Reviewer comments for:

Seasonally varied hillslope and groundwater contributions to streamflow in a glacial till and fractured sedimentary bedrock dominated Rocky Mountain watershed.
Spencer et al.
In Hydrology and Earth System Sciences

Overview

This is an interesting research manuscript with well-defined objectives of using EMMA to understand relative variation in stream water sources in forested and alpine watersheds of the Canadian Rocky Mountains. Overall the manuscript is sound and has relatively minor grammatical errors. However, it is suggested that the introduction and discussion sections more clearly identify the secondary objectives and how the study . It is unclear if the results of this study have a primary goal of improving understanding of the variability between different groundwater sources of (e.g. bedrock groundwater vs. glacial till groundwater) in alpine and sub-alpine watersheds, or to understand/predict how future forest disturbance will impact watershed hydrology and runoff generation.

It is suggested that the study site description be expanded to more clearly quantify the size and extent of surface and sub-surface biological and geological features (talus slopes, alpine areas, glacial till, forested areas, riparian areas, etc.). It was hard to determine where and why the division of upper and lower sub-watersheds was chosen for this study and how that division was critical to addressing the question of the impacts of forest disturbance on hydrologic disturbance. Both upper and lower sub-watersheds had forested areas so the separation of upper and lower sub-watersheds did not appear to be a proxy for forested vs unforested/disturbed areas.

Secondly, the discussion and conclusion sections should be expanded to more clearly indicate how the results in this study advance or improve the scientific understanding of "how forest disturbance may impact streamflow quantity". It is unclear if the study was able to confirm or reject the hypothesis stated in the abstract that "slow release of groundwater from glacial till" (line 24) generates "hydrologic resilience" in the Rocky Mountains?

Line 18:
Suggest defining "old water" as related to time the water has spent in the watershed rather than the true age of water.

Line 20:
In Star east in September and October the stream water was unlike the sources. What is the additional source or is it a mixed signal?

Same statement is in the conclusion but the proposed explanation of the “missing” sources is either absent or not clear in the conclusion. Clarification would be helpful.

Line 29:
What is the specific reference for beetle infestation? A few Studies from the Rocky Mountains to consider reviewing,

Pugh & Small, 2011.
https://doi.org/10.1002/eco.239

Bearup *et al*., 2014.
https://doi.org/10.1038/nclimate2198

Line 53:
Consider reference of Cowie *et al*. (2017) here as that study does use EMMA to examine potential source waters from bedrock groundwater, glacial till groundwater, talus slope water, and soil water on streamflow contributions in forested and alpine watersheds in the Rocky Mountains.

Line 77:
Define area weighted precipitation. Was precipitation measured at multiple elevations? With > 1000m elevation change how much does the total precipitation change over that gradient? One suggestion is use of a hypsometric curve to distribute precipitation over elevation (see Cowie et al., 2017)

Line 78:
Please cite the precipitation and % snow. Is this from the same study (Spencer et al., 2019) which is cited in the discussion in reference to the sub surface storage capacity of the watersheds?

Line 83:
“Talus slopes” Please expand this description to include more information on the relative size of this geographic feature in the upper watersheds. Previous studies of source waters to alpine watersheds in the Rocky Mountains (suggested references listed below) indicate that talus slopes and underlying features can be significant source water areas.

Is there any information or indication of permafrost, ice lenses, or rock glaciers in the alpine talus areas that could provide a unique source water?

Caine, N, 2010. Recent hydrologic change in a Colorado alpine basin: an indicator of permafrost thaw?
https://doi.org/10.3189/172756411795932074

Clow, D. W., Schrott, L., Webb, R., Campbell, D. H., Torizzo, A., and Dorblaser, M.: Ground water occurence and contributions to streamflow in an alpine catchment, Colorado Front range, Ground Water, 41, 937–950, 2003.

Hood, J. L., Roy, J. W., and Hayashi, M.: Importance of groundwater in the water balance of an alpine headwater lake, Geophys. Res. Lett., 33, L13405, doi:10.1029/2006GL026611, 2006.

Roy and Hayashi, 2009. Multiple, distinct groundwater flow systems of a single moraine-talus feature in an alpine watershed.
https://doi.org/10.1016/j.jhydrol.2009.04.018

Williams et al., 2006. Geochemistry and source waters of rock glacier outflow, Colorado Front Range.
https://doi.org/10.1002/ppp.535

Line 86:
Can the amount of glacial till deposits be estimated or quantified for the sub-watersheds? There is no indication of spatial extent beyond description on line 80. It would help the reader to understand the potential storage capacity of the till especially since till water was excluded as a potential source water due to sampling well contamination (line 181). One suggestion is moving the citation on line 444 (AGS, 2004) to section 2 study site description and elaborating on the description of the “spatially heterogenous surficial deposits…” to help describe the watershed(s) in more detail.

Line 95:
Figure 1. It would be helpful to define tree line (separation of alpine from forested area within the sub-watershed. Important because the paper is framed as a study related to “forest disturbance” so the alpine portion of the study areas should be clearly separated from the forested areas.

Also please add the locations of the seeps that were sampled and used as potential end members in EMMA.

Line 125:
Snowmelt collection methods. Perhaps expand explanation of the snowmelt sample timing in order to reduce known uncertainty of changes in snowmelt chemistry related to timing of the melt. There is a known ionic pulse at the initiation of snowmelt (see Williams et al., 2009), which can be followed by dilute meltwater.

Are there any occurrences of dust on other impurities in the snowpack in this region which could impact the snowmelt chemistry or the timing and magnitude of snowmelt? Dry deposition was mentioned for rain water collection (line 121) but not for snowmelt.

Line 171:
Is the data from the Hobo sensors used in this paper? If not then this method does not support the paper and should be removed.

Line 274:
Bedrock groundwater, “excluded as a source at the upper sites”. Please explain how the groundwater seep used in SEU (line 313, figure 8b) was classified as having consistently cool GW temperatures, but was not considered to be a “bedrock groundwater source”?

Line 276:
Suggest replacement of “a couple samples” with a more quantitative description.

Figures 5-8:
Suggest a more detailed explanation of the hysteresis present in the stream water samples. One option is to place the day of year (DOY) on each sample so readers can decipher movement within months which are plotted as one color. For example in figure 7A are the September samples temporally migrating in the mixing space or are sample points randomly distributed?

Figures 7 and 8
SEU and SEL both appear to have an unidentified source water in October as the October samples plot further away from the identified potential end-members. A more detialied interpretation of this observation is recommended for the discussion?

Line 325:
Section 5.3
It is understood that you were not able to sample in the winter, however you state that sampling stopped “before fall rains” (line) in previous section and in this section the “end” of seasonal sampling is stated as “start of the next year’s snow accumulation period” (line 326). Just want to be clear on the terms used to describe the end of seasonal study periods.

If precipitation is lumped by rain and snow how do you know which form of precipitation is influencing stream flow in which season? For example line 342, the stream is “more similar to precipitation in June and July” Is this recent precipitation from rain or assumed to be the lagged input of snowmelt from the previous winter?
What would be helpful is a hyetograph over the study period so reader has some better sense of when the annual precipitation occurs. Also is there a way to present the timing and magnitude of snowmelt? Figure 10 suggests that there are multiple snowmelt pulses in winter and spring, can this be elaborated in the description of site climate and hydrologic inputs?

Line 399:
“increases the concentration in water” should be “increases tracer concentrations in the soil water..” if you are speaking about the inverse of water chemistry “dilution” from snowmelt.

Line 429:
Please clarify "increases in stream water chemistry" to specify that you are speaking about tracer concentrations or "concentration of stream water ions" (line 450). Consistent terminology will help the flow of the manuscript.

Line 457:
Please provide citation for this statement "Excess water associated with forest disturbance would infiltrate into the subsurface". These assumed hydrologic dynamics should be discussed in more detail because there is potential for a varying hydrologic response from forest disturbance.
For example, in a forested snowmelt dominated watershed the timing and magnitude of snowpack accumulation and ablation in relation to canopy cover/density dynamics may be variable depending on forest dynamics.
Sublimation rates on canopy snow interception (see Classen and Downy, 1995), and impacts of forest shading on radiative forcing on snowpack ablation could influence infiltration rates.

I would also suggest mention of rainfall intensity relative to infiltration capacity in forested vs alpine or disturbed areas.

Recommended references to review

Molotch *et al*., 2009. Ecohydrological controls on snowmelt partitioning in mixed-conifer sub-alpine forests
https://doi.org/10.1002/eco.48

Harpold *et al*., 2014. Soil Moisture response to snowmelt timing in mixed-conifer subalpine forests.
https://doi.org/10.1002/hyp.10400

Musselman *et al.,* 2012 Influence of canopy structure and direct beam solar irradiance on snowmelt rates in a mixed conifer forest.
https://doi.org/10.1016/j.agrformet.2012.03.011

Line 475:
Figure 10 caption revision. Second sentence is an interpretation of the graph rather than a description and should be included in the text. Recommend clarifying text description of "more responsive" and "slower recession slopes" in reference to depth to groundwater below the surface.

Figure 10: In the soil/till GW, what causes the sharp response (increase in water table elevation) in November? Is this related to early season snowfall that melts or other factor such as vegetative senescence? Does the chemistry change in that water source in late fall?

Can you explain the two separate groundwater level increases in the till well that occur in February and then again in March/April? Is this related to intermittent snowpack throughout the winter (as briefly mentioned in the snowmelt sampling methods line 125)?

Line 480:
Replace “old water” with a more accurate description representative of transit time or sub-surface residence time rather than speaking to the age of the water, or define old water to mean “reacted” waters that have had extended contact time with the sub-surface (see Liu *et al*. 2004) The same suggestion was made previously for defining the use of “old water” in the abstract.

Line 485:
Indicates that till groundwater could be slowly released to the stream (longer recession in Figure 10). It is not clear if the intention was to suggest that this could be the unidentified source water end member in late fall in Star East, but was not was not captured or used in EMMA due to experimental design issues leading to well contamination?

Line 486:
Please expand the conclusion/suggestion that till groundwater (although not used as an end member for EMMA) has the potential to mute the effects of disturbance on peak flow. I assume you are referring to forest disturbance, but it is not clear of the locational relationship between till groundwater sources and forested areas within the watersheds. Is the till groundwater believed to be sourced from direct overhead recharge (in the same location as currently existing forests)? or is there another hypothesized mechanism of recharge such as mountain block recharge from higher alpine regions already void of forest cover?