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Hydrology and Earth System Sciences Discussions



# *Interactive comment on* "Temporal variation in depth to water table and hydrochemistry in three raised bogs and their laggs in coastal British Columbia, Canada" *by* S. A. Howie and H. J. van Meerveld

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Response to Referee #1

We thank the reviewer for his/her thorough review of this paper. The attention to detail is greatly appreciated. We address each specific comment in detail below.

General Comments:

1. Depth to water table measurements: The reviewer expressed concerns about the



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Interactive Discussion

Discussion Paper

field methodology that we used to measure depth to water table. The reviewer is correct that wells should be used to measure depth to water table, whereas piezometers measure pressure and thus may not be as accurate as wells for the measurement of depth to water table. Short piezometers were used instead of wells in this study to avoid "short-circuiting" of water during rainfall events or flooding. Although we agree that wells would have been better for measuring depth to water table, we suggest that the error in our study was likely minor (e.g. <1-2 cm), and that adding some discussion in this paper on the potential error due to using piezometers rather than wells should be sufficient to address this point. The reviewer assumed that the piezometers were placed at 1.5 m below the surface. The actual depth varied (0.47-1.20 m below the surface) depending on the water table observed in the borehole during installation; mean depth was 0.85 m below the surface (standard deviation: 0.21 m). We will state this range of installed piezometer depths more clearly in the Methods section. Table 1 gives the depth of each piezometer as well as the distance between the highest observed water level in the piezometer and the top of the screening (a value of 0 indicates that the piezometer functioned as a well). It can be seen that this maximum difference was not large (0-0.73 m; mean: 0.36 m).

We therefore suggest that these relatively shallow depths indicate minor pressure effects (minor vertical gradients) and that the water level measured in the shallow piezometers thus reasonably represents the water table. See additional information below (i-iii) for further evidence to support our assumption that the water level measured in the piezometers reasonably represents the water table, that the uncertainty in the location of the water table due to the use of shallow piezometers instead of wells is similar to the measurement accuracy and the uncertainty in determining the bog surface, and to thus justify the use of shallow piezometers in this study to measure depth to water table.

i) We have found that shallow piezometers (i.e. screening <1.5 m below the surface) act similarly to wells in bogs in coastal BC. For example, a piezometer in Burns Bog, Delta,



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BC, installed with screening at 0.6-1.5 m below the surface, and a well installed less than 1 m from the piezometer (both sites not included in this study), showed similar water levels. From 2007-2012, the water level in the piezometer was within 1 cm of measurements from the adjacent well for 63 of 73 measurements (86%), and within 2 cm of the well measurements for 68 of 73 measurements (93%) (see Figure 1 below). The largest differences were observed in late summer when the water table was lowest. The mean difference in water table elevation between the piezometer and the well was 0.8 cm (standard deviation: 1.3 cm) (source: unpublished monthly data measured by lead author of this study). Since the piezometers in this study were installed less deep (on average 0.85 m below the surface, with a screening between 0.45-0.85 m below the surface) than the piezometer shown in Figure 1, it is reasonable to assume that the difference in the water level measured with a well and that deduced from a shallow piezometer would be even smaller. This thus suggests that the error as a result of using shallow piezometers instead of wells is comparable to the measurement uncertainty due to changes in surface elevation and the rounding of our measurements to the nearest 0.5 cm.

ii) The reviewer notes that the lagg is a discharge zone, which could affect the depth to water table measurements in the piezometers. Data from a piezometer nest in a lagg swamp of Burns Bog that is a relatively strong discharge zone (site also not included in this study) show that gradients between the shallow (screening 0.38-1.28 cm below the surface) and deep (screening 0.85-1.75 m below the surface) piezometers are small and are generally less than 2 cm (mean difference: 1.5 cm, standard deviation: 3 cm). See Figure 2 below. These results also suggest that the measurement error due to using shallow piezometers instead of a well is likely less than 1-2 cm and comparable to the measurement uncertainty due to changes in surface elevation and the rounding of our measurements to the nearest 0.5 cm.

iii) For 13 additional shallow piezometers in Burns Bog (2011 data; not included in this study) we measured 1) depth to water table and 2) depth to surface water at times



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when the sites were flooded. Differences between these two values (which would be identical if a well was used instead of a piezometer), were similar (mean difference: 1.2 cm; standard deviation: 0.9 cm).

2. Water chemistry measurements: The reviewer is also concerned with the methods used to measure pH and EC, specifically the time between purging and measurement of pH and EC in the piezometers and sampling. It is true that two weeks is a long time between purging and sampling, and that pH can be affected by aeration. However, this measurement schedule was necessary for this study due to the very slow recharge rate of some of the piezometers located in areas with dense soils (e.g. the "lagg" and "mineral" sites on the transects). In order to determine the water chemistry along the transects on the same day, it was necessary to allow all piezometers to recharge prior to the measurements and sampling. We can add a discussion about the potential range of error due to this method of sampling.

We are aware of stratification within peat and piezometers. While we have observed stratification (and changes in EC and pH with depth) in the peat, we have not observed this in the shallow piezometers, likely in part because of the shallow water depths in the piezometers (see Table 1 for the maximum length of the water column in the piezometers). In order to be consistent between sites and different dates regardless of the volume of water present in the piezometer, and to avoid any variation due to the potential effects of stratification on our measurements, we only measured these variables in the top 10-15 cm of the water column. Our goal was to only sample pH and EC of shallow groundwater (i.e. near the water table). Thus we purposefully avoided mixing water in the piezometers to ensure that only this portion of the water column was sampled. We can add an explanation of our reasoning to the Methods section for clarification. For sample collection for the analysis of cations, anions, DOC, and acidity, water was pumped from the pizeometers at the rate of recharge whenever possible.

The piezometers were capped so that aeration, dustfall, litter, etc. was minimized; we



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can add this information to the Methods section.

3. Introduction: The descriptions about bog hydrology and bog distribution were meant to inform an audience that may not be well-versed in bog research. If these sections are seen as superfluous, we can shorten them, and focus more on laggs about which little is known. We agree that the purpose of the research could be pointed out more clearly. Thank you for your note about our citations of review papers; we can replace these with the primary sources where applicable. Our secondary goal to address the required sampling frequency can be discussed in more detail in the introduction; we believe that this is an important aspect of the paper as there is little information in the literature about the necessary sampling frequency to determine the hydrochemical characteristics of bogs and their marginal zones. Management agencies generally do not have time or funding for frequent measurements, and thus it is important to determine how variable the measurements are in order to assess the value and representativeness of the measurements. If a one-time survey is enough to reasonably characterize a bog and its lagg, perhaps several bogs within an area can be studied or surveyed prior developing regional bog management plans. If a one-time survey does not provide representative results, it has to be pointed out that bogs and their laggs need to be surveyed several times before management and protection plans are developed.

4. Results: The reviewer notes that results are sometimes discussed in the Results section; we will move this text to the Discussion. We agree that more information could be presented about the data itself as opposed to the variation in the data; we will add a table to address this. However, the purpose of the paper is to describe the temporal and spatial variability of depth to water table and hydrochemistry across the transects from bog to margin, so we believe that the descriptions of variability are central to the paper. We will carefully read through this section and reduce the “wordiness”.

5. Discussion: The reviewer comments that the Discussion doesn’t refer to the figures. We can add references to the figures in the Discussion so that it is clearer to what



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results these discussion points refer.

Specific Comments:

14066:16 We will rewrite this sentence (e.g. noting that bogs develop in response to adequate moisture availability, which is related to precipitation and evapotranspiration), or alternatively remove the paragraph in order to shorten the introduction as suggested by the reviewer.

14066:18 We will make our description of the connection between precipitation and bog distribution more clear and remove the unintentional suggestion that precipitation intensity affects bog distribution. We thank the reviewer for pointing out that this sentence is a bit ambiguous and will rewrite it.

14068:17 Since laggs are an element of raised bogs, our rationale of the layout of the Introduction was to describe bogs first and then laggs. However, this Introduction can be shortened to focus on more on laggs.

14072:14 The reviewer suggests that we use the phrase “relatively pristine” instead of “undisturbed” when referring to the areas of Burns Bog that were spared from peat mining, due to the effect of large-scale peat-mining on the water mound of the bog. We agree with this suggestion and will make this change.

14072:19.20 These lagg descriptions are cited in an earlier paper (Howie et al. 2009). We agree that the definitions of the lagg forms could be clearer, and will endeavour to do so.

14073:1 We did not mean to suggest that piezometers PF100 and PF200 (which are 100 m apart) are representative of the water chemistry of Burns Bog. In fact, water chemistry is highly variable across the 3,000 ha bog (the data in Tables 3-4 and Figures 4-5 show this as well). The purpose of including these additional data was to provide a longer time series of hydrochemistry measurements for comparison with our transect data. We will make this distinction more clear in the description and explicitly state that



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we do not consider these data to be representative of the entire bog but just of this particular part of the bog. We will reword the rationale so that it is clearer why these data are included.

14073:13 See response to "14072:19.20". An "upland lagg" is a lagg that is adjacent to an upland area, as opposed to a lagg that is adjacent to a flat area; the lagg itself is not an upland. We will reword this sentence to make this clearer.

14073:15 We agree that the description of the climate data at the end of the Study Sites section could be replaced with a table, and will do so.

14073:25 We agree that the naming conventions for the transect locations are not always clear. We plan to replace the names in quotations (e.g. "bog", "trans1", "trans2", "lagg", "mineral") with site codes (BG, R1, R2, LG, MN, where R refers to the rand of the bog). This will also help to avoid confusion between a bog (or lagg) and the "bog" (or "lagg") transect location.

14074:9 The two lagg sites on the Sherwood and DNR transects were quite different in terms of vegetation, which is why we included two "lagg" study sites on these transects. A large difference in vegetation suggests a difference in depth to water table and hydrochemistry between the two "lagg" sites on a given transect. We will make this reasoning more clear.

14074:15 The digital elevation model derived from the 2008 LiDAR data had a relative accuracy of 15 cm and absolute accuracy of 30 cm. We will include this information in the text.

14074:18 See response to General Comments (depth to water table measurements).

14074:22 See response to General Comments (water chemistry measurements).

14075:6 See response to General Comments (water chemistry measurements).

14077:1-15 We did not intend to suggest that the change in water level between the



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2010 and 2011 measurements itself proved an increase due to logging. We compare the difference in water level between the 2010 and 2011 measurements in this site to the difference at the other sites to prove that the change in water level in the logged site was larger than in the other sites. Differences in precipitation between 2010 and 2011 should be similar for the different sites. In Figure 2 we show that the increase in water table was larger in the logged site than the unlogged sites on the same transect and also show that the difference was larger for the logged site than for any of the other transects. We describe this on Page 14077, Lines 1-7, and Page 14086, Lines 11-16. We can focus even more on the 2011 data and reword the comparison between 2010 and 2011 to avoid unintended confusion.

14077:21 The data from Campbell River Bog were only collected in May 2010 and May 2011. Thus, we agree with the reviewer that there is little information on temporal variability for this site. However, the data provide some information about year to year variability, show spatial variability across the transect, and provide a range of values for comparison with the other bogs. If the editor believes that the Campbell River data are not useful in this paper, we can exclude them.

14078:1 The purpose of this information (e.g. EC varied by 0-25 at 28% of the sites) was to show how variable pH and EC were over time. This is central to the objective of this study as it tells us how representative data from one survey are for the (average) conditions in the bog and lagg and how much one can expect pH or EC to vary during other periods. This range of values for pH and EC could be summarized in a table, rather than described in detail in the text.

14070:18 See response to General Comments (results).

14080:13 The reviewer suggests that we describe spatial variability before temporal variability. We can change the order of the text to do this, but the main topic of this paper is temporal variability and how well a one-time survey describes the conditions in the bog and lagg.



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14086:7 See response to “14077:1-15”.

14086:20 We will rewrite this section to make it clearer.

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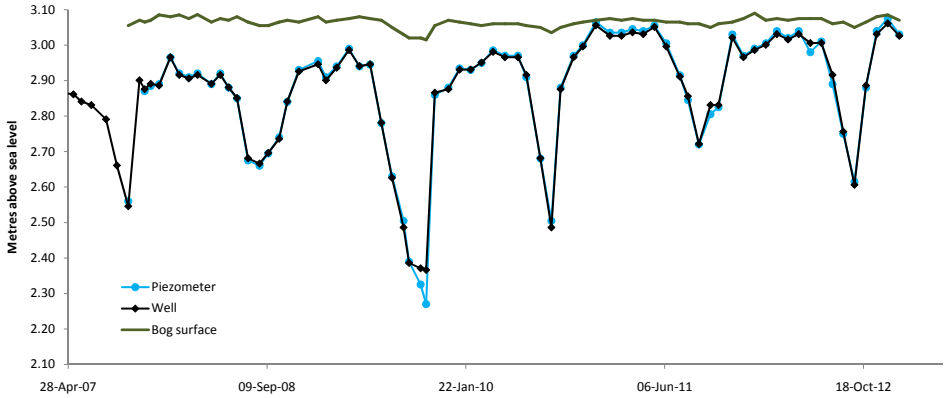


**Figure 1:** Comparison between the water level elevation (masl) for a well and a piezometer (with screening at 0.6-1.5 m below the surface) less than 1 m apart in Burns Bog, Delta, BC.

**Fig. 1.**



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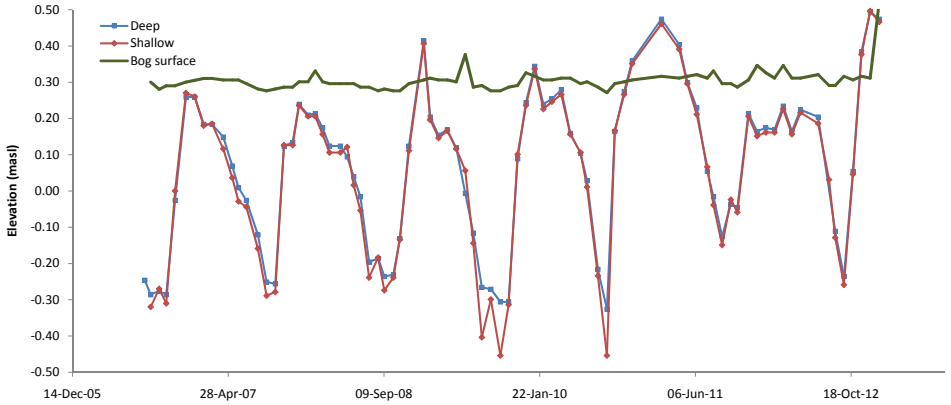


**Figure 2:** Comparison between the water level elevation in a shallow pizeometer (screening 0.38 – 1.28 m below the surface) and a deep piezometer (screening 0.85 – 1.75 m below the surface) of a piezometer nest in a lagg swamp discharge zone in Burns Bog, Delta, BC.

**Fig. 2.**



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**Table 1:** Piezometer installation depths and difference between highest measured water level in the piezometer and top of the piezometer screening for all sites in this study. Codes for study sites on transect: BG = bog, R1=between bog and lagg, closer to lagg, R2 = between bog and lagg, closer to lagg, LG = lagg, MN = minerotrophic site outside the bog.

| | Sample Location | Depth of top of 0.40 m piezometer screening below the surface | Difference between top of piezometer screening and highest water level measured in the piezometer |
|---|---|---|---|
| Burns Bog | SW – BG | 0.27 | 0.23 |
| | SW – R1 | 0.58 | 0.45 |
| | SW – R2 | 0.59 | 0.45 |
| | SW – LG1 | 0.69 | 0.45 |
| | SW – LG2 | 0.61 | 0.53 |
| | SW – MN | 0.73 | 0.61 |
| | DNR – BG | 0.34 | 0.35 |
| | DNR – LG1 | 0.32 | 0.46 |
| | DNR – LG2 | 0.65 | 0.52 |
| | DNR – MN | 0.27 | 0.44 |
| | CW – BG | 0.18 | 0.19 |
| | CW – R1 | 0.80 | 0.73 |
| | CW – R2 | 0.17 | 0.30 |
| | CW – LG | 0.25 | 0.34 |
| | CW - MN | 0.79 | 0.34 |
| Blaney Bog | BU – BG | 0.60 | 0.49 |
| | BU – R1 | 0.61 | 0.44 |
| | BU – R2 | 0.58 | 0.41 |
| | BU – LG | 0.69 | 0.62 |
| | BU – MN | 0.59 | 0.44 |
| | BF – BG | 0.62 | 0.44 |
| | BF – R1 | 0.49 | 0.41 |
| | BF – R2 | 0.43 | 0.35 |
| | BF – LG | 0.32 | 0.36 |
| | BF – MN | 0.24 | 0.50 |
| Campbell River Bog | CR – BG | 0.28 | 0.27 |
| | CR – R1 | 0.28 | 0.29 |
| | CR – R2 | 0.28 | 0.31 |
| | CR – LG | 0.07 | 0.09 |
| | CR – MN | 0.40 | 0.00 |
| | **MEAN** | 0.46 | 0.39 |
| | **MEDIAN** | 0.46 | 0.43 |
| | **MODE** | 0.28 | 0.44 |



**Fig. 3.**



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