Reply to Anonymous Referee #2

We thank the reviewer for their valuable comments, which help better place the proposed methodology in the context of the existing literature on the connectivity index.

In what follows, we reply to each comment, explaining how we plan to address it in the revised manuscript.

1. **Lines 217-230—It is unclear how implementing an "along-the-stream network" differs from the well-known IC_outlet approach from Cavalli et al. (2013) and several other researchers/papers. It is necessary to explain why to choose this new approach over IC_outlet.**

   In the past literature on the connectivity index, the IC_outlet metric has been proposed to directly characterize connectivity between hillslopes and catchment outlet. It is calculated using the traditional formulation by Borselli et al. (2008) (with some adaptations to the weighting coefficient and/or the flow direction algorithm adopted, depending on the specific application; see, e.g., Cavalli et al., 2013), but considering flow paths directed from each hillslope cell all the way to the outlet (hence, including paths along the stream network), instead of shorter flow paths along hillslope surfaces only, until reaching the stream network at the nearest pour point.

   In our methodology, we consider separately hillslope-to-stream and stream-to-outlet flow paths. This allows us to focus more on hillslope-to-stream connectivity, which is crucial when assessing the impacts of urbanization on hydrologic response. Land development primarily affects overland flow, occurring over the hillslope component of a basin. We aim to frame the connectivity between any hillslope patch (including urbanized sectors) and its nearest stream, to effectively analyze the hydrologic impacts of developed pixels, depending on their location relative to the stream network and all other pixels with different LULC types along the path to the pour point. Once runoff reaches the stream network, the effects of travel distance along the stream network must still be accounted for, but this is performed in the separate, second step, considering a narrower range for the weights. This ensures that HCIU displays adequate sensitivity to urbanized sectors that are adjacent to the stream network, but at reaches located far upstream from the outlet.

   Maybe more importantly, from an application perspective, we need to be able to quickly compute HCIU for any basin (in a region, country, province, state, etc.), as selected by the final user. If we were to use a "cell-to-outlet" scheme, such as the IC_outlet metric, we would need to recompute everything from scratch, every time a user chooses a different basin (i.e., a different outlet location along a stream of the river network). By splitting the

HCIU computations from cell to pour point, and then pour point to outlet, we can precompute all connectivities and normalized connectivities for all the pixels over large areas, once for all, irrespective of any basin and its outlet. Then, the final computation of HCIU, for any desired basin of interest (i.e., given a specific outlet along the stream network) only involves a much-quicker lumping via a weighted average of the precomputed at-a-cell normalized connectivities, only considering those cells within the basin and their along-the-stream-network distances to the desired outlet.

In the manuscript, we will clarify these differences by introducing the following additional considerations after Eq. 7 (i.e., after line 238 in the first version of the manuscript).

"In summary, the proposed methodology provides a lumped metric ($HCIU$) that is able to conceptually capture the varied hydrologic effects arising from the spatial arrangement of different LULC patches, both natural and developed, depending on their relative location with respect to each other, the stream network, and the basin outlet. First, hillslope-to-stream connectivities, weighted depending on the hydrologic effects of distinct LULC types, are normalized with respect to a fully impervious benchmark (Fig. 1a, 1b, 1c, and 1d), which allows to compare the effects of heterogeneous levels of urbanization both across and within basins. Then, $HCIU$ is obtained as a weighted average of normalized connectivities across the entire watershed, assigning different weights to each pixel depending on the "along-the-stream-network" distance of that cell's pour point to the basin outlet (Fig. 1e and 1f).

The proposed two-step formulation – where the flow paths of hillslope cells to the pour points along the stream network and then the distances of those pour points to the basin outlet are considered separately – is different from other established, outlet-focused applications of the connectivity index, such as the IC_outlet distributed metric proposed by Cavalli et al. (2013). The latter is calculated following Borselli et al. (2008; with some adaptations to the weighting coefficient and the flow direction algorithm) but considering flow paths all the way to the outlet (hence, considering both overland flows and subsequent channelized flows within the same path), instead of flow paths to the closest stream link, following only hillslope surfaces. The two main components of a basin's hydrologic response, i.e., overland and channel flow, generally involve quite different temporal scales, because of the different orders of magnitude in roughness and water depths. The IC_outlet metric is able to capture these differences, as IC_outlet raster maps typically exhibit the highest connectivity values along the watershed stream network (comparable only to connectivities in the hillslope sectors closest to the outlet), followed by connectivities in zero-order valleys or hollows adjacent to channels (Cavalli et al., 2013). On the other hand, our methodology focuses on the hydrologic effects of land development, which mostly influences the overland-flow component by locally decreasing infiltration and increasing runoff speeds. Considering only the hillslope-to-stream connectivity in our first step allows us to enhance the method's sensitivity to the effects of land development on hydrologic response, by focusing on how runoff interacts with the distinct LULC patches encountered along the hillslope path, which control (i.e., enhance or mitigate) the connectivity. Once runoff reaches the stream network, the effects of travel distance along the stream network must still be accounted for, but this is performed in the separate, second step, considering a narrower range for the weights. This ensures that $HCIU$ displays adequate sensitivity to urbanized sectors that are adjacent to the stream network, but at reaches located far upstream from the outlet.

Breaking down the calculations for $HCIU$ in two parts (the hillslope-to-stream and then stream-to-outlet flow paths) also presents a practical advantage, particularly for large-scale implementation of the index. To ensure broad applicability of the proposed methodology, we need to be able to quickly compute $HCIU$ for any basin (in a region, country, province, state, etc.), as selected by the final user. If we were to use a "cell-to-outlet" scheme, such as the IC_outlet metric, we would need to recompute everything from scratch, every time a user chooses a different basin (i.e., a different outlet location along the stream network). Splitting the computations from cell to pour point, and then pour point to outlet, offers the opportunity to precompute "static" (i.e., independent of outlet location) raster maps of connectivity and normalized connectivity, for all the pixels over large areas. In this way, later, when a user selects a specific outlet location, the final computation of $HCIU$ only involves the much-quicker weighted averaging of the precomputed at-a-cell normalized connectivities, only considering those cells within the selected basin and their along-the-stream-network distances to that desired outlet."

Other minor issues:

1. **Figure 4: What do the blue bars represent?**

   They indicate the proportion (expressed in percent) of cells within a given range of n *(or* CN*, or* S*, depending on the considered row in the subplots), with respect to the total number of basin cells for each homogeneous region (also see lines 311-313). For instance, for the VA case study, a little more than 25% of all basin cells (from all basins of that region) have a value of* n *between 0.7 and 0.8 (Fig. 4c). To address this as well as a comment from Reviewer 1, we will expand the legend to also include the description of the blue bars, "Proportion of cells (%)", consistent with the associated y-axis label.*

2. **No comment exists about how the urban drainage structure could affect urban hydrology.**
   To address this and a similar comment from Reviewer 1, we will include an additional paragraph in the Introduction, highlighting that the proposed methodology currently considers topography as the only driver of hydrologic connectivity. This may be a

limitation for highly urbanized basins, typically characterized by the presence of a dense stormwater drainage system, possibly including detention tanks and sections where stormwater may be pumped against topographic gradients. We will therefore note that, for highly urbanized basins, it may be necessary to consider these additional sources of connectivity, to reliably obtain estimates of HCIU; we will also briefly mention that adaptations to the current methodology to incorporate the effects of the stormwater drainage network are straightforward, as explained in more detail in the Discussion section.