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Discussions
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Interactive comment on "Are hydrological pathways and variability in groundwater chemistry linked in the riparian boreal forest?" *by* Stefan W. Ploum et al.

Anonymous Referee #2

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I have reviewed the draft manuscript: 'Are hydrological pathways and variability in groundwater chemistry linked in the riparian boreal forest?' submitted by Ploum et al for possible publication in HESS. I like the general premise of this study, eg that preferential flowpaths from hillslopes through riparian zones need to be better considered when characterizing the baseflow controls on stream chemistry and dissolved organic carbon availability (DOC). Too many riparian studies are based around 'uniformed' or random piezometer transect designs, and without the hydrological flow context, the groundwater chemistry data are difficult to interpret. I do think this material is appropriate for HESS, though the paper could benefit from a change in emphasis and additional heat tracing data that it seems the authors may have already collected.

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Discussion paper

Currently, the primary question addressed by the study is posed as: 'Are hydrological pathways and variability in groundwater chemistry linked in the riparian boreal forest?' There have been many studies to document strong variance in groundwater chemistry as controlled by varied advective flowpaths, too numerous to list here. The current study by Ploum and all is unique from many of these as the preferential flowpaths in question source varied dissolved constituents to headwater streams. I suggest the authors refocus the main question to something like: 'Do DRIP's represent preferential conduits of DOC-rich groundwater to headwater streams in a boreal forest?' Or something at least more specific to this study than 'variability in groundwater chemistry'. It seems that the most compelling data presented in this study show the 'DRIPs' in this boreal headwater system are enriched in DOC, which presumably results in higher flux of DOC to the channel via preferential shallow groundwater discharge compared to more diffuse flow through till (though hydrological fluxes are not actually measured or inferred here). Further, the authors document interesting temporal trends in DOC and SpC, the latter being much less meaningful without additional chemical characterization.

In general, I feel the LMM statistical analysis was appropriate for assessing DRIP/non DRIP well DOC, pH, and EC. The results between these binary classifications are interesting, though for all the effort on well installation and sample collection some basic hydrological data seem missing. Where lateral gradients measured between wells and the stream? Were any hydraulic conductivity tests performed? Do we have any idea of groundwater flow rate/flux to the stream from DRIP vs non-DRIP zones? This is a flowpath-based study but the reader is left without any real flow-based hydrogeological information. The addition of some basic quantitative hydrogeological data, and perhaps some additional measured parameters such as dissolved oxygen, could have nicely increased the impact of this study. Without any evaluation of piezometer water age (eg dissolved gas-, isotope-based) the discussion of old vs new water contributions is highly speculative and should be scaled back. I really like the concept you put forth of DRIPs as drivers of younger water fractions in streams where low permeability soils dominate (eg tills), though it is difficult to support this using EC as the primary parameter. Despite these criticisms I do think this work could make an important addition to HESS after some revision considering the major comments below and that of the other reviewers.

The statement is made toward the end of the Introduction: 'However, in order to determine whether DRIPs matter for stream biogeochemistry, chemical characterization of the discharging groundwater is needed.' Yes, but this is only half of the equation, the other being the flux of groundwater to the stream which was not evaluated here in any way. It seems at least some data specific to groundwater discharge was collected in these streams and presented by Ploum et al 2018. Where many of the DRIPs instrumented here with piezometers identified in the stream as preferential discharge points using heat tracing? If so that data could be briefly included here with an additional figure, and go a long way to convincing the reader that the wet topographic low points mapped here as DRIPs are actual preferential flowpaths from the hillslope to the stream. Without any such thermal or hydrological gradient/permeability data it is difficult to accept with confidence that the DRIPs mapped here are actual preferential flow zones, compared to the surrounding soils. To be clear I think that the hydrogeologic interpretation of DRIPs made by the authors is likely generally correct, particularly after reading/watching Ploum et al 2018, but the current paper would benefit greatly from some groundwater flow-based data. I list several more major comments below (I realize some are a bit redundant with this narrative) followed by some more minor text suggestions:

1. A main conclusion of this work is stated as: 'We concluded that hydrological pathways and spatial variability in groundwater are linked, and that DRIPs are important control points in the boreal landscape.' Can you build on this statement in the abstract to be more specific to your study? Near stream shallow chemical variability has long been linked to flowpaths. Perhaps comment more specifically in the abstract regarding the spatial variability you observed to set your work apart from previous studies. The

Results section discusses some temporal patterns, but I do not see this data reflected in any of the figures or tables. You could develop a figure specific to the interesting temporal patterns, this information is shown somewhat in Table 1 'TIME' variable analysis but could be shown more explicitly. Also, I think the fact that your research indicates DRIPs our important DOC pathways to the boreal stream corridor is quite important.

2. Under your definition, are DRIPs only driven by surface topography and wetness? There are numerous instances of preferential discharge of groundwater and interflow through the riparian zone through highly permeable sediments that are not correlated with surface topography, and in glacial sediments often occur at local topographic high points (sand and gravel deposits transecting the riparian zone). I agree that local topographic depressions often lead to saturated conditions in the riparian zone, but that is not the same thing as strong hydrologic connectivity to the stream channel, which depends on the combination of lateral gradient and sediment permeability. Previous work by this group (Ploum et al 2018) used heat tracing methodology to locate/confirm preferential discharge of riparian water to the stream channel, which makes sense. However the current work does not seem to tie the definition of DRIP to actual observed high-discharge points, which I think is unfortunate. Not all saturated depressions will be points of preferential discharge to the channel, which strongly depends on soil permeability. Further, according to your statement: 'water in DRIPs travels a longer distance horizontally; in presumably wet, highly permeable, organic rich soil." It seems your definition of DRIP is relatively narrow, and based around forested headwaters similar to where your study has been conducted. I think it would be quite helpful for you to more specifically define 'DRIP' early in the manuscript (in the Introduction), and acknowledge that this definition applies to only a subset of preferential riparian groundwater discharge zones in headwater systems. Your broad definition of DRIP in section 2.2 (eg 'groundwater discharge zone, groundwater hotspots, cryptic wetlands, swales, focused seepage, discrete seepage, springs, upwelling zones, preferential discharge, ephemeral streams and zero-order streams') does not seem to apply to the functional definition you apply here for shallow lateral flow above the mineral soil horizon, so

please be clear on what definition you are using for this study.

3. It is not clear to me how DRIPs are defined for 'upland' areas... do you use the same definition based on topographic depression and wetness index that you use for the riparian zone DRIP areas?

4. Abstract L10 and elsewhere: it is somewhat of a misnomer that all riparian flowpaths lead to biogeochemical alteration of discharging water chemistry. Low-carbon mineral soils and highly preferential flowpaths such as peat pipes and other macropores can yield little alteration in hillslope and deeper groundwater discharge. In fact your findings indicate that DRIPs lead to less net reaction then more diffuse groundwater discharge through the riparian zone: 'Moreover, DRIPs were chemically more stable from the upland area to the stream'. You might check out this commentary for some relevant discussion : (https://onlinelibrary.wiley.com/doi/10.1002/hyp.11153)

5. It would seem fully screened wells down to apprx 1.5 m depth would integrate shallow 'DRIP' water and deeper mineral soil water, how did you account for this? I think your statements in the Discussion section regarding 'old' and 'young' water are a bit to speculative, as this is essentially only based on EC data, a parameter influenced by a number of flowpath process. It does not seem like any age dating/isotope analysis was performed, so how confident can you be regarding relative water ages/residence times? Also, you mention the piezometers were installed until they reached a hard layer. Did this depth vary systematically from DRIP to non-DRIP locations? If so you could include that data, as depth to rock/confining layer can also be a strong control on shallow groundwater flowpath chemistry.

Fig 1: Although we might expect local shallow percolation in non-DRIP near stream zones, groundwater flow is likely dominated by the lateral component toward the stream (in gaining stream reaches), though the discharge magnitude may be reduced compared to preferential discharge points. I suggest you alter the 'vertical groundwater flow' language in the 3rd panel of this Figure, the vertical flow you refer to may instead by non saturated percolation toward the water table, where groundwater flow is predominantly horizontal. Have you measured any vertical head gradients at the wells, and lateral gradients between wells, to support these conceptual diagrams? Fig 3- The caption could be simplified, you do not need to define DRIPs in the caption as this is done in the text

Minor points: Pg 2: L2 repeat of the word 'landscape', please look for replacement L3 I am not sure what you mean by 'newly introduced water', can you be more specific? L19 do you have a reference example to associate with: 'Traditionally, streamflow generation has often been assumed to be driven by spatially diffuse groundwater exchange often released at a constant rate.'? pg 4 L20: could cite here the hydrographs shown in Ploum et al 2018 L24: you would not consider the fall period to be 'baseflow' dominated as well or is this just a winter condition in your watershed system? Pg 7 L13: replace 'double as high'

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