We thank the Reviewer for highlighting these crucial points.

Please find our detailed responses below.

Reviewer #2:

This paper by Antonelli et al. presents the methodology and results of the morphological analysis of hydrographic network derived from historical land use maps in Switzerland, with the purpose of linking catchment geographic descriptors with hydrological connectivity.

While I understand the general framework of the study (eg assessing the hydrological connectivity in the past as a reference to assess how it has been altered by anthropogenic modifications) and its interest for assessment of ecological quality of rivers, I don't really see how the methodology and results presented here contribute to this general framework.

In particular:

1) The concepts of surface hydrological connectivity, and also longitudinal and lateral connectivities are not defined. I would have wished to have at least a correspondence with hydrological processes (eg lateral connectivity = groundwater-river interaction?).

1) Reply:
A general definition of hydrological connectivity is presented at the beginning of the introduction, and we expanded on this concept within the first two paragraphs of the introduction. We acknowledge the lack of a clear definition of longitudinal and lateral connectivity within the manuscript: we have added this information in the introduction from line 40, which now reads:

"The spatio-temporal patterns of connectivity within a catchment are strongly driven by the structural configuration of the landscape, including its geological and topographic setting, and the vegetation cover (Jencso et al., 2009; Van Nieuwenhuyse et al., 2011; Wohl et al., 2019). These heterogeneous landscape characteristics represent natural elements of (dis)continuity (Benda et al., 2004a; Poole, 2002), which influence the water movement across different dimensions of the hydrographic network - longitudinal (from headwaters to estuaries), lateral (river to and from floodplains or riparian areas) and vertical (river to and from groundwater) (Brierley et al., 2006; Lexartza-Artza and Wainwright, 2011; Pringle, 2001, Turnbull et al., 2018; Ward, 1989)".

2) The historical maps that were used date from the late XIXth century. At this time, the river morphology was not free of human influences, a lot of rivers were already significantly modified / engineered. How do the authors relate this to the more general framework of the introduction about using historical maps as « references » for river restoration?

2) Reply:
Our goal is not to propose a framework about using historical maps as a reference for river restoration. In fact, we never mention the word "reference" in our manuscript, and we are fully aware of the risks of treating historical conditions as a fixed standard for restoration. Instead, in the introduction we wished to emphasize the value of historical sources as providers of contextual information rather than a reference model or restoration target.

Since our study does not aim to reconstruct "reference conditions," the fact that the historical maps depict a landscape already influenced by human activity to some extent does not diminish their value. On the contrary, these maps still offer crucial insights into a period when river morphology was not yet subject to fundamental catchment-scale modification and fragmentation (i.e., dam construction, culverting, draining).

We modified the paragraph in the introduction starting at line 50, which now reads: "In today's highly anthropised landscapes, the primary drivers of fundamental catchment's functions such as connectivity are likely to have shifted from environmental to human factors (Allan, 2004; Allan et al., 2021). Historical information can provide essential insights into the past spatial distribution and primary drivers of connectivity, before the hydrographic networks were subjected to fundamental catchment-scale modification and fragmentation (i.e., dam construction, culverting, draining). The historical perspective is crucial for gaining a holistic view on today's catchments functioning, informing modern restoration and conservation efforts, and assessing the outcome of current actions (Higgs et al., 2014). For instance, historical connectivity patterns can provide contextual information for developing and monitoring river restoration projects (Mould and Fryirs, 2018; Wohl et al., 2015). They can also aid in identifying near-natural water bodies and catchments, thus informing conservation prioritization strategies and ensuring efforts are grounded in the natural range of variability of the landscape (Speed et al., 2016; Grabska-Szwagrzyk et al., 2024)".

3) The metrics that were chosen are very classic / general geomorphology metrics. I don't see how they can be informative on river connectivity (how can Strahler order be informative?) and the authors provide no explanation. I would have expected for example something about dams. This is not discussed at all.

3) Reply:
We provide an explanation of how we employ the hydromorphological metrics as a proxy of surface hydrological connectivity in section 2.2 and Table 2.

Since our observations are based on two-dimensional cartographic maps, our analysis of connectivity is inherently tied to the riverscape structure and the interaction between the hydrological network and the surrounding landscape. In this context, (hydro)geomorphological metrics, such as drainage density and confluence density, provide valuable insights into longitudinal connectivity within a catchment. Higher values of these metrics typically indicate areas with greater structural connectivity, as a denser and more interconnected network enhances water movement across the landscape [we added this information in line 104, which reads "Higher values of drainage and confluence density typically indicate areas with greater longitudinal connectivity, as a denser and more interconnected network enhances water movement across the landscape".].

While hydrological connectivity is influenced by geomorphology, it is also shaped by the hierarchical organization of the river network. Although stream order does not directly quantify hydrological connectivity, it serves as an important descriptor of network hierarchy. This is why we found it important to include stream order within the employed metrics.

Concerning the expected discussion about the presence of dams, we did not discuss this aspect because there were not dams in the studied catchments at the time considered in this study. We added this information in line 149, which reads: "No dams or other major obstructions to water flow were present in the ten selected catchments at the time of the mapping".

4) The explanatory factors chosen are very general and calculated at the catchment scale. I would have expected more precise / local factors. In particular I am very surprised by the coarse geology classification, with only 2 classes (permeable, not permeable), which is not justified nor discussed. Geology variability can have a lot of effects in particular on groundwater-river interaction, at local

scales. I find also very suspicious that karst is never mentioned, although the presence of karst plays a great role in river morphology (and I believe karst is present in Switzerland).

4) Reply:
This study focuses on large-scale hydrological connectivity, as stated in the abstract and introduction. We now modified the title of the manuscript to better convey this message: "Metric-based analysis of the historical drivers of surface hydrological connectivity at catchment-scale". We also changed "large-scale" to "catchment-scale" within the manuscript.

Because the study focuses on catchment-scale, a refined geology classification with a focus on local scales is overly detailed and not appropriate. Instead, we adopted a classification that aligns with the broader spatial scale of our analyses.

Before starting our analyses, we discussed the geological aspect and a possible classification to use in this study with geology experts. The distinction between permeable and impermeable geology is a standard distinction used by the Federal Office of Environment (FOEN) for the classification of river typology (Schaffner, M., Pfaundler, M., Göggel, W. (2013) Fliessgewässertypisierung der Schweiz. Eine Grundlage für Gewässerbeurteilung und -entwicklung. Umwelt-Wissen 1329, 63). Specifically, FOEN differentiates between siliceous and calcareous geological categories, which provide relevant information about rock permeability: calcareous formations generally exhibit higher permeability, while siliceous formations tend to be less permeable.

When defining the permeable and impermeable categories used in this manuscript, we initially considered a more detailed classification considering all categories present in the used sources (Geological map of Switzerland (1:500000) and Hydrogeological map of Switzerland (1:100000)). This has been reported in Table 4, where we specify the rock types included in each category. This approach ensures that our classification is not arbitrarily simplified but rather derived from an aggregation of detailed geological information suited to our study's scale.

Karst is surely present in Switzerland (two of our study catchments are located in the karstic region of Jura). However, karst is never mentioned in the manuscript because the word "karst" refers to a landscape type, or landform, consisting in a combination of limestone with other components (which are mentioned in Table 4).

5) The results are presented separately for two groups of catchments according to the sca3le of the land use maps (1:25000 and 1:50000). However the effect of the scale on the results is never discussed although these results appear to be different for both groups.

5) Reply:
We purposedly kept the analyses, results and discussions for the catchments at the two different scales separated because we are aware of the difficulty of directly comparing them. We acknowledge the lack of a discussion on the effect of scale on our observations at the 1:50000 scale compared to the 1:25000 scale. We added this information in the discussion, which reads:

"The lower accuracy and higher cartographic generalization of the features extracted from the map sheets at the 1:50000 scale compared the map sheets at the 1:25000 scale can potentially bring to a general underestimation of the values of the derived metrics in the Alpine catchments. However, the values of the different metrics in the Alpine catchments did not show to be systematically lower than the values of the same metrics in the other catchments (see paragraph 3.1). Despite the primary limitation in detecting smaller features at the 1:50000 scale, the overall structure of the hydrological network is preserved, and the map sheets at the 1:50000 scale remain a valuable source of information for identifying and comparing catchment-scale hydrological patterns".

6) The paper presents the results of many statistical analyses according to various explanatory factors. Some of these results are obvious, some are more surprising. However there is no or very little interpretation of these results in terms of physics / hydrological processes. Without physical interpretation, the impact of the paper falls short.

6) Reply:
Since our data are derived from historical cartographic maps, discussing physical hydrological processes (e.g., infiltration, surface runoff, groundwater recharge, and streamflow generation) in detail would be mostly speculative. We lack historical records of past hydrological conditions that may have influenced the patterns observed in the maps. Moreover, since our study focuses on catchment-scale spatial patterns of surface hydrological connectivity, reliable measures of these processes at catchment scale are still very difficult to obtain. That is why most of the times hydrological models are used to investigate these processes at catchment-scale, yet difficult to validate with field data. We believe our manuscript provides a valuable example of how historical maps can offer insights into past hydrological networks, revealing essential information about historical catchment-scale hydrological properties, including connectivity.

7) The authors mention in the discussion (p 25, l 425-435) that the hydrographic network that was considered already incorporates artificial elements. Then I don't understand the purpose of the study that is presented in the introduction as establishing a "reference" of connectivity (see comment 2).

7) Reply:
As pointed out in our reply to comment 2, we did not aim at proposing a framework about using historical maps as a reference for river restoration. We clarified this in the introduction where we now state that the historical perspective can inform modern restoration and conservation efforts and can provide contextual information for developing and monitoring river restoration projects. This is different from promoting for the definition of reference values.

Since our goal is not to identify reference conditions, the hydrographic networks we examine can still offer valuable insights into the past spatial distribution and primary drivers of connectivity, even if they are not entirely pristine. Nevertheless, we focus on networks with relatively low human influence, especially when compared to systems that have been extensively modified by dam construction, and extensive culverting and drainage.

8) Following the same idea, I would have expected a comparison with "connectivity" based on a current map. Why was it not done?

8) Reply:
The aim of this manuscript is to explore the historical state of the studied catchments, recognizing the past as valuable in its own. Exploring historical connectivity patterns provides critical insights into the long-term shaping of the riverscape, independent of direct comparison with the present. While a temporal comparison can highlight change, it also risks framing the past solely as a point of reference rather than appreciating its significance as a foundation upon which today's riverscapes have developed.

Obviously, we acknowledge the importance of assessing changes over time, and we are currently developing a separate study specifically focused on locating and quantifying such changes. However, that was not the aim of this manuscript, as we believe that the wealth of information and insights gained from analyzing historical maps deserved a dedicated study.

More technical comments

Tables and Figures in the Results sections are too busy and difficult to read. Particular mention to Table 5 that is completely illegible.

Reply:

We understand the reviewer's concern. In preparing the tables, we followed the journal's formatting guidelines for submission (i.e., avoid colored table cells and vertical lines; use horizontal lines only above and below the table, as well as between the header and main body). We are confident that the tables will be more readable once formatted according to the journal’s official style in case of publication.