Reviewer Responses to HESS comments re:

Leveraging a time-series event separation method to untangle time-varying hydrologic controls influence on wildfire disturbance on streamflow

**The comments from HESS and the reviewers are in black and our responses in blue.

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Reviewer 1

General Comments

The study from Canham et al. explores the time-varying hydrological controls on 5042 rainfall-runoff events from 9 western US watersheds, with aiming to untangle the influence of wildfire on streamflow. The paper is well-crafted, with the supporting data and text well recorded in the supplementary file. However, my main concern is that I think the focus of this paper should be on exploring the influence of wildfire on streamflow. Given that there are already lots of studies focus on rainfall-runoff event separation method or large sample events temporal-spatial controls investigation. Thus, the novelty of this paper should be exploring the wildfire influence on streamflow. Yet, the current paper structure contains large proportion of text describing event separation and also the controls for undisturbed events. So, I think the structure of the paper should be adjusted to highlight your contributions on untangling the wildfire impact on streamflow. My detailed comments can be found below. By the way, I was accidently uploaded my review comments as community comment before. Just ignore the community comment.

Thank you for taking the time to review and provide comment. We value your suggestions regarding the focus of the paper within the general comment and additionally noted within specific comments 9 and 11.

Our paper that you reviewed attempted to both perform a large sample hydrologic analysis of time-varying controls with a new event separation method and to assess the wildfire influence on streamflow. As the reviewer alluded to, this seems to be too much to accomplish in a single paper. However, we respectfully disagree with the reviewer's suggestion that large sample rainfall-runoff events temporal-spatial controls have been well established. A better understanding of hydrologic controls is needed in the context of an increasing disturbance regime (lines 33-40). Furthermore, there remain several identified limitations of existing rainfall-runoff event separation methods highlighted in our paper that the RREDI toolkit seeks to address. To the authors knowledge there has only been a single large sample event analysis evaluating rainfall-runoff controls in the USA as described on lines 61-63, and there is no known western USA specific study. Thus, the authors feel that the RREDI toolkit is a novel event separation method that merits detailed coverage and performance assessment prior to applying it to watershed disturbance analysis. Specifically, the study addresses a need identified by Giani et al. (2022b) to use time-series signal processing to increase transferability across watersheds, and addresses several issues that have been limiting in other studies as described on lines 442-459. Thus, we have re-focused the aims of this paper, as defined on lines 71-74, to: (1) describe and evaluate the performance of a novel time-series event separation method, and (2) apply this method to investigate the influence of time-varying hydrologic controls on event runoff response. Then a second paper will be written to specifically tackle the wildfire influence on streamflow. Therefore, in this revision, we instead *reduced* the focus on wildfire impacts on streamflow in the Introduction, Study Area and Discussion sections and consolidated the application to wildfire disturbances to sections 3.4 *Statistical assessment in wildfire disturbed watersheds*, 4.3 *Hydrologic variability in wildfire disturbed watersheds*, and 5.3 *Hydrologic variability in wildfire disturbed watersheds*. The wildfire disturbed portion of the paper now focuses on two burned case study watersheds leveraging what had been learned in questions 1 and 2 to investigate question 3. There, we briefly demonstrate how accounting for the identified significant time-varying controls could then facilitate an evaluation of the influence of the wildfire disturbance. This sets us up for a second paper focused on wildfire effects on rainfall-runoff patterns, which the reviewer (and the authors) have identified as another novel contribution of this research.

Specifically, in this re-framing of the manuscript, we hypothesize that the observed variability in both rainfall-runoff and post-fire response could be a result of differences in time-varying hydrologic controls including water year type (WYT), season, and antecedent precipitation. To test this, we first evaluated how nine undisturbed study watersheds were influenced by these controls. We found that across the undisturbed watersheds, WYT and season were influential on the event runoff response. We then performed a more in-depth analysis in two burned watersheds, Arroyo Seco and Clear Creek to investigate how these influential controls may have obscured the post-fire rainfall-runoff response influence. We found that antecedent precipitation and seasons, respectively, may have obscured the post-fire streamflow response.

In summary, to address the general comment and specific comments 9 and 11, we have re-worked portions of the paper to separate the post-fire analysis from the large event sample assessment. We have refocused the analysis of the nine study watersheds on the hydrologic control exploration in undisturbed watersheds (research questions 1 and 2). We have more clearly separated and described the wildfire portions of the analysis in the methods, results, and discussion (created sections 3.4 *Statistical assessment in wildfire disturbed watersheds*, 4.3 *Hydrologic variability in wildfire disturbed watersheds*, and 5.3 *Hydrologic variability in wildfire disturbed watersheds*). We believe that these modifications bring better balance and increase the quality of the work while maintaining each novel portion of the research.

Specific Comments

1. Table1: It would be better to add hydrologic characteristics in this table for these catchments, i.e., mean annual precipitation, mean annual potential evapotranspiration, mean annual streamflow and also maybe the streamflow regimes that you mentioned in the line 120-123.

We have included the suggested characteristics including mean annual streamflow, precipitation, and potential evapotranspiration and streamflow regime to Table 1. Additionally, we have removed fire characteristics, see response to general comment.

Table 1: Watershed characteristics for the study watersheds. Where P is precipitation and PET is potential evapotranspiration.

Watershed	State	USGS Gage ID	Contributing area (km^2)	Streamflow (mean annual) ($m^2 s^{-1}$)	P (mean annual)* (cm)	PET (mean annual)* (cm)	Streamflow regime
Arroyo Seco	CA	11098000	42	0.27	79	777	Rain
Ash Canyon Creek	NV	10311200	14	0.10	76	479	Snow
Cache La Poudre	CO	06752260	2966	4.9	53	449	Snow
Camp Creek	CO	07103703	25	0.03	56	479	Snow
Clear Creek	UT	10194200	426	1.0	54	508	Snow
Shitike Creek	OR	14092750	57	2.2	157	492	Snow
Thompson River	MT	12389500	1652	12.1	76	476	Snow
Valley Creek	ID	13295000	376	5.7	88	401	Snow

Watershed	State	USGS Gage ID	Contributing area (km^2)	Streamflow (mean annual) ($m^2\ s^{-1}$)	P (mean annual)* (cm)	PET (mean annual)* (cm)	Streamflow regime
Wet Bottom Creek	AZ	09508300	94	0.39	62	780	Rain

*(Falcone, 2011)

2. Line 132: Can you explain what PRISM means?

We have added text to clarify what the PRISM dataset is and updated the citation. PRISM provides many different types of datasets, so we clarified that we used the gridded annual precipitation dataset for the study period in each watershed.

Lines 111-114: "The total annual precipitation at the centroid of each study watershed for each year with available USGS annual streamflow was retrieved from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) gridded annual precipitation dataset (PRISM Climate Group, Oregon State University, 2022)."

PRISM Climate Group, Oregon State University. (2022). *PRISM Climate Data*. https://www.prism.oregonstate.edu/

3. Line 240-242: why it needs to use two different statistical tests to evaluate the effect of WYT and season/antecedent precipitation respectively? In Figure 7, you compared their results in one figure, yet I'm not sure whether the results of these two methods are comparable or not?

We have updated the text to clarify the use of the two tests. The use of each statistical test as used here is appropriate, as the Mann Whitney U test is used to compare two groups while the Kruskal Wallis is used to compare between greater than two groups. The comparison as presented in Fig. 7 is appropriate because there is no direct comparison between results of the two tests as each remains within their respective hydrologic condition. The significance of the two tests were assessed at the same confidence level (line 247).

Lines 245-247: "The non-parametric Mann Whitney U Test was used to evaluate the effect of WYT between the two hydrologic conditions, and the non-parametric Kruskal Wallis Test was used to evaluate the effect of season and antecedent precipitation between three hydrologic conditions, all at a 95% confidence level."

4. Table 2: Does symbol # represent the number of events? If so, please clarify.

We have clarified the text in Table 2 caption as it pertains to this comment.

Lines 296-297: "Table 2: RREDI toolkit performance results including pre- and post-flagging rainfall-runoff event accuracy rates and pre- and post-flagging retention numbers (#) and rates across the study watersheds."

5. Line 289: How you selected these two contrasting watersheds? The explanation of why you selected these two watersheds as example is needed. Is that possible to compare the results between Arroyo Seco and Valley Creek (this one has similar characteristics with Clear Creek)? Or Maybe Arroyo Seco and Shitike Creek (this one has similar contributing area with Arroyo Seco)? Will the results you observed from Arroyo Seco and Clear Creek also apply to Arroyo Seco and Valley Creek?

To demonstrate the utility of the RREDI toolkit for applications analyzing large hydrologic datasets, we evaluated a suite of undisturbed time-varying hydrologic controls across nine study watersheds, and then performed a more in-depth exploration of watershed disturbance on rainfall-runoff events in two of our study watersheds: Arroyo Seco (CA) and Clear Creek (UT). These watersheds were selected first and foremost because they both experienced wildfires during the period of available streamflow record that burned a significant portion of the watershed (>25%) and with particularly high severity. Additionally, these two case studies provided an interesting comparison with respect to watershed characteristics, as they are an order of magnitude difference in area, are rain vs. snow-melt dominated (respectively), and have a four-fold difference in mean annual streamflow. We utilize the two burned watersheds as a case study for how the investigated hydrologic controls may be obscuring post-fire rainfall-runoff. We expect that the results from this study are transferable to other watersheds, regardless of the burned watersheds selected for the post-fire analysis as we conclude that these controls should be considered when isolating the influence of wildfire on rainfall-runoff patterns (lines 23-25). We have updated the statement within the results noting some results are only presented for the two case study watersheds. Additionally, we have included text within the methods to detail the selection of the two watersheds as case study watersheds for greater in-depth analysis. See response to general comments for more details on this.

Lines 80-100: "Nine study watersheds in the western USA were hand-selected to satisfy a wide range of watershed properties and streamflow regimes from those with streamflow data availability (Fig. 1 a). First, we identified western USA watersheds from the GAGES-II dataset (Falcone, 2011) with at least 20 years of continuous 15-minute streamflow data including at least 10 years of undisturbed streamflow including from wildfire (MTBS, 2023). The selected nine study watersheds spanned a large range of watershed characteristics (Table 1). The contributing areas ranged over three orders of magnitude, from 14 km^2 (Ash Canyon Creek) to 2,966 km^2 (Cache La Poudre River), with extents defined by the installation locations of the long-term USGS gauges. The mean annual streamflow ranged from 12.1 m^3s^{-1} in Thompson River to 0.03

m^3s^{-1} in Camp Creek. The mean annual precipitation ranged from 157 cm in Shitike Creek to 53 cm in Cache La Poudre River (Falcone, 2011) and the mean annual potential evapotranspiration ranged from 780 cm in Wet Bottom Creek and 401 cm in Valley Creek (Falcone, 2011). The watersheds included a range of streamflow regimes including seven snow melt dominated systems with average annual hydrograph peak dates between April and June and two wet season rain dominated systems with average annual hydrograph peak dates between January and February.

Two of the nine study watersheds were selected for a more in-depth exploration of watershed disturbance on rainfall-runoff events: Arroyo Seco and Clear Creek (Fig. 1 b, c). . These watersheds were selected first and foremost because they both experienced wildfires during the period of available streamflow record that burned a significant portion of the watershed (>25%) and with particularly high severity. The Station Fire (2009) burned 100% of Arroyo Seco (78% high and moderate burn severity) and the Twitchell Canyon Fire (2010) burned 25% of Clear Creek (15% high and moderate severity) (MTBS, 2023). Additionally, these two case studies provided an interesting comparison with respect to watershed characteristics, as they are an order of magnitude difference in area, are rain vs. snow-melt dominated respectively, and have a four-fold difference in mean annual streamflow."

Lines 267-270: "Additional statistical methods were performed on two burned study watersheds, Arroyo Seco and Clear Creek, to further explore the influence of wildfire disturbance relative to other time-varying hydrologic controls (Q3; Fig. 2). Arroyo Seco and Clear Creek were contrasting watersheds, with differing watershed characteristics, notably contributing area and streamflow regimes (Table 1) and burn characteristics (Fig. 1 b, c)."

6. Figure 6: Can you explain what negative values on the x-axis for volume, peak flow and response time mean?

Plotted values are representative of the natural log (ln) of the volume, peak, duration, and response time metrics. As such, values can be negative if less than 1. We have updated the figure so that this is noted appropriately in the x-axis labels. We have clarified this is the natural log transform in the Fig. 6 caption.

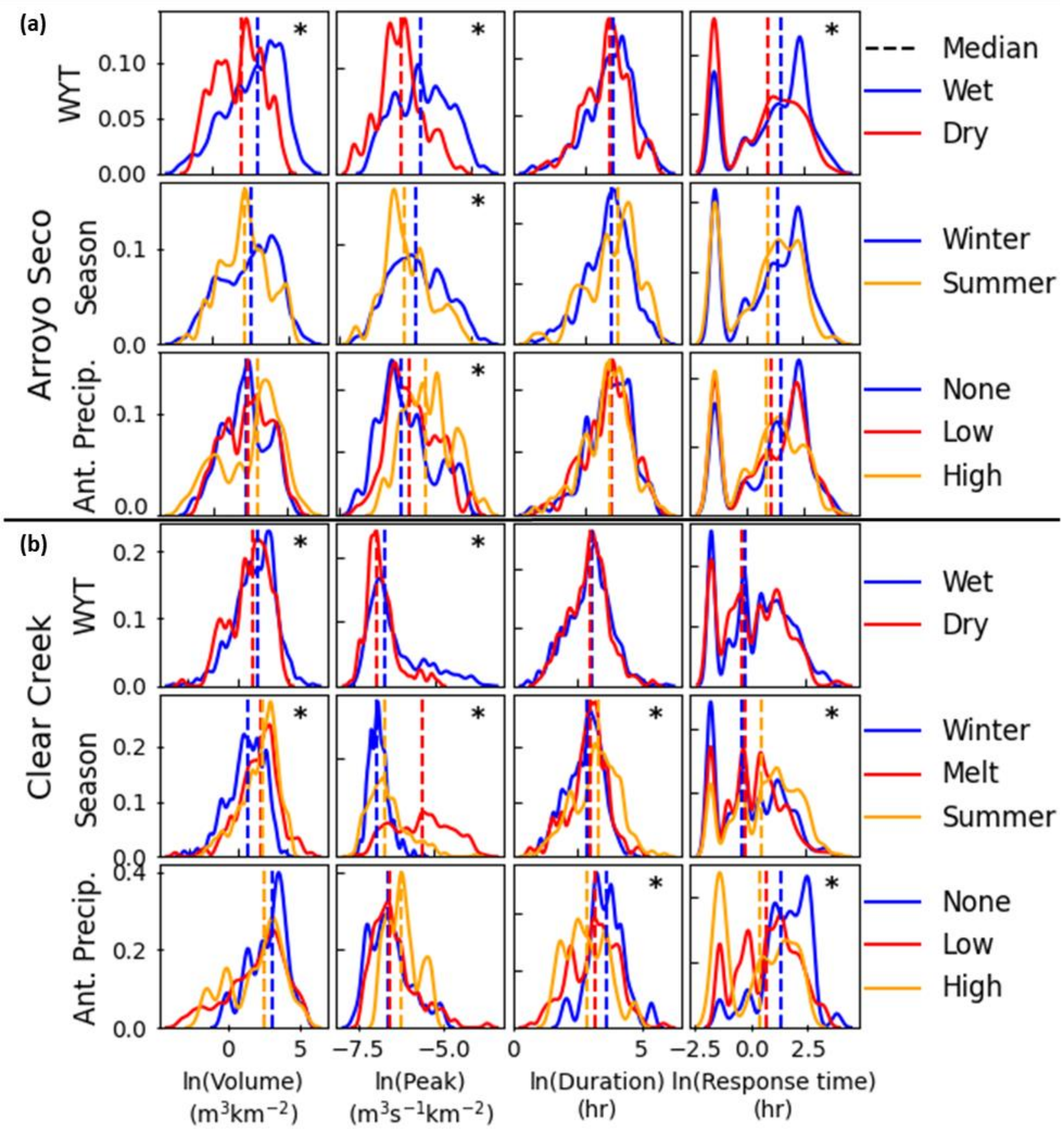

Figure 6: Undisturbed rainfall-runoff event KDE distributions for hydrologic conditions for natural log transformed WYT, season, and antecedent precipitation in (a) Arroyo Seco and (b) Clear Creek for four selected runoff metrics: volume, peak, duration, and response time. Distributions are colored by hydrologic condition. The median value of each distribution is shown (dashed line). Significant difference between distributions is indicated (*). Note there is no melt season in Arroyo Seco.

7. Line 329: How do you calculate this relative significance rates?

We have added clarifying text within the methods section to address this confusion.

Lines 253-265: “The statistical test results for all area-normalized metrics were summarized into relative significance rates for each of four runoff metric groups across and within study watersheds to highlight important hydrologic controls on event runoff response. The use of the relative significance rate reduced the issue of multiple comparisons and reduced the emphasis on specific metric calculation methods. Summarizing by area-normalized runoff metrics facilitated comparison between different sized watersheds while summarizing by runoff metric groups facilitated comparison between time-varying hydrologic controls. For each runoff metric group, the significance rate was calculated, either across all study watersheds or for an individual watershed, by dividing the number of significant rainfall-runoff event metrics (based on the Mann Whitney U or Kruskal Wallis test) by the number of metrics in the runoff metric group. When a single hydrologic condition (e.g., melt season) was identified as significant by the Dunn Test, the significance rate for this condition was similarly calculated by dividing the number of significant rainfall-runoff event metrics for the condition by the number of metrics in the runoff metric group. The relative importance of each time-varying hydrologic control was assessed by comparing the significance rates for each watershed and runoff metric group.”

Lines 355-259: “For example, in Arroyo Seco, the relative significant rate for the WYT runoff volume metric group was 100%, as two out of the two metrics within this group, runoff volume and runoff ratio (Table S3), were found to be significant by the Mann Whitney U Test (Table S7) while the significance rate for the runoff duration metric group with respect to WYT was 33% because only one out of three metrics was significant. The relative significance rate for the runoff duration with respect to WYT averaged across all nine study watersheds was 72%.”

8. Line 350: Can you re-phrase this sentence? It is a bit confused by ‘for in no metric groups’.

The paragraphs and figure 7 caption discussing the significance rates have been clarified to refer to differentiating of runoff event metric values across study watersheds with respect to hydrologic controls and the identified sentence grammar has been corrected.

For example, on lines 379-382: “In Arroyo Seco, no runoff metric groups were better differentiated with respect to season than the average significance across all watersheds (Fig. 7 b). Conversely, all runoff metric groups in Clear Creek were better differentiated with respect to season than across all watersheds (Fig. 7 c).”

9. The results section contains a large proportion of analysis on undisturbed rainfall-runoff events, while the analysis of wildfire impacts on streamflow is not sufficiently thorough. Only examples from two watersheds were presented. The focus of the paper should be on

wildfire disturbed streamflow. Adjustment of results proportions and focus of analysis is needed.

We have separated the wildfire portion of the results into a single, smaller section, "4.3 *Hydrologic variability in wildfire disturbed watersheds*". We think that this clarifies how RREDI and time-varying hydrologic controls can be used to assess wildfire disturbed streamflow patterns and brings balance to the results. Additionally, please see response to the general comment.

10. Discussions with more recent large sample rainfall-runoff events controls analysis should be added, i.e. Jahanshahi and Booij (2024) https://doi.org/10.1080/02626667.2024.2302420, Zheng et al. (2023) https://doi.org/10.1029/2022WR033226.

We highlight that there are a number of studies with large sample rainfall-runoff events that we have mentioned and cited in the paper. We appreciate the reviewer bringing our attention to these more recent additions to this body of literature, and we have added additional discussion regarding Jahanshahi and Booij (2024) and have added both to our general comments about these types of studies throughout the paper. We do not feel that any additional commentary above what has already been stated about these types of studies is necessary in the context of the present study.

Lines 507-510: "Past studies have found conflicting results in the significance of antecedent precipitation. Both 10-day antecedent precipitation (Merz et al., 2006) and antecedent soil moisture in Italy (Merz & Blöschl, 2009; Tarasova et al., 2018b) and 5-day antecedent precipitation in Iran (Jahanshahi and Booij, 2024) have been found to influence event runoff response.

Jahanshahi and Booij (2024) included on lines 48, 52, 54, 472, 490, 495, 497, 506, 513.

Zheng et al. (2023) included on lines 49, 51, 53, 61, 473, 491.

Jahanshahi A., Booij M. J. (2024). Flood process types and runoff coefficient variability in climatic regions of Iran. *Hydrological Sciences Journal*, 69:2, 241-258. https://doi.org/10.1080/02626667.2024.2302420

Zheng, Y., Coxon, G., Woods, R., Li, J., Feng, P. (2023). Controls on the Spatial and Temporal Patterns of Rainfall-Runoff Event Characteristics - A Large Sample of Catchments Across Great Britian. *Water Resources Research*, 59. https://doi.org/10.1029/2022WR033226.

11. In the discussion section, it should also have a separate subtitle and section focus more on the impact of wildfire to streamflow.

This comment appears to reflect the reviewer's general comment above. We have separated the wildfire portion of the discussion out to a separate section, "5.3 *Hydrologic variability in wildfire disturbed watersheds*". Additionally, we streamlined the "5.2 *Hydrologic variability*" section of the discussion to focus on the nine watersheds. For more detail, please reference our response to the general comment above.