.0296% of the reported Manitoba emissions in 2019 which were 23 Mt CO2e (ECCC, 2021), about 0.000931% of the reported 730 Mt CO2e from Canada in 2019 (ECCC, 2021).

Mitigation Measures

In an effort to minimize the production of GHG emissions from the Project, the Proponent committed to implementing the following measures:

- Emissions will be minimized by regularly maintaining equipment and vehicles and minimizing idling of vehicles.
- Vehicles and equipment will meet required emission standards.

Based on the following considerations, the Proponent concluded that the impact of the Project on Greenhouse Gas contributions to the atmosphere is "Negligible".

Magnitude of Effect:	Negligible
Direction of Effect:	Adverse
Duration of Effect:	Long-term
Frequency:	Intermittent
Scope of Effect:	Beyond the Project Regional Area
Reversibility:	Irreversible

Arcadis Impact Assessment

While Arcadis supports the general conclusions and greenhouse gas emissions estimates presented in the Project Proposal, we note that similar calculations presented on the sand processing facility under-estimated the emissions from the sand processing facility by three orders of magnitude. This represents a significant error in the proponent's assessment, albeit for a separate EA proposal.

With regard to emissions reductions, we recommend that the Proponent undertake the following additional measures:

- Adopt the Mining Association of Canada's (MAC) Climate Change Protocol.
- Commit to periodically review the technologies used to implement the Project, with the goal of reducing net greenhouse gas emissions. This includes but is not limited to evaluating the feasibility of replacing internal combustion equipment with emerging technologies capable of achieving lower greenhouse gas emissions.

Arcadis Conclusion #9: Climate/Greenhouse Gas Impacts

Arcadis has no material concerns with the Proponent's assessment of climate/greenhouse gas impacts. However, given the extended duration of the Project (i.e., 24 years), proactive reviews of approaches that can be used to minimize future emissions are justified.

5.6 Noise Impact Assessment

Proponent's Impact Assessment

Proposed Activity

The Project Proposal determined that noise generated by Project activities (e.g., extraction well drilling; operation of vehicles and machinery such as pumping stations) has the potential to adversely affect wildlife and could result in nuisance noise to people living within the Local Project Area. Example noise sources associated with Project activities include mobilization of extraction well drilling equipment, drilling of wells and operation of pump stations.

The Proponent has committed to implement the following measures to reduce noise generated from Project activities:

- Vegetation clearing will be minimized to the extent feasible.
- Project activities will setback a minimum of 100 m from nearest residences.
- Mobile equipment and vehicles will be kept well maintained and will be fitted with mufflers, and other noise mitigation equipment as required.
- Unnecessary idling and revving of engines will be avoided.
- Additional noise mitigation measures will be applied (e.g., portable noise barriers) as required.

Mitigation Measures

In consideration of the above measures to minimize noise levels due to Project activities, the Proponent anticipates that potential noise levels at the nearest residences will be adequately attenuated. Noise disturbances to wildlife are expected to be moderate in the vicinity of Project activities but are not expected to measurably affect wildlife populations within the Interlake Plain Ecoregion within which the Project is located.

Magnitude of Effect:	Minor to Moderate
Direction of Effect:	Adverse
Duration of Effect:	Short-term
Frequency:	Intermittent
Scope of Effect:	Variable due to changing locations of Project activities within the Project Site
Reversibility:	Reversible

Arcadis Impact Assessment

The Project Proposal does not include noise modelling to verify that noise levels will remain below applicable regulatory criteria in the vicinity of potentially sensitive receptors (e.g., off-site residential properties). Such modelling is commonly performed for mining sector and other industrial developments to verify that significant noise impacts will not occur. In the absence of this information, the conclusions presented in the Project Proposal are based solely on the opinion of the Proponent. Arcadis also notes that the Proposal lacks a commitment to perform noise monitoring during operations.

Arcadis Conclusion #10: Noise Impacts

Quantitative analyses are required to confirm the Proponent's conclusions that the Project will not result in significant noise impacts. These analyses should include baseline noise assessments of the study area, noise modelling and monitoring.

5.7 Biological Environment (Components Not Formally Assessed by Arcadis)

It is Arcadis' understanding that the scope of our technical review was to be limited to the environmental components discussed in Sections 5.1 to 5.6 (excluding Section 5.3 – Groundwater Impact Assessment). In addition, the

following biological environmental components were included in the Project Proposal but were not formally assessed by Arcadis:

- Surface Water
- Fish and Fish Habitat
- Vegetation
- Wildlife
- Species of Conservation Concern

While the above-noted biological environmental components were not formally assessed by Arcadis, we performed a high-level review of the Proponent's evaluation. Based on that review, we have concluded:

1. **Limited Scope** – As indicated in Section 4.3 of this report, the Project Proposal considers only the extraction activities of the Vivian Sand Project (i.e., the Processing Plant is not included). Furthermore, the temporal scope of the Project Proposal is limited to the first four years of sand extraction, instead of the full 24-year mine life. This serves to inappropriately limit the temporal and spatial scope of environmental impacts from the Vivian Sand Project. As with other environmental components, the limited scope of the Project Proposal has the potential to underestimate impacts on the biological environment.
2. **Baseline Information** – Information on the existing biological environment in the Project Proposal is very limited. For example, the baseline aquatic environment (Section 4.3) is described in only three pages. This level of detail would typically be insufficient for a mining project, including developments that are anticipated to have minimal interactions with the aquatic environment. We anticipate that biological experts assisting the CEC will require more baseline information prior to reaching conclusions on potential project impacts.
3. **Analysis** – Similar to the prior point and our findings as presented in Sections 5.1 to 5.6, the Proponent's analysis of potential impacts lacks the level of rigor that would typically be required in Environmental Assessments of mining projects.

5.8 Socio-Economic Environment (Components Not Formally Assessed by Arcadis)

In addition to the biological environmental components identified in the preceding section, the following socio-economic environmental components were included in the Project Proposal but were not assessed by Arcadis:

- Labour Force and Environment
- Infrastructure and Services
- Land and Resource Use
- Human Health
- Indigenous and Treaty Rights
- Heritage Resources

Arcadis' reviewers do not have expertise in areas related to the socio-economic environmental components noted above. As a result, we have not reviewed those aspects of the Project Proposal.

6 Additional Aspects

In addition to the environmental components discussed in Section 5, Arcadis identified deficiencies with other aspects of the Project Proposal. Those aspects, which are described in the following sections, include:

1. Closure Planning
2. Cumulative Effects
3. Impacts of Climate Change
4. Accidents and Malfunctions
5. Management Plans
6. Confidential Information
7. Public Engagement

6.1 Closure Planning

Descriptions of the mine closure approach in the Project Proposal are limited to a single page, as presented in Chapter 7. While additional information was presented in a brief supplemental document titled "Progressive Well Abandonment and Site Closure Additional Information" (Sio Silica, 2022), the information provided in the report is not commensurate with what would typically be required in a conceptual closure plan for a mine.

Arcadis notes that the Project Proposal indicates that a Closure Plan will be developed and submitted to Manitoba Conservation and Climate, in accordance with the Manitoba Mine Closure Regulation. Further, in a letter to CEC (17 June 2022), the Proponent states they are:

> *"currently working with Mines Branch and third-party experts to develop a Closure Plan, which will provide the foundation of and inform the Progressive Well Abandonment Plan. A Closure Plan would also be in place prior to any operations."*

Based on our experience in other jurisdictions, EA submissions such as Project Proposals typically include conceptual closure plans. These plans are provided as part of the EA submission to allow regulators and the public to identify and better understand any post-closure impacts that might be associated with the proposed undertaking. The evaluation of conceptual closure plans also allows reviewers to identify potential changes during the operational phase of the Project that are necessary to ensure future closure strategies perform as required. Ideally, any required changes should be identified before the Project is authorized to proceed and construction begins.

Arcadis Conclusion #11: Closure Planning

In the opinion of Arcadis, the CEC's EA decision should be informed by a comprehensive conceptual closure plan. The Project Proposal and supporting documents do not include the level of detail that would typically be required in such a plan.

6.2 Cumulative Effects

Environmental Assessments of major projects such as mines typically involve evaluations of potential cumulative effects. Such effects result from the impacts of the Project under consideration, when combined with impacts from other past, existing and reasonably foreseeable activities. Significant cumulative effects can occur when too much is happening within too small an area and in too brief a period of time. Depending on the circumstance, a threshold may be exceeded and the environment may not be able to recover. The potential for this to occur needs to be considered when making decisions regarding whether a Project should be allowed to proceed and under what conditions.

As described in the Project Proposal, the site was previously disturbed and there are multiple commercial, extractive, agricultural, transportation and residential activities within the Study Area. Nonetheless, the Project Proposal does not address potential cumulative effects and limits its analysis to the proposed extraction activities. In the absence of such an assessment, reviewers are unable to determine whether the Project might result in significant cumulative impacts.

Arcadis Conclusion #12: Cumulative Effects

The Project Proposal and supporting documents do not include an assessment of cumulative effects. Given the wide range of land uses in the vicinity of the Project and the importance of the groundwater resource, this represents a substantive deficiency in the Project Proposal.

6.3 Impacts of Climate Change

As discussed in Section 5.5 above, the extent to which the Project will contribute to climate change is evaluated in the Project Proposal. This was achieved by calculating the predicted greenhouse gas emissions from the Project. Arcadis has no material concerns with the Project Proposal's assessment in that regard.

The Project Proposal does not, however, evaluate how climate change might affect the environmental performance of the Project. For example, the Project Proposal does not assess the impact that climate-induced changes to the hydrological cycle could affect extraction activities and any associated environmental impacts. Such an assessment would typically be included in Environmental Assessments of major projects and is justified in the current case.

Arcadis Conclusion #13: Impacts of Climate Change

The Project Proposal and supporting documents do not include an assessment of impacts that climate change could have on the environmental performance of the Project.

6.4 Accidents and Malfunctions

Section 6.9 of the Project Proposal presents high-level discussions of potential accidents and malfunctions, including: spills and leaks; fires and explosions; and transportation accidents. While the section provides overviews

of potential events and mitigations that will be implemented, there are no assessments of the environmental impacts that will occur if the mitigations are ineffective. As an example, Section 6.9.2 describes a range of actions that will be taken to avoid and mitigate spills of silica sand and other potentially hazardous materials. The section does not, however, evaluate whether such releases would result in significant impacts to people or the environment if mitigations fail to perform as intended.

In addition to being silent on the potential impacts of accidents and malfunctions, the Project Proposal does not evaluate the implications of an underground geotechnical failure that results in a major subsidence at surface (e.g., a large sink hole). As described in Section 5.1 of this report, the Project is being designed to reduce the risk that such a failure will occur. Notwithstanding this design process, the assessment of accidents and malfunctions should consider the possibility that the Project will inadvertently result in an underground geotechnical failure that propagates to surface, either during operations or the post-closure phase. The impacts of such a failure should be evaluated.

Arcadis Conclusion #14: Accidents and Malfunctions

The Project Proposal and supporting documents do not include an assessment of impacts that would be caused by accidents and malfunctions. In addition, it does not assess the potential impacts associated with an underground geotechnical failure that results in a major subsidence at surface.

6.5 Management Plans

On 17 June 2022, in response to inquiries about Follow Up Plans for the Vivian Sand Extraction Project, the Proponent provided "example drafts" of the following documents to the CEC:

- Erosion and Sediment Control Plan – Example only
- Groundwater Monitoring and Impact Mitigation Plan - Draft Example
- Waste Characterization and Management plan – Draft Example
- Water Management Plan – Draft Example

In submitting the plans, the Proponent stated:

> *At this time the Plans listed above are in preliminary draft stage only which illustrate at a high level the approaches to monitoring and management that Sio intends to implement for the Project. Final versions would be completed during the final design stage and prior to operations commencing. The final Plans will also incorporate any conditions as outlined in the Environment Act License and any other applicable authorizations, permits and approvals.*
>
> *Other Plans that will be completed include an Environmental Emergency Response Plan, Revegetation Monitoring Plan, and Heritage Resources Protection Plan. These Plans are typically site specific and would follow the industry accepted practices. These types of Plans are often quite standard in their measures.*

Arcadis agrees that the plans are currently at a preliminary draft stage. The documents are generally limited to high level descriptions of the topics that will ultimately be presented in future submissions. While Arcadis concurs that these plans can and should be submitted as part of future approvals processes, complete versions of the documents

should also be available during the EA processes to confirm that management practices will adequately address any potential environmental impacts. To illustrate, we expected that the *Groundwater Monitoring and Impact Mitigation Plan* would provide detailed descriptions of the Proponent's commitments to ensure local and regional groundwater is adequately protected. Unfortunately, with the exception of cursory and preliminary descriptions, the plan provides limited insights into the steps that will be taken to protect the groundwater resource.

Arcadis Conclusion #15: Management Plans

The Management Plans submitted to date lack the information necessary to confirm that operational practices will be capable of identifying and mitigating potential environmental impacts from the Project.

6.6 Confidential Information

Citing confidentiality concerns, the Proponent requested that some documents not be publicly available as part of the Public Record for the Environmental Assessment. This request has been addressed by redacting portions of some documents and/or requiring that the CEC's technical advisors (including Arcadis) sign non-disclosure agreements.

Based on our experience in other contexts, none of the information provided to Arcadis to support our review would normally be classified as confidential and withheld from the Public Record. Nonetheless, the Proponent has submitted some evidence on the condition that it be kept confidential. To illustrate, the report "*Geotechnical Analysis for Sio Silica Extraction Project*" Stantec (2022), contains information that is necessary to evaluate whether the Project is likely to result in significant environmental impacts. Despite the importance of this information, the document is currently classified as confidential by the Proponent. We are unaware of any reasons for withholding this or any other document that has been provided to date from the Public Registry. In the opinion of Arcadis, doing so has the potential to limit the use of the information as evidence during the EA decision-making process. It also has the potential to unnecessarily erode public trust that the EA process is open and transparent.

Arcadis Conclusion #16: Confidential Information

The Proponent has provided some information on the condition that it be kept confidential and withheld from the Public Record. None of the information provided to Arcadis to date would normally be classified as confidential. This has the potential to limit the use of critically important information during EA decision-making and to erode public trust.

6.7 Public Engagement

Arcadis' review did not include a formal assessment of whether public engagement performed by the Proponent is adequate. Nonetheless, based on our experience working on other high-profile and potentially contentious mining projects, the level of public engagement in this case appears to be less than we would have expected. This is particularly true given the extensive spatial scope of the 24-year mine life and the importance of the potentially impacted groundwater resource. We also note that members of the public have expressed significant concern regarding the Project. Further, in the opinion of Arcadis, the Proponent's conclusion that the Project will not result

in significant impacts to Indigenous people should be confirmed through engagement with relevant regional Indigenous groups.

Arcadis Conclusion #17: Public Engagement

The Proponent's level of public engagement on the proposed undertaking is not commensurate with known and potential public concerns.

7 Summary of Arcadis Conclusions and Recommendations

7.1 Summary of Conclusions

Table 2 presents a consolidated summary of Arcadis' conclusions.

Table 2 Summary of Conclusions

No.	Topic	Conclusion
1	Extraction Method	When compared to other conventional aggregate extraction techniques (i.e., open pit excavation), the proposed extraction method is less invasive and has the potential to result in lower environmental impacts. This does not, however, imply that reduced impacts would necessarily be acceptable; it is simply an acknowledgment that the Proponent selected an extraction method that appears to have important advantages over conventional alternatives. The "air lift" method has not been used as a full-scale mining method. This introduces a degree of uncertainty regarding which justifies adopting a more precautionary approach when developing and implementing project designs. This is particularly important given the need to protect local and regional groundwater resources.
2	Project Scope	In the opinion of Arcadis, the abbreviated temporal scope, substantively smaller spatial scope and exclusion of critical project components constitutes "project splitting". In simple terms, this involves breaking a project into smaller pieces that individually fall below EA impact thresholds that might otherwise result in significant impacts. Arcadis considers this to be a material deficiency with the Project Proposal and recommends that the CEC explore options to evaluate the potential environmental impacts of the entire Vivian Sand Project, not just sand extraction.
3	Geotechnical and	If the Project implements the design parameters recommended by Stantec (2022), Arcadis supports the Proponent's conclusion that the undertaking will not result in

No.	Topic	Conclusion
	Topographic Impacts	significant adverse impacts to the geotechnical / topographic environment. This conclusion applies exclusively to impacts at surface and does not address potential hydrogeological impacts that may occur as a result of sub-surface geotechnical failures. The conclusion does not apply to areas outside of the spatial scope assessed by Stantec (2022) and is subject to change as additional information becomes available. In addition to the conclusion noted above, Arcadis has provided a series of Geotechnical Findings and Recommendations in Appendix A.
4	Soil Impacts	If the Project is subjected to standard regulatory requirements and implements appropriate environmental controls and mitigation measures, Arcadis supports the Proponent's conclusion that the undertaking will not result in significant adverse impacts to soils.
5	Hydrogeology – Shale Aquitard	The Project Proposal does not identify the collapse of the shale aquitard as a critical failure mode, nor does it evaluate the hydrogeological implications of such a failure. While Arcadis considers this to be a material deficiency in the Project Proposal, we defer to the CEC's hydrogeological advisors on the topic.
6	Hydrogeology – Water Treatment	The design of water treatment systems to sterilize extracted groundwater prior to re-injection into the Winnipeg Sandstone aquifer remains at an early conceptual stage. As a result, there is currently insufficient information regarding the treatment requirements and process to confirm whether there are any potentially significant impacts associated with the reinjection of treated water. The topic should be pursued further during the course of the Environmental Assessment.
7	Hydrogeology – Air Injection	In the opinion of Arcadis, further quantitative assessment and modelling may be necessary to support the Proponent's conclusions that oxygen introduced by the extraction process will not have an adverse impact on groundwater geochemistry. Consideration should also be given to potential microbial contamination of groundwater aquifers from the injection of large volumes of air during the sand extraction process. Arcadis defers to the CEC's hydrogeological advisors on these topics.
8	Air Quality Impacts	Quantitative analyses are required to confirm the Proponent's conclusions that the Project will not result in significant air quality impacts. These analyses should include baseline air quality assessments, the preparation of emissions inventories, atmospheric dispersion modelling and air quality monitoring.
9	Climate / Greenhouse Gas Impacts	Arcadis has no material concerns with the Proponent's assessment of climate / greenhouse gas impacts. However, given the extended duration of the Project (i.e.,

No.	Topic	Conclusion
		24 years), proactive reviews of approaches that can be used to minimize future emissions are justified.
10	Noise Impacts	Quantitative analyses are required to confirm the Proponent's conclusions that the Project will not result in significant noise impacts. These analyses should include baseline noise assessments of the study area, noise modelling and monitoring.
11	Closure Planning	In the opinion of Arcadis, the CEC's EA decision should be informed by a comprehensive conceptual closure plan. The Project Proposal and supporting documents do not include the level of detail that would typically be required in such a plan.
12	Cumulative Effects	The Project Proposal and supporting documents do not include an assessment of cumulative effects. Given the wide range of land uses in the vicinity of the Project and the importance of the groundwater resource, this represents a substantive deficiency in the Project Proposal.
13	Impacts of Climate Change	The Project Proposal and supporting documents do not include an assessment of impacts that climate change could have on the environmental performance of the Project.
14	Accidents and Malfunctions	The Project Proposal and supporting documents do not include an assessment of impacts that would be caused by accidents and malfunctions. In addition, it does not assess the potential impacts associated with an underground geotechnical failure that results in a major subsidence at surface.
15	Management Plans	The Management Plans submitted to date lack the information necessary to confirm that operational practices will be capable of identifying and mitigating potential environmental impacts from the Project.
16	Confidential Information	The Proponent has provided some information on the condition that it be kept confidential and withheld from the Public Record. None of the information provided to Arcadis to date would normally be classified as confidential. This has the potential to limit the use of critically important information during EA decision-making and to erode public trust.
17	Public Engagement	The Proponent's level of public engagement on the proposed undertaking is not commensurate with known and potential public concerns.

7.2 Recommendations

Arcadis' assessment was based exclusively on the information contained in the Project Proposal and associated supporting documents. As indicated by the conclusions in the preceding table, multiple potentially significant concerns were identified during the course of the review. Prior to issuing formal recommendations to address these concerns, Arcadis is of the view that working-level technical meetings would be beneficial. Such meetings would allow the Proponent to provide additional information and perspectives on the concerns identified herein. Based on this additional information, the CEC and Arcadis would be in a better position to determine the most appropriate next steps, including the issuance of formal recommendations to address our concerns.

Note that the above recommendation was provided to the CEC in the 27 July 2022 draft report submission. The CEC agreed with this recommendation and a technical meeting was arranged with Sio Silica and its technical consultants for 6 September 2022. The topics discussed at the meeting included:

1. Shale aquitard integrity
2. Validity of field investigations (hydrogeology and geochemistry)
3. Conceptual and numerical models (hydrogeology and geochemistry)

Appendix A

Technical Memorandum – Review of Geotechnical Analysis of Sio Silica Extraction Project Near Vivian Manitoba

Memo

SUBJECT
Review of Geotechnical Analysis for
Sio Silica Extraction Project
Near Vivian Manitoba

TO
Gerd Wiatzka

DATE
18 May 2022 (*updated 26 July 2022*)

OUR REF

DEPARTMENT
SEC

PROJECT NUMBER
30130539

COPIES TO
File

NAME
Charles Gravelle
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At the request of Manitoba's CEC, Arcadis has undertaken a review of the following report to identify any geotechnical concerns with the above referenced project:

1. Geotechnical Analysis for Sio Silica Extraction Project, dated 14 January 2022, as prepared by Stantec Consulting Ltd.

Supplementary information was provided by CEC in July 2022 and the following documents were reviewed:

1. Stantec Borehole Clarification Letter dated 13 July 2022;
2. Borehole logs for boreholes BH10-17, BRU 121-1, BRU146-1, DEN 216-1, BRU 96-1, BRU 96-2, and BRU 95-6 to 95-9 as advanced by Norwest Corporation, Stantec and AECOM.
3. Guidelines for Use of the Scaled Span Method for Surface Crown Pillar Stability Assessment, as prepared by Trevor Carter, Golder Associates, 2014.

Report Contents

This report included the following:

1. A summary of the mining method to be used for extraction of the silica sands (compressed air), the local geology and groundwater conditions (based on literature review and investigation results), and seismicity conditions in the area based on the National Building Code data.
2. A summary of data from previous subsurface investigation programs undertaken by others [AECOM and Norwest Corp] to characterize the formations overlying and underlying the Carman Sands of the Winnipeg formation (target material for extraction).
3. A summary of the geotechnical parameters derived from laboratory and field testing of the caprock limestone within the Red River Formation which will provide the primary rock mass supporting the overburden and weaker rock formation overlying the caprock.
4. Discussion of the ABI/OBI (acoustic borehole imaging/optical borehole imaging) results as well as Side Scan Survey Results on initial two trial extraction wells.
5. Discussion of the surface settlement monitoring results for the initial trial extraction wells.

6. An initial evaluation of the different potential failure modes that could arise and full evaluation modelling of those modes of failure most likely to occur based on the strength parameters and nature of the formations within the study area (i.e., shear and bending failure mode analysis).
7. Also included an evaluation of the effects of adjacent extraction wells on overall stability of the well cluster.
8. Conclusions based on the investigation and modelling work completed to date.
9. Recommendations for moving forward with this project so that the silica sand can be extracted in a safe manner that will not result in significant or permanent damage to the overlying weaker bedrock and overburden stratigraphy.

Note the report is clear that this assessment work is limited to only the areas of operations to be disturbed in the **first five years of operation**. Stantec states that additional assessment and evaluation work will be required prior to operations extending outside the limits of the current study area.

Prior to this Stantec report being prepared, earlier investigation work was completed by Stantec and undertook a caprock analysis on extraction cavity shear failure mode stability. A copy of this report was not provided nor reviewed by Arcadis as part of this current review, and we are working on the premise that the data collected in this earlier program were accurately reported within the above referenced report.

Supplemental Input

Pursuant to Arcadis' original review of the Stantec Crown Pillar Stability Assessment (2022) report, supplementary information was provided in July 2022 and comprised the following:

1. Borehole logs were provided on which Stantec relied in their evaluation of the crown pillar stability. It is not clear to Arcadis how the general project setting, i.e., site stratigraphy, was derived from this information (see further comments below). Furthermore, Stantec did not provide copies of any laboratory analytical work undertake on the caprock as used in their evaluation. Arcadis would still like to see copies of the laboratory reports on bedrock testing (e.g., compressive strength testing) to confirm the values used by Stantec in their evaluation.
2. The Stantec report was prepared using the fundamental principles outlined in the Carter 2014 paper which is an appropriate guidance document for the preparation of Surface Crown Pillar Stability Assessments. In general, the Stantec report did set up their evaluation of the crown pillar stability in a prudent manner with the exception of some of the concerns raised by Arcadis later in this memo.

Project Setting

In general, the project site comprises a layer of overburden till underlain by weak "weathered" caprock (not supporting), limestone caprock (supporting), shale and weak caprock (not supporting), all of the Red River Formation, Carman Sands of the Winnipeg Formation which includes Equiv. Ice Box shales and Black Island sands, neither of which are to be disturbed as part of the mining operations.

The overburden ranges from 5 to 43 m in thickness which is underlain by the limestone of the Red River Formation that ranges in thickness from 0 to 43 m (*which likely included the weak weathered caprock though not explicitly stated by Stantec*) and underlying shale ranging from 0 to 11 m in thickness. The Carman Sands within the Winnipeg Formation range from 20 to 23 m in thickness. Of note is that during extraction trial work, the groundwater table within the lower aquifer formation (i.e., within the Winnipeg Formation) dropped 10 m and had recharged to 80% of the pre-extraction piezometric surface within two days of pumping.

[Arcadis Comment: On the basis of Arcadis' additional review of the borehole logs provided by Stantec in July 2022, it is unclear how the thickness ranges provided for the various strata where derived. From the ten borehole logs that were provided, the thickness of the overburden ranged from 32 to 42 m, the limestone of the Red River Formation ranged from 7 to 13 m with one result at 21 m, and the underlying shale 1.5 to 3.8 m with one result at 13 m. It is evident that more borehole investigation information was used by Stantec as outlined in the spreadsheet of data provided however, we have some concerns (lack of justification) with the use of a 15 m depth interval as being the representative thickness of competent limestone given the information in the ten borehole logs recently provided.]

The project site has been identified as being within a low seismic hazard level based on the 2015 Seismic Hazard Map as provided by the Geologic Survey of Canada and used by the National Building Code to define the seismic hazard values to be used when deriving peak horizontal ground accelerations and corresponding return periods. Furthermore, for this evaluation a 50-year design life was used. Stantec concluded, based on the low seismic hazard level for the area, that the probability of seismicity impacting the stability of the project site is low. [Arcadis Comment: While it can be agreed that the site is in a low seismic hazard level area, it is unclear what impact the local rail corridors would have on the underlying ground within the study area. It is recommended that the proponent address potential concerns which may arise from their operations as it relates to the presence of rail corridors within the study area.]

Results Reported

The results of the site investigation presented in the report were as follows:

Geological Strength Index (GSI) based on Rock Mass Ratings (RMR), which are related the RQD and joint conditions within the bedrock, were evaluated. The results of this evaluation by Stantec are tabulated within the report and appear to be consistent with the nature of the bedrock reported, however no information was provided on any calculations that may have been used to derive these GSI and RMR values. On the premise that the evaluation completed by Stantec is correct, then the use of a GSI value of 60.0 would be considered representative of the competent supporting limestone considered the caprock for this project.

[Arcadis Comment: On the basis of the information contained within the borehole logs provided to Arcadis for review, the GSI value used by Stantec is appropriate for the competent limestone.]

Laboratory testing in the form of Brazilian tensile strength testing, Uniaxial Compression testing and Triaxial Compression testing was undertaken on various samples of the limestone collected during the 2018, 2020 and 2021 investigation programs:

- The results of the tensile strength testing ranged from 1.5 to 10.1 MPa.
- The results of uniaxial compression testing reported values between 34 and 112 MPa with an average of 68.1 MPa, which was used by Stantec in their modelling.
- For the purposes of modelling the competent caprock, Stantec used the lower end laboratory value for the tensile strength i.e., 1.5 MPa, however for the uniaxial compression strength (UCS) they used a value of 50 MPa.

Arcadis Comments: In our opinion, the use of 50 MPa in lieu of the lowest reported value for the UCS may not be appropriate as there is the potential for the model to not be representative of the bedrock conditions with the study area. Half of the reported UCS values were below 50 MPa and as such it is recommended (by Arcadis) that some sensitivity analysis be done to confirm the modelling is representative of the variability within the bedrock formation across the subject site.

No concerns were identified as part of the ABI/OBI data reported, however, in the absence of a report that includes these data, Arcadis cannot confirm its accuracy.

No concerns were identified with the data presented as part of the side scan survey of the caverns formed within the trial extraction wells (BRU 92-2 and BRU 92-8) completed as part of this program. The trials were run twice per extraction point at 52 and 60 hours after the extraction work. The results of the trial work did report a different cavity expansion with the BRU 92-8 having a cavity expansion in a SW/NE direction as compared to the BRU 92-2 cavity expansion having a more uniform shape.

Furthermore, the results of laboratory testing have not been provided to Arcadis for review. Arcadis would like to review these results to confirm if they were appropriate for use in the stability models.

The results of settlement monitoring were measured at the ground surface in areas in close proximity to three extraction wells (BRU 92-2, BRU 92-3 and BRU 92-8). The measured values of deformation ranged from 0.000 to 0.002 m as measured over six rounds of monitoring (April to December 2021). Stantec deems that at or near zero deformation has been measured to date. Arcadis' main concern with this work relates to the distance between the monitoring points and the extraction wells. The figure provided did not include a scale, so it is not clear how close the monitoring points were to the extraction wells. Given the size of the cavities formed, it would appear that some of the monitoring points may or may not be within the limits of the cavity. Furthermore, a monitoring point should be placed in very close proximity to the extraction well (i.e., within 1 m).

The Basis of Geotechnical Design was undertaken with the following eight considerations:

1. Selection of controlling failure modes: five options considered and two evaluated (more details below).

   Arcadis Comment – no concerns with the five options initially considered and the two evaluated.

2. Stability Factor of Safety: FOS of 2.0 was considered sufficiently conservative by Stantec.

   Arcadis Comment – no concerns however a sensitivity analysis on the key input parameters to the model should be completed to provide the proponent and the project stakeholders with an understanding of what will occur should the caprock not perform per the model input expectations.

3. Lifetime of Project: Stantec used a 50 life of project for the seismic assessment but here have said that the design life expectancy for post extraction stability is set as long-term (quasi-permanent) with a lifetime of 50 to 100 years. They have assumed that if the adverse stability effect is not observed during this time frame, there is minimal risk for development of adverse effects in a longer-term.

   Arcadis Comment – document needs to be consistent in its use of 50 years or 100 years. We recommend the assessment be done for both the 50-year and 100-year life expectancy so as to confirm that in the future the crown pillar stability will remain intact.

4. Use of Site Data to Develop Design Parameters for BRU Property: Stantec assumed the results of prior investigations have collected representative information on the lithologic units, in particular the rock mass characteristics for the supporting limestone.

Arcadis Comment – no concerns with using information collected from previous investigations however, a sensitivity analysis should be completed when modelling to see what impact these changes would have on the design. There is a potential that extraction well space may have to be changed to ensure settlement issues do not arise.

5. Use of monitoring data to develop design parameters: Stantec has assumed the results of settlement monitoring to date is representative of probable settlement during full scale mining and the long-term. They acknowledge there is some potential for changes in local support conditions to generate settlement in the short- or long-term.

   Arcadis Comment – It is unclear from the information presented in the report how reflective the current settlement monitoring is relative to what could be expected immediately adjacent the extraction wells. It is recommended that settlement monitoring be conducted closer to the extraction wells and another trial be conducted to collect the information required to monitor impacts during and post extraction.

6. Use of downhole side scan sonar data to develop design parameters: Stantec has assumed that the results of the downhole side scan sonar of the cavity after mining (as recorded for two trial extraction holes) is representative of probable behaviour of the void during full scale mining. They acknowledge there is potential that additional changes to the cavity and the area of influence of sand extraction may change over time.

   Arcadis Comment – no concerns with the use of side scan sonar to measure the extraction cavity post-extraction. Consideration could be given to completing this work at timesteps closer to the completion of the extraction, i.e., 1 hr and then at 12, 24 and 36 hours. Furthermore, monitoring a week or more after the extraction work is done should also be considered at select locations to ensure the assumptions made with respect to the long-term stability of the cavity sidewall are reasonable.

7. Development of operational level monitoring systems: Stantec included as part of their design recommendations for operation, monitoring systems to confirm the design assumptions and performance during extraction processes.

   Arcadis Comments – no concerns with the recommendations presented by Stantec in their document and in fact, Arcadis considers these recommendations to be paramount requirements in the implementation of the program.

8. Development of operation level monitoring options: Stantec included in their design operation level recommendations for mitigation options should monitoring data show changes in design assumptions or if less favourable conditions are observed during operations.

   Arcadis Comments – no concerns with the recommendations presented by Stantec in their document.

Stantec presented a table of the Summary of Basis of Design (Table 7) within their document. In general Arcadis has not concerns with the information included in this table.

Failure Mode Analysis

As part of this work, Stantec considered the following modes of failure:

1. Shear Failure – caprock shears in a vertical or near vertical plane at the limits of the cavity.

2. Bending Failure – caprock yields due to the unsupported weight "bending" the caprock resulting in delamination of the bedrock to the point of failure thus collapsing the overburden and bedrock into the cavity.
3. Cross-joints Failure – caprock has both horizontal and vertical joints which could cause unravelling of rock blocks within the caprock resulting in the collapse of the caprock under the weight of the overburden and any unsupported bedrock. NOTE: given the nature of the bedrock on site (massive without cross-joints) which had minimal to no vertical joining, this mode of failure was not considered reflective of site conditions and as such was not modelled for the report.
4. Caving Failure – caprock fails as a result of the heavily broken nature of the bedrock. This was not considered a representative mode of failure as the thickness of broken caprock was not considered to be supportive of the overlying overburden and weather/fractured bedrock and as such was modelled as a load to be supported by the competent caprock.
5. Chimneying Failure – caprock fails due to the presence of weak rock unable to support the overlying material. Given the nature of the bedrock on site this mode of failure was not considered appropriate.

Stantec selected to complete modelling for scenarios 1 and 2. Arcadis agrees that this approach was reasonable and reflective of the site conditions identified from the three subsurface investigations completed within the study area.

The overall design parameters used in the modelling of the two failure modes were presented in Table 8 of the report. No concerns were identified by Arcadis with respect to the input parameters used however, a sensitivity analysis would be prudent for some of the input parameters where the lowest reported or calculated values were not used (e.g., UCS values 34 vs. 50 MPa).

No concerns with the Fast Lagrangian Analysis of Continua (FLAC) shear failure mode modelling. Various models were run with overburden thicknesses ranging from 25 to 35 m and caprock limestone thicknesses varied between 15 to as high as 100 m. GSI values on the range of 50 to 65 were also modelled. The results of the modeling were plotted on an X-Y plot with caprock thickness on the X-axis with values between 15 and 100 m and Maximum Mining Cone Diameter (m) on the Y-axis calculated to range between 20 and 100 m as a function of the input parameters to the model. It is Arcadis' opinion that a reasonable amount of sensitivity analysis was completed for this mode of failure assessment.

No concerns with the Bending Failure Mode assessment which also used FLAC modelling. The results of the modelling are presented in Table 9 and used caprock thicknesses ranging from 10 to 25 m, overburden thicknesses of 25 and 35 m and variable long-term allowable unsupported limestone spans between 24 and 50 m as a function of the model and extraction disturbance zone dimensions ranging from 14 to 40 m on the top diameter of the extraction to as low as 0 and as high as 21 m at the base of the extraction cavity profile on the assumption that the long-term spans are 10 m greater than the short-term extraction diameters noted. No concerns with the sensitivity analysis completed to calculate the allowable unsupported open spans as it relates to the parameters discussed in this paragraph. However, consideration must still be given to using lower UCS values in this evaluation in the event it changes the model performance resulting in different and potentially more restrictive outcomes as it relates to sand extraction works.

The assessment of the effects of adjacent extraction areas on stability was run for one model scenario, namely overburden thickness of 33.5 m, caprock thickness of 13.5 m and a 20 m deep and 20 m radius extraction cavity within the sand formation. It is recommended that different scenarios be run consistent with some of the models run

above for the shear failure and bending failure assessments. No concerns with the results of the one model scenario run however, it does not reflect the amount of variability identified across the site as part of the various subsurface investigation programs completed on site.

No concerns with the conclusions and recommendations provided by Stantec. They are prudent given the amount of variability across the study area. The sequencing of the extraction process is not discussed in this report. It is recommended that the proponent provide the results of the prescribed work detailed by Stantec in their recommendations and the proponent be asked to provide the modelling results as done for the current report, namely Shear and Bending Failure Mode assessments along with evaluations of the impact multiple extraction wells are having on the local bedrock and overburden with due consideration of the settlement monitoring results.

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