Anonymous Referee #1

“Climate change and climate-driven disturbances in the San Juan River sub-basin of the Colorado River” submitted by Bennett et al. addresses the timely and important question of the interrelated influences of vegetation and climate change on a Colorado River headwater’s system. I found the title to be appropriate and the abstract to represent the discussion presented in the manuscript. While I generally agree that vegetation dynamic may present an important complication to modeling future climate states, I feel the authors did not clearly explain the mechanisms driving the modeled change or thoroughly fit their work into a greater body of growing literature as summarized in my general comments below.

1. The vegetation properties and dynamics are not clear, particularly for a reader that is not familiar with the dynamic vegetation processes in Earth Systems Models (ESMs). The authors should provide additional details on how vegetation dynamics are modeled in the ESMs used here, as well as in the VIC simulations of vegetation change. This description should include the range of relevant vegetation parameters for each scenario/land cover classification (LAI, coverage, etc.) Ultimately, this discussion should also support a better description of the mechanisms behind the modeled hydrologic change. For example, the authors state that LAI values are similar between shrubs and forests (pg 10 ln 16), and that the changes in water and energy balances are therefore related to changes in snow processes. LAI is known to have a strong control on snow processes, so in the absence of LAI differences, the authors should explain what physical vegetation characteristics are driving these changes.

Response: This critique appears to apply both to ESMs in general, and to VIC as employed in this study. Regarding ESMs in general, we have now added an additional paragraph discussing the limitations of current ESMs and their dynamic vegetation processes on page 4. As we mention in the manuscript and now repeat in the newly added text, the ESM vegetation changes we include in this study are limited because the limitations within ESM projections of vegetation dynamics. This is why we include a second approach (McDowell et al., 2016) to estimate future changes to vegetation.

Regarding the range of relevant vegetation parameters for each scenario used in VIC, we now include, in addition to LAI being a panel in Figure 4, a description of the average forest and shrub fractions under each scenario and LAI, albedo and canopy fraction for average forest and shrub as Table 3 in the manuscript. The way in which we modified forests within the VIC model meant that we only changed the fraction of the forests in each grid cell, as described in the Methods section 3.3. LAI, albedo and canopy fraction values do not change through the scenarios, but as LAI, for example, is different cell-by-cell for shrubs versus forests, different values are applied when the model is run using different fractions of these land cover types.

Regarding LAI values being similar between forests and shrubs for the forested regions of the watershed (greater than 50% forest cover). The MOD15A2 (Myneni et al., 2002; Schaaf et al., 2002; Huete et al., 2002) data product, which is what our Leaf Area Index estimates are based on, provides shrub LAI values that are similar to forests. Note that this isn’t an issue if we were to examine the entire San Juan River basin as a single unit, for instance. In that case, the LAI for shrubs is approximately half or less than that of the forests. As LAI isn’t changing very much in our scenarios, the main differences between forest and shrublands is (a) overstory vs. no overstory, (b) deeper root depths, and (c) differences in sensitivity of stomatal resistance to solar radiation and sensitivity of canopy resistance to LAI. These are all vegetation library parameters. We think (a) is the most important of these, as overstory is what creates canopy snowpack, which has a big impact on how long it takes the snowpack to melt. We describe these physical changes leading to streamflow shifts on page 11. However, this may be a model weakness that is worth noting in the paper and we have done so in the updated Discussion section of the manuscript.

2. The authors failed to cite a substantial number of recent references on vegetation and climate change in the Rocky Mountains, often relying on references from other regions such as Canada and Alaska. The differences in aridity and evaporative demand suggest regional references are more appropriate. (For example see Pribulek et al 2016 and Carroll et al. 2017 for additional modeling studies on vegetation and climate change effects on hydrology using more integrated modeling approaches, Penn et al. 2016 for a modeling study of the effect of vegetation change across scales, Livneh et al. 2015 for another bark beetle modeling study that shows muted streamflow effects with regrowth, and Bearup et al. 2016 for a paper on vegetation effects on changes in streamflow partitioning). These references may also help to support a discussion on the importance of groundwater and evapotranspiration in this system and across scales.

Response: We have added the following references to the manuscript as suggested by the reviewer. We have added text and cited Livneh et al. 2015 on page 3, lines 23-24. We have also added the recently released Buma et al. 2017 to this paragraph as per comments by Reviewer #2. Bearup et al. (2014 and 2016) were added to the same paragraph and in Section 2 of the paper. Penn et al. 2016 was added to the Introduction and also presented in Section 2 and the Discussion. Pribulek et al. 2016 and Carroll et al. 2017 were cited in the Discussion section. One important point to note is that this paper is focused on a study of landscape change and disturbances (drought, forest forests, pests) under climate change. As such, there are a number of fundamental differences in this study in comparison with previous work, the most important difference is time scale. In this work, we consider the time scale of multiple decades and thus we account for replacement of *forests with shrublands* occurring in these watersheds. As we note, this regrowth dominates streamflow response. Our other main point is that there are important scalar effects occurring when considering the watershed response to impacts by forest cover disturbances; these scalar effects are related to the amount of forest impacted in relation to other land cover types in the basin and the size of the basin. We have altered the manuscript to make these points more clearly and used the above citations to support the points. Please see revised version of the manuscript.

Technical Corrections:
Pg 4 Ln 16-18: Check section numbers

Response: Thank you, we have corrected the section numbers where they were incorrect.

Pg 7 Ln 10-13: At what timescales are the model results and observations compared for calculation of NSE? Hourly?

Response: We have added in “monthly” to the sentence to indicate the simulated-observed calibration/validation periods. Only monthly naturalized streamflow data is available for calibration and validation hence this is the time scale we calibrated for. The caption of Table 1 has also been edited to make it clear that monthly data was used.

Figure 3: It is not clear what the light gray shading is or why there is a gap in the dark grey shading near peak streamflow (i.e. late April).

Response: We thank the reviewer for this comment and the attention to detail. We have removed the light grey shading background to make it clearer and changed the legend in this figure to indicate that the envelopes of color represent the range of results across ESMs. We have also updated the caption of this figure appropriately.

Figure 3 Caption: Clarify if historical period is from model runs or observations (throughout). Response: Thank you. We have changed the legend to read “simulated historical”.

Figure 4: It would be interesting to see how rain and snow is partitioned differently due to temperature change in these scenarios, either here or in another figure. Also, the axes units are not provided.

Response: This is an interesting comment. We did not output separate rain and snow simulation results and thus we would need to rerun all our simulations in order to answer this question. However, we do believe that mid-winter warming events or rain-to-snow transitions are occurring under future scenarios in the San Juan River basin and this is the focus of alternate work on climate change impacts we are pursuing. However, the focus of this study is on the vegetation scenarios versus climate change signals, and since all scenarios have the same four climate model inputs, all scenarios have the same partitioning of snow/rain. Therefore, this is not a contributing factor to the differences between the simulations we are exploring in this manuscript. Thus, we have not altered Figure 4 panel a to add in partitioning of precipitation between rain and snow. We have added axes units to the panel titles.

References:

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Bearup, L.A., Maxwell, R.M., Clow, D.W. and McCray, J.E., 2014. Hydrological effects of forest transpiration loss in bark beetle-impacted watersheds. Nature Climate Change, 4(6), pp.481-486.

Carroll, R.W., Huntington, J.L., Snyder, K.A., Niswonger, R.G., Morton, C. and Stringham, T.K., 2017. Evaluating mountain meadow groundwater response to Pinyon-Juniper and temperature in a great basin watershed. Ecohydrology, 10(1).

Livneh, B., Deems, J.S., Buma, B., Barsugli, J.J., Schneider, D., Molotch, N.P., Wolter, K. and Wessman, C.A., 2015. Catchment response to bark beetle outbreak and dust on-snow in the Colorado Rocky Mountains. Journal of Hydrology, 523, pp.196-210.

Penn, C.A., Bearup, L.A., Maxwell, R.M. and Clow, D.W., 2016. Numerical experiments to explain multiscale hydrological responses to mountain pine beetle tree mortality in a headwater watershed. Water Resources Research, 52(4), pp.3143-3161.

Pribulick, C.E., Foster, L.M., Bearup, L.A., Navarre-Sitchler, A.K., Williams, K.H., Carroll, R.W. and Maxwell, R.M., 2016. Contrasting the hydrologic response due to land cover and climate change in a mountain headwaters system. Ecohydrology, 9(8), pp.1431-1438.

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Huete, A., Didan, K., Miura, T., Rodriguez, E. P., Gao, X., and Ferreira, L. G.: Overview of the radiometric and biophysical performance of the MODIS vegetation indices, Remote sensing of environment, 83, 195-213, 2002.

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Myneni, R. B., Hoffman, S., Knyazikhin, Y., Privette, J. L., Glassy, J., Tian, Y., Wang, Y., Song, X., Zhang, Y., Smith, G. R., Lotsch, A., Friedl, M., Morisette, J. T., Votava, P., Nemani, R. R., and Running, S. W.: Global products of vegetation leaf area and fraction absorbed PAR from year one of MODIS data, Remote Sensing of Environment, 83, 214-231, http://dx.doi.org/10.1016/S0034-4257(02)00074-3, 2002.

Schaaf, C. B., Gao, F., Strahler, A. H., Lucht, W., Li, X., Tsang, T., Strugnell, N. C., Zhang, X., Jin, Y., and Muller, J.-P.: First operational BRDF, albedo nadir reflectance products from MODIS, Remote sensing of Environment, 83, 135-148, 2002.