Final Author comments to RC2. HESS-2024-338

Major Comments

<u>-Comment 1:</u> We understand the point about not explaining enough the existing 'gap' in the research and how the proposed metric (HRI) addresses it. As indicated by Reviewer 2 in RC2 the development of the HRI was motivated by the inability of existing metrics to quantify hydrologic regimes of non-permanent rivers. This is expressly indicated in the introduction section where it is described that the usual scarcity of detailed data (i.e. lack of distributed daily records, discontinuous flow record series, lack of records during no flow conditions) in semi-arid regions limit the use of flow alteration assessment indices (Leone et al., 2023; Gómez-Navarro et al, 2024).

Nonetheless, and to further guide the reader about the need to develop a new metric in intermittent rivers, the following paragraph was modified and added in the Introduction at the end of line 58:

"Indeed, indices based only on flow statistics, such as the interquartile variation range (IQR), the coefficient of variation (CV) or the flow duration curve (FDC), used as proxies for the seasonality of flows, among others; may not be suitable when no flow conditions are present. They require very detailed information not always available or not relevant to the dominant processes in the basin (e.g. allochthonous seasonal flow, interaction with groundwater), or they are based on complex theoretical functions of flow distribution of limited representativeness when runoff is not natural (e.g. only dams discharges; drainage flows), or the difficulty to standardize flows using statistical proxies (e.g. CV, IQR, FDC) for a given period when the average flow rate is zero. Therefore, new approaches to evaluate the modification of hydrological regimens in non-perennial rivers are needed. Two main reasons motivate this necessity. First and as indicated, the need to be able to mathematically solve relationships that adapt to intermittency flow conditions. Second, to have the capability to apply the index in a temporal and/or spatially distributed manner for the purpose of evaluating the hydrological connectivity in the large basins, which is a factor of fundamental importance for the quantification of E-flows."

Further, to expand the discussion of hydrological regime metrics in non-permanent rivers, in the Discussion section (Point 5) the second paragraph (lines 530-537) and third paragraph (lines 538-548) in page 24 were modified as indicated in the following:

"As described, there are several point measurements of change in the flow regime. They are usually based on simple characteristics or statistics of the river flow hydrograph, such as mean, maximum and minimum flow values, CV, and flow frequency for a given percentage of time, whereas flow variation is usually addressed by establishing ratios between some of these parameters or by the average flow in a given season. These metrics do not necessarily represent the flow distribution over the hydrological or water year in different conditions. Indeed, under the intermittence of flow for long periods, some of the statistics are not appropriate (e.g. CV cannot be mathematically solved under no flow conditions, the FDC curve is a straight line of zero flow for the period

considered). Similarly, the occurrence of unnatural variability (e.g. contributions of temporally lagged drainage from irrigation areas) may not necessarily be captured by seasonal averages or be assumed as natural if they are not compared with the flow upstream when a local or point evaluation index is used. Furthermore, the fact that many metrics are specific measurements limits the study of temporal and spatial hydrological variability, such as the analysis of hydrological connectivity that is usually lost in semi-arid basins under conditions of drastic flow alteration. This determines that the hydrological regime at a point downstream has no relationship with that upstream, a phenomenon that can hardly be evaluated with specific site measurements.
The proposed HRI is a single and dimensionless metric that considers the impacts on the annual distribution of flows, which is the more general definition the hydrological regimen. Therefore, monthly mean flows are used to evaluate the different impact factors. This method allows its application in large basins, where daily flow variations do not necessarily represent the river-aquifer interaction, or the activation of a wetland, or the maintenance of ecosystem functions downstream the reservoirs. Additionally, this approach allows addressing the usual lack of daily flow data especially during no flow conditions. Furthermore, it is not a specific measurement but is based on the comparison of flow records between upstream and downstream locations, a characteristic that allows evaluating, in addition to alterations resulting from hydraulic infrastructure, impacts of tributaries, interaction with groundwater, and the storage effects of wetlands. It is a flexible method based on the comparison of sites or time series of the flow magnitude (i.e. attenuation of flow), the timing of maximum flow (i.e. occurrence of the peak flow) and annual variation of flows (i.e. temporal pattern of flow variability). Conceptually, HRI is similar to the index proposed by Haghighi Toraby and Kløve (2013) and Haghighi Toraby et al (2014), however, a simpler approach is used to compute the river regime index. HRI does not use conceptual hydrographs and somehow complex functions to represent the monthly river regime. Instead, the differences between the natural o reference regime and a uniform regime representing full regulation or no flow conditions are calculated."

<u>-Comment 2:</u> Following the indication of the RC 2 about the manuscript organization, in the Introduction a new paragraph was included to guide readers regarding the expectation of being able to evaluate, through the HRI, the hydrological expression at different relevant points of the basin. Thus, the last paragraph of the Introduction (lines 77-82) was rewritten in two paragraphs as it is indicated in the following:

"Since the flow regime is an integrated basin response, a comprehensive approach should be used to evaluate its temporal and spatial distribution under both permanent and non-permanent flow conditions in areas with data scarcity. The hydrological metric must be able to describe the flow under natural (i.e. low modified) and modified conditions to varying degrees. For example, in the tributaries of the DSCC River the index must be capable to adequately discriminate between the hydrological conditions observed upstream and downstream of the main hydraulic structures. In the DSCC River, other hydrological characteristics also arise that must be appropriately evaluated, such as river reaches with or without interaction with groundwater, contributions from tributaries with modified flows, and the effect of wetlands storage in the hydrological regime. These characteristics also have an important impact on the hydrological connectivity of the basin”.

“Therefore, to fill this gap where many metrics did not properly evaluate the hydrological regime changes under no flow conditions, the objective of this study was to investigate the effect of flow regulation on the hydrological river regime by the development of a single, simple and dimensionless index that can be applied in different regimes but especially under no flow conditions with low data requirement.”

Further, in Section 3 (Materials and methods) in point 3.2 (Data set) the first paragraph (lines 262-269), second paragraph (lines 270-278) and third paragraph (lines 285-298) were modified to improve the manuscript structure as it is indicated in the following:

“The HRI was applied in the DSCC river basin, which is currently characterized by its hydrological discontinuity and intermittent flows. Moreover, to validate the applicability of the index, the HRI was also applied to the CO River with a defined hydrological connectivity throughout the basin and permanent runoff in natural regimen, and with both low and high impoundment conditions.”

“Therefore, natural flows (i.e. low modified flows) were evaluated in the tributaries upstream the main reservoirs, by comparing at least two gauging stations. The gauging stations were selected for their proximity, to ensure that there are no significant contributions from streams or interactions with groundwater. In the case that the distances are greater, the criterion was based on the allochthonous nature of the flows, that is, there are no obvious contributions in the analysed section that result in greater flows at the downstream gauging station. Based on the above and the availability of information, the MZ River at GUI and CAC (1956-90) and AT River at ESO plus the contribution of the Salado (SL) River at CAA respect to the records downstream in LAN (1972-03), were evaluated. In the CO River basin, the HRI for natural or low modified flows was implemented in the headwaters (LGT and BAR) with respect to the monthly flows registered in BRQ, and in the main channel between BRQ and PMA gauging stations, for the 1976-2011 and 1940-1971 periods respectively (Table 4).”

“Further, to analyse the HRI performance in evaluating the impact of reservoirs on flow conditions, the HRI was applied in the DSCC River basin in two sectors, the tributaries and the lower reaches of the DSCC River, based on flow data availability. The effect of the reservoirs and their operation on the hydrological regime was contemplated for different impoundment conditions. The comparison between the flow records downstream of the reservoirs with those upstream in natural or low modified flow regime, was discriminated between periods with low impoundment conditions (i.e. storage reservoirs < 2 hm^3, see Table 2) where water for irrigation was derived mostly from diversion and small dams, and periods with high impoundment conditions (i.e. reservoirs with greater storage capacity, >100 hm^3) that represent current conditions (Table 5). In this case, only in the SJ River (km 47.3 vs PLT) was possible to evaluate the effect of a low impoundment condition from 1937 to 1950 and in the CO river (BRQ vs PMA) for the 1940-1971 period. "

"For the current impoundment conditions, the modification of the hydrological regime was analysed in the majority of the tributaries of the DSCC River (SJ, MZ, DT and AT) in two periods, the historical available records till 2010 and the 2010-2023 time series that represent both the current impoundment and climate conditions. In the SJ River, the sum of natural or low modified flows at SJ-km 47.3 or SJ-km 101 and in the MZ River at MZ-GUI were compared with those observed downstream of QUL, PTN, CAL, ETA and POT reservoirs in SJ-EEN (modified flow) for the two indicated periods extending from 1993 to 2023. In the DT River, the natural or low modified flows at DT-LJA were compared with modified flows recorded downstream of ETI, LRE and ADT reservoirs in DT-MOC for the historical and current periods, while in the AT River the natural or low modified flows at AT-LAN were contrasted with the modified flows registered downstream of VGR and ENI reservoirs at AT-CAR and AT-PTU for the 1985-2023 and 1980-2010 time series respectively splitting the analyses in the two previously indicated periods."

"Similar approach was applied in the CO River, where for low impoundment conditions natural or low modified monthly flows recorded in BRQ were compared with the modified observed in PMA downstream of DPU diversion dam for the 1972-1990 period. For high impoundment conditions, flows recorded BRQ were contrasted with flows in PMA, downstream of CDP reservoir, for the available historical (1994-2010) and current (2010-2023) periods. Missing records in PMA between 2015-2018 and 2023 were completed with CDP flow discharges while the flow contributions of the DSCC River in the 1980s were subtracted."

-Comment 3: Regarding to the confusing terminology, we agree with the observations. Thus, 'actual' was changed to 'current' in the text, tables and figures. When possible, the ''natural' vs. 'modified' terms were replaced to 'upstream' vs. 'downstream'. However, it is not always de case, as most of the basin is downstream the main hydraulic structures. Besides, most of the times flow records upstream the reservoirs represent natural flows. Therefore, in the text natural flows (i.e. low modified flows) was used when necessary.

Furthermore, the terms low and high impoundment conditions are better described in section 3.2 (Data set) in the third paragraph (lines 285-298) as indicated above in the answer of Comment 2.

"The comparison between the flow records downstream of the reservoirs with those upstream in natural or low modified flow regime, was discriminated between periods with low impoundment conditions (i.e. storage reservoirs < 2 hm^3, see Table 2) where water for irrigation was derived mostly from diversion and small dams, and periods with high impoundment conditions (i.e. reservoirs with greater storage capacity, >100 hm^3) that represent current conditions (Table 5)."

Minor Comments

Introduction

-About the topic connectivity: we do consider that it is relevant in large semi-arid basins where the flow is usually intermittent. Therefore, to better describe this topic in Section 1 (Introduction) it is indicated that changes in the hydrological regime due to modification in basin connectivity was one of the motivations to develop the HRI. The inclusion is described in the above answer to Comment 1.

Moreover, in Section 2 (Study area) many implicit mentions to basin connectivity are already included, such us:

"…The DSCC River is distinguished by being an axial collector that receives on its right bank all its tributaries forehead mentioned and connecting important wetlands…." (lines 102 and 103): The functioning of the lower basin depends on the connectivity between the tributaries and the DSCC River itself.

"….The wetlands of the DSCC River are epigenic as a result of the fluvial contributions with null groundwater discharge…" (line 114): Therefore, its occurrence does not depend on local contributions but on river connectivity.

"The headwater of the DSCC River basin is the CA, where winter precipitation due to the orographic lifting of Pacific air masses by the mountains, constitutes the principal hydrological forcing of the basin". (lines 121 and 122). This paragraph was edited as will be described later in the following:

"This orographic configuration determines that the CA is the headwaters of the DSCC River basin, where winter precipitation due to the orographic lifting of Pacific air masses by the mountains, constitutes the principal hydrological forcing of the basin (Bruniard, 1986).": In both cases, it is implicit that fluvial connectivity is a key feature of the hydrological expression of the lower basin.

"….The runoff in the DSCC River is allochthonous due to the reduced rainfall that dominates the lower basin." (lines 162 and 163): The functioning of the lower basin depends on the connectivity between the tributaries and the DSCC River itself.

Moreover, in Section 3 (point 3.2 data set) and in the Discussion (point 5) the edition of the text included more explicitly this topic as it is described later in the Discussion section:

-Lines 27 and lines 29-31: We agree with the observations. Therefore, we edited the paragraphs trying to be more generalist and considering that large semi-arid basins are hardly fully activated (they usually do not depend only on climate configuration) but rather they typically present a more humid area where precipitation occurs (topographic configuration or proximity to the sea, etc., plus climatic variation) and the rest of the basin is dryer and usually has allochthonous flows. The modification is indicated below:

"In semi-arid regions, large basins are hardly fully activated since they usually do not depend solely on a climatic configuration. In contrast, there are other factors such as relief or geographical location that determine the occurrence of precipitation. If the basin has a mountainous area, it usually constitutes the headwaters since precipitation is favoured by the orographic effect. Thus, the hydrological input function is restricted to those areas and almost none is manifested in the lower part. Moreover, higher temperatures result in important evapotranspiration losses which accentuate the hydrological deficit of the lower part of the basin."

-Lines 58-60: We modified the text for a better understanding. The term 'fail' is replaced in the following paragraph. Furthermore, a context for the description and examples of the limitations of the metrics in no flow conditions is provided in the above answer to Comment 1.

"Indeed, indices based only on flow statistics, such as the interquartile variation range (IQR), the coefficient of variation (CV) or the flow duration curve (FDC), used as proxies for the seasonality of flows, among others; may not be suitable when no flow conditions are present. They require very detailed information not always available or not relevant to the dominant processes in the basin (e.g. allochthonous seasonal flow, interaction with groundwater), or they are based on complex theoretical functions of flow distribution of limited representativeness when runoff is not natural (e.g. only dams discharges, drainage flows), or the difficulty to standardize flows using statistical proxies (e.g. CV, IQR, FDC) for a given period when the average flow rate is zero."

-Line 62: A location of the DSCC River basin is provided as indicated in the following:

"In this context, the Desaguadero Salado Chadileuvú Curacó (DSCC) River located in the central-west part of Argentina, provides a representative case study because it is an extensive semi-arid basin severely dammed which has undergone noticeable changes in its hydrological expression over the past century mainly due to the fragmented water governance along its transboundary water systems (Dornes et al., 2016)."

Study Area

As suggested, the section was reorganized considering the indicated contributions. It is an extensive basin that is characterized by both its relief and heterogeneous climate, which results in a complex hydrological expression and also with different levels of hydrological information. Therefore, we consider that it is important to provide an adequate description of these aspects to give the reader the possibility of understanding the results which are illustrated spatially distributed in the basin. Thus, first the aspects of the relief and climatic configuration were reorganized, then the description of the tributaries and finally the DSCC river itself and the wetlands. The headings of Table 2 and Figure 3 were also edited. The following paragraphs contains the reorganized Study Area Section:

"The DSCC River basin is the largest basin that extends entirely in Argentina. The DSCC River basin is located in the central-west part of Argentina lying to the east of the of the Cordillera de los Andes (CA) mountain range with a north–south orientation (27° 47′ S, 38° 50′ S). The basin belongs to the Colorado (CO) River that drains into the Atlantic Ocean (Figure 1). It encompasses partially or totally the provinces of Catamarca, La Rioja, San Juan, Mendoza, San Luis and La Pampa. The total area is approximately 315,000 km^2 and includes the sub-basins of the Vinchina-Bermejo (VB), Jáchal (JL), San Juan (SJ), Mendoza (MZ), Tunuyán (TY), Diamante (DT) and Atuel (AT) rivers. The DSCC River basin located in the CA piedmont is defined by mountain ranges such as the Cordillera Principal, the Cordillera Frontal and the Precordillera to the West and North, the Sierras Orientales and Sierras Pampeanas to the East, whereas the lower basin is developed on flat terrain as part of the occidental area of the Pampean region (Ramos, 1999). This orographic configuration determines that the CA is the headwaters of the DSCC River basin, where winter precipitation due to the orographic lifting of Pacific air masses by the mountains, constitutes the principal hydrological forcing of the basin (Bruniard, 1986). The rest of the basin is isolated from the influences of wet air masses driven by the extratropical high-pressure systems of the Atlantic and Pacific Oceans, a condition that results in an arid climate to the North and semiarid to the South (Prohaska, 1976). These conditions generate a north-south precipitation gradient that ranges from values around 100 to 350 mm per year respectively, however this precipitation does not contribute to the average hydrological expression of the lower basin of the DSCC River which is strongly defined by the allochthonous snowmelt runoff from de CA (Dornes et al., 2016).”

“The tributaries drain the eastern slope of the CA through well-defined valleys and canyons towards the piedmont. All the tributaries have a defined snow-fed hydrological regimen, given that neither the glacier cover at the middle CA is significant nor the summer precipitation. Northern sub-basins have considerably less runoff than the central and southern sub-basins as is the case of the VB River with a mean discharge value around 1 $m^3 s^{-1}$, and JL River with an average annual flow of 10 $m^3 s^{-1}$. The SJ River is the tributary with the greatest discharge with a mean annual flow of 65 $m^3 s^{-1}$ as a consequence of the development of the basin over a large part of the CA covering a mountain front of more than 200 km. It is followed by the MZ River with 44 $m^3 s^{-1}$, whereas the TY, DT, and AT have 27, 31, and 34 $m^3 s^{-1}$respectively. The tributaries show both a great interannual flow variability that is consistent with varying snowmelt processes occurring in a complex mountain environment and a defined synchronicity with above and below-average flows strongly related to positive and negative ENSO episodes (Compagnucci and Vargas, 1998, Aceituno and Vidal, 1990; Waylen and Caviedes, 1990; Masiokas et al., 2006; Araneo and Villalba, 2014). The maximum flow magnitudes observed in 1980s, 1992, 1995, 2005, and 2006 and to a lesser degree in 2008 were associated with El Niño episodes. On the opposite, the last decade showed very low flow values, according to the dominance of negative ENSO phases (La Niña), with the exclusion of 2015 classified as an El Niño episode that resulted in average flow values (Table 1). As a consequence, lesser natural flows are seen in all the tributaries for the current conditions.”

“Tributary streams reach their confluence with the DSCC River usually through depositional sediments forming alluvial fans where the reduction of the terrain slope and the discharge of alluvial local aquifers, led to the occurrence of extensive wetlands. The DSCC River initiates as the outlet of the Lagunas de Guanacahe (LG) wetland, which is fed by the VB, SJ and MZ Rivers (see Figure 1). It follows a North-South trajectory along approximately 1.450 km until its mouth in the CO River at the Pichi Mahuida point in La Pampa province (38° 49′ S and 64° 59′ W). The DSCC River is distinguished by being an axial collector that receives on its right bank all its tributaries aforementioned and connecting important wetlands (Bereciartua et al., 2009; Chiesa et al., 2015), such as LG, Bañados del Tunuyán (BT), Bañados del Atuel (BA) and Lagunas de Puelches (LP). Between these wetlands and until its mouth into the CO River, the DSCC River has different names. Thus, it is called Desaguadero River (DSCC-I) between LG and BT, Salado River (DSCC-II) between BT and BA, Chadileuvú River (DSCC-III) between BA and LP, and Curacó River (DSCC-IV) from LP to the CO River.”

“The wetlands of the DSCC River are epigenic as a result of the fluvial contributions with null groundwater discharge. They are characterized by extensive flooded areas with numerous channels and lagoons, and acquire an ecological relevance due to their location in a semi-arid region and for being hydrological regulation nodes of the basin. The LG, BT, and BA wetlands are located at the distal part of extensive alluvial fans developed at the confluence of the corresponding tributary with the DSCC River, therefore their hydrological expression depends more on the flow contribution of the tributary than on the DSCC River. On the other hand, the LP wetland is characterized by the presence of extensive lagoons (e.g. La Brava, La Leona, La Julia, La Dulce, Urrelauquen, and La Amarga) all of them linked by the DSCC River.”

“The DSCC River basin has twelve large reservoirs; all located on its tributaries (Figure 2 and Table 2). Currently, El Tambolar (ETA) on the SJ River is under construction and there is more planned such as El Baqueano (EBA) on the DT River. None of them were built for flood control; instead, they were built for irrigation purposes and hydropower generation. The prevalent use of inefficient gravity-fed surface irrigation systems determines that irrigation demands are unusually high with respect to natural supply (Llop et al., 2013). As a result of these impoundments and reservoir operation, none of the tributaries contributes in natural regimen to the DSCC River. Further, in the DSCC River, two small dams (Azud Norte, AZN, and Azud Sur, AZS) were built to generate impoundment conditions and prevent erosion in the LG wetland. The CO River, has the Dique Punto Unido (DPT) diversion dam used for irrigation and water consumption, and the Casa de Piedra (CDP) reservoir that regulates the different water allocations in the lower basin.”

“The runoff in the DSCC River is allochthonous due to the reduced rainfall that dominates the lower basin with high flow records strongly associated with El Niño episodes, such as in the 1980s decade when the DSCC River drainage network was fully active with discharges to the CO River. The historical information is not synchronous, given that it is generally only available in periods with runoff, reveals highly modified and severely attenuated annual hydrographs along the DSCC River. The current situation shows an even more drastic hydrological condition with almost no flow in all its extension. Thus, as a consequence of the described flow regulation in the tributaries, the DSCC River is actually dry. Furthermore, no groundwater discharge is observed from outside the alluvial plain. Groundwater flow follows the regional gradient of the river and it is majorly constrained to the alluvial plain of the DSCC River where the phreatic aquifer is fed by fluvial recharge (Páez Campos and Dornes, 2021)."

"The resulting lack of hydrological connectivity of the DSCC River with the upper basin where snowmelt runoff is generated determines a strong hydrological deficit in the lower basin that has significant ecological effects and the lack of contribution to the CO River. Figure 3 illustrates the annual hydrographs for both the available historical information and the current period (2010-2023) of the tributaries and the DSCC River."

-Line 84: What is meant by "fully developed"? Could you just say "Argentina" instead of "Argentine territory" to improve clarity? The DSCC River basin is the largest basin entirely developed in Argentina. Other basins, such as La Plata River basin or even the Paraná River basin have greater areas in Argentina, but their total area also includes neighboring countries. Therefore, the following text seem to be appropriated:

"The DSCC River basin is the largest basin that extends entirely in Argentina"

-Line 90: Is the Cordillera de los Andes the same as the Andes mountain range (line 86)? The following text more appropriately describes what is indicated:

"The DSCC River basin is located in the central-west part of Argentina lying to the east of the Cordillera de los Andes (CA) mountain range with a north–south orientation (27° 47' S, 38° 50′ S)….."

"…The DSCC River is located in the CA piedmont is defined by mountain ranges such as the Cordillera Principal, the Cordillera Frontal and the Precordillera to the West and North, the Sierras Orientales and Sierras Pampeanas to the East, whereas the lower basin is developed on flat terrain as part of the occidental area of the Pampean region (Ramos, 1999).

-Line 96: The precipitation doesn't contribute to the hydrology? Can that be true? The opposite is said in line 122.

The sentence was rewritten as indicated in the following:

"This orographic configuration determines that the CA is the headwaters of the DSCC River basin, where winter precipitation due to the orographic lifting of Pacific air masses by the mountains, constitutes the principal hydrological forcing of the basin (Bruniard, 1986). The rest of the basin is isolated from the influences of wet air masses driven by the extratropical high-pressure systems of the Atlantic and Pacific Oceans, a condition that results in an arid climate to the

North and semiarid to the South (Prohaska, 1976). These conditions generate a north-south precipitation gradient that ranges from values around 100 to 350 mm per year respectively, however this precipitation does not contribute to the average hydrological expression of the lower basin of the DSCC River which is strongly defined by the allochthonous snowmelt runoff from de CA (Dornes et al., 2016)."

-Line 100. "and the MZ River through the last one". Unclear what this means. The sentence was rewritten as indicated in the following:

"The DSCC River initiates as the outlet of the Lagunas de Guanacahe (LG) wetland, which is fed by the VB, SJ and MZ Rivers (see Figure 1)."

Materials and methods

-Line 195: "…which is by definition the hydrologic regime". The modified text of the definition of the hydrological regime is described below:

"It is based on the comparison of the annual distribution of monthly flow records in natural or low modified with modified regimes (i.e. upstream vs downstream of a reservoir) which represent the long-term pattern of water flow and therefore the hydrological regime."

-Line 226: The modification of the description of the number of month (TQmN.max and TQmM.max) in equations 4 and 5 is detailed in the following:

"where TQmN.max and TQmM.max are the time (i.e. month number within the hydrological year) of occurrence of the monthly natural and modified maximum flow respectively".

-Line 230: Could you add a sentence somewhere to clarify what 0.0833 means in this equation? Why 0.0833 and not a different number?

The number 0.0833 is the slope of the linear relationship between the minimum value (TIF=0 when TD=0) and the maximum value (TIF=0.5 when TD=6). The following text was modified to clarify:

"To scale the TIF to a maximum value of 0.5 (i.e. natural flow) and a minimum value of 0 (i.e. maximum TD) applying a linear relationship with a slope of 0.0833 is calculated as following Eq. (6):"

-Line 239: Is Qsm always going to be equal to or greater than 8.33? If so, is it necessary to take the absolute value in eq. 8, since it should always be positive?

In the scaled hydrograph (Eq.1), Qms= 8.333 when the monthly quantities are equal or constant throughout the year. When the Qms vary throughout the year, its value may be greater or less than 8,333. Therefore, to analyse the interannual variability, the differences with respect to a constant flow are calculated. Consequently, the use of the difference in absolute value $MRI=|Qsm-8.333|$ ensures this calculation.

-Table 4: CAA is mentioned as an upstream gage in the table, but not in the text (Line 275); Do we need this table in addition to table 1? Or could they be combined? I'm also wondering if it would be useful/possible to label the gages (highlight in a different color) that are used in the analysis in either Figure 1 or 2 – not necessary, just a thought

The following paragraph shows the addition of the CAA gauge station in the text. "Based on the above and the availability of information, the MZ River at GUI and CAC (1956-90) and AT River at ESO plus the contribution of the Salado (SL) River at CAA respect to the records downstream in LAN (1972-03), were evaluated"

Table 4 tries to synthesize the information and details the common data period between gauging stations used in the calculation of the HRI in natural regime. Table 1 indicates location and the available record periods (historical and current) for each gauge station in the basin. Table 4 helps to link the Materials and methods section with the results (e.g. Figure 4).

Gauging station labels Figures 1 and 2 were edited highlining its colour (white in Fig 1 and black in Fig. 2)

- Paragraph at line 285: This is a difficult paragraph to follow. Edit to improve clarity.

The paragraph was edited to improve clarity as it is shown in the following. It is also showed in the above answer to Comment 2 where more context is provided.

"Further, to analyse the HRI performance in evaluating the impact of reservoirs on flow conditions, the HRI was applied in the DSCC River basin in two sectors, the tributaries and the lower reaches of the DSCC River, based on flow data availability. The effect of the reservoirs and their operation on the hydrological regime was contemplated for different impoundment conditions. The comparison between the flow records downstream of the reservoirs with those upstream in natural or low modified flow regime, was discriminated between periods with low impoundment conditions (i.e. storage reservoirs < 2 hm^3, see Table 2) where water for irrigation was derived mostly from diversion and small dams, and periods with high impoundment conditions (i.e. reservoirs with greater storage capacity, >100 hm^3) that represent current conditions (Table 5). In this case, only in the SJ River (km 47.3 vs PLT) was possible to evaluate the effect of a low impoundment condition from 1937 to 1950 and in the CO river (BRQ vs PMA) for the 1940-1971 period."

Results

-Paragraph at line 414, and elsewhere: There is a lot of explaining and providing contextual information in the results section…

The text that provided contextual information was edited so that the it refers to the results of the figures or tables. For example, the following paragraph shows the changes:

“The comparison of flow conditions upstream (i.e. natural regime) and downstream (i.e. modified regime) of the main reservoirs in the tributaries of the DSCC River and in the CO River revealed a different degree of modification of the hydrological regime (Figure 8). In tributaries, downstream of reservoirs and adjacent irrigation areas, runoff is intermittent. However, this runoff is not natural but is the result of direct and diffuse drainage contributions from irrigation surpluses as a consequence of the use of very inefficient gravity irrigation systems. Therefore, flows show a strong attenuation or an intermittent condition with an inverted hydrological regime since they are mostly present in winter. This runoff disappears downstream and does not contribute to the DSCC River.”

Discussion

Line 549: Here and elsewhere, the authors claim that HRI is able to quantify the spatial impacts on the flow regime, but based on my reading, this is not true. No spatial analysis is incorporated into this metric. Please edit to clarify.

The determination of the impact factors (MIF, TIF and VIF) of the HRI are determined based on the comparison between flows upstream and downstream of a given point, which is why the HRI does consider spatial distribution. Likewise, the following paragraphs of the discussion were edited for clarity:

“The proposed HRI is a single and dimensionless metric that considers the impacts on the annual distribution of flows, which is the more general definition of the hydrological regimen. Therefore, monthly mean flows are used to evaluate the different impact factors. This method allows its application in large basins, where daily flow variations do not necessarily represent the river-aquifer interaction, or the activation of a wetland, or the maintenance of ecosystem functions downstream the reservoirs. Additionally, this approach allows addressing the usual lack of daily flow data especially during no flow conditions. Furthermore, it is not a specific measurement but is based on the comparison of flow records between upstream and downstream locations, a characteristic that allows evaluating, in addition to alterations resulting from hydraulic infrastructure, impacts of tributaries, interaction with groundwater, and the storage effects of wetlands……”

“….The HRI, due to its low data requirements and the determination of impact factors based on the difference between upstream and downstream flows, proved to be a suitable indicator to discriminate both the spatial and temporal impacts on the hydrological regime in the DSCC and CO Rivers under continuous and discontinuous flow conditions and different degrees of regulation or impoundment conditions”

-Line 600, elsewhere: The authors say that HRI is a useful tool for defining E-Flows, but it is not clear how HRI would be useful in this context. Please expand on exactly how HRI could be used to define e-flows.

The lack of runoff for long periods constitutes a drastic environmental impact on a basin and limits the application of hydrological metrics. One of the needs to avoid these impacts is the definition of E-Flows. In this context, the measures taken to mitigate these impacts must be able to be quantified to evaluate their effectiveness. This is where HRI is appropriate. The following paragraph indicates the changes made:

“From a simple visual inspection, it is obvious that there is a drastic modification of the hydrological regime in the DSCC River, however, the HRI allows us to quantify the degree of impact effects and discriminate the type of impacts (i.e. attenuation of flows, time lag of maximum flows and reduction of variability) on the natural hydrological regime. In this way, the determination of these parameters contributes to the definition of E-Flows. Therefore, the HRI constitutes a very useful tool for evaluating the efficiency of structural and non-structural management measures that should be implemented to restore the environmental damage of the fluvial ecosystems of the DSCC River caused by the absence of runoff.”

-Line 603: This paragraph feels disconnected from the rest. Please consider either removing, or expanding to better integrate it.

Since climate change (i.e. modification of hydrological forcing) can be an impact factor on the hydrological regime, the current period of data was analyzed. However, the effects of anthropic regulation dominate the hydrological expression of the DSCC River, similar to what was expressed by Arheimer et al (2017). The following paragraph indicates the changes made:

“Climate change is another critical factor of regime modification whose effects can be evaluated with the HRI. The current period showed less runoff as a result of less snowfall in the basin and predictions for the study area indicate less snowfall and an increase in rainfall. However, according to Arheimer et al (2017), the anthropogenic influence on the snow-fed hydrological regime of the DSCC River proved to be severe with respect to the possible effects of climate change on the input function of the basin. Therefore, for sustainable freshwater management, the proposed HRI will contribute to focus on the adaptation to climate change and other environmental stressors (Poff and Matthews, 2013) such as the lack of integrated water resources management in the basin.”

Technical

- Line 87: Change ‘partial’ to ‘partially’: Changes were applied.

- Line 101: Change “till” to “until”: Changes were applied.

- Line 103: I believe you mean “aforementioned”, not “forehead”: Changes were applied.

- Line 198: Change “similarly” to “similar”: Changes were applied.

- Line 203: typo: Changes were applied.

- You use different phrases when referring to no-flow events (no flow, non-flow). Consider standardizing the language used: Changes were applied, and no flow was used.