Dear HESS Editorial Board and Reviewers,

We would like to submit Author Comments of our manuscript entitled " Accounting for environmental flow requirements in global water assessments [Doi:10.5194/hessd-10-14987-2013]" submitted to Hydrology and Earth System Sciences. “

First of all, we would like to express here our deep gratitude for the suggestions that were helpful for us to revise our manuscript. We apologize for the fact some parts of our manuscript that were confusing for the Referees.

Please find below a detailed response to each referee. We have revised our manuscript according to the direction given by referees and the Editorial board. After this, we sincerely believe that the new version is up to satisfying the comments of both referees.

Again, our gratitude to you and all referees.

Sincerely yours,

Amandine PASTOR (On behalf of all authors)

Response to Referee #1

We would like to express our gratitude for the comments, critics, and suggestions that has helped us to improve our manuscript to Referee 1. Our responses (in blue) are provided here together with the original comments (in black).

While the research design presented is reasonable, the presentation is very poor. This includes the structure of the text, the description of methods and data, the analysis of the data and the use of the English language.

In order to improve the presentation of our manuscript, we have included one new figure and one new table. Therefore, the order of Figures and Tables has changed compared to the previous version of our manuscript. We have improved the presentation of our paper by:

- Refining the structure of the text,
- extending the description of environmental flow methods types (Table 1, section 4.1) and the description of global EF methods (Table 4),
- including a detailed description of the hydrological data and their geo-localization (Figure 1, Table 2),
- clarifying the choice and the details of our data analyses (in our response below).

We also had our manuscript checked for the use of the English language.

In addition, the framing of the research is insufficient; the lack of actual information of the effect of river discharge alterations on freshwater-dependent biota,

In the revised manuscript we have included in the introduction a section on how difficult it is to quantify the impact of river discharge alteration on freshwater-dependant biota (page 4, lines 20-29). We also clarified the purpose of developing a new global environmental flow model (page 4, lines 29-37 and page 4 lines 1-2).

as well as the fact that EFRs are societal decisions, is not reflected.

We acknowledge this comment and we extended our discussion with a new paragraph on societal decision (section 5.6, Page 17 lines 23-34)

Specific comments

Abstract

It is not correct to say (or at least not meaningful) that the "VMF method mimics for the first time" natural flow regimes:". The Tessmann method also seems to do this (even though the explanation of the method in section 3.3. and Table 2 is not clear), and so does the "presumptive standard for environmental flow protection" of Richter et al. (2012) which would allocate 80% of mean monthly flows to the environment . It was cited in the literature review in 2.2.1 but not further discussed later.

We have extended the description of EF methods in Table 4 with a description of the flow season algorithm and the EF algorithm per method. We reviewed the sentence "VMF method mimics for the first time" and acknowledged the comments of the reviewer by changing it to: "*For the first time, five hydrological EF methods including the new "Variable Monthly Flow" (VMF) method were compared* *and "validated" at global and local scales by including intra-annual variability of the natural flow regime*". In a context where water withdrawals were usually prioritized over environmental flows, we consider that the VMF method could be applicable for the achievement of "*fair ecological conditions*".

We have reviewed the "*presumptive standard for environment flow protection*" which only allows 20% of MMF depletion and we would like to clarify that this method was defined with desired achievement of "*good ecological conditions*" validated with four study cases (Richter et al., 2012). Therefore, we specified in the text: "*We also excluded the Hoekstra et al. (2012) method because they defined EFRs to achieve good ecological conditions and we defined our ecological conditions to "fair ecological conditions"*." Moreover, the VMF method such as the Tessmann methods use different percentage of flow per month depending on the flow season (dry/wet season) while the Hoekstra method allocates the same percentage of flow each month.

1 Introduction

The introduction is too broad and does not guide the reader well to work presented later. For example, the first paragraph is, in my opinion, superfluous.

In a revised manuscript, we reframed the whole introduction, removed the unnecessary information and discussed the difficulties and uncertainties of how difficult it is to determine EFRs at any spatial scale (page 3-4).

On the other hand, important information on the poor degree of scientific knowledge about the effect of flow alterations on freshwater ecosystems is not presented (e.g. Poff, N. L. and Zimmerman, J. K. H.: Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows, Freshwater Biol., 55, 194– 205, 2010). This would be required for the reader to understand how extremely uncertain any quantification of EFRs to achieve a "fair" or "good" status of the ecosystem is.

In the revised manuscript, the introduction now contains a paragraph explaining the limited knowledge and the difficulties to quantify EFRs in function of ecosystems, we also refer now to the suggested journal article from Poff and Zimmerman (2010). We also included a section on how difficult it is to determine ecological conditions (section 3.1.1, page 9 lines 13-26). In this section, we explain that determining ecological conditions of rivers can be done in many different ways and that there is no existing dataset on the desired ecological conditions of rivers worldwide.

However, we do acknowledge that some rivers should stay in good or excellent ecological conditions and that ecological conditions should be decided at local scales (section 5.7 page 18).

2 and 2.2 have the same title.

We have removed paragraph 2.1 on legislation of environmental flows and start section 2 with the "Review of environmental flows".

The Xenopoulos et al. (2005) study does not deal with EFRs but quantifies the effect of mean river discharge on fish species number.

We acknowledge this comment and we rephrased this section in the introduction (page 4 lines 24-28).

2.1 There is no "legislation of environmental flow methods"; what is described here relates to legislation regarding environmental flows. The scope of the European WFD is incorrect or at least misleading, as good ecological status does not (directly) relate to EFRs. The section should be deleted (or rewritten and moved to the introduction.

We agree with the reviewer and we deleted section 2.1 from the manuscript and we leave societal and legislation issues of EFRs to be addressed in other journal articles however we wrote a new section in the discussion (section 5.6, page 17).

3.1: It is not well explained which flow data were used to compute the five EFR values for each case study. In particular, how well are "natural" conditions represented in each case study=

In the new version of the manuscript we added a new table explaining how "natural" flow data were obtained (Table 2). Natural flows were obtained from historical datasets from 8 to 30 years before dam contruction or simulated with a hydrological model without any anthropogenic influences (no agriculture, no irrigation, no dams).

3.3 and Table 2. A clearer description of the five EFR methods is required, and a description of the rationale of each methods. E.g. in Table 2, the explanations in superscripts are not well formulate or are even wrong (b).

We have extended the description of EF methods in Table 4 as such:

1. by describing the algorithm to determine high, intermediate and low-flows for each method

2. by describing each EF method algorithm for each flow-season

We also explained that methods such as Tennant, Smakhtin and Q50_Q50 were adjusted from annual to monthly time step because there was not existing literature of how those methods could be applied on a monthly time step. For that, we developed an algorithm which determines flow seasons (Table 4).

In addition to table 4, Smakhtin method in described in section 2.5 (page 7) and Tennant and Tessmann methods are described in section 2.1 (page 5).

Finally, a description of selected existing EF methods can be found in section 3.5.2 and a description of the new EF methods can be found in the section 3.5.3 (pages 9-10).

4.2 Not meaningful to correlate EFR of case studies to computed EFRs in absolute numbers, as you did in Figure 2, better to do it, as in Table 4, normalized. Absolute numbers of EFR vary by a factor of 1000, which is a much higher number than the ratio of mean annual flow to EFR! In addition, it seems inconsistent that in three out of the five methods (b,c,e), one case study EFR is related to many computed values. E.g. in the Smakhtin method, only eleven points altogether should be shown. Is this maybe the reason for the lower R2 of these three approaches?

Table 3: Not clear how the number of high/intermediate/low flow months are defined (Tessmann of FVM), and why intermediate months and in Table 4 only low and high flow requirements mentioned?

We acknowledge the comment of the reviewer and we apologize for misleading the reviewer for our lack of information in Figure 3. Therefore we would like to clarify that in Figure 3, each point represents one EF value per study case and per month. Therefore, for each sub-figure, one EF method is presented with 11 study cases *12 monthly EF values. Each monthly EF value was plotted by using log10 because, as the reviewer shows, results vary by a factor of 1000 in absolute numbers and data was required to be transformed in a normal distribution. With the log10 transformation, the values are now limited to a range between -1 and 2. If we would normalize each EF value as the reviewer has suggested, we would obtain the same outcomes because each observed and calculated EF value would be divided by the same number (which is the mean monthly flow). Finally, relative share of EFRs on average flow is also shown in Figure 2 (of the new manuscript) because EFRs (represented by lines) are compared to monthly flow (represented by blue columns).

To acknowledge this comment, we changed the legend of Figure 3 from "*Validation of five environmental flow methods with the locally-calculated EFRs of 11 case studies with (a) Variable Monthly Flow, (b) Smakhtin, (c) Tessmann, (d) Q90_Q50, (e) Tennant*" to "*Relation between the calculated EFRs and the locally-calculated monthly EFRs of 11 study cases with (a) Variable Monthly Flow, (b) Smakhtin, (c) Tessmann, (d) Q90_Q50, (e) Tennant. In each sub-figure, each dot represents EFRs for one month and for one case study.*"

In Table 4, descriptions on how low/intermediate/high flows can be found. Thanks to this flow-month algorithm per method, we could calculate EFRs for each month for each method. Once, we obtain our 12 EF values per study case and per method, we calculated exclusively EFRs for high-flow and low-flow season by taking the average values of EFRs during high-flow and low-flow season. The first reason is because intermediate months usually only accounted for 1 or 2 months out of 12 months and the second reason is that we wanted an homogenous comparison of EF method per season and per year for each study case (Table 5). Low-flow months are defined when mean monthly flow is below or equal to mean annual flow and high-flow months are defined when mean monthly flow is above mean annual flow.

5.1. Hoekstra and Mekonnen (2011) (HOEKSTRA, A.Y. & MEKONNEN, M.M. (2011): Global water scarcity: monthly blue water footprint compared to blue water availability for the world's major river basins, Value of Water Research Report Series No. 53, UNESCO-IHE, Delft, Netherlands) already considered interannual variability of EFR in their global-scale water scarcity study.

First, we think that the reviewer aimed to write *"...considered intra-annual variability.."* instead of "*...considered inter-annual variability*.." because none of the studies mentioned including our study rose the issue of inter-annual annual variability except in our study in the discussion sections 5.6 and 5.8. At this stage, the only way to tackle inter-annual variability was to define EFRs on long-term hydrological database (at least 15 years) to account for dry and wet years.

Second, it is true that Hoekstra et al. (2012) already used "*the presumptive standard for environmental assumption*" a method using percentage of monthly flow and we have neglected to explain why we do not use it in our study. First, Hoekstra and Mekonnen (2011) allocate the same percentage of flow during the year (80% of MMF) so they do not differentiate between high/low months, second, they used 80% of mean monthly flow and validated the percentage of flow with 4 study cases with desired "*good/outstanding*" ecological conditions (Richter et al., 2012) while we aim at "*fair*" ecological conditions and we validated our methods with 11 study cases spread in different continents and freshwater ecoregions (see Figure 1 below). Finally, we think that restricting water extraction to only 20% of monthly flow would not be realistic in many regions. For example, in the Mediterranean and in south-east Asia current surface water extraction is already above 75% of monthly flow (Viala et al. 2008)

To acknowledge this comment, in the revised manuscript we have changes part of our abstract and we have clarified why we excluded Hoekstra et al. (2012) method in section 3.5.1.

5.3. It is incorrect to say that Tennant, Smakhtin and Q90_Q50 method allocate too large amounts of water during low-flow seasons etc. At least Smakhtin et al. only deal with total annual EFR such that also the representation in Figure 1 is incorrect, and the discussion at the end of 5.3 is not meaningful.

We agree with the reviewer that it is not correct to use "*too low or too large amount of water*". We have clarified this in the revised manuscript by only comparing EFRs between EF methods.

We would also like to clarify why and how the Smakhtin and Tennant methods were adjusted in our study. To be able to define how much water is available for irrigation or other users, it is essential to define EFRs at shorter timescales than annual timescales because irrigation is always planned on sub-daily, daily or monthly time-step. So, to make those methods applicable at monthly time scale and be reliable when compared to monthly irrigation requirements, there are two options:

1. To divide the total annual environmental flow requirements volume into 12 equal values (representing the EFR volume per month).
2. Or to take into account intra-annual variability and develop a simple rule dividing the river hydrograph into low/high flow months. Thus, for Smakhtin, Tennant, Q90_Q50 methods, we separated annual flow into high/low flow season (see Table 2 below) and allocate a different percentage of mean annual flow according to the flow season. For example, for the Smakhtin method, we made the assumption that BFRs (Q_{90}) was allocated during the low-flow season and HFRs (Q_{90} + 0-20% MAF) was allocated during the high-flow season.

In our paper we selected option 2 because we think that option 2 was an improved representation of EFRs compared to option 1 and we wanted to include intra-annual variability with an emphasize on different flow seasons (high and low-flow periods).

Finally the explanation 5.3 was reformulated as such: *"Using annual flow quantiles to calculate EFRs is not appropriate for certain type of flow regimes. For example, by using the Q90_Q50 or the Smakhtin method, the calculated EFRs was always lower than the locally-defined EFRs of variable rivers and was always higher than the locally-defined EFRs of perennial rivers (see Figure 1 of the manuscript). Hence using higher annual flow quantiles (paragraph 5.3) such as Q50 and Q75 (Smakhtin et al., 2004) does not improve the quantification of EFRs and using a parametric EF method such as a percentage of flow is more appropriate than non-parametric methods such as flow quantiles."*

5.4. (Sentence on p. 15009, l. 18). Given the underestimation of EFR in xeric basins and the low fit in polar ones (Table 4) of the VFM, it is not correct to write this sentence.

We have changed the sentence (p. 15009, l. 18) into: *"The Tessmann and the Variable Monthly Flow methods performed better than methods using annual thresholds because temporal representation of EFRs was defined with a parametric monthly time-step algorithm. However the quantification of EFRs of xeric freshwater ecosystems and polar freshwater ecoregions is still difficult to achieve compared to the quantifications of EFRs of temperate flow regimes."*

Response to Referee #2

We would like to express our gratitude for the comments, critics, and suggestions that has helped us to improve our manuscript to Referee 2. Our responses (in blue) are provided here together with the original comments (in black).

General comments: - The paper clearly states the questions that the authors seek to address. - The authors show familiarity with literature on setting environmental flows. Major papers and schools of thought appear to be accurately summarized and referenced. - There is a lot presented in this paper: (a) comparison of five hydrologic methods with local methods for determining EFRs; (b) comparison of environmental flow methods applied globally (presented in Figs 3-5); (c) application to 14 global river basins (presented in Fig 6). - The bulk of the paper is on (a), and the related methods, results, discussion and conclusions are pretty well presented and explained. In comparison, (b) and (c) receive almost cursory treatment and may be better presented as separate papers - expanding on them here would likely be too much to digest in one paper. I could follow (a) to its conclusion about advantages/disadvantages of the five hydrologic methods and whether they EFRs are high/low relative to each other and in different major habitat types, which will be useful context for understanding both global and local applications of these five methods. In contrast, there was relatively little discussion and few conclusions to take away from the analyses in (b) and (c) . They seem almost as an afterthought.

We agree with the reviewer that the focus of the paper is on part (a). However, we are of the opinion that part (b) and (c) are essential part of our paper and we would like to clarify and justify why parts (b) and (c) were included. Comparing and "validating" EF methods at local scales (a) was done to be implemented in global water assessment to restrict other water users such as irrigation. Hence, it is important to show how applicable those methods are at global scale by using the global hydrological and vegetation LPJml model (b) and give some preliminary estimates of EFRs at river basin scale (c). Part (b) shows the spatial representation of the 5 EF methods at global scale while part (a) shows the temporal representation of EFRs at local scale and finally part (c) aims at giving a range of EFRs estimates for some large river basins. Part (b) and (c) were included to show how EFRs can be used in future global assessment of land-use and climate change. In the revised version of the paper we better explained why part (b) and (c) were included.

Specific comments:
- Page 14989, line 15: The terms 'green' and 'blue' water may not be familiar to all readers. To clarify the point, which is important, consider replacing these terms with a description of these two components of the water cycle.

As suggested by the reviewer, we would like to clarify the term "green water" by the amount of water evaporated from plants and soils coming from precipitation and "blue water" as the amount of water evaporated coming from surface waters such as rivers, lakes and reservoirs. As our study is focused on blue water, we removed the part on green water and we keeped the text below: "*about 60 % of the world population could face water shortages coming from blue water (or the part of water coming from surface waters such as rivers, lakes and reservoirs)*".

– Page 15002, lines 15-20: I suggest saying a little bit more about the 'locally-calculated EFRs', perhaps a short paragraph explaining some of the 'environmental flow type methods' used. As written, there is only one sentence referring the reader to Table 3, where the methods are listed in a column. I read past that section without noticing that that was where the local methods were referenced. And since these are the basis for many conclusions about how the global methods perform, the reader deserves a little more information about them.
We acknowledge the comment made by the reviewer and we have extended the paragraph as such: *"In five out eleven study cases, hydrological methods were used to determine EFRs at local scale. Those*

methods were developed and validated with statistical analyses of daily flow datasets (e.g. GEFC, Hugues method, Tennant, Desktop reserve model). One study case was defined with a hydraulic method based on the river cross section of the river in order to assess suitable habitat area for fish habitat (R2 cross method). Three study cases used EF methods with eco-hydrological relationships such as PHABSIM and RHYHABSIM and the Hong Kong study case which developed an empirical relationship between macroinvertebrates survival and river flow. Finally, one study case used a holistic approach by including expert knowledge (Swedish case study)." For further descriptions on EF methods, we refer to the literature review of local EF methods (section 2.2).

- The comparisons between the global and local methods used to calculate EFRs are pretty well summarized, although in several places the authors make comments that the amount allocated to the environment is ’too large’ (e.g., p 15008, line 14-15). The authors should revise to clarify that the EFRs are ’higher’ or ’lower’ than the local method, and not imply that they are allocating ’too much’ to the environment. The strength of the paper is the comparison of methods - none of which actually estimate how much water these rivers need based on ecological goals. The authors should refrain from concluding that the methods allow ’too much’ or ’too little’ for the environment - such conclusions could only be drawn if they also present presented data on ecological impacts that confirm that EFRs (either local or global) are too conservative or not protective enough. Instead, the authors should use language that emphasizes consistencies and differences among methods.

We agree with the reviewer that the focus of the research is about comparing methods applicable at global scale and we replaced the sentence: *"Those methods tended to allocate too large amount of water during low-flow seasons and too little amount of water during high-flow periods* (Fig. 1)." by *"Compared to methods based on monthly values such as Tessmann and VMF methods, we found that methods based on annual thresholds allocated more water during low-flow season and less water during high-flow season than locally-calculated EF methods."*

Again in page 15008 lines 19-20, we replaced: "*The calculated EFRs with the Tennant methods were too low in high-flow season and too high in low-flow season in variable rivers*." By "*The calculated EFRs with the Tennant method were lower than the locally-defined EFRs in high-flow season and higher than the locally-calculated EFRs in low-flow season of variable rivers."*

Table 1. Description of tested hydrological environmental flow methods with MAF the Mean Annual Flow, MMF the Mean Monthly Flow, Q90 the flow exceeded 90% of the period of record and Q50 the flow exceeded 50% of the period of record. HFRs, IFRs and LFRs are respectively used to high, intermediate and low flow requirements.

Hydrological season	Smakhtin (2004)	Tennant (1976)	Q90_Q50 (2013)	Tessman (1980)[b]	Variable Monthly Flow (2013)[c]	Hoekstra (2012)
Determination of low flow months	MMF<= MAF	MMF<= MAF	MMF<= MAF	MMF<= 0.4*MAF	MMF<= 0.4*MAF	-
Low flow requirements (LFRs)	Q90	0.2* MAF	Q90	MMF	0.6*MMF	0.8*MMF
Determination of high flow months	MMF>MAF	MMF>MAF	MMF>MAF	MMF>0.4*MAF & 0.4*MMF>0.4*MAF	MMF> 0.8*MAF	-
High flow requirements (HFRs)	0 to 0.2*MAF[a]	0.4*MAF	Q50	0.4*MMF	0.3*MMF	0.8*MMF
Intermediate flow determination	-	-	-	MMF>0.4*MAF & 0.4*MMF<= 0.4*MAF	MMF> 0.4*MAF & MMF<= 0.8*MAF	-
Intermediate flow requirements (IFRs)	-	-	-	0.4*MAF	0.45*MMF	-

a. If Q90>30%MAF, HFRs=0,
If Q90<30% and Q90>20%, HFRs=7%MAF,
If Q90<20% and Q90>10%, HFRs=15%MAF,
If Q90<10%, HFRs=10%MAF.

b. Only the Tessmann and the Variable Monthly Flow methods require intermediate flow determination as their methods are based on monthly flows. The other methods (Smakhtin, Tennant and Q90_Q50) only allocate EFRs in high and low flow seasons and finally Hoekstra method does not distinguish between high flow and low flow season.

Table 2. Description of geographic coordinates of the study cases and their hydrological datasets

Study cases	Latitude	Longitude	Daily flow data used in study cases	Daily flow data used in this study
Bill William river, US (Shafroth et al. 2009)	34.23	-113.60	Pre-dam data (1940-1965)	GRDC 4152120
Ipswhich river, US (Armstrong et al. 1999)	42.57	-71.03	Ipswhich flow data (1961-1995)	20 years LPJml simulation without landuse and irrigation (PNV run)
Silvan river, Spain (Palau and Alcázar, 2010)	42.37	-6.63	Natural flow data (1980-1998): no flow regulation	Dataset from the authors
Osborne river, Zimbabwe (Symphorian et al., 2003)	-18.75	32.25	Naturalized flow data (1961-1973)	Dataset from the authors
Voijm dam, Sweden (Renofalt et al., 2010)	62.80	17.93	Pre-dam data (1909-1940)	Dataset from the authors
Newhalen river, Alaska (Estes, 1998)	59.25	-154.75	Pre-dam data (1951-1986)	USGS 153000000
Hong Kong, China (Niu and Dudgeon, 2011)	22.27	113.95	Natural flow data (2007-2008)	20 years LPJml simulation without landuse and irrigation (PNV run)
la Gna river, Vietnam,(Babel et al., 2012)	10.82	107.15	Pre-dam data (1977-1999)	Dataset from the authors
Great Ruaha river, Tanzania (Kashaigili et al., 2007)	-7.93	37.87	Pre-dam data (1958-1973)	20 years LPJml simulation without landuse and irrigation (PNV run)
Huasco river, Chile (UICN, 2012)	-28.43	-71.20	Historical data (1975-1988)	Dataset from the authors
Urmia lake, Iran (Yasi et al., 2012)	37.70	45.32	Pre-dam data (1949-2004)	Dataset from the authors

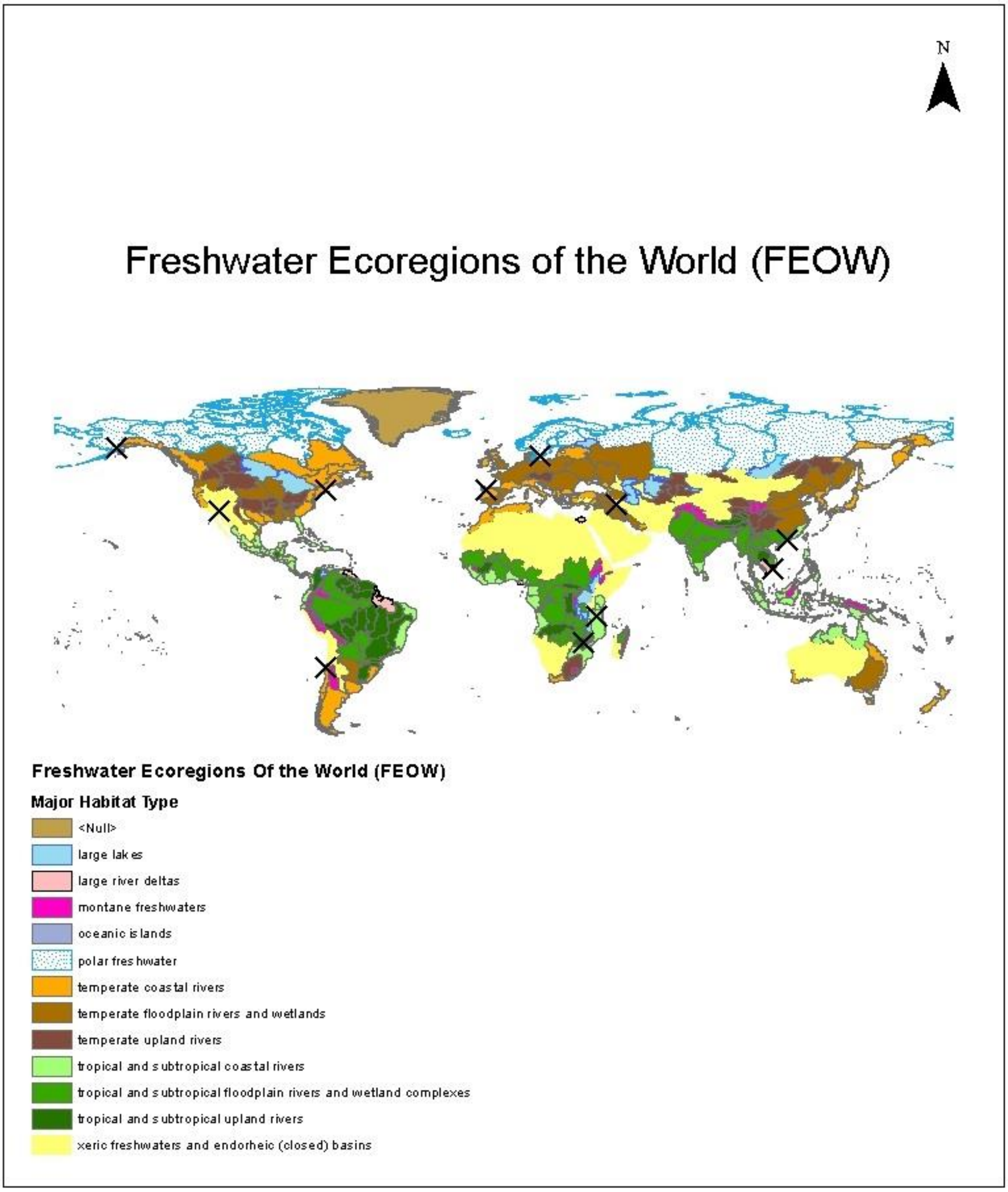

Figure 1 (in the new version of the manuscript). Location of 11 study cases where environmental flow requirments (EFRs) were locally defined.

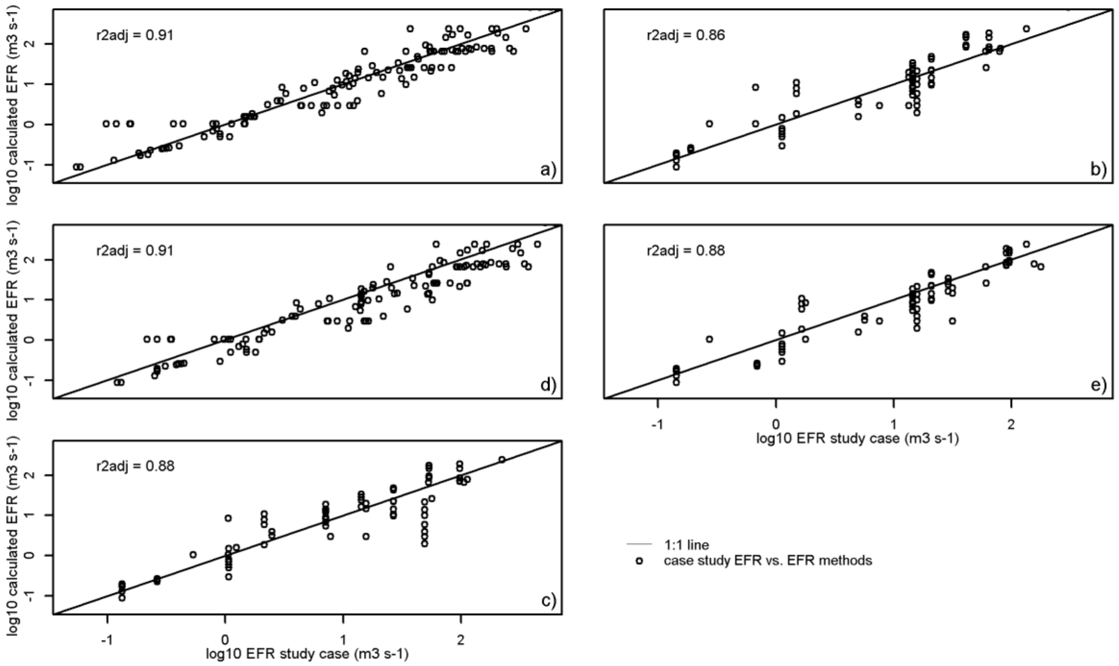

Figure 1. Relation between the monthly calculated EFRs and the locally-calculated monthly EFRs of 11 study cases with (a) Variable Monthly Flow, (b) Smakhtin, (c) Tessmann, (d) Q90_Q50, (e) Tennant methods. In each sub-figure, each dot represents an EFR for one month and for one case study.

Literature

Hoekstra, A. Y., Mekonnen, M. M., Chapagain, A. K., Mathews, R. E., and Richter, B. D.: Global monthly water scarcity: blue water footprints versus blue water availability, PLoS One, 7, 2012.
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