Author Comments

AC: We thank the referee for their comments on our manuscript and have proposed ways in which these may be addressed in a resubmission. Our revisions place a stronger emphasis on the context of the study (water harvesting, data-poor locations), hydrological processes (supported by the inclusion of a new figure), and a more rigorous analysis of performance (PCA and subsequent appraisal of catchment characteristics).

Referee #2

RC: Summary:

This manuscript presents a novel framework to incorporate transmission losses into existing rainfall runoff models. The authors present a workflow that uses publicly available datasets to calculate hydrometrologic fluxes and watershed structure to quantify the amount of transmission losses. The results presented found that incorporating transmission losses into models have a mixed rate of success (9 out of 28 catchments saw improvement) but showed marked success in those catchments.

Overarching thoughts:

First, I want to thank the authors for presenting a framework that highlights the recent advancements and interest in non-perennial systems. Work such as this is important to our fundamental understanding of these systems. Below I summarize some suggestions that could help strengthen the manuscript.

AC: The authors are pleased that work in this subject area is regarded as important. They believe that research into non-perennial runoff, particularly where observed data is unavailable or inadequate, is crucial, especially given the vast proportion of the Earth's land surface classified as drylands.

RC:

1. Comment: This manuscript is unique in that it uses publicly available and accessible data as inputs into the workflow as well as providing processing code (the DOI provided did not work unfortunately). However, this seems contrary to the processing tools used of ArcGIS and Matlab both of which require expensive licenses to run analysis, and the workflow presented here. While I don't want to disparage the authors on this choice, highlighting freely available datasets in line 529 with the paid nature of the software seems counterintuitive.

Suggested action: I would consider not highlighting the point that the data is freely available.

AC: Apologies for the DOI not working. This was an oversight on the part of the authors, as the DOI had not yet been "minted." This issue has now been resolved, and the DOI should hopefully be functioning correctly.

The authors accept this point regarding the proprietary nature of both the ArcGIS and MATLAB licences, as well as the associated costs. We will certainly consider removing the text about freely available data. Should HRRTLE be developed into newer versions, the authors believe that the use of proprietary software should be replaced with open-source alternatives.

2. Comment: On the topic of data used, I am curious to why the authors did not use CAMELS/CARVAN datasets that leverage all the needed precipitation, watershed attributes, and land use data needed for the analysis in one common location? I worry that presenting a workflow that leverages many datasets that a user must collect and provide rationale for using, outside the standard for the hydrologic modeling community, might present problems for users as well as produce duplicate tools.

Suggested action: Either a comparative analysis of how the products used here compare to other data sources (i.e. CAMELS) or a rationale why these products were used over other more accessible products.

AC: Thank you for this suggestion. The CAMELS/CARVAN datasets were not something the authors were previously aware of, so this is valuable information. Should HRRTLE be developed into newer versions, the CAMELS/CARVAN datasets would certainly be worth considering.

To provide some background on the choice of datasets and the rationale behind the development of HRRTLE as presented: the authors observed that researchers working on water harvesting site selection studies often rely on "runoff maps," which they generate by creating their own land-use layers to produce curve number rasters for runoff computation. This laborious procedure can be streamlined by using an existing global curve number dataset (e.g., Jaafar et al., 2019), which is precisely what the HRRTLE tool does. Since the authors are unfamiliar with the CAMELS/CARVAN datasets, we are uncertain if they include a global curve number dataset or if one could be integrated. If they do, that would be ideal, but it is essential for the HRRTLE tool that a global curve number dataset is available for its operation.

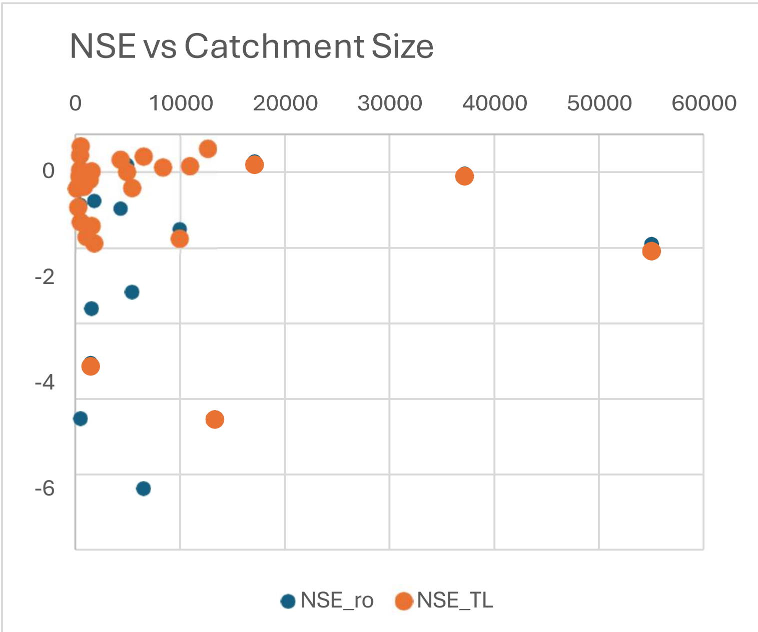
In defense of HRRTLE regarding the use of "many datasets," we do not necessarily accept this characterization. Only three datasets (plus satellite imagery) are required to compute runoff volume: precipitation, a digital elevation model (DEM), and a global curve number (GCN) dataset. The same GCN dataset is used twice, in both the runoff computation and transmission loss processes, making HRRTLE relatively parsimonious in terms of the number of required datasets.

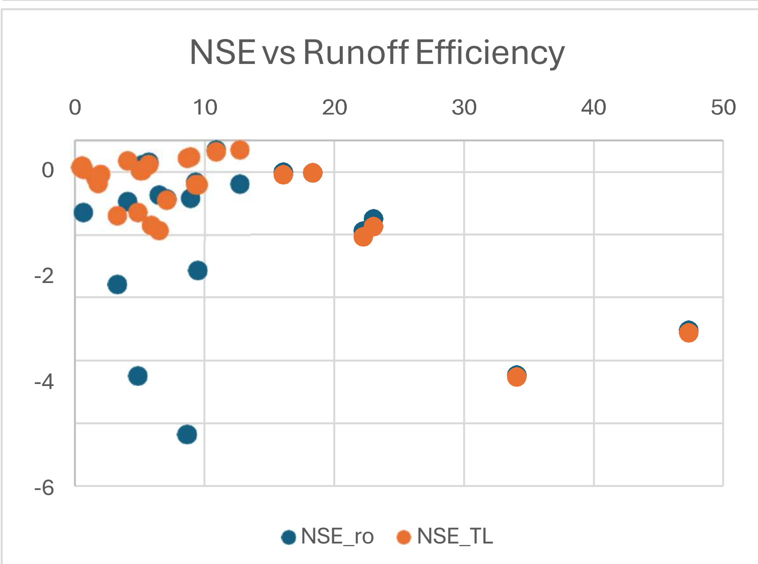
However, we take your point regarding the need for additional datasets in the context of HRRTLE tool research aimed at evaluating catchments and associating specific catchment types with degrees of model performance. This aspect of the analysis does require numerous datasets, and the CAMELS/CARVAN datasets would indeed be helpful in this regard, as suggested.

RC:

3. Comment: A theme that perplexes me throughout the manuscript is what is it within the catchments that make the model perform "better" or "worse". Are there spatial patterns? Is it related to a baseflow, groundwater influence, etc.? The relationships of "why" this model performs better don't seem to be well established instead this model behavior as presented now seems to be an emergent behavior. For example,

the authors state on lines 479-480 "…HRRTLE exhibits improved performance with smaller catchment sizes.." and in subsequent paragraphs highlight runoff ratios as potentially important. However, in simply plotting NSE vs these characteristics there seems to be little correlation between goodness-of-fit and these watershed characteristics (see below).





<u>Suggested action</u>: A more rigorous exploratory analysis of model results that include statistical tests (t-test, correlation plots, PCA, etc.) or any additional quantitative analysis that relates model performance to hydrologic and watershed function.

AC: The authors appreciate this suggestion and accept that a more rigorous analysis of the model results is warranted. We propose implementing your suggestion of utilising PCA and applying it to the seven catchment characteristics (see Figure 5 of the manuscript). This analysis might reveal whether there is a cluster of 'good' model results based on the principal components of the seven characteristics.

If no such cluster emerges, the analysis could help identify paired catchments—those that are similar to each other based on the principal components of the seven catchment characteristics. By identifying these 'twinned' catchments, where one demonstrates 'good' model performance and the other 'bad,' differences between the two might become apparent. These differences could potentially be observed by comparing imagery of the two catchments, examining disturbances or obvious differences in land use/land cover. While this approach may be somewhat subjective, it represents an improvement on the existing analysis.

RC:

4. Comment: The title of the manuscript uses the word "ephemeral" but the basis of the manuscript is largely focused on arid regions which is not exclusively 1:1 with

ephemeral networks. For example, Brinkerhoff et al. (2024) showed that between 40% and 60% of the river and stream network in the contiguous US is ephemeral with significant portion of ephemeral networks located in humid regions.
Additionally, the large-size of some of the watersheds in this study may incorporate majority ephemeral systems, but higher-order streams are analyzed for losses.
Suggested action: I would drop ephemeral from the manuscript where appropriate and replace with arid/semi-arid.

AC: Thank you for this observation and suggestion. HRRTLE was developed with the assumption that it would be most suitable for catchments containing ephemeral systems. The authors believe that such catchments are often encountered by planners and researchers seeking suitable sites for water harvesting structures.

The challenge, however, lies in obtaining observed runoff data specific to the type of catchments described. Ideally, we would have had access to runoff data exclusively from ephemeral systems. The absence of this data, coupled with the subsequent testing of HRRTLE on runoff observed in higher-order streams, strengthens the argument for omitting the term 'ephemeral'.

The authors are open to removing the term ‘ephemeral’ and suggest that ‘drylands’ may be a more suitable alternative to reflect the range of catchments tested.

RC:

5. Comment: It would be great to know the magnitude of transmission losses predicted in HRRTLE to understand how much streamflow is being lost in these systems, and therefore cannot be captured with water harvesting practices. This could add significant impact to the manuscript.

Suggested action: Calculate transmission loss to streamflow ratio or volume of streamflow lost for catchments.

AC: Thank you for this suggestion. This should be entirely feasible. We know the total runoff generated at each pixel and the runoff volume reaching the catchment outlet, so we can calculate the volume lost due to transmission losses and, as suggested, provide a suitable ratio.

6. There have been other studies that have looked at spatial/watershed connectivity on a higher resolution or related to climate, physiography, etc. It would be good to highlight them or at least cite them as they would help bolster the introduction and discussion.

- Husic et al., 2022: https://doi.org/10.1029/2022GL099898
- Chen et al., 2019: https://www.nature.com/articles/s41586-019-1558-8

Suggested action: Authors choice.

AC: Thank you for highlighting these two studies.

Husic et al. (2022) is particularly interesting for several reasons. It addresses how reservoirs significantly reduce longitudinal downstream connectivity. A potential avenue for further exploration, should the results warrant additional analysis, is quantifying the degree of connectivity for each catchment modelled using HRRTLE. The authors of HRRTLE hypothesise that the tool yields better model performance when catchment connectivity is high. An option worth considering is employing the "SedInConnect" software utilised by Husic et al. (2022) and applying it to the HRRTLE catchments.

Chen et al. (2019) is also noteworthy. This study offers further evidence regarding the characteristics of catchments that the authors of HRRTLE believe the tool is particularly well-suited for—namely, those with high losses through dry porous beds (transmission losses) and a water table situated well below the riverbed.

RC: Specific feedback:

RC: Line 334: This is confusing to me. The catchments have streamgages that are used to calculate the runoff ratio? Please clarify.

AC: The authors agree that this is confusing and could have been better worded. The development of HRRTLE stems from the authors' ultimate goal of seeing its application, most likely in dryland regions where no observed runoff data are available. For the purposes of developing HRRTLE and verifying its results, we opted to use runoff data from catchments that are (mostly) located in arid and semi-arid regions.

To clarify, the sentence in question could be improved by stating that the intended purpose of HRRTLE is to serve as a tool for researchers and practitioners working with ungauged catchments. A possible replacement for the sentence could be:

"Here, as we envisage HRRTLE being typically used in conjunction with ungauged catchments, we argue that the criterion for good performance should be somewhat relaxed. Therefore, we consider an absolute value of Pbias less than 50% as indicative of the threshold between adequate and inadequate performance."

RC: After figure 3: Larger map (like figure 2) where watershed points are colored by goodness- of-fit metric of choice. This would help a reader discern spatial patterns (if any).

AC: The authors consider this to be a helpful suggestion. Additionally, it may be valuable to include, in the supplementary materials, a figure showing the best-performing and worst-performing catchments, illustrating the catchment boundaries and associated imagery.

RC: Lines 478-479: Superior compared to what? There were no other instances of models compared, correct? Just incorporation of TL and non-TL simulations?

AC: Here, we are discussing the various HRRTLE model performances across the 28 catchments tested. The "superior" performances, as determined by NSE and Pbias, are considered to be better than others.

Possibly, the sentence in question could be reworded as follows:

"It is therefore valuable to explore the factors that contribute to HRRTLE's stronger performance in some contexts and weaker performance in others."

The above reworded sentence may help eliminate any ambiguity suggesting that HRRTLE's performance is being compared to outputs from other model(s).

RC: Line 491: What was the degree of development in the catchments? Comparing how much "disturbance" is in a catchment could lend insight into the varying degrees of runoff efficiency and therefore how important transmission losses may be in a catchment.

AC: Thank you for this question and comment. The authors suspect that the extent of “disturbance” could play a significant role in model performance. In a revised version of the manuscript, we would be willing to place further emphasis on the level of disturbance in each catchment. Some thought is required on how to (objectively) quantify the degree of disturbance in each catchment. Extracting urban areas from land cover/land use maps could prove useful. Additionally, quantifying the extent of standing water within each catchment may provide valuable insights.

The additional catchment characteristics mentioned in the above paragraph could also be included in a Principal Components Analysis alongside the catchment characteristics provided in Figure 5 of the original 'pre-print' manuscript.

RC: Lines 535-545: This paragraph seems disorganized and a bit tough to read. This seems like it would be better as a table or reduced to a single line that states “Studies that utilize varying types of hydrologic models (rainfall-runoff, hydrodynamic, process-based, etc) do not explicitly represent transmission losses (citations).” Then transition to why this is important tied to the results of this study. Right now, this reads as a “bashing” of other studies.

AC: The authors acknowledge that this paragraph can and should be improved. We believe it should be reworded to position HRRTLE as building upon the work of others by accounting for transmission losses, while still incorporating key aspects of the aforementioned studies.