Manitoba Clean Environment Commission
Hearing for the Vivian Silica Sand Extraction Project (Project)

Sio Silica Corporation (SSC) Responses to Information Requests (IRs) Round No. 2

IR Number: **CEC-IR-010**

Submitted by: CEC

Date Submitted: December 23, 2022

Subject Matter: Sand Cavity Stability

Reference:

i) Stantec, 2022 Geotechnical Analysis for SioSilica Extraction Project, January 2022.

ii) AECOM, 2021: CanWhite Sands Corp.: Vivian Sand Extraction Project Environment Act Proposal, July 2021. Section 2.2.6

Request: The extraction of silica sand will create voids within the Winnipeg Sandstone aquifer. The Geotechnical Analysis of the Project (Stantec, 2022) concludes that no large-scale surface subsidence is expected to occur as a result of sand extraction, provided that the design guidance issued in the Geotechnical Analysis is followed. CEC seeks additional information to confirm that the assessment was appropriately conservative.

1. What is the basis of the assumption that the final wall slope will be 65 degrees?
2. Given the fully softened state of the sandstone in the long term can result in a propagation of the cavity radius equal to 5 m in 100 years, at what cavity radius and timeframe would the propagation stop?
3. Were hydrostatic considerations (i.e., buoyancy effects) included in the FLAC model set up?
4. What impact would seismic events have on the long-term stability of the undisturbed sand unit? Specifically, would seismic events affect the slope of the sand cavity walls, thereby increasing the open span of the voids?

Response:

1. The final wall slope is expected to be shallower than 65 degrees. The short-term cavity shape measured by side scan sonar showed very steep to overhanging sand slopes above a loose sand-backfilled area. Fast Lagrangian Analysis of Continua, (FLAC) modelling was used to evaluate the undisturbed sandstone shape in the long term. The FLAC model predicts that the very steep and overhanging material will slough over time to slopes shallower than 65 degrees.
2. The maximum probable increase in cavity radius is estimated to be 5 m in 100 years. Propagation after 100 years is expected to be limited in comparison to the first 100 years propagation due to increasing support in the cavity from natural backfilling of failed sand from the cavity wall.
3. Hydrostatic pressure (i.e., buoyancy effects) was not included in the FLAC modelling. Because the overall strength to shear failure is mainly influenced

by the limestone cohesion strength and considering that the buoyancy weight is smaller than the dry weight, this is a simplification that is conservative for average site conditions. The water level will be recorded prior to extraction and in areas of high groundwater the extraction limit will be adjusted to a safe extraction limit.

4. The Seismic Hazard Calculation from the National Building Code of Canada (NBCC) shows that the seismic hazard level at the project site area is low. The NBCC PGA (Peak Ground Acceleration) of the project site for a 100 year return period (design lifespan of the project) is 0.002 g. Due to the low seismic hazard level for the area, seismicity is estimated to have a low probability of impacting cavity stability.

IR Number: **CEC-IR-011**

Submitted by: CEC

Date Submitted: December 23, 2022

Subject Matter: Cumulative Effects

Reference: i) Response to Technical Review Issues 2 & 3:

ii) Cumulative Effects

Preamble: The current application is for mining activity that is limited geographically and temporally. However, the analysis of geotechnical and hydrogeology are based on a regional analysis over the longer term.

The proponent states that “mining activities will remove a very small proportion of the aquifer materials”. However, it is proposed that 1,360,000 tonnes of sand product (not including waste) will be removed each year for 24 years.

This is estimated to total up to 32,640,000 tonnes (or 32,640,000 kg) of pure sand.

Assuming densities of the sand at 1.7kg/m3, this could cover an area of 19km2 at a 1m depth.

The result of widespread sand removal has the potential to affect aquifer properties in an area of 1,680 km2 (about 40 km X 40 km).

The extraction of this sand will leave water filled voids that will increase the storativity, porosity and hydraulic conductivity, and render the aquifer highly variable within the development zone.

Request:

1. Please provide any supporting information, calculations or simulations that assess the effects on aquifer storativity, porosity and hydraulic conductivity in consideration of large scale sand removal.

2. How would any changes in the described characteristics affect new water well developments in the project area?

3. In response to issue 3, it is indicated that a Groundwater Monitoring and Mitigation Plan will be developed and implemented to monitor groundwater levels and quality during and after mining and to verify modelling results.

   Can you please describe what specific actions will be taken to monitor groundwater levels and quality. What will be the geographic and temporal scope of the monitoring. Will monitoring be done inside the project area as well as locations outside the project area? Within what time frame will the monitoring be done, as effects may not be measurable until some years later? If monitoring indicates that the regional groundwater flow modeling is inaccurate, what actions will be taken to ensure that the aquifer is not negatively affected?

4. What are the cumulative effects on the aquifer considering current and potential future uses, multiple well clusters, and large scale sand removal? What steps were taken to assess cumulative effects?

Response: 1. Aquifer properties including storativity, porosity and hydraulic conductivity have the potential to change at the local scale in response to removal of sand from the aquifer. Changes in aquifer properties at the regional scale are anticipated to be less significant and may not be measurable.

It is anticipated that aquifer properties will remain very similar within undisturbed portions of the aquifer but will change locally within the water filled voids created following sand extraction. However, at the regional scale the water filled voids created following sand extraction will be separated by intact aquifer materials that will be largely unaltered. Overall, the aquifer is anticipated to maintain its current characteristics, but will locally have more variable properties in proximity to sand extraction wells.

Several example calculations and additional explanation are offered below to provide context to the statements above:

<u>Volume of Aquifer</u>: The volume of the Winnipeg Sandstone aquifer was estimated for the Project Site Area for the initial development footprint. The volume of the aquifer was calculated using the following assumptions: 1) area covered by extraction wells over 5-year application period: 9,000,000 m^2 (3 km x 3 km = 9 km^2); and 2) average aquifer thickness: 25 m. Therefore, the calculated volume of the Winnipeg Sandstone aquifer within the footprint of the extraction wells is 225,000,000 m^3 (225 km^3).

<u>Volume of Sand Removed</u>: The volume of sand removed from the aquifer over the 5-year application period was calculated using the following assumptions: 1) mass of sand extracted per well: 3,000 metric tonnes; 2) number of extraction wells: 1,793 wells; and 3) in-situ bulk density of sandstone: 2,000 kg/m^3. The volume of sand removed from the aquifer was calculated to be 2,689,500 m^3.

<u>Porosity</u>: The existing porosity of the Winnipeg Sandstone aquifer was assumed to be approximately 25 % based on literature values reported for similar geologic materials. Because the aquifer is saturated, this amounts to approximately 56,250,000 m^3 of water-filled void space in the aquifer within the footprint of the extraction wells (225,000,000 m^3 x 25 %). Following operations, the water filled void space will increase to 58,939,500 m^3 (56,250,000 m^3 + 2,689,500 m^3) within the overall aquifer volume of 225,000,000 m^3, and the estimated porosity will be 26 % (58,939,500 m^3 / 225,000,000 m^3), or 1 % (26% - 25%) higher than previously assumed. Although not calculated, it is possible that changes of this order of magnitude may be reduced as a result of an increased effective stress state of the residual sand. If the existing porosity of the Winnipeg Sandstone aquifer is assumed to be 15%, mining would result in

a post-mining estimated porosity of 16%.

Storativity: The governing equations describing the storativity of a confined aquifer is given as (Freeze and Cherry 1979):

$$S = S_s \times b$$

where:

S = storativity (dimensionless)

S_s = specific storage (1/L)

b = average thickness of aquifer (L)

Specific storage is defined as:

$$S_s = \rho g(\alpha + \eta_e \beta)$$

where:

S_s = specific storage (1/L)

ρ = density of fluid (M/L^3)

g = the gravitational acceleration constant (L/T^2)

α = compressibility of the aquifer solid structure (T^2L/M)

η_e = effective porosity (dimensionless)

β = compressibility of water (T^2L/M)

The Winnipeg Sandstone aquifer is a confined aquifer with a groundwater elevation several tens of metres above the top of the aquifer so we have assumed that there will not be drainage of pore space. Therefore, water is derived from two mechanisms: 1) the compaction of the aquifer (reduction in pore volume) caused by an increase in the effective stress (i.e. the difference between the total pressure exerted by the overlying material and the pore water pressure); and 2) the expansion of the water caused by the decrease in pore pressure. The first mechanism is controlled by aquifer compressibility (α) and the second mechanism is controlled by fluid compressibility (β).

The compressibility of water (β) is small at 4.4×10^{-10} m^2/N whereas the compressibility of the aquifer (α) whether sand (1×10^{-7} to 1×10^{-9} m^2/N) or jointed rock (1×10^{-8} to 1×10^{-10} m^2/N) is up to three orders of magnitude larger. This suggests the majority of water release from a confined aquifer results from changes in aquifer compressibility. The

Winnipeg Sandstone aquifer will locally include some voids following sand extraction, but the total pressure exerted by the overlying material will remain the same. Pore water pressure will temporarily decrease during sand extraction until hydraulic heads recover following extraction.

Storativity values for the Winnipeg Sandstone aquifer are reported to range from 1.0×10^{-5} to 1.7×10^{-4} in the literature that was reviewed as part of the Hydrogeology and Geochemistry Assessment. Pumping test analysis in proximity to a historical sand extraction well found that storativity ranged from 1.1×10^{-4} to 1.7×10^{-4} depending on the method and observation wells used for the analysis. The changes in porosity described above will increase the volume of water stored in the aquifer at the local scale following project operations due to the establishment of water filled voids in the Winnipeg Sandstone aquifer. However, because the aquifer is confined, the compressibility of water is very small and the change in porosity is relatively small, there should not be a measurable change in the storativity of the aquifer. Impacts may be different for an unconfined aquifer, where pores drain and fill in response to changes in hydraulic head but those governing relationships do not apply to the confined aquifers under consideration.

<u>Hydraulic Conductivity</u>: The existing hydraulic conductivity of the Winnipeg Sandstone aquifer is reported to range from 1×10^{-6} m/s to 1.1×10^{-3} m/s based on individual measurements in the literature reviewed as part of the Hydrogeology and Geochemistry Assessment. Reported geometric mean values range from 2.4×10^{-5} m/s to 9.5×10^{-5} m/s. Pumping test analysis found that hydraulic conductivity ranged from 4.82×10^{-5} m/s to 1.11×10^{-4} m/s depending on the analytical solution and observation well data used for the analysis. Changes in porosity are known to alter the permeability and hydraulic conductivity of aquifers, but the changes within the range of values calculated above (i.e. 25-26%) are anticipated to be very small. The porosity and hydraulic conductivity will increase <u>within the water filled voids</u> established in the Winnipeg Sandstone aquifer. However, the changes are not anticipated to produce measurable differences in regional scale aquifer properties because most of the sandstone will remain in place and groundwater will continue to flow through the intact portions of the Winnipeg Sandstone aquifer between the source of recharge and the point of discharge.

2. It is difficult to postulate on the impact of mining on a hypothetical new water well development in the project area because it will depend on the location of the proposed well, the targeted aquifer (i.e. overburden, carbonate or sandstone), well depth, desired pumping rate, the configuration of the pumping system in the well and the timeframe for evaluating the impacts. However, some broad statements can be made. The impacts on water supply wells during operations were evaluated and the results have been discussed in detail in Sections 6.10.2, 7.2 and 7.3 of the Hydrogeology and Geochemistry Assessment. While modelling

contemplated changes in hydraulic conductivity of the Winnipeg shale aquitard, it did not contemplate changes in storativity of the Winnipeg Sandstone aquifer because the aquifer is confined and the model is not a coupled groundwater and geomechanical model. Any changes in storativity will be largely the result of any changes in effective stress and the compressibility of the aquifer. Future groundwater modelling could investigate the impact of poroelastic deformation on permeability and hydraulic conductivity of the aquifers. It is hypothesized that the water filled voids within the project footprint may serve to locally increase the volume of water stored in voids within the Winnipeg Sandstone aquifer but are not anticipated to affect the yield of wells following sand extraction and recovery of hydraulic heads in the aquifer.

3. The Groundwater Monitoring and Mitigation Plan has been developed in draft with the intention that it will be modified to address comments received from regulatory agencies, landowners and groundwater users. This plan will be provided in draft prior to the Hearing.

   Specific actions taken to monitor groundwater levels include establishment of a monitoring well network that is able to monitor groundwater levels at a range of distances between sand extraction wells and adjacent wells. It will include wells proximal to operations, upgradient of operations and downgradient of operations. These wells will be both inside the project area and outside the project area. Wells will be completed in both of the primary aquifers including the Red River Carbonate and Winnipeg Sandstone aquifers. Actions may also include direct monitoring of existing water supply wells with the permission of well owners.

   The wells will be instrumented with pressure transducers outfitted with telemetry to communicate real-time water levels to a centralized location for live monitoring and archiving of data. Manual measurements will also be collected to supplement the pressure transducer data. Barometric pressure transducers will also be installed to allow for compensation of water level measurements and determination of geodetic groundwater elevations.

   Specific actions taken to monitor groundwater quality will include regular sampling of groundwater from the monitoring well network described above. Samples will be collected following industry standard methods and submitted to an accredited environmental laboratory for analysis of parameters of interest including anions, total metals, dissolved metals, nutrients, microbes and other regulated constituents. Field parameters including pH, temperature, electrical conductivity, oxidation-reduction potential and dissolved oxygen will be monitored using a calibrated handheld water quality monitoring probe and/or in-field water quality kits. Results will be compared to applicable regulatory guidelines for the protection of drinking water, irrigation water, livestock watering and aquatic life.

It is presently envisioned that groundwater quality samples will be collected in advance of development and following development for a period of two (2) to five (5) years under the direction of a qualified professional with experience in the interpretation of geochemistry and groundwater quality. The monitoring program will continue until groundwater quality is stable and similar to background (pre-development) concentrations.

Monitoring of groundwater levels and groundwater quality alone should not be used to judge the accuracy of the groundwater flow modelling. It will be important to monitor the location, magnitude and duration of sand extraction activities with particular focus on measurement of the volume of groundwater and sand extracted and reinjected to the Winnipeg Sandstone aquifer. The characterization and monitoring data collected before, during and after operations will be used to update the groundwater model through a continuous improvement process. Models are useful tools for exploring the impacts of the project and guiding a response to any unexpected results. The response will include actions defined in a Trigger Action Response Plan, that may include: 1) Quarterly evaluation of water level information from private wells by a qualified hydrogeologist, with results shared directly with well owner; 2) Proactive adjustment of the location and number of extraction wells, or rate of sand extraction to reduce impact of operations on water levels in nearby private water wells so they do not exceed Safe Available Drawdown; 3) Provision of potable water to any affected parties via certified water purveyor until the situation is assessed and rectified if impacts deemed related to Project operations; 4) Quarterly evaluation of water quality by qualified hydrogeologist and/or geochemist, with results shared publicly; and others. Private Well Owners notified in the event there are deemed to be risks to water quantity and quality in private wells.

4. The cumulative effects of other groundwater and/or sand extraction activities were not specifically assessed. However, available Licensed Water Wells were incorporated into the groundwater model as described in Section 6.6 of the Hydrogeology and Geochemistry Assessment. Growth projections and the magnitude of future groundwater use in the area was not available at the time of the assessment. Further, at the time of the assessment the authors were not aware of other projects that may induce cumulative impacts on the quantity and quality of groundwater in the aquifers . The net use of groundwater as part of this project will be relatively small, and the majority of the water will be reinjected to the aquifer following appropriate treatment, minimizing the project’s potential contribution to cumulative effects.

IR Number: **CEC-IR-012**

Submitted by: CEC

Date Submitted: December 23, 2022

Subject Matter: Shale Aquitard

Reference: Response to Technical Experts Report – Hydrology Issue 7: Shale layer

Request: 1. It is stated that "It is agreed that it is important to understand the role of the shale aquitard".

Are we correct in our interpretation from the discussion provided that one should not be concerned about the aquifer waters mixing as they are already?

According to Wang et al. (2008) the carbonate layer does not extend into much of the Sandilands area. It is not possible for the aquifers to be connected there.

It is recognized that there are notable areas of direct connection; but it is well documented that hydrologists consider the major aquifers as confined. This was attested to in other places in the response document.

Please explain the effects on regional groundwater flow if the shale layer between the two aquifers over the entire development area was severely degraded.

Response: 1. It would be incorrect to draw the interpretation that the reason one should not be concerned about the aquifers mixing is because they are mixing already. Rather, one should not be concerned because the potential for mixing of waters between aquifers has been investigated, and Sio has committed to monitor the aquifers before, during and after operations to address any residual uncertainty and to guide implementation of mitigation measures if required. Key natural mitigating factors include: 1) The aquifers both contain fresh water within the project area, which dramatically reduces any concerns over upwelling of saline water from the Winnipeg Sandstone aquifer into the Red River Carbonate aquifer; 2) Water levels measured in observation wells indicate the vertical gradients between the two aquifers are downward and near zero meaning that downward flow from the universally fresh Red River Carbonate aquifer across the Winnipeg Shale aquitard and into the underlying Winnipeg Sandstone aquifer is the more likely flow direction, with little potential for saline impacts; 3) The relatively small gradients will result in a relatively small quantity of groundwater exchange; 4) There are a large number of existing wells that have interconnected both aquifers, but have not produced any widespread water quality issues except in areas where the Winnipeg Sandstone aquifer is brackish or saline (which is not the case in the project area); 5) Geochemical equilibration modelling to simulate the result of mixing indicates that changes will be minimal; and 6) The potential for contamination from surface to reach the Winnipeg Sandstone aquifer would remain very low due to the presence of relatively low permeability overburden materials from ground surface to a depth of approximately 25 m, and the presence of a much more permeable aquifer overlying the Winnipeg Shale aquitard, which will act to convey any contaminants laterally rather than vertically downward toward the sandstone at a depth of approximately 75m below ground surface.

It is understood that the Red River Carbonate aquifer subcrops (terminates) approximately 10 km east of the project area, and the Winnipeg Sandstone aquifer subcrops approximately 12 km east of the project area. Both units are thought to terminate in the relatively permeable Sandilands Glaciofluvial Complex and would therefore be indirectly hydraulically connected where the bedrock units terminate. This hydraulic connection is supported by the synchronous fluctuations in measured groundwater elevations for many years with seasonal high values typically observed following snowmelt and seasonal low values typically observed in late winter.

It is agreed that the Red River Carbonate aquifer and the Winnipeg Sandstone aquifer are generally regarded as confined, with several locations where historical wells allow for direct communication between the two aquifers (i.e., leaky aquitard).

The effects of Winnipeg Shale degradation within a 200 m radius of each sand extraction well cluster was simulated using the numerical groundwater model. A second scenario was simulated where the shale was assumed to retain its hydraulic properties following sand extraction. By comparing the results of both scenarios during a period of sand extraction operations, it can be seen that shale degradation would increase the magnitude and extent of drawdown in the overlying Red River Carbonate aquifer and decrease the magnitude and extent of drawdown in the Winnipeg Sandstone aquifer. The same amount of groundwater would be removed, but it would be derived from both aquifers. Following operations, groundwater elevations will recover in both aquifers and will tend to equilibrate locally. Vertical gradients may diminish over time as they have elsewhere in the aquifer where there are multiple interconnections associated with open boreholes extending across both the Red River Carbonate and the Winnipeg Sandstone. Until the hydraulic heads equilibrate, there would be some exchange of groundwater between the aquifers in accordance with prevailing vertical gradients (if any) at the time. Modelling shows that groundwater flow directions and the quantity of groundwater moving through the aquifer system will be similar with and without the project, even if the Winnipeg Shale is degraded.

IR Number:	**CEC-IR-013**
Submitted by:	CEC
Date Submitted:	December 23, 2022
Subject Matter:	Groundwater Flow
Reference:	Response to Technical Experts Report – Hydrology Issue 10: Groundwater flow

Request:

1. The groundwater flow direction is west to the Red River and northwest to Lake Winnipeg.

   Please provide the rationale why boundary conditions in the groundwater model close off flow to the northwest. What is the rationale for forcing water in the confined aquifer to discharge into the Red River? What evidence supports this conclusion?

Response:

1. Specified Head (Type I) boundary conditions were assigned in the model to represent prominent surface water features including the Red River and Red River Floodway. The Red River is known to be connected to the underlying groundwater flow system, and the Red River Floodway is known to have intersected the carbonate aquifer resulting in lowering of groundwater elevations in that area following construction. Both hydrologic features are conceptualized to be groundwater discharge areas where upward groundwater gradients are present, and hence, they were adopted as regional boundary conditions in the model. These boundary conditions are greater than 35 km west of the project area and will have a relatively small influence on simulated groundwater elevations within the footprint of the project. Several regional hydrogeology studies (notably, Kennedy and Woodbury 2005) have assigned Specified Head (Type I) boundary conditions to the Red River and Red River Floodway, and to the underlying bedrock aquifers. Conceptualizations of the flow system indicate the presence of converging eastward and westward groundwater flow in the Winnipeg Sandstone below the Red River. This will result in upward groundwater gradients across the overlying Winnipeg Shale aquitard toward the Red River. While other projects have utilized groundwater model domains that were centred further west, groundwater flow directions and the flux of groundwater to the Red River was not a core modelling objective. In either case the direction of groundwater flow (i.e. WNW vs. NW) is not likely to materially affect the conclusions of this study.

IR Number:	**CEC-IR-014**
Submitted by:	CEC
Date Submitted:	December 23, 2022
Subject Matter:	Pilot Testing
Reference:	Response to Technical Experts Report – Hydrology Issue 13: pilot testing

Request:

1. In the response, it states that "several post extraction surveys have been conducted".

   Please provide the methods and results of these surveys.

   Were any well tests carried out post sand extraction showing drawdowns in observation wells?

2. In the response it states that "pilot testing" was carried out and essentially all groundwater that was extracted from the slurry was reinjected.

   Please define "essentially".

   Please provide these test results.

   What is the cumulative effect on the aquifer of this water loss over time.

3. Please clarify in your documentation where the results refer to slurry pumping rates versus groundwater rates.

Response:

1. The surveys referenced in the Response to Technical Experts Report – Hydrogeology Issue 13: pilot testing are sonar surveys that were conducted by a third-party wireline logging company. Some of these results are shared as examples in the confidential version of the Geotechnical Assessment submitted to the CEC.

   Sonar surveys were conducted on Bru 92-8 and Bru 92-2. Bru 92-8 was surveyed during extraction after 3500 tonnes (Operation #1) was removed, and then again just after extraction ceased (Operation #2). Two follow up surveys were performed after at 1 month post extraction (Operation #3) and 4 months post extraction (Operation #4).

   Bru 92-2 was surveyed (10/05/2021 operation #1 3000 tonnes) just after extraction ceased.

   Copies of the sonar results for both Bru 92-8 and Bru 92-2 are included in **Appendix A**.

   Appendix B contains draw down information from the most recent Bru 92-8 extraction test.

Sio Silica collected this data utilizing manual measurements and transducers placed in monitoring and extraction wells on the site and at a distance away to establish monitoring wells that were used for the Hydrogeology and Geochemistry Assessment. This data has not been interpreted and is provided for information purposes only. This data was collected during an extraction test in August 2021, during which time Sio stopped testing intentionally for a sonar logging exercise, and then resumed testing.

The barometric pressure datalogger memory reached capacity nine hours after the end of sand extraction, and water level data could not be corrected to remove the effects of barometric pressure fluctuations from August 26 to August 31. However, the 9 hours of recovery can still be seen on the results and does show levels had returned to very close to pre-extraction levels before the memory capacity was reached.

Appendix C is also provided with a list of all extraction wells conducted to date, locations, well names and corresponding borehole license, dates of extraction and total tonnage extracted per well.

2. In this context “essentially” was used, as there was some residual water remaining from the extraction that was discharged on surface. This is because of the tankage used. Not all the water could be returned to the aquifer because the gravity feed tank outlet is not at the bottom of the tank (to avoid any sand that might end up in the tank from clogging the system). This volume of water had to be discharged on surface. Please note this was a testing configuration only. The proposed operations would not leave residual water that needs to be discharged on surface.

   Please see Appendix A, B and C for the test results and additional data provided.

   The 9 hours of recovery post extraction testing can be seen on the results in Appendix B and does show levels had returned to very close to pre-extraction levels before the memory capacity of the barometric pressure data logger was reached. This demonstrates very little effect on the aquifer during an extraction test. With additional wells operating, it is expected that the recovery time would be longer then the 9 hours overall and within the parameters outlined in the Hydrogeology and Geochemistry Assessment, “W*ater levels were simulated to recover relatively rapidly, with approximately 80% recovery approximately two days following the end of production at each well cluster. Groundwater levels are anticipated to return to static water level conditions approximately 20-80 days after production ceases at each well cluster*.” These results account for other existing draws on the aquifer, and therefore account for cumulative effects with existing water wells and other industrial activities in the region.

3. Please see Appendix A, B and C.

IR Number: **CEC-IR-015**

Submitted by: CEC

Date Submitted: December 23, 2022

Subject Matter: Aquifer qualities

Reference: Response to Technical Experts Report – Hydrology Issue 28: aquifer qualities

Request:

1. In the response, it is clarified that "each layer is anisotropic not isotropic as noted by the reviewer".

   Could you please provide further information:

   How were the anisotropic properties validated without well test data?

   Was sensitivity testing done with respect to the ratios of K that were adopted?

2. With respect to Kennedy's (2002) work on density dependency. That work was based on modeling at the time without taking into consideration current conditions or planned changes in the hydraulic properties (sand mining) on a large scale. Also, the RMS errors on concentration were good fits.

   We note that observations made in the response only refer to the effects of linking density on hydraulic heads. But the linkage between saline water and mass transfer is still there through the effects of groundwater flow alone.

   Please demonstrate, quantitatively, in consideration of current conditions that saline water intrusion will not be enhanced by the proposed development.

3. It is stated that salinity is not of concern in the Project Site. This site encompasses a very small area in comparison to the area to be mined in longer term plans.

   As the mining operation expands and gets closer to the current saline water boundary what methods will be used and what precautions will be taken to monitor and prevent saline water intrusion into the aquifer?

   What actions will be taken if, due to circumstances outside the mining operation, cause the expansion of the zone of salinity to encroach on the area of the mining operation?

Response:

1. The anisotropy of the hydrostratigraphic units was determined through literature review and assigned during model development. The ratio of horizontal to vertical hydraulic conductivity was utilized as a fitting parameter and adjusted during calibration within a range of reasonable values to minimize the difference between observed and simulated

groundwater heads. The calibration data set included static groundwater elevations and those measured at multiple depths and lateral distances from the pumping well during an extended pumping test. The model was able to reasonably replicate hydraulic responses observed during pumping, suggesting anisotropy ratios were reasonable. The hydrostratigraphic units are deeply buried and, therefore, direct measurements of both horizontal and vertical hydraulic conductivity at the same location are challenging.

As described in Section 6.11 of the Hydrogeology and Geochemistry Assessment, the hydraulic conductivity of hydrostratigraphic units was evaluated through sensitivity analysis, and the ratio of horizontal to vertical hydraulic conductivity (i.e., anisotropy ratio) was explored during the calibration process. However, the sensitivity of the model to the anisotropy ratio assigned to each hydrostratigraphic unit was not specifically evaluated as part of the sensitivity analysis. Rather, during sensitivity analysis the hydraulic conductivity values were adjusted while anisotropy ratios were maintained.

2. It is acknowledged that the modelling conducted by Kennedy (2002) did not take into consideration the current conditions or any changes contemplated in Sio's licence application. Notably, the investigations of Kennedy (2002) were focused on an area of Manitoba west of the project area, where the salinity of groundwater in the Winnipeg Formation is several orders of magnitude higher than observed in the project area.

   Compared to the Kennedy model, the AECOM model is a more local scale model that leverages natural hydrologic boundaries to establish a reasonable and representative groundwater flow domain. The model domains are different in focus area (i.e. southwestern Manitoba vs. southeastern Manitoba) and size (AECOM model is approx. 1/5th the size). Because the model is more localized, it allows for improved refinement of the mesh and improves resolution of the model for making local scale predictions. Further, the variability in the observed and simulated chemistry for the model domain established by Kennedy (2002) is much greater than observed within the AECOM model domain. Notably, the simulated salinity differences in southwestern Manitoba are much greater (10^{-8} g/L to 10^{+1} g/L) at an observed concentration of 10^{-3} g/L as shown on Figure 7.17 of Kennedy (2002). The fundamental differences between aquifer salinity in the Kennedy model domain and that to the east (i.e. the area simulated by AECOM) are acknowledged by Kennedy (2002), where it is stated "*The bulk of the Sandstone Aquifer samples were obtained from fresh water regions and therefore, the dataset was not representative of what was occurring in the salt-water region to the west.*" For the reasons stated above, it is not appropriate to use the Kennedy model as a basis for comparison to AECOM's model, which is focused on the area of the aquifer that contains measured TDS concentrations below 10^{-3} g/L.

   Within the carbonate aquifer, Grasby and Betcher (2002) define the fresh water-saline water boundary to the west of the Red River Floodway, which is west and outside the boundary of the AECOM model. This boundary also coincides with an inferred hydraulic divide near the Red River. They also state “*there is limited diffusion of saline waters across the hydraulic divide*”.

Wang et al. (2008) developed a numerical groundwater model covering a similar area of Southeastern Manitoba as was simulated by AECOM, and there is no mention of density-dependent flow simulations or the calculation of equivalent freshwater heads or point-water heads using measured TDS concentrations, which would require contemporaneous measurements of groundwater levels and groundwater quality from thousands of wells. Much of the available data is outdated, and many of the wells are screened across the full thickness of the carbonate and sandstone aquifers, meaning that measured hydraulic heads and water quality are in many cases averaged across the thickness of each aquifer, or both aquifers for wells screened across both the Red River Carbonate and Winnipeg Sandstone Aquifers.

Unfortunately, current water levels and water quality results were not available to allow for quantitative calculations of point water heads or equivalent freshwater heads across the entire model domain. The AECOM model quantitatively calculates changes in hydraulic heads in response to project activities. The model demonstrates that changes in hydraulic heads will be temporary during operations but will be restored following seasonal operations each year. This shows that groundwater flow directions and patterns will largely be preserved, and there should not be any eastward migration of saline water. As shown in Section 7.2.1 of the Hydrogeology and Geochemistry Assessment Report, domestic use is estimated at 439,000 m^3/year. Licensed groundwater use for commercial, municipal, and industrial wells is estimated at 4,070,000 m^3/year. Groundwater extraction rates associated with sand extraction amounts to an estimated 13% of the existing allotment to the other large industrial users within the model domain over the 5-year operational period if none of the groundwater is reinjected (i.e. highly conservative scenario).

Within the Winnipeg Sandstone Aquifer, groundwater elevations drop from approximately 320 masl below the Sandilands Area to less than 180 masl between Anola and Winnipeg, which corresponds with the base elevation of the Winnipeg Sandstone aquifer within the project area. The lowest simulated groundwater elevations during project operations were approximately 261 masl (50% re-injection) and 252 masl (0% re-injection), indicating it would be physically impossible to reverse groundwater gradients and induce west to east groundwater flow toward the project area.

Although wells that interconnect the sandstone and carbonate systems have experienced changes in salinity in the past due to vertical groundwater flow from the Winnipeg Sandstone aquifer to the Red River Carbonate aquifer, existing groundwater use has not caused eastward migration of saline groundwater. These observations are direct observations of the response of the system to pumping and are arguably more valuable than any calculations or groundwater modelling work that has or could be conducted, and clearly demonstrate that large scale migration of saline groundwater to the east has not been observed to date and will not likely be observed in response to proposed sand extraction activities.

3. Although portions of the Winnipeg Sandstone aquifer several kilometers west of the project area are brackish or saline, water quality within the project area is fresh. The scope of the Hydrogeology and Geochemistry Assessment includes five years of operation and the impacts of any hypothetical future development have not been directly assessed. However, Sio notes that, subsequent mining areas and years would involve, additional groundwater modelling, taking into account all available data, including monitoring data from the initial project operation.

The Progressive Well Abandonment Plan will decommission extraction wells after their useful life and minimize the potential for migration of any surface contamination into the underlying aquifers. It will also limit interaction between the Red River Carbonate and Winnipeg Sandstone aquifers.

The Water Management Plan will include provisions for monitoring of all materials (sand and water) extracted from the Winnipeg Sandstone aquifer and subsequently reinjected. This will allow for comparison of measured data with model simulation results to understand how results compare, and whether any modifications to the sand extraction and reinjection process are required. The data will also allow for updates to the groundwater model in the future to guide design of any required mitigation measures or understand the impacts of any future domestic, agricultural, municipal or industrial groundwater development projects.

The Groundwater Monitoring and Mitigation Plan will include provisions for monitoring of groundwater for constituents (e.g., electrical conductivity, anions, total and dissolved metals, etc.) found in saline groundwater. Analytical results will be regularly evaluated by a qualified professional to specifically determine whether there is evidence of saline water intrusion from areas of the aquifer that are presently brackish or saline. Should any changes be identified, mitigation measures will be implemented in accordance with a Trigger Action Response Plan (TARP).

The expansion of the zone of salinity into the area of the mining operation is unlikely as literature suggests it has been slowly migrating eastward over several millennia. While hypotheses have been stated that the saline front has and will continue to slowly migrate (e.g., 1 m/yr) a short distance eastward in response to isostatic rebound of the land mass following deglaciation, the authors note the rate is highly uncertain. These processes are likely to be very slow and can easily be monitored using conventional groundwater monitoring techniques. Water quality will be monitored near the interface between fresh and brackish water in both aquifers, and water quality will be reported to regulatory agencies. Any eastward migration of salinity will trigger implementation of the TARP as discussed above to determine the root cause and develop and implement further mitigation measures.

IR Number:	**CEC-IR-016**
Submitted by:	CEC
Date Submitted:	December 23, 2022
Subject Matter:	Boundary conditions
Reference:	Response to Technical Experts Report – Hydrology Issue 31: Boundary Conditions

Request: 1. We appreciate your response to Issue 31, however it lacks the detail that provides for a full understanding of the boundary conditions.

Please detail all the boundary conditions that were adopted on all major surfaces and the rationale for their adoption.

Response: 1. The assignment of boundary conditions to the model is described in Section 6.6 of the Hydrogeology and Geochemistry Assessment and illustrated on Figure 6-1. It was based on the conceptual model and included a combination of input parameters from literature and values derived through calibration with spatial areas assigned based on textural changes in mapped surficial geology. Recharge values were assigned as input parameters for the Sandilands Glaciofluvial Complex based on academic research, but values assigned to other areas were treated as fitting parameters and adjusted within a range of reasonable values as determined using professional judgment. Additional information regarding the assignment of boundary conditions and rationale for the approach taken is provided in the table below.

Boundary Condition	Descriptor	Value	Rationale
Recharge	Fine Grained Sediments (clay)	6 mm/yr	Fitting Parameter; 1% MAP
	Medium Grained Sediments (fine sand / silt)	50 mm/yr	Fitting Parameter; 8% MAP
	Coarse Grained Sediments (sand / gravel)	100 mm/yr	Fitting Parameter; 16% MAP
	Sandilands Glaciofluvial Complex	189 mm/yr	Cherry (2000); Ferguson et al. (2003); 30% MAP
	Bird's Hill Complex	250 mm/yr	Fitting Parameter; 39% MAP
Specified Head	Red River	Variable (topographic elevation)	Inferred Groundwater Flow Divide
	Red River Floodway	Variable (topographic elevation)	Inferred Groundwater Discharge Area
	Regional Stream Network	Variable (topographic elevation)	Inferred Groundwater Discharge Area
	Winnipeg Sandstone	Variable (measured groundwater elevations)	GIN Database
No Flow	South, East and North Model Boundaries	0 m^3/yr	Inferred Groundwater Flow Divides
	Base of Model (0 masl)	0 m^3/yr	Beyond depth of flow system being investigated
Wells	Licensed Groundwater Wells	Various (licensed rate)	Large known licensees