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Appendix B

Expert Peer Review of Draft Hydrogeological Assessment Report

Appendix B: Expert Peer Review of Draft Hydrogeological Assessment Report: Vivian Sand Extraction Project

Report Subject	From	Comment Number	Reviewer Comment	AECOM's Response
Introduction	Friesen Drillers Limited*	FRIESEN-1	In the initial sentence in the introductory section it might be a better approach to suggest that AECOM has been retained to assess the hydrogeology and geochemistry of the proposed silica sand extraction/mining program. Suggesting that the assessment is simply there to support the application leaves the reader with the impression at the onset that the results of the assessment are a foregone conclusion.Providing more of a balanced approach will be beneficial the members of the public reading this section.	Wording has been modified as suggested by Friesen to clarify AECOM's role on the project.
Background	Friesen Drillers Limited*	FRIESEN-2	It is our feeling that a significant opportunity was missed to provide some background on the extensive mining of silica sand that has occurred in the past in the Province of Manitoba. There is a very detailed publication by the Province of Manitoba that provides a great deal of information on the past surface mining of silica sand (D.M. Watson, 1985). This report discusses the concept of silica sandstone mining in many areas of Manitoba. One aspect that is particularly valuable from a historical point of view is the former mining operations on the Black Island, which had some initial development over 110 years ago.	Additional discussion has been added to Section 1.2 of the report to provide context on historical silica sand mining in Manitoba without any significant environmental impacts. Reference to the historical interest in silica sand exploration and mining within the Regional Project Area has also been added with reference to the lack of economically viable extraction methods at the time of the study.

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			This background is very important, as it presents silica mining as a concept that has previously occurred in Manitoba, without any significant environmental effects.The 1985 report describes the current proposal that was put forward to mine the Carmen Sands of the Winnipeg Formation in 1966 by Norlica Minerals Limited. This work was undertaken by Underwood McLellan and Associates on behalf of the developer. At the time, it was stated that although the product was viable, the extraction methodology was the key limiting factor for development. Some additional historical text in this area would go a long way in describing the proposed project.	
Introduction	Friesen Drillers Limited*	FRIESEN-3	There is some discussion in the introductory section about domestic water wells in the area. Although there are a large number of wells in the area, the general population density is generally quite low: The report states that many of these wells are completed into the carbonate aquifer. Although this is the case in some instances, there are a great many water wells that have been drilled through both formations, creating interconnection to the sandstone. We feel that it would be valuable to introduce the concept that the bedrock aquifer and the underlying sandstone aquifers are highly related to each other. Within the GWDRILL database,	AECOM agrees that the literature and historical drilling practices suggest a large number of wells are screened across both the carbonate and sandstone formations. Some additional discussion has been added to section 1.2 of the report. We have also added some additional description to section 5.8.2 of the report, which discusses the hydrograph data represented on Figure 5-12 (G05SA003/G05SA013).

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			the number of interconnecting water wells has been estimated by Betcher and Ferguson as high as 10,000 water wells (Betcher, and Ferguson, 2007). This number is only representative of water well records that have been submitted under provincial requirements since 1964.The practice of drilling through both formations has been ongoing in Manitoba for over 130 years. It is our opinion that the extent of natural and induced connection of the two formations should be expanded upon further. There is a great deal of hydrograph evidence, both from the province and the private sector, which shows the direct response between both formations. It is our opinion that interconnection will result from this project in some way shape or form, and that an approach to address this will be needed in this report.	It is acknowledged that data indicates the water levels in the Red River Carbonate and Winnipeg Sandstone aquifers equilibrated at some point between January 2017 and late 2018. Prior to that, there was a relatively consistent mildly upward gradient from the sandstone to the overlying carbonate aquifer at that location. However, as shown on Figure 5-13 (G0SA014/G05SA015) and Figure 5-14 (G050J163/G050J175), water levels remain significantly different in each aquifer, indicating the aquitard remains intact. Further, the pumping test conducted by AECOM in 2020 indicated the aquitard was intact despite the presence of several wells in the area. Regardless of the interconnection, relatively minor drawdown was simulated by the groundwater model to occur in each aquifer in response to sand extraction for a range of scenarios where the aquifers remain separated, or are interconnected during development. The results of Scenario Testing and Sensitivity Analysis are presented in Tables 6-1 and 6-2 of the report and evaluated scenarios where the hydraulic conductivity of the shale was equivalent to the aquifers. The interconnection of the aquifers will be considered during development and implementation of the Groundwater Monitoring and Impact Mitigation Plan.
Introduction	Friesen Drillers Limited*	FRIESEN-4	A more straightforward and concise description of the project would be a benefit. There were several scenarios used in the text that ultimately were not included in the overall description/analysis/project plan. A clear and direct plan of exactly what is proposed would be a benefit to the report.	A high level description of the project is provided in section 2 of this report, with specific discussion of project components and activities (2.1), the sand extraction process (2.2), the layout of extraction sites (2.3), groundwater use during sand extraction (2.4), materials management (2.5) and closure and reclamation (2.6). A more comprehensive description will be provided separately in forthcoming EAP application documents.

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Regulatory Review	Friesen Drillers Limited*	FRIESEN-5	Within the regulatory review, there are several comments that were noted to be an issue. Although the report references the Groundwater and Water Well Act/Water Well Drilling Regulation on several occasions, there is no section in the report which provides background to the reader, as to what rules and regulations will apply to this project, and to the testing/project as a whole. Additional details would fill in some of the gaps in the information in the report. There are some aspects of the regulatory review that are incorrect, where regulations from one act are stated as having been in another act. These regulations are a great source of misinformation to the general public, so this report should take the opportunity to provide an overview of each regulation/ act and how things will impact this project.	A high level description of the regulatory setting is provided in section 1.7 of this report, with specific discussion of The Mines and Minerals Act (1.7.1), Environmental Assessment and Licensing (1.7.2) and Water Rights Licensing (1.7.3). It is acknowledged that the regulatory overview is at a high level that intends to support the technical assessment of hydrogeology and geochemistry. A more comprehensive description will be provided separately in forthcoming EAP application documents.
Regulatory Review	Friesen Drillers Limited*	FRIESEN-6	Typically, if one is applying for a license under the Water Rights Act, these aspects would be included in the report. It was never explicitly stated that CanWhite was going to be applying for an allocation, and what that impact would be regionally across the aquifer(s) at the requested allocation. Usually when a Groundwater Exploration Permit (GEP) is issued, there are a aspects of the testing that must be completed and reported to the province. If a GEP is filed, what would the impacts be to the other licensed users in the area? If a defined radius of influence is not stated, the public will often invent their own radius of influence.	The need for any licenses (allocations) under the Water Rights Act will be addressed within the forthcoming EAP application documents. As noted throughout the document, the consumptive water use is anticipated to be very low. The Groundwater Exploration Permit was obtained by CanWhite and appended to the report (Appendix A). Wells owned by nearby licensed well users were monitored during testing so the radius of influence of the test is known and supported by factual data. To AECOMs knowledge, all 9 conditions of the GEP were satisfied.

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Description of Proposed Development + Hydrogeological Investigation	Friesen Drillers Limited*	FRIESEN-7	The details on the grouting are difficult to understand. It is not clear as to what impact would occur on the aquifer hydraulics from a regional sense be if the wells were sealed by cement. The ongoing issue of the interconnection between the two aquifers is vague and requires some definition. As noted above, the interconnection of these two aquifers is likely to become a major theme of this project, so some additional text would be beneficial. In the aquifer hydraulics section, the consultant went to great lengths to install vibrating wire transducers in the shale to monitor the response during testing. This would have been a highly interesting technical aspect of the analysis that was not included. The nature of the response across the shale would warrant a section in the report, as this is excellent work.	As stated in Section 2.2 grout would be used to backfill across the shale and isolate the Red River Carbonate aquifer from the Winnipeg Sandstone aquifer during the extraction process. As described in Section 2.6, each extraction well will be progressively abandoned in accordance with provincial regulations. Permeable material will be used at depths of known aquifers therefore the hydraulics of both the shale and the aquifer should remain relatively unchanged.The hydraulic response in the shale unit during hydraulic testing is shown on Figure 3-2 (Bru 95-8 VW3 and Bru 95-9) and discussed in Section 3.7.2. Additional text describing our interpretation of vertical gradients at the VWP nest has been added to Section 3.7.2.3. The impact of sand extraction on water levels is discussed in detail in Section 7.2, with methods described in Section 6. Scenario analysis and sensitivity analysis were used to evaluate a range of possible outcomes should the effectiveness of the shale aquitard become reduced and are discussed in Sections 6.10 and 6.11.

Report Subject	From	Comment Number	Reviewer Comment	AECOM's Response
Aquifer Testing	Friesen Drillers Limited*	FRIESEN-8	The aquifer testing aspects of the report are rather challenging and somewhat non-standard, according to major texts on the subject. The details are also a bit vague in the text, but it appears that the step test was started at a higher rate, and the rates were backed off to maintain a consistent water level. The step test intervals also seemed to vary in duration. Regardless of which, the numbers obtained in the analysis appear to be reasonably consistent with published data. The details of the well development, the well performance was also not included. It is expected that other reviewers may find additional challenges in this section that have not been mentioned in this letter. In our review, the aquifer testing section is the most challenging aspect of this report.	The purpose of the step test was to determine an approximate pumping rate for the constant rate pumping test. While it is standard practice to utilize step test results to determine specific capacity and well efficiency for water supply wells, that was not the objective of this assessment. Well development is described in the 3rd and 4th paragraph of Section 3.4.2. An analysis of well efficiency was not part of the scope of work. As described in Section 3.7.2.1 the step test consisted of 4 steps, each with a duration between 2 and 2.5 hours. The pumping rate during each step was maintained constant to the best of the operator's ability, as is standard practice. The long duration of 72-hour pumping test provided a much better estimate of aquifer properties because a larger volume of the aquifer was tested than would have been if focus was placed on the step test. We agree that the results of the pumping test are consistent with published data and the other testing completed at individual wells installed as part of this study.

Report Subject	From	Comment Number	Reviewer Comment	AECOM's Response
Groundwater Elevations	Friesen Drillers Limited*	FRIESEN-9	The lack of use of the regional hydrograph data in the assessment of static water level impacts from pumping is interesting to note. From the experience of the undersigned, it is thought that the level impact is overstated in a regional sense. If for example, the regional hydrograph data shows an annual fluctuation of over 12 feet in the potentiometric surface over many years of observation, inducing a few inches/one foot of drawdown in an area will be non-detectable. Often reports will utilize a standard of some sort, although there is rarely justification of this in the report. Within the Province of Manitoba, on a water rights licensing spectrum, the assessment of impacts is usually related to the regional hydrograph network. Selecting an arbitrary standard does not work overly well in this area.	The hydrographs for provincial observation wells are presented on Figure 5-12 (G05SA003 / G05SA013), Figure 5-13 (GO5SA014 / GO5SA015) and Figure 5-14 (GO50J175 / GO50J163), and discussed in detail in Section 5.8.2 of the report. We appreciate Friesen's opinion that the impacts on the aquifer may be "overstated in a regional sense", but the goal was to conservatively quantify the magnitude of impact using numerical modelling techniques, which is an industry-standard approach. We also agree that using annual water level fluctuations as a benchmark for evaluating impacts is a useful approach as it puts water level impacts into the context of natural seasonal variability in response to changing inputs, outputs and storage in the aquifers. The seasonal range in elevations for the perod of time between 2006 and 2021 is discussed near the end of Section 5.8.2, with calculated benchmarks provided. The simulated magnitude of impacts is provided in Section 7.2.1 and 7.3. Benchmarks are used to provide context to predicted water level impacts in Section 8.2. Additional detail can be provided during water rights licensing in the future.

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Existing Groundwater Use + Impact Assessment	Friesen Drillers Limited*	FRIESEN-10	This comment also holds true for the impacts to domestic water wells. The report uses the term windshield survey for an assessment of private well wells in the inventory. This approach has not been found to be successful in Manitoba, and often puts the project at risk for an unsubstantiated complaints/well replacements. The pumping systems/hook up in private wells in the area must be assessed prior to any development. A condition of the well will need to be assigned and agreed to. Lowering of pumps is not a practical solution in this area when most pumps are traditionally set at the base of the casing. Throughout the report, the treatment of private water wells/private water well resident concerns throughout the course of the project is inadequate. Projects that could develop a widespread area of impact typically also include a groundwater interference plan, or some means in which a resident can have a private well complaint assessed. Groundwater interference plans are mandatory on projects such as this one. The province will also request additional details on the well monitoring program after the construction of the project, as there are few details contained in the AECOM report.	Section 5.3 uses the term "windshield survey" to highlight the need to conduct field surveys to ensure the database of well users in the area is kept up to date, and support analysis of impacts to specific wells. It is helpful to understand that the majority of pumps are installed at the base of the casing (assumed to be at the overburden/bedrock contact around 240 m ASL) and that lowering of pumps further may not be warranted because static water levels are much higher and would allow for significant drawdown (>10 m) in the carbonate aquifer before wells experienced diminished yield. Regardless, as part of due diligence, it is recommended that wells within the zone of influence surrounding sand extraction activities be identified and their wells be surveyed to ensure impacts to well users are avoided. The details of the Groundwater Monitoring and Impact Mitigation Plan will be provided during licensing as described in Section 7.5. As noted in the report, the plan will establish a framework for survey of existing domestic wells in advance of operations, monitoring of groundwater quantity and quality during and following project operations, and responding to well owner complaints. It will establish the parameters that will be monitored, the frequency of monitoring, monitoring locations and reporting requirements. Mitigation measures will be developed to avoid and/or mitigate any well interference issues as required by the Manitoba Water Rights Act. Mitigations may include lowering of pumps, provision of alternate water supply or adjustment of operations. Findings will be reported to the community on a regular basis.

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Geochemistry	Friesen Drillers Limited*	FRIESEN-11	The geochemistry section of the report was extremely interesting and informative. This aspect of the report was very well done and provided a lot of information. This section is one that we intend to refer to in the future for various aspects.	Noted. We see this as a good example of how industry can contribute to the advancement of the scientific understanding of the subsurface for the benefit of the community, science and the consulting industry.
Numerical Modelling	Friesen Drillers Limited*	FRIESEN-12	The numerical modelling section is not something that we typically do a great deal. Since a great deal of the report appears to be focusing on these results, we are suggesting that CanWhite obtain a third party to review the model specifically. Modelling can be a very valuable tool in assessing the impact of a project, so these results need to be treated carefully.	Noted. We have engaged Dr. Grant Ferguson of the University of Saskatchewan to review the entire report and provide comments on the model and all other aspects of the document. Dr. Ferguson completed his Ph.D. work at the University of Manitoba and investigated the hydrogeology of the aquifer systems from Winnipeg to the Sandilands area. He is a recognized expert in the fields of hydrogeology, geochemistry and isotopic analysis with an excellent understanding of the historical hydrogeological studies in the area. He has authored numerous technical papers on this aquifer system in peer reviewed journals. His comments are included below for transparency.
Whole Report	Friesen Drillers Limited*	FRIESEN-13	It is evident that multiple authors have prepared the various sections of the report, as there are some internal inconsistencies throughout the text. An overall edit would assist in eliminating these. There are some grammatical issues as well, along with some sentences that start with "because". Again, an overall edit would help. The only reason this is mentioned, as it has been mentioned to us before on similar reports.	Thank you for the comments. We will endeavour to clarify the language in the report to the extent possible.

Report Subject	From	Comment Number	Reviewer Comment	AECOM's Response
Modelling Assumptions and Limitations	Dr. Grant Ferguson**	FERGUSON-1	The well inventory appears to be rigorous but a limitation of this will be that there might be wells in the area that do not appear on the Province of Manitoba database. This could include improperly abandoned wells that connect the Winnipeg Formation with the overlying Red River formations. This could introduce some uncertainty into the results of the model.	Dr. Ferguson's point is noted and has been added to the assumptions given in Section 6.3. AECOM agrees that the possible presence of additional water wells presents some uncertainty in the modelling results and wells that may require mitigation during operations. However there are a large number of water wells spread across the entire study area to constrain the geological interpretation and provide an adequate spatially distributed water level calibration dataset. Coverage is quite good in the model domain, but AECOM agrees that it will be important to identify all wells (active and abandoned) within the zone of influence of sand extraction activities to allow for effective monitoring and mitigation. To supplement a physical survey of the land for water wells, a comprehensive monitoring plan is proposed to aid in this by indirectly determining the presence and overall magnitude of cross-connecting wells based on the observed water level response in each aquifer.
Introduction	Dr. Grant Ferguson**	FERGUSON-2	The literature review conducted here discusses most of the key groundwater studies in south-eastern Manitoba. There were a few studies not mentioned, including a few examining the hydrogeology of glaciolacustrine clays and glacial tills (see detailed comments). p. 16 There are some missing references on the hydrogeology of this region: • Theses by Day (1977), Pach (1994) and R.J. Ferguson (2005) have data for this region of Manitoba for properties of clays and tills. • Underwood et al (2008, J. Hydrology) looks at the presence of elevated barium concentrations in south-eastern Manitoba. • Bob Betcher's 1988 (CJES) paper on uranium may also be worth looking at.	The Underwood and Ferguson reference has been added to Section 4.2.1. The other publications listed by Dr. Grant Ferguson could not be located through any publicly available online sources, and therefore have been excluded from AECOMs literature review. We will endeavour to obtain these technical papers to support future work.

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Aquifer Testing	Dr. Grant Ferguson**	FERGUSON-3	The hydraulic testing follows standard methods and is an appropriate level for this project. The analysis method for pumping tests could use slightly improved method (details explained below in specific comments).	Response to Dr. Grant Ferguson's more specific comment provided under comment FERGUSON-7 below.
Isotopic Analysis	Dr. Grant Ferguson**	FERGUSON-4	The water chemistry and isotopic analyses are rigorous and include some analyses that are not typically done. This study presents what are, at least to my knowledge, are the first isotopic analyses for samples from the shale at the top of the Winnipeg Formation. These shales have long been suspected to provide a low permeability barrier between the sandstone of the Winnipeg Formation and the overlying carbonates of the Red River Formation and the analyses presented here support that idea.	Noted. We see this as a good example of how industry can contribute to the advancement of the scientific understanding of the subsurface for the benefit of the community, science and the consulting industry.
Numerical Modelling	Dr. Grant Ferguson**	FERGUSON-5	The numerical models presented here reasonably represent the observations. The trial-and-error approach to calibrate these models does present some issues with equifinality (i.e., use different combination parameter values could provide similar fits). However, it is unclear if using a probabilistic approach to understand the uncertainty in the model results would provide additional benefits. Measured hydraulic responses during development should be compared to model predictions to assess the quality of those predictions. If significant discrepancies are observed during development, the model may need to be adjusted to improve predictions.	It is agreed that equifinality or non-uniqueness is an issue that is associated with the majority of numerical modelling studies. However, aquifer properties are relatively well understood in the area, providing a higher degree of confidence in modelling results than if there was not a wealth of academic literature and aquifer evaluation reports on the aquifer system. The transient model predictions of response to hydraulic stress testing were analyzed as part of the calibration as detailed in Section 6.8.

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				Observed water level data collected during the 72-hour pumping test completed in 2020 is compared to simulated water levels on Figure 6-4. The comparison illustrates the model was able to simulate system behaviour reasonably well, although some improvement could be made with a better understanding of well completion details for every domestic water supply well, and thereby allow for evaluation of cross-connection of the two aquifers. The groundwater model is a tool that will be utilized and updated regularly as the aquifer response and well network in proximity to the project are better understood over time.
Existing Groundwater Use + Impact Assessment	Dr. Grant Ferguson**	FERGUSON-6	p. 16 Are there wells that are completed in both the Winnipeg and Red River formations in area that will potentially be affected by operations? Is there a contingency plan for the effects of these wells if they are in the study area? They may not show up in the records.	The wells included in the provincial well database are presented on Figure 1-3 (by aquifer) and Figure 1-4 (by type of use). It is acknowledged that there may be additional wells that are not included in the database. These wells will be identified in advance of operations to the best of CanWhite's ability as described in a forthcoming Groundwater Monitoring and Impact Mitigation Plan as described in Section 7.5 of the report. As part of the reconnaissance, new wells, their use, their allocated water quantity will be incorporated as boundary conditions into the model to improve the predictive ability of the groundwater model over time. Contingency measures for ensuring water supply to well users is maintained will be described in detail in the Groundwater Monitoring and Impact Mitigation Plan. It will include a Groundwater Interference Plan as required by provincial regulations.

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Aquifer Testing	Dr. Grant Ferguson**	FERGUSON-7	p. 30 The pumping test analysis should use techniques to examine all data at once. See course notes by Chris Neville for example of how to normalize drawdown by radius to compare all data at once. Van der Kamp and Neville (2012, Groundwater) provide a method to analyze pumping and recovery together. These techniques provide a path to estimate the single values of transmissivity and storativity required by the Theis equation, rather than averaging results from different wells or time segments of an individual test. Given the low variability of transmissivity values calculated by using individual wells or by treating the pumping and recovery portions separately, redoing the analysis is unlikely to provide a drastically different transmissivity value.	AECOM agrees the method presented by Neville and Van der Kamp (2012) is a useful technique, especially well suited to analyzing buried valley aquifers (e.g. Estevan Case Study) or other situations where steady state drawdown is not reached during the pumping test (which is not the case here). AECOM included several analyses that simultaneously match the data from multiple observation wells all at once on the same plot. For example in Appendix E-2 the Theis drawdown plot (Theis - Observation Well Fit.aqt), the Theis distance-drawdown plot, and the Cooper-Jacob plot are all simultaneously matched to observation wells Bru 95-6, Bru 95-8, and Bru 96-1. As noted by Dr. Ferguson, the resultant estimates of aquifer properties are remarkably consistent. Well Bru 95-7 was ignored in favor of matching the observation wells as the pumping well was interpreted to suffer from skin effects, turbulent head loss, etc. imparting excess drawdown in the well as compared with drawdown in the aquifer adjacent to the wellbore. The recovery data in this well does not suffer from the same headloss issues and artefacts imparted by well inefficiency.
Isotopic Analysis	Dr. Grant Ferguson**	FERGUSON-8	p. 43 There is evidence of Pleistocene age water in Lake Agassiz sediments from a study by Remenda et al (1994, Science).	AECOM has added additional discussion in consideration of Ramenda et al. (1994) in section 4.2.2.3. It is our understanding that Pleistocene-aged water has been demonstrated to have a uniform δ18O value of -25‰ in the clay-rich sediments below Lake Agassiz (Ramenda et al. 1994), imparting an estimated air temperature of 16°C. Because the isotopic profile through the shale exhibits δ18O values between -12.61‰ and -8.23‰, these waters appear to have become entrapped when temperatures were cooler than observed during the Pleistocene (perhaps during Holocene glaciation).

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Groundwater Quality	Dr. Grant Ferguson**	FERGUSON-9	p. 43 I don't know that "recharge" is the best description for the flux of water with high TDS from the west. It should also be noted that the boundary between fresh and saline water in the carbonates is typically thought to be the Red River (see Grasby and Betcher, 2002, CJES).	AECOM agrees that the term "lateral recharge of saline water" should be reserved for vertically downward infiltration of meteoric waters that originate from precipitation, snowmelt or losses from surface water features. The wording in Section 4.2.1 has been modified to "lateral migration of saline water". We understand that the saline front within the Red River Carbonate aquifer is thought to be near the Red River and we have added some context to this section of the report.
Groundwater Quality	Dr. Grant Ferguson**	FERGUSON-10	p. 43 Barium concentrations are discussed in detail by Underwood et al (2008, J. Hydrology).	Noted . Reference has been added to section 4.2.1 of the report.
Isotopic Analysis	Dr. Grant Ferguson**	FERGUSON-11	p. 43 The Cherry thesis primarily used CFCs to estimate groundwater recharge rather than isotopes.	Thank you for the correction. The text in section 4.2.1 has been corrected to reflect the use of both CFCs and stable isotopes to estimate recharge in the Sandilands area.
Isotopic Analysis	Dr. Grant Ferguson**	FERGUSON-12	p. 44/45 The d18O and d2H values in the shale likely reflect a seawater source mixed with meteoric recharge rather than evaporated meteoric waters. Similar trends have been noted in studies by Grasby et al (2000, Geology) and Hendry et al (2014, WRR).	Thank you for highlighting the additional references and their conclusions on this subject. The text in section 4.2.2.3 has been corrected to reflect this revised interpretation.
Impact Assessment	Dr. Grant Ferguson**	FERGUSON-13	p. 53 Can any of this geochemical modeling be supported or at least compared to some of the mixing observed where dual completions are present?	We agree that it would be worthwhile to compare water quality in groundwater wells that interconnect the Red River Carbonate and the Winnipeg Sandstone to allow for validation of the PHREEQC modelling results. It is vital that this be completed in an area where historical groundwater gradients, relative transmissivity of aquifers and well completion details are known to cross-connect the wells. Given the size of the well database, this was not completed as part of this study. The authors would be glad to hear of any known wells that have historical records to support such an assessment.

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Hydrostratigraphy	Dr. Grant Ferguson**	FERGUSON-14	p. 59/60 Why is there no distinction between the Upper Carbonate Aquifer and the entire carbonate sequence in the conceptual model as described by Render (1970, CGJ)?	The upper and lower carbonate are distinguished and discussed in the second and third paragraphs of section 5.6.2. As stated in the text: "The upper and lower carbonate aquifers are more pronounced in regions where the Red River Carbonate is thickest. In the Regional Project Area, which is less than 10 km from where the Red River Carbonate pinches out (Figure 5-B and Figure 5-3), the upper and lower carbonate aquifers may be grouped into a single hydrostratigraphic unit, which in this study is referred to as simply the Red River Carbonate." Drilling observations and historical well completion practices have likely resulted in extensive cross-connection of both the upper and lower carbonate aquifers as a result of the very large number of wells completed in the Red River Carbonate aquifer as a whole.
Aquifer Properties	Dr. Grant Ferguson**	FERGUSON-15	p. 62 See theses by Day (1977), Pach (1994) and R.J. Ferguson (2005) for K values for tills and clays.	We consider the abundance of aquifer testing results for the bedrock aquifers in the project area to be sufficient for the purposes of this assessment, but acknowledge the overburden is much more variable and improved understanding could be gleaned with more information. The dataset is partly limited by the number of wells completed in the overburden in an area underlain by very productive bedrock aquifers. The values of hydraulic conductivity AECOM was able to locate from publicly available sources have been added to the text in Section 5.7. The authors would be glad to incorporate additional reference materials if/when available.

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Groundwater Levels and Gradients	Dr. Grant Ferguson**	FERGUSON-16	p. 65 Was the effect of unloading and creation of inward gradients considered for the shale?	Inward gradient in the shale from unloading was not included in the numerical analysis. AECOM believes this mechanism is unlikely to affect the outcomes of the analysis especially given the limited thickness of the shale. However, this information may be important for future assessments of groundwater chemistry and isotopic composition within the shale itself.
Numerical Modelling	Dr. Grant Ferguson**	FERGUSON-17	p. 67 The recharge value for clay might be excessive, at least in some areas. Remenda et al (1994, Science) found evidence of Lake Agassiz water remaining in those clays today. Higher values closer to the range used in the current study might be possible where the clay is fractured.	Thank you for the comment. It is good to know the calibrated recharge value is within the range of what is reasonable. Future model refinements may consider this information in more detail, although the influence of those recharge values on model calibration and simulations is likely to be minor due to the relatively small recharge flux that is presently assigned.
Aquifer Properties	Dr. Grant Ferguson**	FERGUSON-18	p. 73 The hydraulic conductivity value used for the shale might be higher that what is actually present. The d2H and d18O suggest that transport might be dominated by diffusion, which implies a hydraulic conductivity value of <10-10 m/s. However, given the possible presence of interconnecting boreholes and variations in hydraulic conductivity due to geological factors, the value used could be representative of hydraulic behaviour. Given the possibility of sloughing, the intact, lower hydraulic conductivity scenario is probably not the one to focus on in terms of risk to groundwater supplies in the region.	Thank you for the comment. AECOM agrees with these statements and has taken steps in the assessment to evaluate the possible influence of interconnecting boreholes or altered hydraulic properties on well users in both the Red River Carbonate and Winnipeg Sandstone aquifers. Greater drawdown was simulated in the sandstone when the shale is assumed to remain intact, while greater drawdown in the carbonate was simulated when the hydraulic conductivity of the shale was assumed to increase following sand extraction. As you have suggested, Scenario 1 was utilized as the basis for our impact assessment, for which the Winnipeg Shale is inferred to be considerably weathered and assumed to degrade (increased hydraulic conductivity) when locally disturbed/unsupported from below due to extraction of the Winnipeg Sandstone.

Report Subject	From	Comment Number	Reviewer Comment	AECOM's Response
				While this scenario is conservative from the perspective of well users utilizing the Red River Carbonate aquifer, the alternative scenario (shale retains low permeability) is also important to consider as it is more conservative from the perspective of users with wells in the Winnipeg Sandstone. Monitoring during and following operations is required to track system behaviour and inform which scenario is most representative.
Aquifer Properties + Numerical Model	Dr. Grant Ferguson**	FERGUSON-19	p. 74 The hydraulic conductivity value of the degraded shale should be provided when discussing the various scenarios. It states that it is increased but doesn't say to what or how that value was estimated. I appreciate that those values are speculative but more detail is required to understand what is being simulated.	From Section 6.10 last paragraph."Shale degradation (i.e. increased hydraulic connection between the overlying Red River Carbonate and underlying Winnipeg Sandstone) was implemented in the groundwater model by converting the aquifer properties of the Winnipeg Shale to those of the Winnipeg Sandstone within 200 m of production wells as a function of time to conservatively assess the impact of operations on nearby users of the Red River Carbonate aquifer." As the production proceeds through the transient model, while an area is producing, the shale properties of the shale within a 200m radius are being gradually changed until they reach the same properties of the Winnipeg Sandstone. We have added text to Section 6.10 to more clearly articulate the changes as follows: "The aquifer properties were changed from the calibrated values for the Winnipeg Shale (Kh = 2.3 x 10-8; Kv = 2.3 x 10-9; S = 1.0 x 10-5) to be equivalent to the calibrated values for the underlying Winnipeg Sandstone (Kh = 3.2 x 10-5; Kv = 3.2 x 10-6; S = 7.0 x 10-6)."

***Friesen Drillers Limited. 2021. Letter from Jeff Bell, B.Sc. (G.E.), P.Eng. Hydrogeological Engineer, Friesen Drillers to Laura Weeden, P.Eng. CanWhite Sands Corp., June 1, 2021 regarding Report Commentary and Review: Vivian Sand Extraction Project – Hydrogeology and Geochemistry Prepared by AECOM Canada Limited.**

**** Ferguson, Grant. 2021. Memorandum from Dr. Grant Ferguson (Ph.D, Pgeo, EngL) Centennial Enhancement Chair in Groundwater-Energy-Good Nexus; Professor; Civil, Geotechnical and Environmental Engineering; Joint Professor, School of Environment and Sustainability, to Ryan Mills (M.Sc., P.Geo [BC, AB, MB]), Senior Hydrogeologist, Environment, AECOM Canada Limited, June 9, 2021 regarding Vivian Sand Extraction - Hydrogeology and Geochemical Assessment Report Review.**

Note: Refer to Section 6.2.3 of the Environment Act Proposal for biographies of the above-listed peer reviewers.