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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Landscape and groundwater controls over boreal lake water chemistry and water balance heterogeneity in an esker complex of northeastern Ontario, Canada" *by* Maxime P. Boreux et al.

Anonymous Referee #1

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General comments

This manuscript describing lake chemistry and physiography relative to elevation and positioning relative to a nearby esker is impressive in its scope (∼50 lakes) and number of variables. The authors nicely show that lakes high in the landscape serve to recharge groundwater and lakes lower in the landscape receive groundwater discharge. Although impressive in the amount of data collected, the overall result of the study is not novel or surprising. The authors state that understanding lake position and relative sources and losses of water are important to lake stability in response

to climate change. Their overall hypothesis is that exchange with groundwater is the most important factor related to the classification that they develop, but they rely on indirect evidence (chemistry and isotopes) to determine the type of lake and degree of groundwater-surface-water exchange. Although interesting, their study does not address uncertainty and lacks confirmation of the extent to which chemistry and isotopes can serve in this function. I don't disagree with their conclusions; they seem logical and well founded. However, discussion about implications of assumptions and the possibility of misinterpretation of lake setting is missing. A slight change to the title may be more representative of the focus of this manuscript, which was to use lake water chemistry and water isotopes to infer exchange between groundwater and lakes. Rather than "Landscape and groundwater controls over boreal lake water chemistry and water balance heterogeneity. . .", it might be more accurate to title the study "Use of water isotopes and chemistry to infer the type and degree of exchange between groundwater and lakes in an esker complex of northeastern Ontario, Canada." A substantial product is the development of a classification scheme based on the authors' results. Numerous other classifications also have been proposed and it would be useful to compare the authors' classification system with one or more of the other lake-classification systems that have bee published. Several that come to mind are: Born, S.M., Smith, S.A., and Stephenson, D.A., 1979, Hydrogeology of glacial-terrain lakes, with management and planning applications: Journal of Hydrology, v. 43, p. 7-43. Bracht-Flyr, B., Istanbulluoglu, E., and Fritz, S., 2013, A hydro-climatological lake classification model and its evaluation using global data: Journal of Hydrology, v. 486, no. 0, p. 376-383. Martin, S.L., Soranno, P.A., Bremigan, M.T., and Cheruvelil, K.S., 2011, Comparing hydrogeomorphic approaches to lake classification: Environmental Management, v. 48, no. 5, p. 957. Wentz, D.A., 1981, Lake classification - Is there method to this madness?: U.S. Geological Survey Circular C0848-B, 15-24 p. Winter, T.C., 1977, Classification of the hydrologic setting of lakes in the north central United States: Water Resources Research, v. 13, no. 4, p. 753-767. This manuscript appears to have been hastily prepared and the numerous errors were not only a distraction, in some cases they led

to substantial confusion. The first example appears in the abstract, where the authors mix up groundwater recharge and groundwater discharge, calling lakes situated high in the landscape groundwater discharge lakes, and lakes situated low in the landscape groundwater recharge lakes. At first, I thought the authors were simply viewing the world from a lake perspective, where groundwater flowing to a lake would provide a recharge function to a lake. But no, the authors did adhere to the common usage for the terms groundwater recharge and discharge; they simply reversed terms in the abstract. I could easily overlook such a mistake, but so many other minor mistakes also are sprinkled liberally throughout the manuscript that they represent a considerable distraction when attempting to follow the logic and conclusions of the manuscript. I provide indications of mistakes where they appear in the first few pages, but I leave it to the authors to carefully read their own manuscript and clean up the rest.

Specific comments pertaining to line numbers

20 Higher elevation lakes are usually groundwater recharge lakes and lower elevation lakes are usually groundwater discharge lakes. Here you state the opposite, which made me think you were viewing flow of groundwater to a lake as providing a recharge function to the lake. Based on the subsequent context of the manuscript, you clearly need to correct this as follows: ". . . higher-elevation groundwater recharge lakes from lower-elevation groundwater discharge lakes." However, this provides an excellent example of how these terms are ambiguous and could easily mean the opposite from the perspective of a lake-centric scientist, who would view the addition of groundwater to a lake as serving a recharge function to the lake. Therefore, you need to define these terms in the introduction or the methods section so the reader clearly knows what you mean. You also use the terms discharge lake and drainage lake interchangeably. This is confusing. Since you first present the term discharge lake, and it is nicely contrary to recharge lake, I suggest you remove the term drainage lake and replace it everywhere with discharge lake.

72-73 You state here that you can determine evaporation and water balance provided

the Craig-Gordon model is used. You state that the Craig Gordon model has to be used to do this, but then you surprisingly cite a paper published in 2015 the title of which implies it is all about software called Hydrocalculator. If you are using the Craig-Gordon model, you should cite Craig and Gordon, 1965. You also need to revise the sentence to indicate that this particular model is either somehow better or more convenient for accomplishing these purposes than the now standard method that is commonly used.

78 You state there are few studies that have used both chemistry and water isotopes, and then you cite 4 such studies. In addition to those four studies, I can think of several more without even perusing the literature. This is not a "very limited number" especially relative to the number of studies in boreal lakes, which likely is smaller. Gurrieri, J.T., and Furniss, G., 2004, Estimation of groundwater exchange in alpine lakes using non-steady mass-balance methods: Journal of Hydrology, v. 297, p. 187–208. Krabbenhoft, D.P., Bowser, C.J., Kendall, C., and Gat, J.R., 1994, Use of oxygen-18 and deuterium to assess the hydrology of groundwater-lake systems, in Baker, L.A., ed., Environmental Chemistry of Lakes and Reservoirs: American Chemical Society, p. 67-90. LaBaugh, J.W., Winter, T.C., Rosenberry, D.O., Schuster, P.F., Reddy, M.M., and Aiken, G.R., 1997, Hydrological and chemical estimates of the water balance of a closed-basin lake in north central Minnesota: Water Resources Research, v. 33, no. 12, p. 2799-2812. Katz, B.G., Coplen, T.B., Bullen, T.D., and Davis, J.H., 1997, Use of chemical and isotopic tracers to characterize the interactions between ground water and surface water in mantled karst: Ground Water, v. 35, no. 6, p. 1014-1028. Turner, J.V., and Townley, L.R., 2006, Determination of groundwater flow-through regimes of shallow lakes and wetlands from numerical analysis of stable isotope and chloride tracer distribution patterns: Journal of Hydrology, v. 320, no. 3-4, p. 451-483. 148-149 Evidently you are only considering watershed slopes for the terrain that is within 100 m of the lake shoreline. For most lakes, this will be a small percentage of the lake watershed. You need to indicate why you are applying this 100-m filter to your analysis.

234-235 Most studies that use water isotopes to look at water budgets go to considerable effort to measure or estimate δE. Here you simply assume that δE = δI minus δL. This method assumes that you know all of the other input and loss volumes and their integrated isotopic signatures. You should address this issue and either indicate that your assumed method for determining δE is well supported by other studies or you should state that this method includes uncertainty associated with all of those other water-budget terms.

244 Because this manuscript is about groundwater and lakes, you should indicate what the groundwater temperatures are in this area. Temperatures of springs are not an accurate indication of groundwater temperature because spring temperature at the discharge point is so influenced by the velocity of the discharging spring and the resulting warming of the discharging water as it approaches the surface. Secondly, is there a difference in lake temperature between the higher and lower lakes? If you have substantially more groundwater discharge in the lower lakes you may see a resulting temperature difference in lake temperature. This is unlikely, however, because so many other factors also affect temperature, but with 50 lakes there may be something.

256-257 It would be very useful if you could include here a figure that maps the lakes with indications of the isotopic value (select 18-O or deuterium) and perhaps also the specific conductance. This would allow the reader to see the spatial distribution of the various isotopic values that are indicated in this paragraph. If you do this, please also show the lakes that have a stream outlet and indicate where that stream goes. As I read farther I see that Figure 5 does a reasonable job of showing this but it lacks mapping of the isotopic lake values. Ultimately, what would be most useful is a map showing the resulting distribution of recharge, seepage, and discharge lakes, perhaps overlain on a map that uses shading to show elevation.

266 The slope of your relation is negative but the r-squared value should be positive.

266 It is not the geographic position that is related. It is the elevation that is related. You

may infer from the elevation the position of the lake relative to the crest or the distance from the crest. If that is the case, you should state that here.

268-269 You state the relation between isotopes and elevation. You should, therefore, also provide a sentence and state the relation between EC and elevation.

277 Why are you relating E to I? You stated in the Methods that you can do this but you didn't say why. You should explain what this accomplishes. Also, since you're determining delE from delI minus delO, your equation 5 is really delI-delL/delI-2delL.

277-278 A small E/I could also simply indicate that the lake has an outlet (I$\sim$Q) and, therefore, a short residence time, which has nothing to do with any indication of whether groundwater or springs undergo evaporation or not. Interpretations related to E/I also incorporate error associated with calculating delE rather than measuring it.

Figure 4 I don't understand how you can obtain E/I values for springs and streams when your two variables for making this calculation are delI and delL. What lake do you use to determine delL for a spring or a stream?

297 You can't have a negative R-squared value. These values must instead be correlation coefficients, which are usually indicated as lower-case r. Also, where do you present these values? DOC is not included in the correlation matrix in Table S1b in the Appendix. You do show TN but the value for r when TN is related to H (elevation) is 0.05, not 0.22 as reported here. And since we're talking about the table, why is the table labeled S1b? Is there a table S1A that is missing?

315 What is d in Table 1? Is it deuterium excess? If so, you have not defined or describe this anywhere.

320 Be sure to clearly show any surface-water connections between lakes. The presence of an outlet, or of surface-water flow from one lake to another, is an important part of your analysis and up to now the reader has not been able to see these connections. You could show this either here or in Figure 1.

325 You use an elevation of 242 m as the dividing line between recharge and discharge lakes. However, in Figure 5, and in the previous paragraph, you show a middle elevation, or an elevation break point of just over 280 m. And there is no elevation in Figure 5 lower than 260 m in Figure 5. If all of the lakes shown in Figure 5 are higher than 260 m, and your previously determined break-point elevation was 282.4 m, how can you now choose an elevation of 242 m to separate your lakes?

327 What additional lake characteristics were used to allow you to divide the lakes into three categories?

336 How does this value of 242 m relate to your break-point elevation of 282.4 m? If indeed these are two separate distinguishing elevations, you need to describe how one is important relative to the other.

370-371 Here you finally indicate that your streams are all upgradient of a lake and that you evidently did not sample any stream reaches that were situated between lakes. This is an important distinction that needs to be made clear much earlier in the manuscript.

416-417 You should not assume that a recharge lake is perched. I greatly doubt that lakes situated in permeable material such as you have in the esker are perched. Unless you have separate information indicating otherwise, you should remove the word perched from the manuscript.

433 Here you do report values as R rather than R-squared.

444 The presence or absence of an outlet is a very important variable in this analysis and this is the first time you have brought up this point. I would think this would be a presence-absence type of variable that would have been part of your statistical analysis. In any case, I was looking for outlets in the figures and it was very difficult to determine whether you showed all of the outlets or not. For some lakes, based on their positioning I would expect an outlet and yet one is not shown in the figure. If you

do show all of the stream segments in your study area, there is a surprisingly small number. If not, you should revise the figure to do so. The presence of both inlets and outlets is important to this type of analysis.

455 You should label and show in a map where these two lakes are.

455-460 A lake without an outlet could also be due to the lake being able to easily lose water to groundwater.

473 What is a mounded recharge lake? This needs to be defined. If this is a lake that loses water everywhere to groundwater, you can't call that mounded unless you have hydraulic gradient data to confirm that. It may instead be that the lake is situated in a small local watershed or that it has more organic sediments than others that creates a low pH. Figure 8 What distinguishes a recharge seepage lake from a discharge seepage lake? Is it only the pH? You talk considerably about recharge seepage lakes and the reasons for their classification, but you say nothing about discharge seepage lakes or how they are different from recharge seepage lakes.

520 Here you finally define a drainage lake. Given that this indeed is the same as a discharge lake, I suggest you use one term or the other and do not use both interchangeably.

545-551 Greater lake evaporation also is related to more isotopically enriched water in lakes. If there is lake-to-lake variation in evaporation, that variation affects your interpretation of the extent to which the lake exchanges water with groundwater. Your classification system does not provide any indication of the extent to which other factors affect your interpretation of exchange with groundwater. It would be helpful to point this out in this paragraph.

567-568 You cannot make this statement unless you either have evaporation data to back this up or you can cite some papers that have reached this conclusion. I strongly doubt that evaporation from lakes that receive groundwater discharge is measurably

different from lakes that recharge groundwater. What is different is the degree of isotopic enrichment in the lake water. The evaporative enrichment is masked by isotopically light groundwater.

591-592 This logic is not complete. If drought reduces groundwater flow to a lake because of reduced water-table elevation, why then would there not be increased flow of lake water to groundwater on the downgradient side of the lake, in which case there would be no net change in exchange with solutes?

598-599 Residence time would be much more greatly controlled by local hydraulic conductivity. If most of your recharge lakes are situated on the esker, then I would think residence time would be relatively short compared to a lake lower in your system that is situated in lower-permeability sediments.

607-614 This paragraph is poorly presented and is confusing. What do you mean by multiple site selection? What sites are you talking about and for what are they being selected? How is this related to paleohydrological reconstruction?

Technical corrections

22-23 You need to place a comma after contrast and remove the comma after lakes so the sentence reads “In contrast, groundwater discharge lakes were isotopically depleted . . .” 31-32 You should remove the parentheses here; otherwise, the sentence is not complete. Also, how can you determine seasonal differences in chemistry when you only have data between early June and August? That period is during summer only. 34-35 Recharge lakes also are affected by changes of greater duration and persistence. Please add the word “only” to write “. . . affected only by hydroclimatological changes of greater duration and persistence.” 47-48 The threat of climate change will not influence lakes. It is the climate change that will influence lakes. Therefore, remove “The threat of” and start the sentence with “Future climate change will. . .” 49 A word is missing. Insert “understand” to write “. . . to better understand relationships of lake hydrology . . .” 55 Another word is missing. Insert “to” to write “. . . the opportunity to

better understand . . .” 64 Now you have an extra word. Delete the word “changing”. 70 Change tracers to tracer because it needs to be singular here. 72 What is a “time and cost effective means”? Perhaps you mean “an efficient and cost-effective means” 98 You state this is near Timmins but you do not show Timmins anywhere on the map. Please add the location of Timmins to the map. You also need to add labels to show the locations of Frederick House and Night Hawk Lakes. 110 What is a popular? I suspect you actually mean poplar. 124 I suggest you add the word littoral to write “. . . forming lateral littoral sand units that drape . . .”. This addition will provide a better tie with the “littoral sand” indicated in Figure 1. 125 You have an extra and unnecessary word here. Delete the word “in” to write “The numerous kettle lakes on the esker formed . . .” 128 Why does only the esker crest have high-K sediments? I would think the entire esker would be much higher in K than your surrounding sediments. If it is just the upper portion of the esker that serves as an aquifer, you need to explain why this esker is geologically different from other eskers. 145 Depths of what? You should write “maximum lake depths” so the reader will know you are not talking about depths of other geographic features. 147-148 What does spatial resolution have to do with lake-surface elevation? This needs a better explanation. 153 You were only there for one week each time? That certainly does not constitute a season. You should replace the word season with something else; perhaps field campaigns or field trips. 154 Earlier you state that the number of lakes is 50, but here you say that this number is approximate. Surely you know how many lakes you sampled and you should provide that number. Otherwise, this text gives the impression that you can’t be bothered with counting up the lakes you sampled or that you were not very meticulous. I suspect this is not the case, but this and the numerous previously identified simple mistakes certainly give a reader pause. 163 The word is triple-rinse, not tripled- rinsed. This mistake is repeated on line 164. 164 You say bottles were “and again with sample water,” which I presume to mean that you triple-rinsed the bottle with sample water after the bottle was triple rinsed with distilled water. But then in the next sentence you write that bottles were triple-rinsed with lake water. Is this simply a mistake or redundancy

in your writing or did you rinse the bottles in lake water twice? 170 Apparatus should be replaced with apparati because the following word, “were”, is plural. 171 Filtrate is singular but that word is followed by were, which is plural. Either change filtrate to filtrates or change were to was. 172 One does not store into. The samples were either stored or they were placed into. 198 Change detections to detection. 201 Detections limits should be change to detection limit. 202 You already defined these three terms in lines 177-178 so you do not need to do so a second time here. 203 What is NDIR? You need to indicate what this abbreviation indicates. Also, since it is only used once in the manuscript, it would be better to simply indicate what this is. 204 Change detections to detection. 207 You need to indicate what TIC is. I assume it is total inorganic carbon. If so, how was this determined? You do not say. Is TIC only the dissolved portion of the sample? 269-270 You could consider deleting this sentence. It is fairly standard practice to just use 18-O (most common) or 2-H and you’ve already shown the strong correlation in Figure 2. You might also modify slightly to write “. . . are enriched in 18-O, and due to their strong correlation, 2-H.” 288 Delete “it” to write “As is the case with stable isotope values. . .” 332-333 This sentence does not make sense. I can’t tell if there are missing words, or if infer is supposed to be inter. In any case, the text in quotations needs to be corrected: “In order to better understand the contribution of infer water chemistry variables,” 342 The table caption states that some lakes are labeled in red. The figure is in black and white (although Figure 5 is in color) so nothing is shown in red here. 349 Panel A shows inter-annual change and panel B shows variability over a single summer; the citation should be to Fig. 7a,b). However, “seasonally” implies comparisons over multiple seasons. Your analysis is not seasonal. You only compared values over parts of one season, that being summer. Therefore, you should replace any inference to a seasonal analysis to something like “summertime” or “over-summer”. 355 Here you again refer to panel B but the solute-related panels are 7c and 7d. 393 Please remove the hyphen between lake and water. 428 Replace delivery with deliver. In fact, this entire paragraph could use considerable help. 448 Here you use lower-case r. Thus far you have used R, R-squared, r, and r-squared. Do

they all mean the same thing in this manuscript? They certainly mean different things in statistics. You need to thoroughly review the manuscript and present your variables and statistical indicators in a consistent manner. 455-471 There are numerous problems with sentence structure, grammar, and lack of clarity in meaning. 487-489 I have no idea what this means; it seems completely out of context. Please revise for clarity. 554-555 You use relation and relationship interchangeably. I suggest you select one word and use it consistently. I was once told that people have relationships but data indicate relations. 587 This should be Figure 7B, not Figure 8B.

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