Responses to reviewers' comments by van der Kamp and Ferris, January 2023

Reviewer Comments on 'Wetland drainage effects on groundwater in southern Saskatchewan' by G. van der Kamp and D.M. Ferris

General comments

This chapter of the report presents a concise and informative review of the current state of knowledge concerning the potential effects of 'wetland drainage' on groundwater. I use quotation marks for wetland drainage because the definition of this word is somewhat ambiguous as pointed out by the authors. Overall, the chapter is well organized and written. A brief review of relevant hydrogeological conditions (Section 1) is useful. The analysis of water level data from monitoring wells are informative and provide a strong support to the main conclusions of the chapter: the effects of 'wetland drainage' are not discernible in the aquifers monitored by these wells. Although this chapter itself is technically sound, I noted some discrepancy between this chapter and Chapters 1 and 2 regarding the extent (i.e. how many percent) of wetland drainage. It will be helpful to present a consistent picture throughout the entire report. Having read the chapter, I was left with an impression that a systematic study will be necessary to find out how the 'wetland drainage' is actually carried out. This will involve remote sensing work, ground-based validation, and most importantly, interviews of farm operators. I will elaborate more on this and other points in my specific comments below. I have added line numbers to the Word file, which are used in my comments below.

Specific comments

Line 130-136. As the authors point out, it is important to make a distinction between the recharge of water-table aquifers and that of deeper semiconfined aquifers. I suggest that it is also important to highlight the difference between the inflow/outflow through semiconfined aquifers under an undisturbed condition and the inflow (i.e. recharge) induced by withdrawal of groundwater (i.e. discharge) from these aquifers. In the context of groundwater resource management, the long-term balance between withdrawal and induced recharge is key to assessing the sustainability of withdrawal. Induced recharge also affects the water balance of the overlying water-table aquifer, as well as the baseflow of creeks and springs provided by groundwater discharge. It will be useful to touch upon this subject.

> **Commented [GvdK1]:** In the revised text we have used the terms "inflow" and "outflow" to describe aquifer water balance, instead of "replenishment" and "discharge". The review comment about induced recharge is valuable but falls outside the scope of this report. However, we have emphasized that the maximum yield of water supply wells can increase or decrease depending on the pre-pumping "static"groundwater level near the well.

Line 138-139. This statement appears to be inconsistent with the graphs shown in Figure 1 and Figure 2. Most hydrographs shown in Figure 2 appear to be just as dynamic as those shown in Figure 1, considering the difference in vertical scales between the two figures. A bit more nuanced explanation will be useful.

> **Commented [GvdK2]:** Response: text is revised to make clear that this statement refers to semiconfined aquifers separated from the water table by a confining layers of clay and glacial till. The hydrographs in fig 1 are for unconfined sand aquifers.

Line 169. In addition to unconfined/semiconfined/confined, hydrogeological settings are also relevant in the context of the area of influence. For example, relatively small inter-till aquifers

> **Commented [GvdK3]:** Response: We have included a statement that: "“However, unique hydrogeological settings such as buried channel aquifers may influence groundwater response, and individual observation well records…”

behave differently from extensive buried valley aquifers, even though both are regarded as semiconfined or confined aquifers. This needs to be explained somewhere in this paragraph.

Line 181. Hydraulic conditions. Is this term used for hydrologic conditions? I think of 'hydraulic' as representing the static property of an aquifer-aquitard system, and 'hydrologic' as representing the dynamic response of the system to external forcings. It will be useful to define the terms and use them accordingly.

Line 185-186. Please report the units of B, T, and c_e.

Line 192. Hydraulic conditions. Please see my comment on Line 181.

Line 212. I suggest 'recharge, discharge, and withdrawal' or 'recharge and discharge including artificial withdrawal'.

Figures 1 and 2. Colours are similar between some symbols in these figures, making it difficult to distinguish them. Can different colours and symbols be used for easier identification?

Line 225-226. The rising groundwater levels. Do these indicate the rate of pumping-induced recharge? If so, does this provide any information on regional recharge rates?

Line 229. The appendix was not included in the report and hence, I did not have an opportunity to review its quality. I assume it is in sufficiently high quality.

Line 239. Prolonged dry and wet periods. It will be useful to include a chart showing these periods. For example, the authors could add a graph showing the standard precipitation index (SPI) or Palmer drought severity index (PDSI). In addition, it will make it easier for the reader to see Figures 1, 2, and the new chart (SPI or PDSI) all together in one figure, similar to Figure 11 in Hayashi et al. (2016).

Line 253. Figure 2 contains potentially relevant information that is not explained in this sentence. For example, brown dots (Smokey A?) had a steady decline from 1970 to 2005, and the rebound in this well during 2010-2016 was not as large as other wells. What caused the difference?

Line 262. Steady increase. This occurs at another well (Conq 500?), too.

Line 278. Most of the wetlands near the wells are intact. This raises an interesting and important question. Does this mean that these wells were selectively drilled in undrained areas? Or, do they represent just an average condition of the province? Chapters 1 and 2 of this report claim that a large portion of wetlands (40-70%) of the province has been drained. Is that an inflated number? My gut feeling is that the actual drainage is much less extensive than 40-70%, more in line with the numbers listed in Table 1. If that is the case, how should the reader interpret the findings of this report? I believe that it is important for this report to send a consistent message from all chapters.

Commented [GvdK4]: Response: We changed "hydraulic" to ":hydrologic conditions including wetland drainage"

Commented [GvdK5]: Response: done

Commented [GvdK6]: Response: We changed "hydraulic: to "hydrologic"

Commented [GvdK7]: Response: this discussion is now in terms of "inflow" and "outflow including pumping"

Commented [GvdK8]: Response: Interesting point, but beyond the scope of this report

Commented [GvdK9]: Response: The appendix was checked and appears fine

Commented [DF10]: This is precisely the kind of visual and statistical correlation that it was\is my intention to represent in my research. Unfortunately, I don't have the ability to do this at this moment.

Defining wet or dry periods based on a threshold SPI, then moving the data into R would allow the groundwater level plots to include shading showing wet or dry periods. This is something that I personally would need a lot of help to accomplish at this moment. If you think it worthwhile, I can look into getting help to do this. However, I think it may be unnecessary for this particular report.

Commented [GvdK11]: Response: This suggestion would better apply for a research paper. But it is beyond the scope of this report because various precipitation indices show the wet and dry periods, but correlation to groundwater level changes are far from trivial.

Commented [GvdK12]: Response: Of course there is a great deal of detailed information contained in Fig 2. However, delving into the details for each well is beyond the scope of this report. The main purpose of Fig 2 is to show that there has been no over-all decline of groundwater levels as would be expected if recharge has decreased over the past 5 decades.

Commented [FD13]: Is my impression that the comment on line 282 -283, but it may be useful to add an additional clause such as ", and may not be representative of conditions in other areas of the province"

I've made a note to look at the percentages of wetland drainage and how these numbers are described in chapters one and two, as well as any other information I can find. I will update you if I draw any conclusions.

Commented [GvdK14]: Response: A sentence is included that summarizes the average % of drained wetlands and average total % of wetland area for the entire inventory area

Line 278. A large wetland. This would have been a discharge wetland, meaning that it would have contributed little recharge. It will be useful to mention this more explicitly.

Line 296. Please use subscripts for 2 and 18.

Line 298. Early spring precipitation. This can also be interpreted as a mixture of snowmelt and summer precipitation.

Line 300. Type 3. Alternatively, is it possible that the effective recharge from Type 3 wetlands occur in early spring, and summer infiltration of enriched water is consumed by evapotranspiration? Have Bam et al. (2020) considered alternative explanations?

Line 300. Type 4 and Type 5. These are likely discharge wetlands, which contribute little to groundwater recharge.

Line 302-304. This based on one study at a local site. I would say it is risky to make such a bold statement based on just one study.

Line 315. This conclusion applies to the local study site. I would say that it is risky to make the bold statement about 'throughout southern Saskatchewan' based on one study. I recommend that a sentence or two be added to acknowledge the tentative nature of this statement.

Line 333-334. Nearly all the water that infiltrates from the pond is lost. This is not entirely accurate. Small but significant portion of infiltration does recharge local groundwater, as indicated by chloride concentration profiles (e.g. Hayashi et al., 1998; Pavlovskii et al., 2019). I suggest a bit more nuanced statement.

Line 338. Add 'little' after 'relatively'.

Line 363. I suggest citing Morgan et al. (2021), which compared root uptake between perennial grass and annual crop.

Line 389. Permanent vegetation. I suggest changing it to deep-rooted perennial vegetation.

Line 399-400. Ephemeral ponding of water within the drained wetland depressions. Is this caused by upland runoff, or snowmelt within depressions themselves? The difference is important, but it is not clearly stated.

Line 476. Native grass. I believe most of the wetlands in this study had catchments seeded with tame grass, not native grass.

Line 479. I suggest citing Morgan et al. (2021) here again.

Line 503-504. Damped and delayed response. I do not see this clearly when Figures 1 and 2 are compared. This needs a bit more explanation.

Commented [FD15]: It is my impression that the most important point is that –regardless of whether the wetland is a recharge or drainage wetland –there is no clearly identifiable impact. For that reason, I am unsure if additional interpretation of this comment is necessary. Furthermore, the comments on line 280 stating the importance of local hydrogeology suitably addresses the ambiguity of the role of the large wetland in hydrograph response.

Alternatively, the sentence starting on line 279 could read: "although large wetlands are typically expected to contribute little recharge, some visible impact…"

Commented [GvdK16]: Response: As stated in the report, the impact of any particular wetland depends on the local conditions and is not known.

Commented [GvdK17]: Response: done

Commented [FD18]: As our sentence refers to aquifer recharge specifically, I think no changes required here? However, perhaps it would be appropriate to use softer language that reflects uncertainty in the science?

Commented [FD19]: Perhaps this comment could be addressed by writing line 302 as "Instead, the isotope data supports the conclusion that most aquifer replenishment…"

Commented [FD20]: It was my impression that the widely held consensus was that smaller, ephemeral wetlands are the primary contributors to groundwater recharge?

The sentence on line 315 is written as a summary of Bam's conclusion. However, any additional sentence acknowledging the existence or absence of supporting research might be useful.

Commented [GvdK21]: Response: A sentence is added to point out that a small but significant portion does recharge the groundwater.

Commented [FD22]: Yes! Good save.

Commented [GvdK23]: Response: good suggestion - done

Commented [FD24]: Supported

Commented [GvdK25]: Response: Not clear why the distinction is important. The point is simply that drained depressions will hold water for at least a short while.

Commented [GvdK26]: This statement refers to vegetation on the uplands outside the wetlands. The word "uplands" has been inserted to make this clear.

Commented [FD27]: Supported

Commented [GvdK28]: Response: This paragraph has been revised to explain the mention of damped and delayed response.

Line 508. 10 to 100 km^2. This may not necessarily be the case depending on the spatial extent of the aquifer and its vertical connection to shallower aquifers. A bit more nuanced explanation will be useful.

Commented [GvdK29]: Response: the phrase "assuming that the aquifers are of large extent" has been added, plus noting that local hydrogeological conditions are generally not known.

Line 523. I suggest adding 'withdrawal' after evapotranspiration. It may induce recharge in semiconfined aquifers.

Commented [FD30]: Supported

Line 527-529. Zhang et al. (2020) used a general-purpose model that did not consider depression-focussed recharge. In contrast, Negm et al. (2021) used a model that was specifically designed to simulate depression-focussed recharge in the Canadian prairies. It will be useful to point out the difference between the two modelling approaches.

Commented [FD31]: Response: A sentence has been added to specify the challenge of modelling such complex, heterogeneous processes.

Line 538. Lingers in the depression. How is it possible? Is it because drainage was imperfect? This needs some discussion.

Commented [FD32]: It may be worthwhile to ask for another opinion on this issue. To me, it is obvious what the meaning is here –despite a drainage channel existing, meltwater and precipitation will still tend to collect in a depression, even if it is slowly flowing out and away. However, if this is not apparent two other readers, a more explicit statement may be required.

Commented [GvdK33]: Response: the temporary retention of water has been addressed in an earlier section.

Line 543. Small cultivated depressions. Are these completely drained? Or, do farmers leave them alone because they become dry by the seeding time? This must depends on the geometry of depressions and the size of catchments.

Commented [GvdK34]: Response: this has been addressed in an earleir section

Line 555. Wetland drainage. What kind of drainage does this refer to? Complete drainage of small depressions leaving no surface storage capacity? Depending on how farmers drain depressions, 'wetland drainage' can affect groundwater in different ways. It seems to me that previous discussion on hydrological effects of wetland drainage have relied on anecdotal information or informed guess. It will be useful and necessary to conduct a systematic examination of how farmers choose which depressions to drain, and how they drain them. Such a study could utilize remote sensing (old aerial photographs, recent satellite images, etc.), ground-based validation, and interviews of farm operators in various parts of the province. It could make an interesting MSc thesis combining natural and social sciences.

Commented [FD35]: Response: We have added a statement to suggest that a detailed and systematic a review of wetland drainage methods be conducted, as is suggested here.

Line 569. Wetland drainage. I suggest adding 'or restoration'.

Commented [FD36]: Supported

Line 589. This is based on just one local study. It would be risky to make a bold statement like this based on one study.

Commented [GvdK37]: Response: The statement has been revised, as in a prior section, to note that groundwater isotope data from across southern SK shows that groundwater is recharged via temporary ponded water and not from large persistent ponds

Line 637-638. Could be increased. How can this be implemented? A specific suggestion or two will be useful.

Commented [FD38]: Response: This is a good suggestion, but identifying how water retention could be increased would require knowledge of how the drainage is being conducted. A sentence has been added to mention that retention could be done by means of control structures or simply by temporarily blocking a ditch

Line 648. Presence of deep-rooted vegetation. Drainage for the purpose of annual cropping would eliminate perennial plants. Has this been the case in existing drainage project? A systematic study will be useful (see my comment on Line 555).

Commented [GvdK39]: Response: A sentence has been added to mention that small cultivated depressions may be allowed to revert to wetland vegetation during prolonged wet periods

Line 693-705. A field study like this will be useful. Another important topic of field study is the drainage method. Do they effectively drain small depressions? Or do they leave some of the storage capacity (e.g. 20-30 cm of water) because such a small amount of water infiltrates quickly, and does not hinder crop production? A systematic study will be useful (see my comment on Line 555).

Commented [GvdK40]: Response: a statement has been added that such studies should include a review of drainage methods.

Line 709. DUS stands for depression-upland system, not storage.

Commented [FD41]: Duly noted!

Reviewer

Thank you for the opportunity to review the report on the potential impacts of wetland drainage on the effects of recharge to the shallow groundwater resources. Some comments for consideration:

- The report is written in a very technical language and may not be suitable to a wider audience. We suggest the inclusion of a Synopsis/Abstract that provides a summary of findings in an easier to read language that highlights the main points from the document.
- The report highlighted the lack of data and information on the relationship between wetland drainage on the regional groundwater system. This lack of relationship is important in identifying the gap in data and the interrelationship between the surface-groundwater dynamics.
  - The SW-GW interchange is complex and spatially variable dependent on the local geological conditions. This may be an opportunity to invest in possible collaborations with researchers on the importance of ephemeral ponds to gw recharge in the prairie pothole landscape.
  - We suggest a section on the 'Gap Analysis' and 'Recommendations' on potential future works to gain further understanding of the relationship of wetlands, shallow aquifers and groundwater zones.

Commented [GvdK42]: Response: A short summary was prepared and submitted during 2022. Presumably a summary of the revised reports will also be prepared?

Commented [GvdK43]: Response: Is follow-up on this comments and the following comment being considered by SK WSA?

Commented [GvdK44]: Response: The section on research needs has been expanded to include the suggestion of "space-for-time" experimental design which would involve multiple drained versus control wetlands.

Reviewer

Selected review comments

For example Report 3 highlighted the role of wetland vegetation management and removal to enhance groundwater recharge, while this management would appear to have significant negative impacts on the value of those same wetlands for wildlife habitat and/or nutrient management

Commented [GvdK45]: Response: The main vegetation management points is that drainage of wetlands nearly always involves removal of the wetland vegetation, so that the drained depression can be cultivated and planted with annual crops. Removal of wetland vegetation without drainage would only be done if enhancement of groundwater recharge is of primary importance and then only in very limited areas. A sentence to the latter effect is included in the revised report

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Reviewer Saskatchewan Drainage Review General Comments

Groundwater: General Comments

Some sections of the document read like a primer on groundwater which, for this reviewer, was useful and appreciated – my thanks!

Not being familiar with the area, the general lack of studies on groundwater which might have addressed the relationship between surface drainage and groundwater has been a bit of a revelation.

Particularly, the relationship between groundwater and ongoing wetland drainage seems especially challenging to tease out. Precipitation ranges over the periods of analysis have been considerable and do not seem to have been considered in this review – or can't in any reasonable way be discerned - as a factor/co-factor explaining observed groundwater fluctuations in long-term data from test wells.

As a potential recharge mitigation activity, the consultants observe that "Retention of surface runoff water in drained depressions and ditches for a few weeks enhances groundwater recharge." Given that the objective of most agricultural drainage is to remove water as quickly as possible, especially on cultivated land, and water retention would require additional infrastructure, possibly even at the farm field scale, this does not seem to be a realistic water management practice on annual croplands.

The consultants discuss the apparent relationship between permanent vegetation and water recharge. While they do not advocate for the removal/drainage of vegetated wetlands, others may advocate for their removal for reasons of improved groundwater recharge. Given that the larger conclusion of this review seems to be that Saskatchewan does not have a groundwater recharge problem, such a position would be premature.

Specific comments inserted in the text

L. 243 Is it possible that the relatively high precipitation periods experienced in the land 25 years are masking changes to aquifer recharge that would be evident if precipitation had been closer to normal or below normal?

L. 263 There have been some exceptionally wet periods in the last 2+ decades possible mask impacts from land use change? If more normal precipitation levels had been the case might impacts of wetland drainage become more evident?

L 642 Given that the objective of most agricultural drainage is to remove water as quickly as possible, and water retention would require additional infrastructure, this does not seem to be a realistic water management practice on annual croplands. As such, it does not seem to be a realistic consideration for recharge mitigation. L 669 This is the general objective for agricultural drainage activities.

Commented [GvdK46]: Response: details of groundwater level response to variations in precipitation are complex: snow vs rain; fast of slow snowmelt; frequent small rain events or one large event; pre-existing runoff conditions on the uplands; etc. Other than a general correspondence between precipitation and groundwater levels, detailed analysis lies outside the scope of this report.

Commented [GvdK47]: Response: Deliberate water retention would be most likely to be done during dry periods with little runoff, but not during wet periods. As such water retention during dry periods would have little impact on access to the land because the intent would be that the water infiltrates quickly. .

Commented [GvdK48]: Response: Agreed. Removal of wetland vegetation for enhanced recharge has been advocated at times, but is unlikely to be implemented unless extremely low groundwater levels occur in a heavily used aquifer.

Commented [GvdK49]: Response: A simple rule-of-thumb might be: don't be desperate to remove every bit of water quickly: leave a bit to infiltrate to the groundwater.