

Response to interactive comments of Reviewer 2 (bg-2018-516)

We thank reviewer 2 for the helpful comments that will aid in significantly improving our paper, particularly through clarification of the measurements made and our interpretations of water and DOC mobilization in the boreal watershed context. Our response to specific comments (reprinted in bold) are provided below

The manuscript presents a thorough assessment of DOC fluxes in boreal landscapes and how they might be affected by forest harvesting and climate change. Principally, the study is well designed and the manuscript is nicely written and the results contribute to our understanding of DOM mobilization in boreal forests. The major shortcoming of the manuscript is the estimate of water (and thus DOC) fluxes that is based on water collected using passive pan lysimeters. Although they seemed to be well designed (using glass beads to mimic a hydrological continuum), it remains uncertain how well they functioned (e.g. by tracer). While water recovery was tested to be 90%, measured water drainage was found to exceed rainfall inputs (+50%) and thus measured drainage was about twice as high as what one could expect. In the discussion, the discrepancy was explained by lateral flow contributing. This implies that the lysimeters acted as funnels draining a greater footprint area and thus, comparisons of DOC fluxes with soil CO₂ effluxes are not valid as they originate from different areas. To me an appropriate estimate of water fluxes seems crucial for the manuscript as the discussion centers all around a mass balance comparing DOC with soil CO₂ effluxes. I would strongly recommend to use a water balance model to estimate DOC export from the organic layer or provide clear evidence on lateral flow or the footprint area. More information on the set-up of the lysimeters and the site conditions (slope) should be added. In contrast to the uncertainties related to the quantitative estimates, conclusions made in relative terms e.g. harvest effects, seasonality etc. are still valid and merit publication.

- 1) Many studies have investigated DOC fluxes as predominately vertical transfers of carbon from organic horizons to the lower mineral soil. The motivation for this study was to understand and discuss DOC dynamics within a hillslope (5-13 % gradient range across plots) to aid in understanding DOC flux dynamics at the watershed scale which has not been well documented. The conceptual idea:

Precipitation that infiltrates the soil surface flows both vertically and horizontally depending on landscape slope, the relative permeability of soil and vegetation layers, antecedent soil moisture and lack or presence of a snowpack. Overlying the mineral soil are 2 layers of permeable material (the organic horizon and moss layer). In winter, the snow also serves as a permeable layer. Therefore, lysimeters potentially collected water that infiltrated vertically through the snow and/or moss and organic horizons, along with additional water that moved laterally through those layers into the lysimeters from upslope. These flow paths are seasonally dependent.

The 90% lysimeter efficiency result did not unfortunately test appropriately for this phenomenon as lysimeters were only watered directly above the dimensions of the

catcher to determine if the design was working (i.e. plumbing all connected between the pan and downslope, buried collection carboy). We do not know what the actual total footprint beyond the lysimeter dimensions is, and therefore that value is not a true description of the lysimeters ability to capture rainfall. We will clarify the purpose of our test and the appropriate application in the methods. A tracer test may have helped us estimate how much of the water flux measured here was from lateral flow upslope, although a better approach will be through complementary use of a model. See our proposal below in item 2.

- 2) While we acknowledge that lysimeters alter soil hydraulic properties making accurate quantification of water fluxes difficult, modelling of water flow also has limitations especially at the organic-mineral horizon interface measured in this study. We will run a model of water flow in order to better facilitate discussion of the two approaches and their respective limitations. We've assessed the requirements of the COUPModel, and have confirmed with the creator of the model that we have the necessary parameters to run this exercise as a supplement to our measurements. Incorporating such a modelling approaches should provide evidence for the relative magnitude of lateral flow and constrain the water fluxes measured. This will enable us to more accurately discuss the hillslope DOC fluxes in the watershed context where both vertical and horizontal flow are relevant.
- 3) The manuscript discussion was not meant to be centered around a mass balance of DOC with soil CO₂ effluxes. We can see how this could be misinterpreted given the title of the first discussion heading and following paragraph. Both values were included as a means of comparing the magnitude of those two ecosystem C fluxes in this boreal system, demonstrating that although DOC fluxes are small in comparison to soil CO₂ effluxes they are similar in magnitude to boreal NEP estimates. Losses of DOC from the ecosystem could potentially affect NEP especially in the harvested stands where water fluxes remain elevated. Further work should be done to investigate the extent of this effect as our manuscript only offers that information as an observation and not as a key finding. The discussion could be reorganized in a revised manuscript to place less emphasis on this comparison, instead highlighting the more impactful results regarding effects of harvesting and seasonality of DOC as the reviewer suggests. This should greatly improve the clarity of the manuscript.

Specific comments:

Abstracts L. 23 ff An Abstract should be informative and contain the key data. The implication/conclusion section is much too long, 10 lines. I missed values and comparison with soil CO₂ effluxes and forest management aspects.

The abstract will be shortened with greater emphasis on the key findings rather than implications and conclusions.

Methods Page 5, Line 5ff lysimeter set-up “It was desirable for this study”. . .please describe what was exactly done and give details on glass beads (size classes), depths of the glass bead layer, length x width of the lysimeter, connection of lysimeter to sample container etc.. How was it installed? Was the organic layer completely removed before- hand? A sketch added to the Supplemental Information might be helpful. According to the test described it seems that lysimeters functioned well but why did they not collect lateral water in your test but later during the regular monitoring? The appropriate capturing/estimate of water fluxes is crucial for estimating DOC fluxes and thus lysimeters known to create sampling artefacts should be tested rigorously (e.g. by a tracer) or backed up with modelling of water fluxes.

We will add a sketch to provide more details regarding the design of the lysimeters used in this study and with that include more details on the steps taken to install these lysimeters. The test conducted only entailed water applied to the actual lysimeter footprint, which will be described in the added methodological details, and not any upslope or downslope areas around that footprint. We recognize that this was not ideal as it did not assess lateral flow. However, by incorporating the modelling comparison as suggested and described above we should be able to place some constraints on what the lysimeter water fluxes provide.

Page 8, Line 15 453 cm as snowfall, typo? If indeed snow depth is meant, please transform it to water equivalent.

“453 cm as snowfall” should read 453 mm water equivalents as snowfall. This will be changed in the revised manuscript.

Page 8, line 19 I would recommend to report no decimal for rainfall (which is beyond any precision possible). . .

Will be revised

Page 9, Line 26 clarify that you mean the SOC stock in the organic layer.

Will be revised

Page 10 How can the water flux in the O horizon (1366 and 2040 mm) exceed or be in the same range as the input via rainfall (1305mm)? Estimates of water fluxes are crucial as DOC fluxes directly depend upon water fluxes. Generally, this is done via modelling of water fluxes (see papers by Fröberg et al., Kindler et al., 2010 GCB). The values you provide indicate that the lysimeters worked well (which is not always the case) but that they might fetch water from a greater area or include a lateral component. How does the topography of the site look like (no information given in the methods. . .).

We will include more information regarding the topography of the site in the methods.

Regional as well as plot level data was used in the estimates of water input via precipitation (rain + snow). The 1305 total annual precipitation recorded could be an underestimate of this input at the plots especially because snowfall was not measured at the plot level but was used from a meteorological station 50km away from the site in Deer Lake, NL. The on-site snowpack data we have available prior to snowmelt (84 and 110 cm in the forested and harvested stands) was deeper than the maximum snow on ground measured at the Deer Lake weather station further suggesting an underestimate of water input as snow at the site level. We will provide more detail and constraints on the estimate of water input to these plots in the revision.

Secondly, yes, lateral flow in this system is very likely given differences in permeability between surface layers (snow, moss and organic layers) and deeper mineral soil layers, as well as the slope of the landscape (5-13%). It is certainly possible, therefore, for soil water fluxes to exceed input via precipitation. In fact our headwater catchment hydrology indicates a good match between discharge and lysimeter water fluxes during snowmelt, a period of little to no evapotranspiration. It is, however, difficult to determine how much of the exceeding soil water flux is driven by natural lateral flow and how much is an artefact of the lysimeter. This is where comparison to a model could be beneficial, although models of water flow also have their limitations. Both approaches are necessary to come closer to a real world description. An exclusive vertical flow application undervalues the data presented, therefore, we will assess vertical and horizontal flow model results for this site.

Page 10 Line 16 please rephrase the sentence – and clarify that ‘corresponding to a total depth of 84 cm and 110 cm’ was the snow depth when snow/water was sampled (?)

Yes, “84 cm and 110 cm” was the snow depth when snow was sampled. Will be revised.

Discussion Page 11, Line 13ff As the DOC fluxes seem to be very high due to an overestimate of water fluxes, the discussion includes a high uncertainty. At a rainfall of 1300 mm, evaporation rates of 100-200 mm and a evapotranspiration of approx. 3-500 mm, the DOC fluxes are probably a factor of two smaller than estimated here. This is also relevant for the comparison with other C fluxes/pools.

Page 11, Line 30ff here it needs to be clarified that the greater water flux drives the management effects

Will be clarified in the revised manuscript as per approach described above using the modelling comparison.

Page 12, Discussion of lateral water fluxes. The appropriate estimation of water fluxes is crucial for the overall manuscript (and appears very late in the discussion. Based on the values given, I was wondering much earlier that something went wrong). Lysimeters are known to have artefacts as they alter the soil continuum: they can act either as a funnel or as a barrier depending on the soil conditions. I would thus not rely on the assumption that the

lysimeters used here captured water fluxes (horizontal and lateral ones) correctly. Probably, there is lateral flow (what is the slope of your site?), but the estimate provided here is too speculative. Moreover, is laterally moved DOC a real export? How can you compare total DOC export (lateral and vertical) with soil CO₂ effluxes in quantitative terms? I recommend to model water fluxes and use these values to estimate vertical DOC loss from the O-horizon.

- 1) The range of slopes measured across plots was 5-13%.
- 2) Export depends on the area of interest. It certainly could be a real export if DOC is leaving from a fixed area, even if it is a source to downslope O horizons. We will be sure to revise in order to clarify this perspective in the context of our study site.
- 3) We agree that a quantitative comparison of CO₂ effluxes and lateral + vertical DOC fluxes is difficult and not appropriate as a mass balance approach. However, a comparison of relative quantities and dynamics is useful to demonstrate for the discussion of the relevancy of the DOC fluxes in the context of NEP.
- 4) We would like to maintain a position that DOC fluxes are not just vertical fluxes of C, which is an important part of understanding the role and behaviour of DOC in the watershed context. However, we do acknowledge that accurate quantification of horizontal flow using the data currently available is not possible.

Page 14 comparison with soil CO₂ effluxes. You might estimate the seasonal pattern of DOC vs. soil CO₂ effluxes (or their temperature dependencies. DOC production was found to be less temperature dependent than CO₂ production (in soil warming studies).

Will consider and revise where appropriate.

Table 1 : Mineral soil bulk density of 2.8 g/cm³ is hardly possible as rock density is generally assumed to be 2.65 g/cm³

We recognize the issue of the high value which is indeed elevated relative to others we have for other sites regionally and are looking into it so that we are able to correct or clarify in a revision.