General comments, referee 1

General comment 1: The hydraulic connectivity of the lake to the sub-permafrost groundwater is one of the highlights of this study. The fact that a talik through the 300 m thick permafrost exists is more interesting than the magnitude of the relatively small groundwater flux to the subpermafrost aquifer. I think it would be a valuable contribution to this paper if you could include a discussion of the temperature regime of the surrounding permafrost and the temperature at the bottom of the borehole in the talik (it was indicated in the paper that the talik temperature was measured via the borehole).

Answer: We agree that the existence of a through talik penetrating the observed 300 m deep permafrost is interesting, but the focus of this study is hydrology and the aim is to analyse and conceptualize the new hydrological data set. Information about the temperature regime has already been published by Harper et al (2011) and is thus not a new contribution of this study. However, we have in the revised manuscript summarized the already published work. The previous section ”Active layer and lake ice” under section 2.2.2 has in the revised manuscript the heading “Permafrost, Active layer and lake ice” and contains more information about the permafrost conditions in the area. Some information that was previously in section 2.2.2 “Borehole data” is now moved to this section, which in the revised manuscript includes the following:

“Temperature profiles from a borehole, DH-GAP03 (Harper et al, 2011), situated between the ice sheet and TBL, but at approximately 150 m higher altitude than TBL, indicate a permafrost depth of c 335 m. The mean temperature along the upper 200 m of this borehole was -2.9°C in September 2009. A 221 m long borehole, DH-GAP01 (Fig.1), was drilled in a 60° inclination under the TBL, reaching a vertical depth relative to the top of casing (TOC) of 191.5 m. Based on borehole temperature data, the upper 20 m of the borehole is considered to be in permafrost. The transition from frozen to unfrozen ground coincides with the lake shoreline, i.e., temperature data indicates a talik being maintained under the lake. The mean temperature in the bedrock under the lake is 1.25°C. There are no indications of decreasing temperatures in the deepest part of the borehole, which would have indicated a closed talik. Geothermal modelling of the DH-GAP01 borehole supports the hypothesis that the investigated lake has a through talik beneath it, penetrating the 300 m deep permafrost (Harper et al, 2011). The temperature in DH-GAP03 at a vertical depth of 191 m, i.e., at the same depth as the maximum depth of the DH-GAP01 borehole under TBL, was measured to -2°C.”

General comment 2: This study is basically a water balance of a closed watershed where P – ET = _S; at least this is what it appears to be during the short one year field study. In such a setting one would expect that certain chemical ions would demonstrate increases in concentration resulting in higher values of variables such as electrical conductivity. Is the electrical conductivity of this lake comparable to other land locked-lakes? This would give some insight into whether the pattern of flow observed in this short study is typical over the long-term.

Answer: The scope of this paper is to understand the site hydrology during the investigation period, rather than to assess the long-term average hydrological condition. We also have a wealth of chemical data available from the same investigation period, but this data cannot be conclusively analyzed and interpreted without first quantifying the hydrological flows and processes, and their uncertainties. The hydrological data set and analyses presented here constitute this first step, which is a prerequisite for subsequently, in a follow-up paper, analyzing the chemical data set.

The area around Kangerlussuaq is well known for the oligosaline lakes formed by a negative precipitation/evaporation balance. Electrical conductivity (EC) in these lakes is in the range 2000-4000µS/cm (Anderson et al, 2001). Anderson et al (2001) investigated 86 lakes in the Kangerlussuaq region, approximately 50% of the lakes had EC values <100 µS/cm and 88% had EC <500 µS/cm . 10 lakes had an EC >800 µS/cm. Data on electrical conductivity in TBL is available but there are no indications that TBL should be a lake where accumulation of salt ions occurs, even though no surface water runoff out of the lake has been observed during the studied hydrological year. The electrical conductivity of TBL is in the same range as in other investigated lakes in the area. The mean observed EC in TBL is 125-135 µS/cm2.

Ref: Anderson N J, Harriman R, Ryves D B, Patrick S T, 2001. Dominant factors controlling variability in the ionic composition of West Greenland lakes. Arctic, Antarctic, and Alpine Research, 33, pp 418–425.

General comment 3: There are two weaknesses in this study that limit the conclusions that can be drawn. First is the short duration of the study, basically one year. This does not allow for any examination of the year to year variation that may be observed in the various fluxes and storage terms.

Answer: The focus of this study is on the quantification of intra-annual variation and uncertainties of water levels and fluxes, and other components of the cumulative net water balance over the given investigation period. The aim was not to assess a representative long-term average water balance and its associated flux components. The relatively small catchment is well investigated, even though the data set is limited in terms of spatial and temporal extent. Relevant fluxes and processes have been measured with high temporal resolution, and given the small size of the catchment, 1.56km^2, also the spatial resolution is high. Evapotranspiration is not measured directly, which is rather typical, but we did measure all parameters needed to calculate the potential evapotranspiration with the Pennman-Monteith formula. The study addresses how to conceptualize and quantify the main hydrological flows and processes in the catchment during the investigated hydrological year and the uncertainties that still remain even with an extensive measured dataset for such a limited time period; this uncertainty assessment is also important for long-term average conditions, as the uncertainties of each year combine to the total ones over the long-term period. The limitation, relative to long-term average conditions, of this study considering only a period of one year was assessed by relating the local values of precipitation to the long-term average values obtained from the nearby Kangerlussuaq station. In addition, we compare also in the revised manuscript local air- and soil temperature data to corresponding long-term values from the Kangerlussuaq station.

We realize that we did not sufficiently explain the focus of the present water balance study, and have reformulated the introduction of the revised manuscript to do so, as follows:

“The present study focuses on the short-term (intra-annual) variability of the linked surface and subsurface hydrological flows and processes in an arctic permafrost catchment in western Greenland. For this catchment, we present a new hydrological dataset, as a controlled field experiment carried out within the relatively small catchment area (1.56km^2) over a relatively short investigated time period (1 year). The spatial and temporal investigation resolution, however, is relatively high within this small area and short time period. This dataset resolution, for many relevant hydrological processes, enables quantification of the net cumulative water balance over the investigation period with a relatively high degree of confidence, considering also the links between surface waters and both supra-permafrost and sub-permafrost groundwater, and between the small catchment and its associated lake talik. Even with such an extensive measurement programme, however, some key uncertainties still remain, and a main study aim is to bound and assess these remaining uncertainties in the quantification of main hydrological flows and net water balance of the study area. For this purpose a conceptual model of the relevant hydrological system is constructed, which can also be further used as a basis for modeling of the permafrost hydrology in this area."

Also the conclusions have been revised in the following way:

"The work highlights the importance of developing a conceptual understanding of hydrological flow variability in a catchment during different time periods within a year. We have shown how this understanding together with the detailed site-specific hydrological data can be used to quantify uncertainties still remaining despite a comprehensive investigation programme. By analysing data from the one-year-study, we can conclude that investigations of snow dynamics (sublimation and snow blowing events) are needed to reduce the identified uncertainties of the water balance. Sublimation from snow and snowdrift are key processes in the water balance during the frozen period. As a consequence of the snowdrift, the precipitation affecting the catchment differs from that affecting the wind exposed lake area when ice is covering the lake.

Based on the hydrological measurements that link the surface and subsurface water systems below the permafrost, we conclude that the water flow between lake and talik is very small relative to the other water balance components, and that for the hydrological year 2011-2012, water from TBL recharges the deeper talik groundwater. Our results support the hypothesis that relative topographical location governs the direction of groundwater flow in a talik. Temporal pressure changes in the talik closely reflect the measured local hydrological processes at the lake surface rather than any larger-scale regional processes in the ice-sheet dominated landscape. These results indicate the investigated catchment hydrology as being rather independent from catchment-external landscape features, including those of the close-by ice sheet."

General comment 4: For example, it was indicated that there was evidence of past outflow from the lake, are these outflow fluxes significant some years relative to other fluxes?

Answer: The observed outflow of water from the lake in 2009 was not related to the investigated fluxes and water levels in the area, since our measurements of the latter, including site meteorology, lake level variation, borehole groundwater pressure and soil moisture, started first in 2010. The reason for mentioning the observed outflow in 2009 is only to inform the reader of the fact that the lake is not generally an isolated system dominated by a negative evapotranspiration/evaporation balance. Surface water outflow does occur occasionally, even though the observed outflow has been zero during the last 3-4 years.

General comment 5: The second weakness is that not all the terms in the water balance equation were measured; the equation was used to determine one or more fluxes. For example, for the catchment surrounding the lake, the ET was estimated to be equal to the residual of the water balance equation. This means that all of the error generated in performing the water balance calculation ends up in the ET term. The longer you implement a water balance study, the better you will understand the magnitude of the error you are facing. Is there meteorological data from nearby sites (Kangerlussuaq)

Answer: As in most catchment studies, also the present one did not include direct measurement of all water balance parameters. However, for the lake area, even though we did not measure the evaporation from the lake, we did measure all parameters required to calculate the potential evaporation (PET). Assuming the calculated PET with the Penman-Monteith equation to equal the actual evaporation from the lake is a commonly used approximation. The fact that all input data used for the PET calculation is taken from a local meteorological station, rather than from some station kilometres away, gives strength to the study. In addition, monitoring of the hydraulic head of the lake as well as in the bedrock underlying the lake allows for quantification of the exchange of water between the lake water and the underlying groundwater. The lake water level variation is monitored with pressure transducers of high accuracy and with high temporal resolution. Also, soil moisture content is measured in 44 points over the small catchment area. In many water balance studies the storage components are the residuals of a water balance calculation, but in this study we have been able to quantify the storage change over the hydrological year both in the lake water and in the active layer. In addition, the studied area has a low precipitation resulting in dry streams and low groundwater levels in the active layer, and a very harsh climate. This complicates monitoring of relevant parameters. We have in this study been able to quantify main flows and processes in the catchment without explicitly measuring groundwater levels or surface water runoff.

Meteorological data from a nearby station in Kangerlussuaq has further been used to relate our observed short-term local precipitation to long-term mean values for the greater area. It is concluded, as also stated in the text, that our observation period is a relatively wet period, both in the TBL catchment and in Kangerlussuaq as a whole. Data on long and short wave radiation needed to calculate PET is not available from the Kangerlussuaq station. Calculated PET values from the TBL catchment can therefore not be related to the Kangerlussuaq station.

Specific comments Referee no 1:

1. Page 9275, Line 12: There is no Frampton et al. 2013 in References.

   Answer: It should be Frampton et al. 2013 and not 2012 as written in the reference list (the error is found on P 9273 line 12, not 9275), the reference list is corrected in the revised manuscript.

2. P 9277, L 15: What is the correct spelling of Alexanderson, two s's in the References.

   Answer: The correct spelling is with two s's, the spelling is corrected in the revised manuscript.

3. P 9278, L 1: To me, exposed slope is the windward slope and the windward slope is generally exposed to erosion (scouring) while leeward slopes experience drifting (deposition). Here you say that drifting occurs on exposed slopes, is this what you meant?

   Answer: We mean that snow is transported away from the exposed slopes, i.e. erosion occurs on wind exposed slopes. The text in the revised manuscript is corrected in the following way:

” Snow depth measurements performed in April 2011 (Fig. 1) indicated an irregular snow cover, with snow accumulation in the valleys, and snow blowing away from wind exposed areas at the hillsides and on high topographical points.”

4. P 9279, L 24: You should indicate here that the hydraulic head of the lake is greater than the hydraulic head of the borehole.

   Answer. We agree and have corrected the sentence in the following way: “The mean difference in hydraulic head over the hydrological year was calculated to be 1.85m with greater hydraulic head in the lake, implying a mean hydraulic gradient of 0.014 with a downward direction (i.e., recharge into the talik).

5. P 9280, L 20 and P 9281, L 6: When deriving these equations, the direction of flow is unknown and therefore some of these terms should be preceded by ±. For example in equation 2 you have + Rgw, it would be better to express this as ±R+gw+ (it turns out it is actually negative). Again in equation 4, it would be clearer to express it as ± ΔSal.

   Answer: The water balance equations (1), (2) and (4) are in the revised manuscript illustrated in a new Figure, see below. The figure illustrates the in- and outflow of water for the lake and the catchment; it also illustrates how equations (2) and (4) are linked to each other via the exchange of surface water (Rs) and water in the active layer (R_{al}). The figure caption clearly explains that positive direction of R is into the lake.

   The heading of Section 2.3 is changed to ” Annual water balance calculations” and the updated version of the section describes in a clearer way the water balance calculations for both the lake and the surrounding catchment on an annual basis.

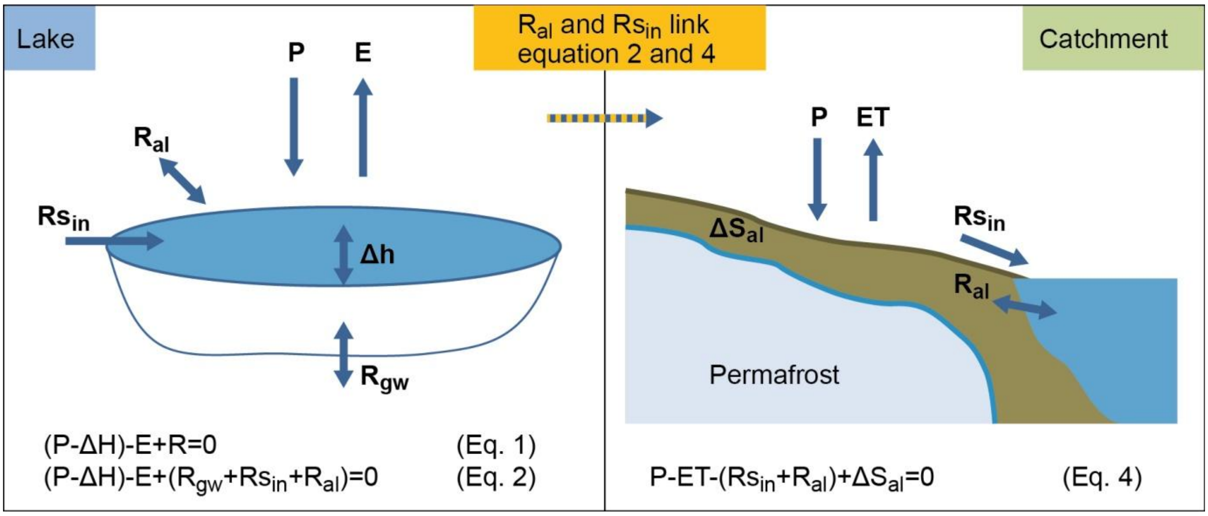

Figure X. Water balance equation for lake (left) and catchment (right). In equations (1) and (2), total inflow minus total outflow from the lake is calculated; positive direction of all R-components is directed into the lake. In Equation (4), total inflow minus total outflow from the terrestrial parts of the catchment to the lake is calculated; positive direction of all R-components is directed into the catchment. Storage components, ΔH and ΔS, are positive if the storage is increasing.

6. P 9281, L 5: I was confused for quite a while about what area you were considering the lake catchment to be, you should make it clear that it does not include the lake, just the land area surrounding the lake.

Answer: We agree. The new Figure (see above) will make this clearer and the sentence is in the revised manuscript rewritten in the following way:

"Based on the calculated annual sum of R_{al} and Rs_{in} for the lake, the water balance for the lake catchment (lake area excluded) can further be calculated by Eq. (4) (Fig. 2c):"

7. P 9282, L 5: It is not clear to me what point you are trying to make here, rewrite.

Answer: The dynamics in the transition zone between the terrestrial areas and the lake is not investigated in this study. The process of water flowing into unsaturated parts of the frozen active layer is not investigated but might occur. This is why we mentioned it as a possible process. We have in the revised manuscript deleted the following sentence since the process is not included in this study.

" If the active layer is unsaturated at the time of soil freezing (Table 4), lake water might flow into the unsaturated parts of the active layer in response to an increased water pressure in the lake; this process can occur only as long as the lake ice has not reached the thickness of the active layer."

8. P 9282, L 13: Should indicate that ΔH is positive (anyway I think it is).

Answer: In the new Figure Illustrating Equations (1), (2) and (4) this is clear. In addition, in the revised manuscript we have changed the sentence in the following way:
"... and ΔH is 73 mm (lake level increased over the hydrological year), resulting in..."

9. Section 3.2: I assume all of these values are for the surface area of the lake (should make this clear).

Answer: Section 3.2 is rewritten in the revised manuscript. The section now only deals with the annual water balance, both for the lake and the terrestrial parts of the catchment. Section 3.4 is removed and included in section 3.2. The new heading is "Annual water balance, base case". It first summarizes the annual water balance for the lake and then the annual water balance for the catchment and refers to Figure 7. Figure 7 has been corrected and the numbers of the water balance are now given for the annual sums with the uncertainty intervals for P, E, ET and R mentioned in parenthesis under each annual sum. All numbers are given in mm/y, both for the lake and for the catchment; different colours indicate whether the numbers are normalized over the lake area or the terrestrial catchment area.

The text from L19 on P9282 in the original manuscript has been included in section 3.3. Section 3.3 has a new heading "Estimation of uncertainty intervals for P, E and (R_{al}+ Rs_{in})"

A new section 3.4: "Annual water balance, uncertainty cases" describes the results of the uncertainty analysis relating to cases 1-3 introduced in section 3.3. Water balances for both the lake and its catchment on an annual basis, but with uncertainty intervals for P, E, ET and R, are given.

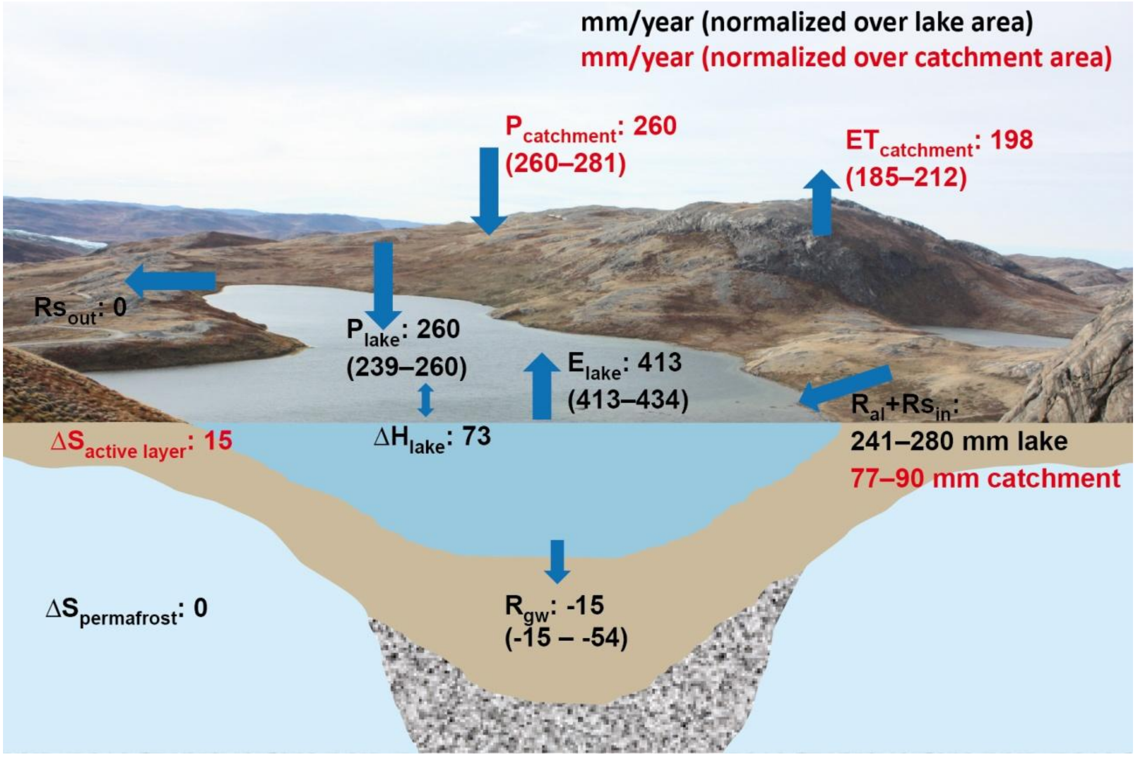

Figure 7. **.** Water balance (mm/y) for the Two Boat Lake catchment based on data from the hydrological year September 1st 2011 until August 31st 2012. Due to snow drift in the area, different values of precipitation, $P_{catchment}$ and P_{lake}, are calculated. Uncertainty intervals are presented for the evaporation (E_{lake}) and evapotranspiration ($ET_{catchment}$), precipitation (P_{lake} and $P_{catchment}$) and runoff (R_{gw} and R_{al}+Rs_{in}) components. Uncertainty intervals are not defined for the change in lake level (ΔH) and storage change in the active layer (ΔS). The numbers given in mm/y are normalized over different areas, i.e., lake area or catchment area. Red colour indicates that numbers are normalized over the catchment area, and black colour indicates that numbers are normalized over the lake area.

10. Section 3.3.1: indicate that fp stands for frozen period.

Answer: It is already mentioned on P9283 L24-26.

11. P 9285, L 18: Should show units (m/s).

Answer: In the revised manuscript, “m/s” has been added to the equation.

12. P 9288, L 14: What is the definition of a snow blowing event?

Answer: A snow blowing event is when the wind speed exceeds the threshold wind speed for snow transport. To make this clear, the text on P9288 L14 in the original manuscript is in the revised manuscript corrected in the following way:

“Snow blowing events are defined as events when the threshold wind speed for snow transport is exceeded. During the 2011–2012 winter, 106 snow blowing events occurred in the studied area, which is in the same range as in other periglacial study sites; in both the Russian Arctic coastal plain and the Colorado alpine region the number of snow blowing events was observed to be over 90 per year (Berg 1986; Groisman et al. 1997).”

13. P 9288, L 19: Change smaller to thinner.

Answer: We have changed from smaller to thinner in the revised manuscript.

14. P9291, References: I did not see the following citations used in the text: Bense et al., 2012; Lyon et al., 2010; Penman, 1948.

Answer: In the revised manuscript, the references are removed from the list.

15. P 9293, References: Delete Hiroyuki et al., 2004. The correct citation is the reference above on L 15 (Hirashima et al., 2004).

Answer: OK, the reference is deleted.

16. P9296, Table 1: Relief implies a range, so it should be "Catchment relief, m 337-505" or "Catchment elevation max, m 505" and "Catchment relief min, m 337"

Answer: OK, in the revised manuscript, the table is corrected to "Catchment relief, m 337-505".

17. P 9297, Table 2: Capatalize Ingoing (column 2) and CS (column 3).

Answer: OK, in the revised manuscript the table is corrected.

18. P 9301, Figure 1: Figure is quite small and difficult to see the details.

Answer: The figure is enlarged in the new manuscript and the two figures are placed one above the other instead of next to each other.

19. P9302, Figure 2: Why doesn't the water balance of the catchment surrounding the lake show up in this conceptualization?

Answer: Figure 2 is updated in the revised manuscript. The text in Box C is: "C. Lake water balance and water balance for catchment. Annual sums". Also, the text in section 2.3 is revised to better explain the water balance calculations of the lake and the surrounding catchment.

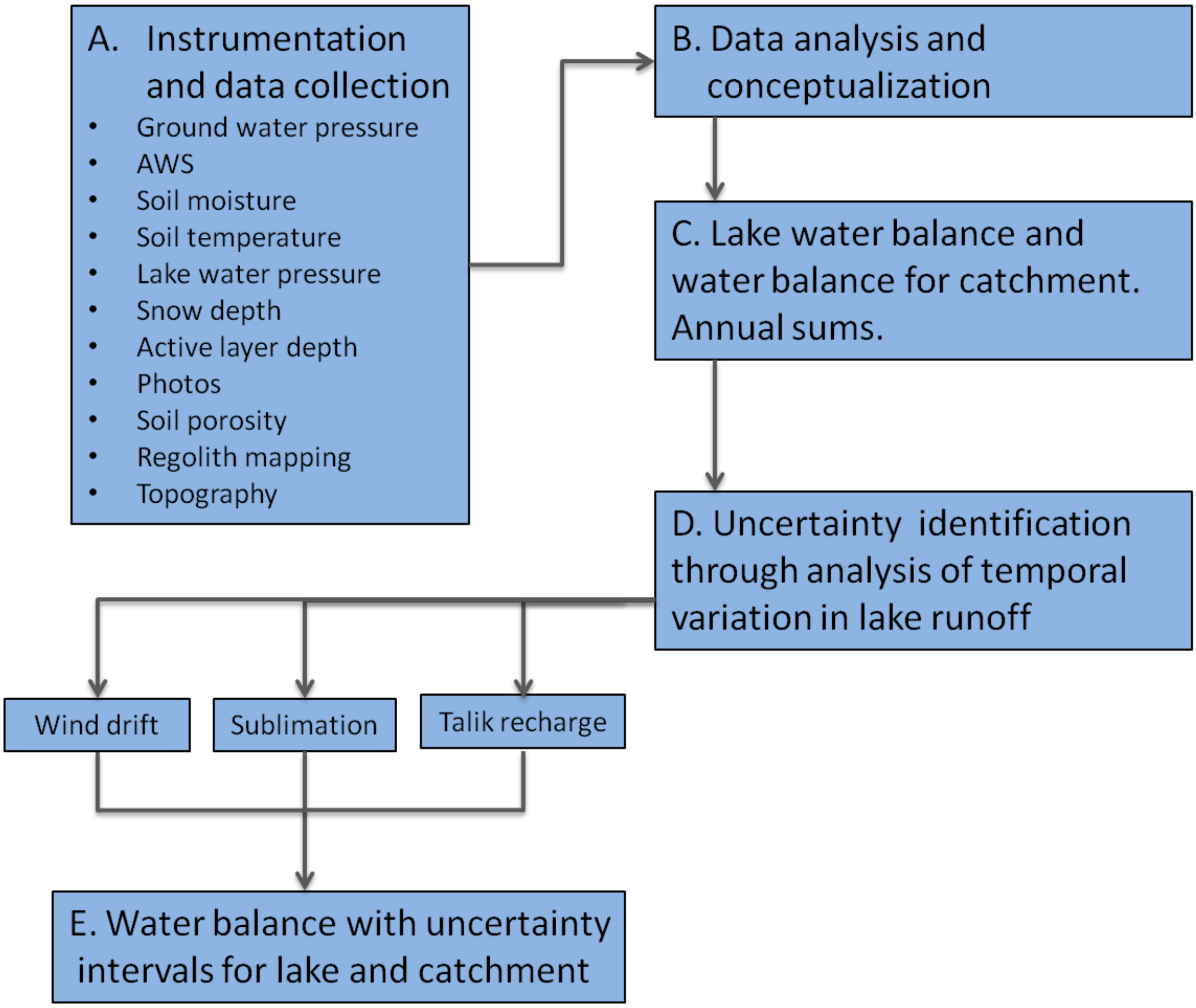

Figure 2. Overall method and workflow, steps A-E, for water balance calculations and conceptualisation of the hydrology in the Two Boat Lake catchment.

20. P 9304, Figure 4B: You show melting (two events) of the snowpack in March, does the air temperature confirm that it was warm enough for melting (versus blowing away at the site).

Answer: Yes, plus degrees are observed at the local AWS during these periods. During the first snow melt event, March 24-March 25, the mean hourly temperature was 5°C (2.5-7.2°C) and during the second event, April 1-April 4, the mean hourly temperature was 3.5°C (0.4-5.6°C). As explained in the supplementary material, snow melting and accumulation were calculated with a degree-day method where threshold temperature for melting/accumulation was set to 0°C and the degree day coefficient was 2mm/day/°C.

21. P 9306, Figure 6: Why not show all the relevant fluxes in this figure?

Answer: Precipitation and SWE have been added to the figure in the revised manuscript.

22. P 9307, Figure 7: For the lake evaporation, shouldn't the values be 156070 (one to many zeros) – 164010.

Answer: Yes, the correct interval should be 156070-164010m^3. However, a new version of the figure is presented in the revised manuscript where all numbers are given in mm/y, see above.

23. P9308, Figure 8: I think the wind and SWE data should be plotted on a separate figure as it is not directly related to the other terms plotted in this figure. Also, what does m vp stand for?

Answer: The variation in lake hydraulic head as well as the co-variation between lakehead and hydraulic head in the borehole are influenced by snow dynamics on the lake ice surface. The snow dynamics influencing the hydraulic head over the lake is sublimation, wind drifting snow, melting and accumulation of snow. Sublimation and wind drift are intimately connected to events with strong winds; this motivates why it is relevant to keep the wind events and the snow melting/accumulation curve together with the lake and bedrock hydraulic head data. However, to make the figure easier to interpret, we now separate the information into two figures; an upper one containing information on lake and bedrock hydraulic head, and a lower one containing information on the wind events and snow water content.

The heading of the right axes is corrected; it should just be “meter”, m v p is deleted.

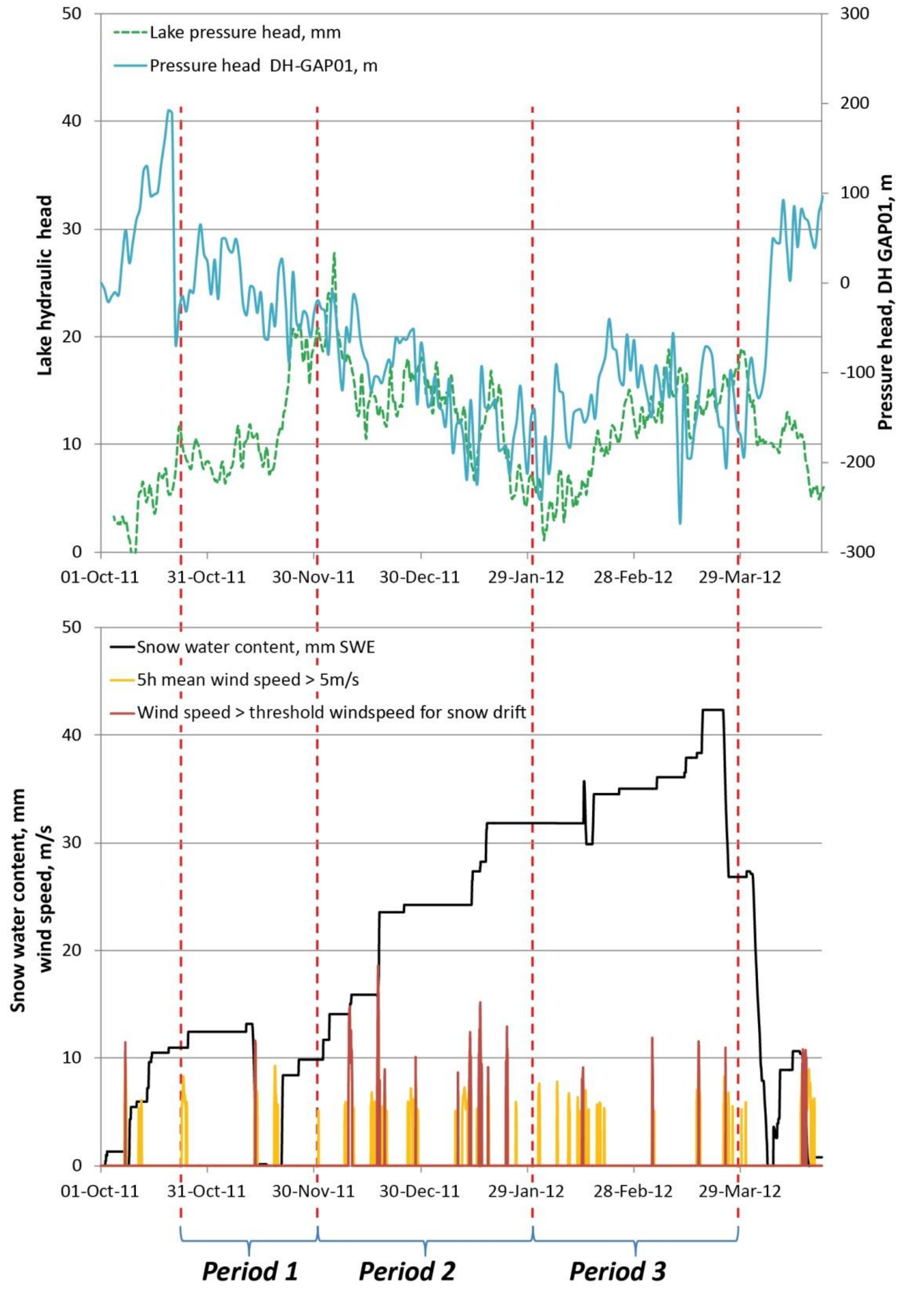

Figure 8. Pressure head in lake (green dotted line) and bedrock (blue line), upper figure. Cumulative snowpack (black line) and events of strong winds (events when the 5h mean wind speed > 5m/s and events when the wind speed exceeded the threshold wind speed for snow drift, 7m/s), lower figure. Data is illustrated for the frozen period 2011-2012. The frozen period is divided into 3 periods, 1-3, based on an increasing or decreasing trend in lake head.