

Interactive comment on “Influence of multi-decadal land use, irrigation practices and climate on riparian corridors across the Upper Missouri River Headwaters Basin, Montana” by Melanie K. Vanderhoof et al.

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Response to Comments

Manuscript: Influence of multi-decadal land use, irrigation practices and climate on riparian corridors across the Upper Missouri River Headwaters Basin, Montana

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Reviewer #2:

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Line 28: would be helpful to specify what “non-center pivot irrigation” includes earlier in the paper (perhaps including in the abstract). There is some discussion of this on lines 321-325. Response: We revised the abstract and no longer use the term non-center pivot irrigation until the Methods section. In the methods section we now expand our description to specify “(e.g., gravity-fed, non-center pivot sprinklers such as tower sprinklers, solid set and permanent sprinklers, side roll, big gun or traveler, or hand move sprinklers)”...

Comment: The lack of distinction between gravity fed irrigation and non-center pivot sprinkler irrigation seems significant. Authors should indicate what is known about the efficiency/consumptive water use rates of non-center pivot sprinkler vs. center-pivot vs. flood. It is my understanding that non-center pivot sprinkler would be much more similar to center-pivot (than to flood) in terms of efficiency/consumptive water use. If non-center pivot sprinkler is not separated out from flood irrigation, authors need to be very clear and specific about what this study tells us about flood/gravity fed irrigation. Response: In response to this comment we added to the Methods that, “Because this irrigation infrastructure was not visible in the Landsat imagery, we did not attempt to distinguish gravity-fed irrigation from non-center pivot sprinkler irrigation. Consequently the datasets as created enabled us to quantify changes in irrigation extent and shifts toward center-pivot irrigation. It did not allow us to make estimates of water consumption or quantify shifts from gravity-fed irrigation to non-center pivot sprinkler irrigation.” We also added a paragraph to the Discussion to directly respond to this comment: “One source of uncertainty in our analysis is that at the Landsat scale we were unable to confidently distinguish gravity-fed irrigation from non-center pivot sprinkler irrigation, methods of irrigation that can be expected to show different rates of water efficiency. This source of uncertainty made it difficult to reach definitive conclusions about reach-scale changes in the consumptive water use using our data alone. However, our assumption of a transition away from gravity-fed irrigation and towards center-pivot irrigation is consistent with other comparable sources of data. Across Montana the FRIS surveys (1984 and 2013) documented an increase in the fraction irrigated with center

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pivot from 9% to 30%, a decrease in the fraction irrigated with gravity-fed irrigation from 77% to 57%, and a minimal change (<3%) in the fraction of agriculture irrigated with non-center pivot sprinklers (USDA, 1985, 2014). Across the UMH Basin, the Montana Department of Revenue's Final Land Unit Classification (FLU) surveys documented a 17% increase in center-pivot irrigation and a corresponding decrease in both sprinkler and gravity-fed irrigation between 2010 and 2017. Despite these ancillary datasets, however, it is possible that shifts from gravity-fed irrigation to non-center pivot sprinkler irrigation, have also contributed to changes in return flow and riparian condition."

Line 50: what is "ditching"? Please re-phrase or clarify Response: We revised this to "drainage and water diversion ditches".

Line 129-131: These citations might be as good or better to make the point that there is increased interest in river resiliency: Montana Drought Demonstration Partners, 2015: A Workplan for Drought Resilience in the Missouri Headwaters Basin: A National Demonstration Project. http://dnrc.mt.gov/divisions/water/management/docs/surface-waterstudies/workplan_drought_resilience_missouri_headwaters.pdf (Accessed May 20, 2019).

Montana DNRC, 2014: Upper Missouri Basin: Water Plan 2014. http://dnrc.mt.gov/divisions/water/management/docs/state-water-plan/uppermissouri/river-basin-plan/upper_missouri_basin_report_final.pdf (Accessed May 29, 2019). Montana DNRC, 2015: Montana

State Water Plan: A Watershed Approach to the 2015 Montana State Water Plan. 80. The citation for McEvoy et al 2018 which is used later in the paper also supports this point – specifically for UMH - and summarizes the goals of the MT Drought Demonstration Project Table 2 & Lines 225-228. Response: We agree, the citations suggested are a better fit to justify this sentence than the original citations. We have replaced the citations as recommended.

Comment: As a social scientist familiar with the issue and study region, my strength

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is not in the technical aspects of remote sensing or hydrology, so please take this comment/question with a grain of salt. I am a bit confused as to why authors report the "average NDWI" and "average NDVI" in table 2 given that they are more interested in trend over time (not average). The text on lines 225-228 perhaps explains this – but the paragraph focuses on the per summer "anomaly" rather "average". Also this text does not refer back to figure 2. Greater explanation of why authors report the average in Table 2 would be helpful. In general, the description of the use of the anomaly seems more complicated than it needs to be (?). Response: Table 2 was meant to provide an overview of reach-specific characteristics. Inherent spectral differences between reaches could contribute to our understanding of why we might see variability in the trends between reaches. We have added this sentence in response to this comment. "Reach-scale average NDVI and NDWI values were provided to give a sense of the reach-scale variability in spectral characteristics (Table 2)." In response to the second part of the comment, NDVI has been much more widely used relative to NDWI for the analysis of riparian areas. For this reason we felt it was important to justify our decision.

Lines 321-325: please see my earlier comment re: lack of distinction between non-center pivot sprinkler and flood irrigation. Authors should include a comment on line 325 about whether/how this lack of distinction affects the results – and more importantly what it allows the authors to conclude about flood/gravity fed irrigation practices. Response: Please see the responses above and the text added to the Methods and Discussion sections. We also note that we substantially revised how the ancillary agriculture datasets are presented so that the statistics can act in direct complement to the data generated within this study.

Line 328: the use of the "̂" symbol in "NDWI ̂ Year" is not clear to me. If the use of "̂" is standard in the field, then ignore my comment, otherwise please specify what that means. This comment might be related to my previous comment about use of "average NDWI" and "average NDVI" in Table 2 and the explanatory text re: use of "anomaly" on Lines 225-228. Response: We have removed the symbol "̂" for

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increased clarity.

Line 374: the phrase “differences in agriculture” seems to be missing a modifier or unit. Is it difference in “agricultural area” or in “agricultural practices”? Please specify what this difference is within agriculture that is referred to. Response: We deleted this sentence as we found it a bit out of place here.

Line 515: the phrase “total amount of agriculture was relatively stable” – should specify the ag unit authors are referring to (I assume this is acres of land in agricultural production? But could be ag output/yield, which could mean an increase in ag productivity on same amount of land or stable output, but on fewer acres). Response: We revised this to specify hectares of land in agricultural production. We also want to note that we caught an error in that the percent change in irrigated area had been mistakenly calculated from the accumulated irrigated area, not the per-reach irrigated area. When we calculated the change correctly we found a 10.5% increase in irrigated area. We added a secondary source to the Discussion that found at the state level an increase of 19% in total hectares of irrigated area over a similar period.

Line 554: same comment as above for phrase “decrease in total agriculture over they study period” – specify unit of ag (acres? Or production/output/yield?) Response: We revised this to “total hectares of irrigated agriculture”. We did not attempt to calculate product, output or yield, just total area growing crops.

Line 667 – same comment “..total amount of agriculture [add units]” Response: We revised to avoid the term “total amount” throughout and instead specified “hectares”.

Line 519-520: Would be helpful if authors can explain how center-pivots get implemented on the ground. If center pivots increase by 506%, but non-center pivots only decrease by 39% where are these newly added center pivots going? Are they not replacing non-center pivot? Are they replacing flood irrigation at a rate of greater than 1:1? Are they being added to newly expanded agricultural fields (this is not allowed under MT DNRC’s water rights laws, which require irrigators to specify place of withdrawal

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– and specifies that there should not be an expansion of irrigated acreage when irrigators switch to new irrigation system – though this most certainly happens.) Response: In response, we changed the way the irrigation statistics were presented to improve clarity. So percent change, of course, depends on the value you started with ($\text{percent change} = (\text{post} - \text{pre}) / \text{pre} * 100$) and because there was very little center pivot irrigation in the mid-1980s our percent change values were large. We now specify the total number of ha and present the relative percent of center pivot and non-center pivot. So center-pivot irrigation went from 9% of irrigated area (8961 ha) to 50% of irrigated area (54,295 ha). We saw primarily conversion from non-center pivot to pivot irrigation, but we also observed land changing from not actively cultivated to center-pivot irrigation. Particularly along the Gallatin River.

Figure 7: I believe the headings in c&d should read “Change to reach-scale pivot irrigation” (not “agriculture”). Response: Caption changed as recommended.

Figure 7: use of term “built-up” and “building area” in both figure and the associated text is confusing. I assume authors are referring to urbanization, but that is not clear. Response: The dataset is called “built-up intensity” which is defined as the summed building area at 250 m resolution. We modified the caption to best match the language used in the figure.

Line 618: why use the word “crop management”? I expected authors to state: “complexities of ag water use and irrigation practices (or C3 methods)”. In my mind, “crop management” refers to things like change which type of crop is grown, fallowing, use of cover crops, timing of planting and harvesting, etc. Response: Wording was changed as recommended.

Line 636: phrase “total water-use for irrigation across the US” should be more specific. Following Perry et al’s 2017 recommendation, authors should specify whether they are referring to water withdraws or water consumption (the following discussion illustrates this point using ET, but it seems like the authors could be more careful/specific with

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their use of the word “water-use” in line 636. Response: This is a good point. We used “total water use” because this was the term used to label the data in the graph in Schaible (2017). To clarify we used the figure caption which specified “total water applied for irrigation”

Line 670: “water use” – again, authors should be more specific. Is this “water with-draws”? or irrigation methods? Or general water use – if so, specify some examples of what this includes Response: We removed the term “water use” here.

Line 636-650: Perry et al 2017 make this same point at the global scale. Seems like their paper should be cited in this part of the discussion. Response: We added references to the Perry et al. (2017) paper to this paragraph.

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