Response to Reviewers' Comments

Dear Editor and Reviewers,

We sincerely thank the editor and reviewers for their careful evaluation and constructive comments. We have carefully considered all comments, including the detailed annotations provided in the marked PDF, and revised the manuscript accordingly. The revisions focus on clarifying the methodology, strengthening the quantitative synthesis of threshold indicators and mechanism transitions, refining the interpretation of runoff mechanisms and structural controls, and improving the clarity and conciseness of the manuscript.

Below, we provide a point-by-point response to each comment and describe the corresponding revisions made in the manuscript.

Response to Reviewer #1:

General comments:

The manuscript provides an interesting review of studies that have reported threshold runoff responses and links them to inferred runoff mechanisms and catchment characteristics. Although there have been several recent review papers on runoff generation mechanisms (e.g., by McMillan et al and Penna), this paper is a valuable contribution as it looks specifically at thresholds.

I reviewed the previous version of the manuscript and find it much improved. In particular the methods are better explained. The wording is more careful and considers the bias in the location of the studies and the dependence on the interpretation of the authors of the original studies. The over-interpretation of the results in the conclusion has been removed. However, there are still some blocks of repetitive text (see annotated pdf) that need to be streamlined. Some new parts of the new text appear to be a bit out of context or to be words of caution related to the previous text that is no longer there and thus feels out of place and either need to be rewritten or removed to make the manuscript easier to follow and shorter (see annotated pdf).

In addition to these editorial comments, I have a few minor comments regarding the title and figures.

Response:

We sincerely thank the reviewer for the careful re-evaluation of our manuscript and for the constructive comments. We appreciate the reviewer’s positive assessment that the revised manuscript has improved, particularly regarding the explanation of the methodology, the more cautious interpretation of the results, and the consideration of potential biases in the reviewed literature.

We agree that several sections still contained repetitive descriptions and that some cautionary statements introduced during the previous revision were no longer well connected to the surrounding text. In response, we carefully reviewed the annotated PDF and revised the manuscript to improve clarity and conciseness. Specifically, we:

(1) removed duplicated explanations of threshold definitions, mechanism transitions, and figure interpretation that appeared in multiple sections;

(2) streamlined the Results and Discussion by retaining detailed methodological definitions in the Methods section while focusing the Results on the main synthesis findings;

(3) moved figure-reading information and technical descriptions to figure captions where appropriate, avoiding repetition in the main text;
(4) removed or rewrote several cautionary statements that were introduced in response to previous comments but had become disconnected from the revised manuscript structure; and
(5) revised the title and figures following the reviewer's suggestions to improve clarity and consistency with the scope of the study.

Comment 1:
Title: The title is not really clear and doesn't fully cover the contents of the manuscript as the review did not collect data on connectivity and connectivity is "just" inferred. Furthermore "runoff threshold mechanism transitions" feels like a jumble of words or would mean something else. Consider changing it to something like: Runoff thresholds, runoff generation mechanism, and catchment characteristics: A global review
Response 1:
We agree. The previous title gave undue prominence to connectivity, which is used in this review as an interpretive framework rather than as a consistently measured variable, and the phrase "runoff threshold mechanism transitions" was unclear. Following the reviewer's suggestion, we have revised the title to:
"Runoff thresholds, runoff generation mechanisms, and catchment characteristics: A global synthesis."

Comment 2:
Figure 5: I suggest that the authors add an extra row that shows the distribution of climate classes for the catchments included in the database so that it is easier to interpret if the dominance of a certain climate for a specific runoff mechanism just reflects the bias in the distribution of studies or is a real indication that that process has been observed more frequently for catchments in that climate class.
Response 2:
We thank the reviewer for this helpful suggestion. We agree that the mechanism-specific aridity distributions in Fig. 5 should be interpreted relative to the overall climatic composition of the reviewed catchment database.
In the revised manuscript, we added an additional reference row showing the aridity distribution of all reviewed catchments in the database (n = 138). This allows direct comparison between the climatic composition of each reported runoff-generation mechanism and the overall sampling distribution of the reviewed literature. The revised figure therefore makes it easier to assess whether the apparent dominance of a particular climate class for a given mechanism mainly reflects the climatic bias of the compiled dataset or a relatively stronger representation of that mechanism in that climatic setting. We also revised the figure caption and the corresponding Results text to clarify that these patterns.

Comment 3:
Figure 8: Explain what the red circles are in the caption
Response 3:
We agree that the red circles were not adequately explained. They were intended only as visual

emphasis and did not represent an additional quantitative criterion in the co-occurrence analysis. To avoid implying an unsupported analytical classification, we have removed the red circles from Fig. 8. The figure now presents only the quantitatively defined node sizes and link widths described in the caption.

Comment 4:
Figure 9: I suggest that the authors consider flipping the y-axis so that flow pathways that are at the near-surface (HOF/SOF) are shown near the top of the figure and pathways that are deeper (GWF) are at the bottom of the figure. To me this would be more intuitive. Also change the label of the y-axis to "depth of flow pathway" as per the caption.

Response 4:
We agree that reversing the vertical orientation makes the conceptual framework more intuitive. We have therefore reorganized Fig. 9 so that surface and near-surface pathways (HOF and SOF) are shown toward the top and deeper subsurface and shallow-groundwater pathways toward the bottom. The y-axis has been renamed "Depth of activated flow pathways."

We emphasize that this axis represents the conceptual depth of the dominant activated flow pathways rather than the chronological order of pathway activation. Therefore, the revised framework does not imply that shallow pathways must always activate before deeper pathways. The caption and corresponding text have been revised accordingly. This graphical change improves the physical interpretation of the vertical dimension without altering the conceptual framework.

Response to Reviewer #2:

Main comments:

Runoff threshold behavior varies across catchments with different climates. Hence, interpretation and cross-catchment comparability of runoff threshold mechanism is of great importance for understanding runoff response behaviors under various climates worldwide. In the revised manuscript, the authors have essentially addressed all the reviewers' concerns and questions, particularly by providing a more thorough explanation of the methodology.

While the synthesis successfully links threshold indicators to mechanisms and structural controls, the paper could more directly address whether runoff threshold mechanisms are widespread across various climates and, more critically, the paper would benefit from a more explicit synthesis of quantitative threshold indicators reported in the literature, i.e., as wetness increasing, how does threshold mechanism change accordingly?

Response:

We sincerely thank the reviewer for this positive assessment and important suggestion. We agree that the manuscript should more explicitly address both the climatic breadth of reported runoff-threshold mechanisms and the quantitative threshold information available in the source literature.

In response, we strengthened the synthesis in three ways. First, we now quantify the climatic distribution of the reported runoff-generation mechanisms relative to the overall composition of the reviewed database. The 138 catchments comprise 101 humid, 20 semi-humid, 16 semi-arid, and one arid catchment. Threshold-related surface, saturation, and subsurface mechanisms are represented across several climatic wetness classes, although their distributions are uneven and the reviewed database is strongly biased toward humid catchments. We therefore revised Fig. 5 to include the climatic composition of the complete database as a reference baseline, allowing mechanism-specific patterns to be interpreted relative to this sampling distribution.

Second, we added a more explicit quantitative synthesis of reported threshold indicators. A standardized threshold variable could be identified for 98 of the 138 catchments (71.0%). Among these, 40 catchments (40.8%) used rainfall-only indicators, 35 (35.7%) hydrological-state indicators, and 23 (23.5%) composite indicators. Hydrological-state and composite indicators therefore accounted for 59.2% of catchments with an identified threshold variable. Source-reported threshold descriptions or values were available for 84 catchments. Because these thresholds include physically different quantities and units—including rainfall amount and intensity, soil moisture, groundwater level, storage, and composite rainfall–state metrics—we did not pool them into a single numerical threshold. Instead, the reported values are now compiled by indicator type in a new Supplementary Table.

Third, we quantified how the reported dominant runoff mechanism changed with increasing wetness in the 23 catchments with explicitly documented within-catchment event-scale transitions. Nine transitions originated from HOF, of which six shifted to SOF, two to SOF–SSF, and one to GWF. Twelve originated from SOF, of which seven shifted to SSF, three to GWF, and one each to SOF–SSF and SSF–GWF. The remaining two originated from SSF and shifted to mixed SOF–SSF or SSF–GWF responses. We additionally compiled the threshold indicators and reported threshold values associated with these transition cases in the Supplementary Material.

We have revised the Introduction, Results, and Discussion accordingly. Importantly, we now distinguish explicitly between cross-catchment climatic patterns and within-catchment event-scale wetness-dependent transitions. The former describe how reported mechanisms are distributed among climatic settings, whereas the latter describe changes in the mechanism dominating stormflow as catchment wetness increases. We also clarify that the observed transition directions represent tendencies within the reported transition subset rather than a universal sequence of runoff-pathway activation.

Specific comments:

Comment 1:

Lines 8-16: What is the meaning of "recurrent" in the key points and elsewhere? In Point #3, "Critical zone structural and hydraulic attributes" might be an alternative to "Recurrent soil–geology–hydrogeology associations." Also, the key points are overly qualitative; a more summarized analysis of quantitative indicators found in the literature would be beneficial. For example, as climates vary with increasing wetness, how does the threshold change?

Response 1:

We thank the reviewer for this helpful comment. We agree that the term "recurrent" in the original Key Points and elsewhere could be ambiguous, as it may imply temporal recurrence rather than repeated associations observed across different catchments. We therefore replaced "recurrent soil–geology–hydrogeology associations" with "mechanism-specific soil–geology–hydrogeology associations" to more accurately describe the co-occurrence patterns identified in this review.

We also agree that the original Key Points were overly qualitative and could better reflect the quantitative synthesis provided in the manuscript. We revised the second Key Point to clarify that the reported wetness-dependent mechanism shifts represent tendencies within the explicitly documented transition subset rather than a universal sequence. In addition, we strengthened the quantitative synthesis in the Results by summarizing threshold-indicator frequencies and wetness-dependent mechanism transitions, and added supplementary tables compiling these quantitative patterns.

The revised Key Points now read:

• Reported runoff thresholds are more often characterized by antecedent or within-event catchment-state indicators than by rainfall metrics alone.

• Wetness-dependent mechanism shifts were commonly reported from surface- to subsurface-influenced runoff responses.

• Mechanism-specific soil–geology–hydrogeology associations provide structural context for interpreting threshold behavior.

Comment 2:

Lines 27-28: The phrase "diverse rainfall-based, state-based, and composite indicators" is a bit obscure. Does this equate to "antecedent and within-event state descriptors"? Clarification is needed.

Response 2:

We thank the reviewer for identifying this terminology ambiguity. We agree that the previous wording did not clearly distinguish between the classification of threshold indicators and the temporal characteristics of hydrological-state variables.

In the revised manuscript, we clarified that rainfall-based, hydrological-state-based, and composite indicators represent different types of information used to identify threshold-like responses, whereas antecedent and within-event descriptors refer to the timing of hydrological-state conditions. Specifically, hydrological-state indicators include both antecedent conditions (e.g., antecedent precipitation, API, antecedent moisture condition, or antecedent baseflow) and within-event states (e.g., soil moisture, storage, and groundwater level).

We revised the corresponding sentence in the Abstract to:

"Across the reviewed literature, threshold-like responses were identified using rainfall metrics (e.g., event rainfall amount and rainfall intensity), hydrological-state metrics (e.g., antecedent or within-event soil moisture, storage, and groundwater level), and composite rainfall–state indicators. Hydrological-state and composite indicators were reported more frequently than rainfall-only metrics.”

We also clarified the terminology in Section 2.3 by explicitly defining the relationship between rainfall indicators, hydrological-state indicators, and composite indicators. In addition, we added definitions of structural and functional connectivity to clarify that connectivity is used as a conceptual framework linking catchment structure and event-scale pathway activation rather than as a directly measured universal index.

Comment 3:

Lines 30-33: Why would the shift not proceed from deeper layers to the surface? In humid catchments, strong biogeochemical weathering and biological activity often lead to high deep percolation, making it plausible that runoff is generated first in deeper layers. The conclusion that responses shift from surface- to subsurface-dominated pathways needs further justification.

Response 3:

We thank the reviewer for this important comment. We agree that the previous wording could be interpreted as implying a universal sequence in which runoff mechanisms always progress from surface to subsurface pathways. This was not our intention. In humid and highly weathered catchments, deeper pathways, including preferential flow, soil–bedrock interface flow, or groundwater-connected pathways, may become active before surface runoff develops.

The transition analysis in this review is based only on catchments where source studies explicitly documented event-scale changes in the dominant runoff-generation mechanism under increasing wetness. Therefore, the identified direction does not represent the chronological order in which all flow pathways are activated, but rather the more frequently reported change in the mechanism dominating stormflow within the compiled transition subset.

In response, we revised the Abstract and Discussion to clarify that surface-to-subsurface or groundwater-influenced shifts represent a reporting tendency rather than a universal mechanistic sequence. We also added text acknowledging that reverse or context-dependent transitions are hydrologically possible, including cases where subsurface pathways are activated before surface runoff or where subsurface flow contributes to saturation-excess runoff through exfiltration.

Comment 4:

Lines 114-117: The key gap the authors identify is whether runoff threshold mechanisms are widespread in various climates and how they change with increasing wetness. This is precisely what HESS readers are most concerned about and should be more sharply focused on.

Response 4:

We thank the reviewer for this important suggestion. We agree that the climatic representation of runoff-threshold mechanisms and their wetness-dependent changes within catchments are central questions that should be more explicitly highlighted in the Introduction.

We have revised the Introduction to sharpen the identified knowledge gaps. Specifically, we now emphasize two related but distinct unresolved questions: (i) how threshold-related runoff mechanisms are represented across climatic wetness classes within the reviewed literature, and (ii) how dominant runoff mechanisms change within catchments as event wetness increases.

Accordingly, we revised the research questions to explicitly address climatic patterns, within-catchment wetness-dependent mechanism transitions, threshold indicators, and soil–geology–hydrogeology associations. We also clarified that mechanism transitions refer only to changes in the dominant stormflow mechanism within the same catchment during events or event sequences, rather than transitions inferred from differences among climatic regions.

Comment 5:

Lines 296-302: There are repeated sentences in this section that should be consolidated.

Response 5:

We thank the reviewer for pointing out the repetition. We agree that the previous version repeated some explanatory information about Figure 3 across the caption, Methods, and Results. The repetition was not due to duplicated sentences within the caption itself, but rather because the description of node meanings, flow bands, and coding categories was explained in multiple sections.

In the revised manuscript, we streamlined the Figure 3 caption to retain only essential information needed for interpretation, while keeping the detailed definitions and coding procedures in Section 2.3. The Results section was also revised to focus on the main patterns revealed by the figure rather than repeating how to read the Sankey diagram.

Comment 6:

Lines 440-444: This is a very interesting summary. The finding that HOF-dominated catchments more often rely on rainfall-based descriptors (e.g., intensity) while SOF-, SSF-, and GWF-dominated catchments rely on storage-related variables needs deeper discussion in Section 4.1. In humid, vegetated catchments, high infiltration due to biological activity explains why SOF and SSF dominate. However, if soils are highly permeable, rainfall intensity should still control the magnitude of flood peaks. Why is rainfall intensity rarely identified as a key factor in these SOF- or SSF-dominated catchments?

Response 6:

We thank the reviewer for this insightful comment. We agree that the original discussion did not sufficiently distinguish between variables used to identify threshold-like behavior and factors controlling runoff magnitude or flood peaks. The lower reporting frequency of rainfall intensity in SOF-, SSF-, and GWF-related studies should not be interpreted as evidence that rainfall intensity is unimportant in these systems.

We have revised Section 4.1 to clarify this distinction. Figure 3 summarizes the indicators used by source studies to identify or characterize threshold behavior, rather than all factors influencing runoff magnitude. In HOF-dominated systems, rainfall intensity is often directly linked to infiltration-excess conditions and therefore serves as a threshold indicator. In contrast, SOF-, SSF-, and shallow-groundwater-related thresholds are more commonly characterized by the hydrological state at which storage fills, saturation expands, or subsurface and groundwater pathways become functionally connected. Nevertheless, rainfall intensity can still influence storage filling rates, percolation dynamics, runoff magnitude, and flood peaks.

We therefore clarify that the observed reporting pattern reflects differences in how threshold conditions are identified in the literature, as well as differences in monitoring design and available observations, rather than a reduced hydrological role of rainfall intensity in SOF- or SSF-dominated catchments.

We sincerely thank the reviewers for their helpful suggestions, which have greatly improved our manuscript. In addition to addressing the reviewers' comments, we have also refined the content and expression throughout the paper for better clarity and coherence. The revised manuscript has been submitted to your esteemed journal, and we look forward to your favorable response.

Yours
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