Response to Referee 1

To facilitate the review process, all referee comments are in **black** while the authors response in **blue**.

This paper presents an interesting study demonstrating the value of geology maps in enhancing hydrological understanding. The authors have developed a reclassification method that transforms the original geology map into numerical metrics related to hydrology, and they illustrate the added value of more detailed, small-scale maps. The findings in this paper are valuable for more effectively utilizing geology maps to improve hydrological insights, making it worthy of publication. However, I would like to raise several major and minor concerns that should be addressed prior to publication.

We thank the reviewer for dedicating their time and expertise to review our manuscript. We have carefully addressed each point in detail and hope our responses can make the manuscript in a better shape for publication.

Major Concerns

1. It is unclear why the analysis incorporating climate and landscape attributes is conducted. This study focuses primarily on the value of geology map details, and most of the results are related to the geology map analysis. The analysis using catchment attributes appears to contribute little to the main objective and conclusions of the study. The authors should consider explaining in greater detail how this part of the analysis connects to the study's primary conclusions.

We appreciate the referee's comment and thank them for highlighting this point. We agree that the inclusion of climate and landscape attributes alongside geological maps was not well justified in our original manuscript. Our inclusion was based on two main reasons:

1. **Establishing a comparison of geology attributes with other commonly used attributes:** One of our research aims is assessing the benefit of using geology attributes (from global, continental, and regional maps) along with catchment attributes more commonly used in large-sample hydrology (LSH) studies—i.e., climate, topography, soils, and land use to explain streamflow signatures. By incorporating all other attributes, we could assess if geology-derived variables add explanatory power beyond what is already captured by these commonly used attributes. For example, as shown in **Section 4.1.1** (**Figure 3**), geology attributes presented the highest correlations with baseflow signatures, in comparison to other attributes in many basins, but this varied across spatial scales and map detail levels. Moreover, this figure allows us to understand whether catchments with low geological correlations also have low correlation to other attributes. For example, perhaps the correlation value found of 0.60, is actually very low compared to other attribute groups. But maybe, 0.60 was the highest correlation among all group of attributes. This is the case for the Moselle basin (DEBU1959), for example.

2. **Testing the "landscape vs. climate" assumption:** As mentioned in the introduction, a recurring finding in LSH is that climate often correlates more with streamflow signatures over landscape. In our study, we were also interested to check whether more detailed geological maps can shift this pattern. Our results showed that when performing a LSH study at the basins level, when geology is represented with sufficient detail and appropriate hydrologically relevant indicators (e.g., relative permeability), landscape attributes—especially geology—can present high correlations. This is discussed explicitly in the introduction (**L34–50**) and further developed in the discussion (**Section 5.1, L495–525**). Including climate and other landscape controls allowed us to demonstrate this shift in explanatory power.

We will therefore modify the paper adding a clear justification for this choice.

2. The authors seem to assume a priori that there is an inherent relationship between geology metrics and hydrological signatures, and that a map producing a higher correlation coefficient (rs) is automatically superior. Although the authors attribute this to "physical understanding," from a physical perspective, hydrological signatures are also influenced by climate and land use factors. More detailed information on climate, land use, soil, and topography would also be helpful for interpreting hydrological processes. I suggest that the authors clarify this issue, explain the mechanisms by which geology metrics affect hydrology, and adjust some statements to avoid presuming that geology metrics are the dominant influence.

We thank the referee for this insightful observation. We agree that this causality should not be assumed a priori but should be a result of a deep investigation. We also agree that hydrological signatures result from the interplay of multiple factors—climate, land use, soils, topography, and geology—and that higher correlation values should not be interpreted as implying causality or universal dominance. Our intention is not to claim that geology attributes are inherently more significant, but rather to investigate whether more detailed geological maps enable higher, and more consistent to our stablished hypothesis, correlations at the studied basins. We will revise the manuscript to clarify this and avoid misleading statements. Moreover, we will avoid the use of “superior”, “more significant”, “better” or misleading statistical terms in the manuscript (also answering your further points). Please see also our response to the **referee 2**.

3. The inherent or fundamental differences among the three maps should be summarized somewhere in Section 2.2. At first glance, the differences appear to be in the spatial range resolution, but this factor does not actually explain the differences observed in the correlation analyses. Clarifying these intrinsic differences would help readers better understand why the regional map performs better.

This is a very good discussion point, and we thank the referee for highlighting it. We therefore will integrate section 2.2. with a clear overview of such differences and add the Table below to summarize them. With that, we believe that the readers do not need to wait to the discussion to see an overview of these differences.

2.2.4 Summary of main differences in the geological maps

The three geological maps used in this study differ not only in spatial scale but also in other fundamental ways, such as the number of lithological classes they include and how finely they delineate geological boundaries. Table X summarizes these differences, which help to interpret why different maps lead to different correlation patterns, as further discussed in Section 5.1 and Section 5.2.

Table X. *Summary of the main differences between the three geological maps*

Main characteristics	***Global***	***Continental***	***Regional***
Spatial coverage	*World*	*Pan-European*	*Moselle basin*
Geological number of classes (spatial heterogeneity)	*Low (16 classes)*	*High (32 classes)*	*High (32 classes)*
Geological detail (Boundary precision)	*High (detailed contours)*	*Lower (smoothed boundaries)*	*High (detailed contours)*

Minor Concerns

L188: Consider mentioning the five selected basins for detailed analysis at this point.
Thank you for this suggestion. We will correct L188 to:

L188: Large scale: This level included 63 river basins across Europe, and selected five basins (the Moselle, Cinca, Garonne, Vienne, and Narew) for further exploration, as illustrated in Figure 1a.

L236: Should "Five" be corrected to "Four"?
Yes, thank you for spotting this detail out. We will correct it to four:
L236: "four"

Section 3.4.3: The use of the geology map seems to be missing here.
Thank you for pointing this out. Besides, I think we should correct some sentences since we focus on this scale on the baseflow index signature. Therefore, the section will be corrected to align more or less as follows in the revised manuscript:

3.4.3. Small-scale
For the five catchments of the Moselle, we employed the following methodology:

- We calculated the correlation between the baseflow index signature and 47 catchment attributes for each of the five catchments of the Moselle, using all available nested sub-catchments within each catchment. This resulted in a total of 1 x 47 x 5 = 235 correlation values r_s.
- Instead of selecting only the maximum $|r_s|$ value per group, we conducted a more refined analysis here, focusing on the coherence of correlations, mainly the derived from geological attributes, consistent with the hypotheses raised in the Introduction. This more in-depth analysis aimed to assess how local factors might alter the relationships identified at broader scales, allowing us to distinguish correlations that are likely to reflect true causal relationships.

L328: A statistical analysis is needed to determine whether the higher rs derived from the continental map compared to the global map is statistically significant. A similar analysis should be conducted elsewhere when describing the differences among the three maps.
Thank you very much for pointing this detail out. Our intention here in the results is to present the results and avoid overselling points. Therefore, we will review the text to avoid the misinterpretation that one is statistically significantly higher than the other. We will also have a look over the entire manuscript to review any other statement with the same nature.

***L328:** Comparing the maps of different detail, the continental map appeared with average |rs| = 0.42, while the global map presented an average |rs| = 0.40.*

Paragraph around L330: In the right part of Figure 3, many basins exhibit much lower rs values with the continental map compared to the global map. We cannot simply regard the higher continental rs in the left part as an "added value" while ignoring the lower values in the right part. This discrepancy reflects the divergence between the two maps, as also shown in Figure 2. The divergence between the maps should be analyzed
carefully, rather than simply judging which map performs better based solely on a higher rs.

We thank the reviewer for this insightful observation. We agree that using higher correlation values alone to judge one map as "better" is overly simplistic, especially given that many basins exhibit lower correlations with the continental map compared to the global map (as seen on the right side of Figure 3). To address this, we will revise the relevant text to avoid framing one map as superior. Instead, we plan to emphasize that the maps provide complementary information—e.g., the continental map offers greater class diversity, while the global map provides finer boundary detail. We believe this adjusted framing will better reflect the divergence between the maps and the complexity of their respective contributions to the analysis.

L330: *This suggests that the continental map offers complementary value in basins where the global map performs poorly, due to its higher geological heterogeneity. However, in some cases, the global map yields higher correlations—likely due to its finer boundary detail—highlighting that both maps carry distinct, context-dependent advantages rather than one being universally superior. More on that is discussed in Section 5.2.*

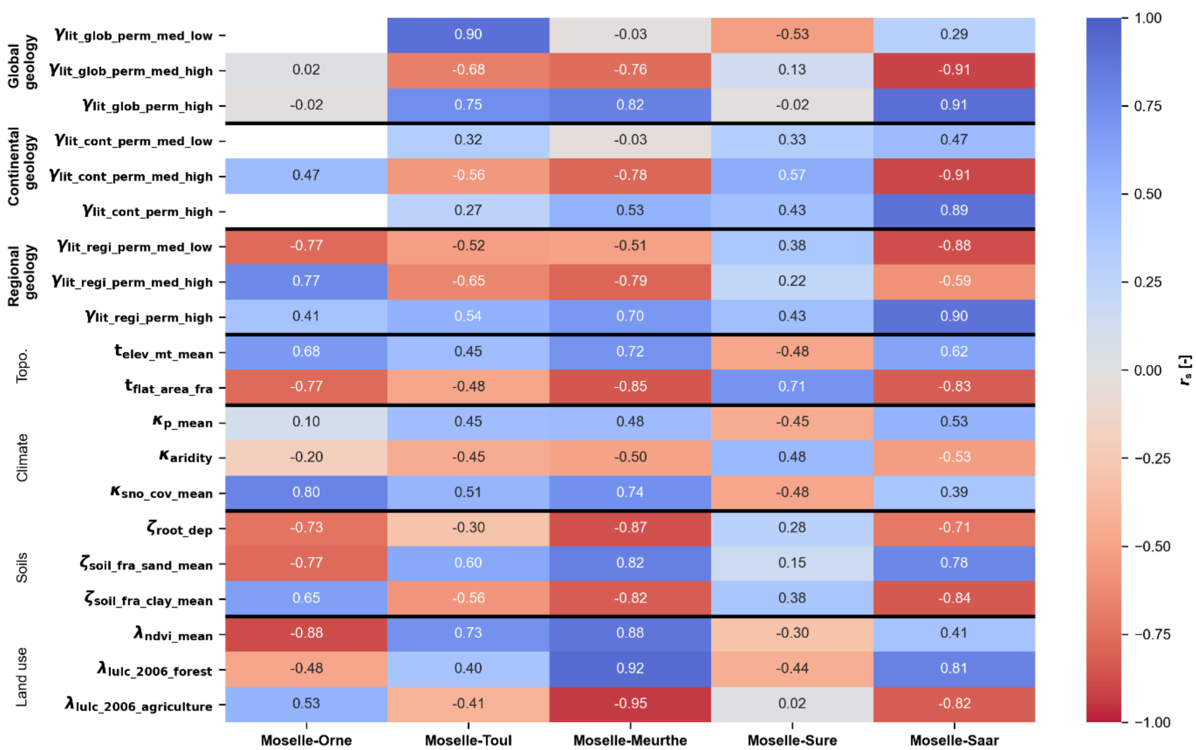
Paragraph around L480: The conclusion that the regional map provides the most stable correlations appears inappropriate. Among the three regional metrics, only one consistently produces the same sign, while the other two have one and two exceptions, respectively. However, similar patterns can be found in many other metrics.

Thank you for your comment. We agree that the original phrasing may have overstated the consistency of the regional map. While it is true that only one of the three regional geological attributes consistently produced correlations with the same sign across all five catchments, it was also the only map-attribute combination that showed both consistent sign and correlation values above 0.40. We will therefore revise/correct the sentence in the manuscript to reflect this more cautiously and accurately.

L477-479: *Among all geological attributes considered, only the high-permeability attribute from the regional map consistently produced correlations with the same sign (positive) and values above 0.40 across all five catchments.*

Figure 8: Consider adding separating lines between the different groups to enhance the figure's readability.

Thank you for your comment. We will take this into consideration and the figure will be updated as follows:



L483: The value "0.93" is not found in Figure 8.
Thank you for your comment. The value should be "0.90", therefore we will correct the statement.