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Comparison and Validation of Hydrological E-Flow Methods through Hydrodynamic Modelling

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Abstract

Flow regime determines physical habitat conditions and local biotic configuration. The development of environmental flow guidelines to support the river integrity is becoming a major concern in water resources management. In this study, we analysed two sites located in southern part of Portugal, respectively at Odelouca and Ocreza Rivers, characterised by the Mediterranean climate. Both rivers are almost in pristine condition, not regulated by dams or other diversion construction. This study presents an analysis of the effect on fish habitat suitability by the implementation of different hydrological e-flow methods. To conduct this study we employed certain hydrological e-flow methods recommended by the European Small Hydropower Association (ESHA). River hydrology assessment was based on approximately 30 years of mean daily flow data, provided by the Portuguese Water Information System (SNIRH). The biological data, bathymetry, physical and hydraulic features, and the Habitat Suitability Index for fish species were collected from extensive field works. We followed the Instream Flow Incremental Methodology (IFIM) to assess the flow-habitat relationship taking into account the habitat suitability of different instream flow releases. Initially, we analysed fish habitat suitability based on natural conditions, and we used it as reference condition for other scenarios considering the chosen hydrological e-flow methods. We accomplished the habitat modelling through hydrodynamic analysis by using River-2D model. The same methodology was applied to each scenario by considering as input the e-flows obtained from each of the hydrological method employed in this study. This contribution shows the significance of ecohydrological studies in establishing a foundation for water resources management actions.

Keywords: ecohydrology, e-flow, Mediterranean rivers, river conservation, fish habitat, River-2D, Hydropower.

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1 Background and Motivation

Run-off-River (RoR) Hydropower is a widespread non-consumptive water use that causes alteration of aquatic ecosystems. Taking into account the increasing numbers of constructed and ongoing projects of RoR hydropower (Kelly-Richards *et al.*, 2017), the cumulative impact on the ecosystem per unit generated electricity may be increasing. Since the RoR hydropower are not associated with any regulation system, their power production is directly interconnected with the instream flow requirements of the river reach downstream the diversion weir. Thus, it is critical to define the trade-off between the fraction of flow allocated as instream flow, and the fraction of flow allocated for electricity generation, which is a desirable renewable energy resource. Flow regime determines physical habitat conditions and local biotic configuration. The development of environmental flow guidelines to support the river integrity is becoming a major concern in water resources management. This study presents an analysis on implications and reliability of seven hydrological based e-flow methods in the electricity generation and fish habitat alteration.

2 Methodology

2.1 Environmental Flow Methods (EFMs)

- *Percentiles **Q75** and **Q80*** of FDC (Verma *et al.*, 2016)
- *Minimum Mean Flow in August (**NMQ_August**)* (Tharme, 2003).
- *Linearised Matthey (**L.M**)* (Penche, 1998).
- *10% of Mean Annual Flow (**10%MAF**)* (Tharme, 2003).
- *Minimum Annual Flow (**NNQ**)* (Penche, 1998).
- *10% of Daily Flow (**10% Daily**)* (Penche, 1998).

2.2 Energy Model

- The potential energy is computed according to following formula: $P = 9.81\,\varrho\, Q\, H\, \eta$, where P is the power output, 9.81 the acceleration due to gravity (m sec^{-2}), ϱ is the density of water (1000 kg m^{-3}), Q is turbine flow in (m^3 s^{-1}), H=20 m is net head, and η=0.85 is overall efficiency of the system. Assumed installed power is approx. 1MW.

2.3 Reliability Index (RI) Analysis of EFMs

- This index is computed as the fraction of time when natural flow exceeds the flow suggested by EFMs (Eq.1).

$$RI = (T_{exceedance}\, T^{-1}_{total})\, 100\,\% \quad \text{(Eq.1)}.$$

2.4 Indicators of Hydrological Alteration (IHA)

- 33 IHA and 34 Environmental Flow Components (EFC), IHA software, V.7.1, (Richter *et al.*, 1996).

A brief description of methodology applied in this study is given in the following sections while the procedures followed are presented schematically (Fig.1).

2.5 Hydrodynamic Modelling

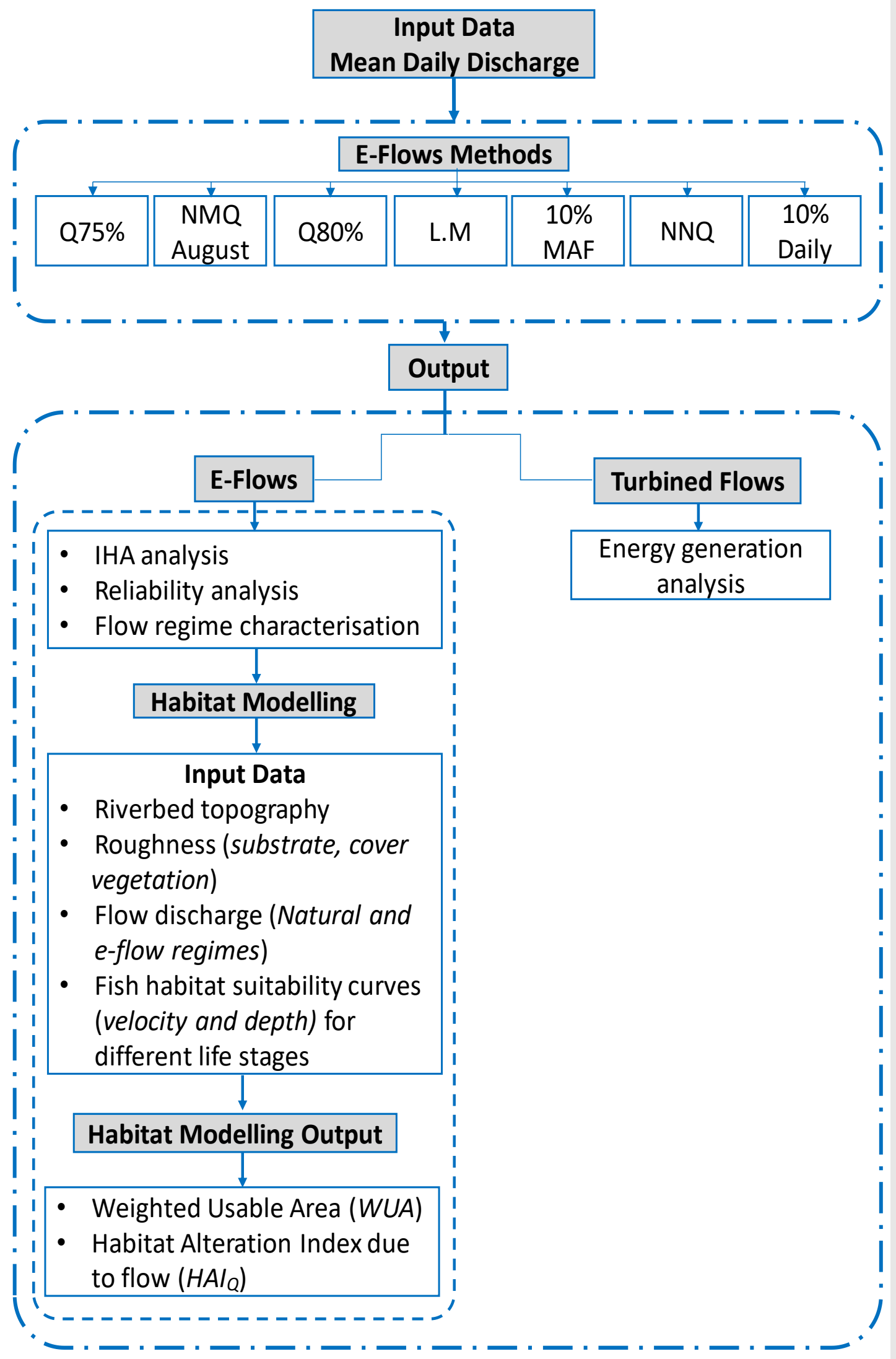
- Two flow regimes; inter-annual mean low flow and 3-day min flow in October (i.e., natural and altered).
- Three cyprinid fish species, two life stages (i.e., juvenile and adult).
- River 2D V. 0.95a was used to conduct the hydrodynamic modelling.

2.6 Habitat Alteration Index Due to Flow Alteration (HAI$_Q$)

- This index is measured by using (Eq.2).

$$HAI_Q = |WUA_{Qn} - WUA_{Qa}|\, WUA_{Qn}^{-1} \quad \text{(Eq.2)}.$$

WUA_{Qn}–Weighted usable area, natural flow
WUA_{Qa}–Weighted usable area, altered flow


Input Data
Mean Daily Discharge

E-Flows Methods
- Q75%
- NMQ August
- Q80%
- L.M
- 10% MAF
- NNQ
- 10% Daily

Output

E-Flows
- IHA analysis
- Reliability analysis
- Flow regime characterisation

Habitat Modelling

Input Data
- Riverbed topography
- Roughness (*substrate, cover vegetation*)
- Flow discharge (*Natural and e-flow regimes*)
- Fish habitat suitability curves (*velocity and depth)* for different life stages

Habitat Modelling Output
- Weighted Usable Area (*WUA*)
- Habitat Alteration Index due to flow (*HAI$_Q$*)

Turbined Flows

Energy generation analysis

Fig.1 General overview of analysis and procedures from hydrological analysis to habitat modelling

3 Study Site and Data

We considered one study site in the Ocreza River, East Portugal (Fig. 2). The river drains a watershed of 1429 km^2 with 90 km length and mean annual flow of 16.5 m^3 s^{-1}.

- **Flow Data** - (i.e., 29 year mean daily), from Portuguese Water Information System (SNIRH)
- **Hydraulic Data** - (i.e., flow velocities and depths), measured along the study site, considering several cross sections; measured with ruler and probe (model 002, Valeport) positioned at 60% of the local depth below the surface.
- **Riverbed Topography** - surveyed in 2013 using a combination of a Nikon DTM330 total station and 30 a Global Positioning System (GPS).
- **Fish Species, Preference Curves** - Barbel, Calandino (Bordalo) and Iberian Straight-mouth Nase (Boga), two life stages (i.e., juvenile and adult). Sampling: conducted during 2012 and 2013, October at undisturbed or minimally disturbed sites, Ocreza river (Boavida *et al.*, 2015).
- **Substrate Composition** – It was visually assessed and represented to define the effective roughness heights along the riverbed.

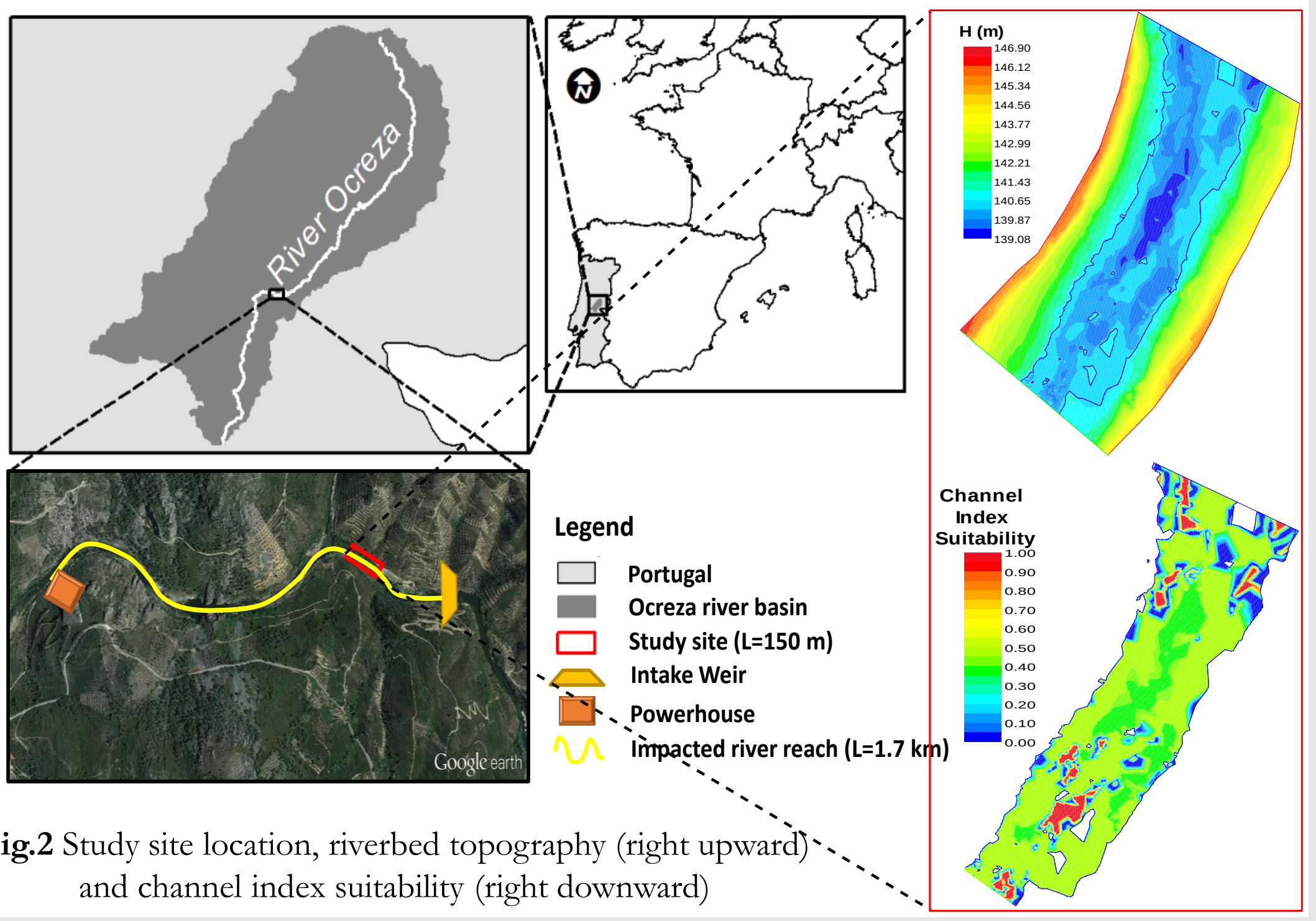


Fig.2 Study site location, riverbed topography (right upward) and channel index suitability (right downward)

4 Results

Concerning flow regime (Fig.4), 10% Daily is the only method that provides a flow regime almost similar to the natural one. In terms of reliability (Fig.5), 10% Daily is the most reliable, while 10% MAF the least reliable method. Regarding water allocation (Fig.6), almost all methods show similar performance. 10% MAF provided the lowest energy production (Fig.7). The highest WUA is provided by 10% MAF (Fig.8). The lowest habitat alteration is provided by 10 % MAF, followed by 10% Daily (Fig.9).

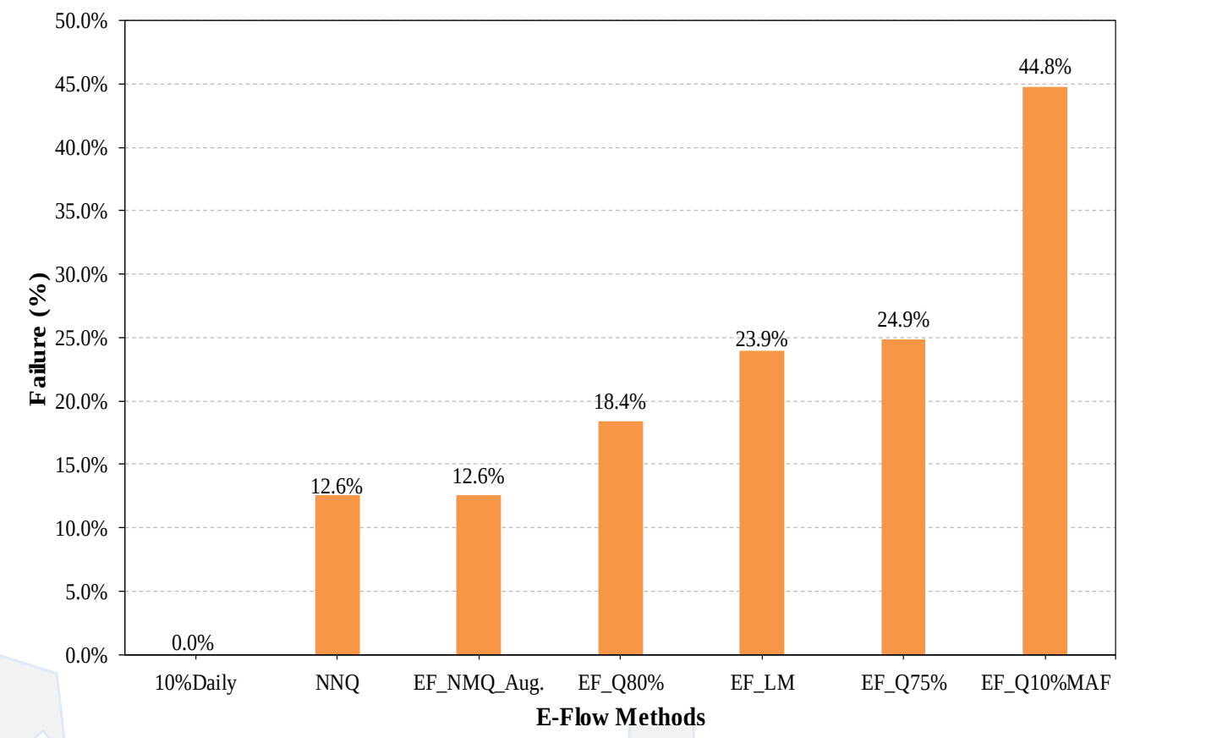


Fig.5 Reliability of environmental flow methods to satisfy natural flow regime, expressed as rate of failure

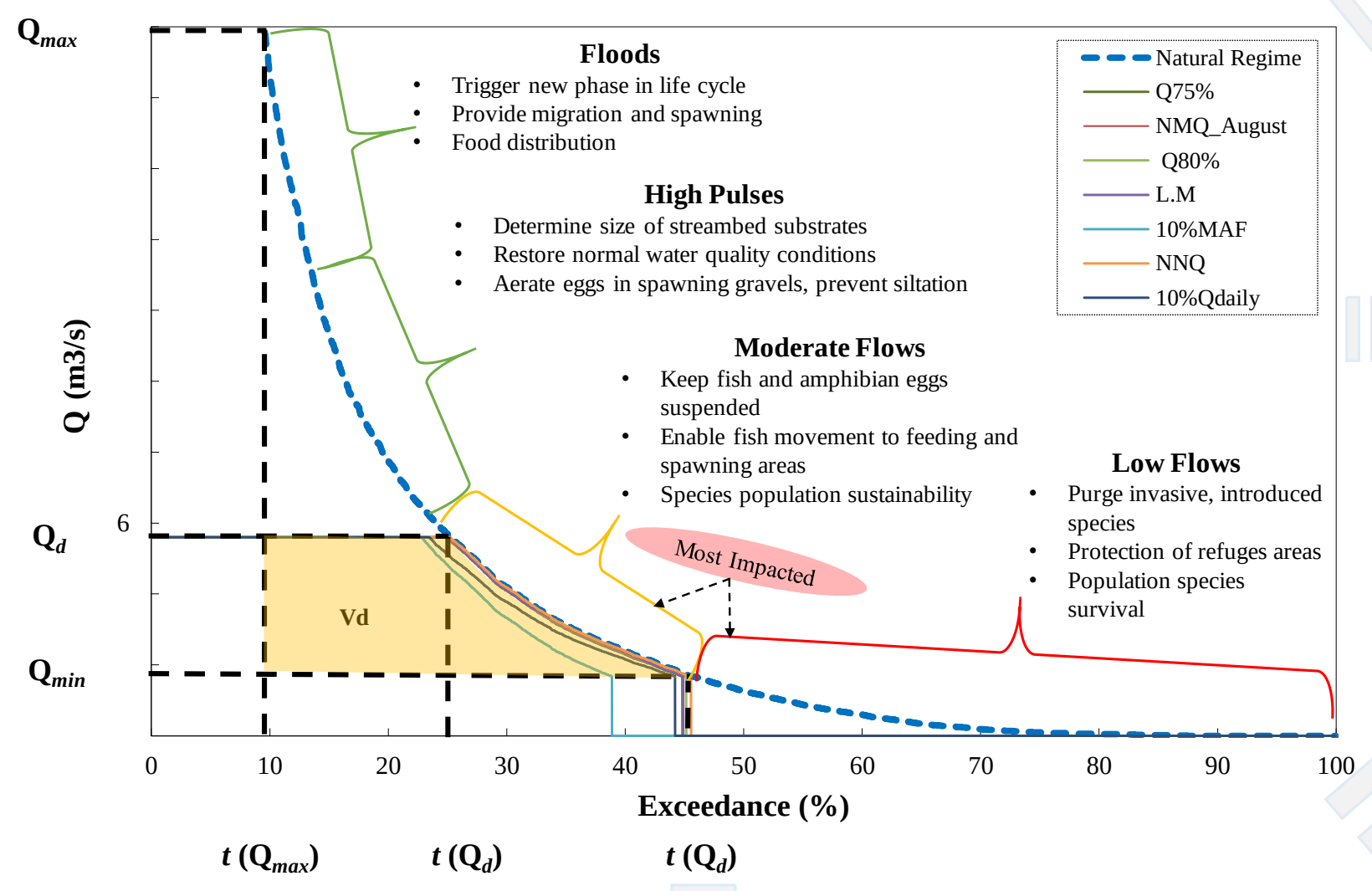


Fig.3 Long-term flow duration curve of natural flow regime and flow allocated for energy generation. Q$_d$ is the design flow Q$_{min}$, Q$_{max}$ are the minimum and maximum discharge, and V$_d$ is the design volume used for energy generation. Along the dash blue line are presented biological processes supported by certain flow regime

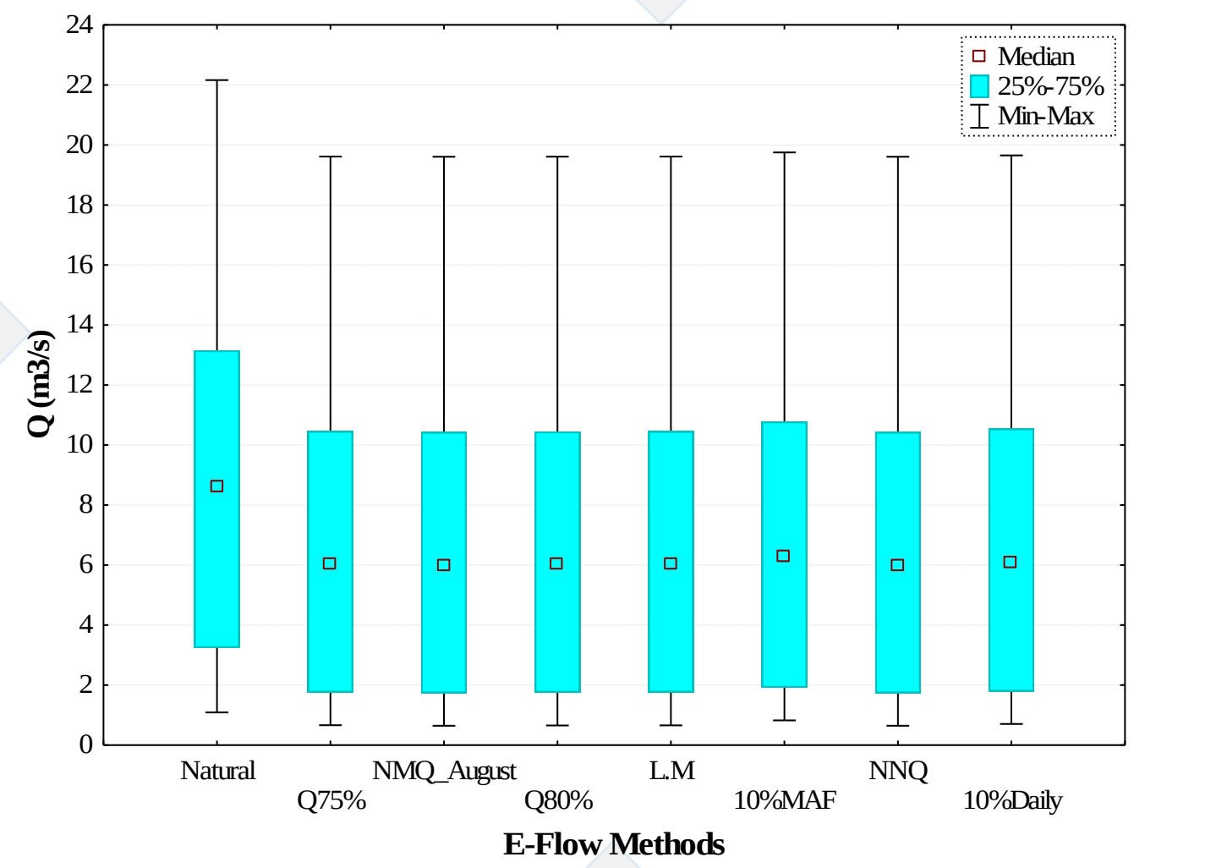


Fig.6 Inter-annual natural and altered flow discharge expressed as percentile of 25 and 75%, median and min, max. All EFMs provide almost the same flow discharge except 10% MAF which provide slightly higher flow discharge than other methods

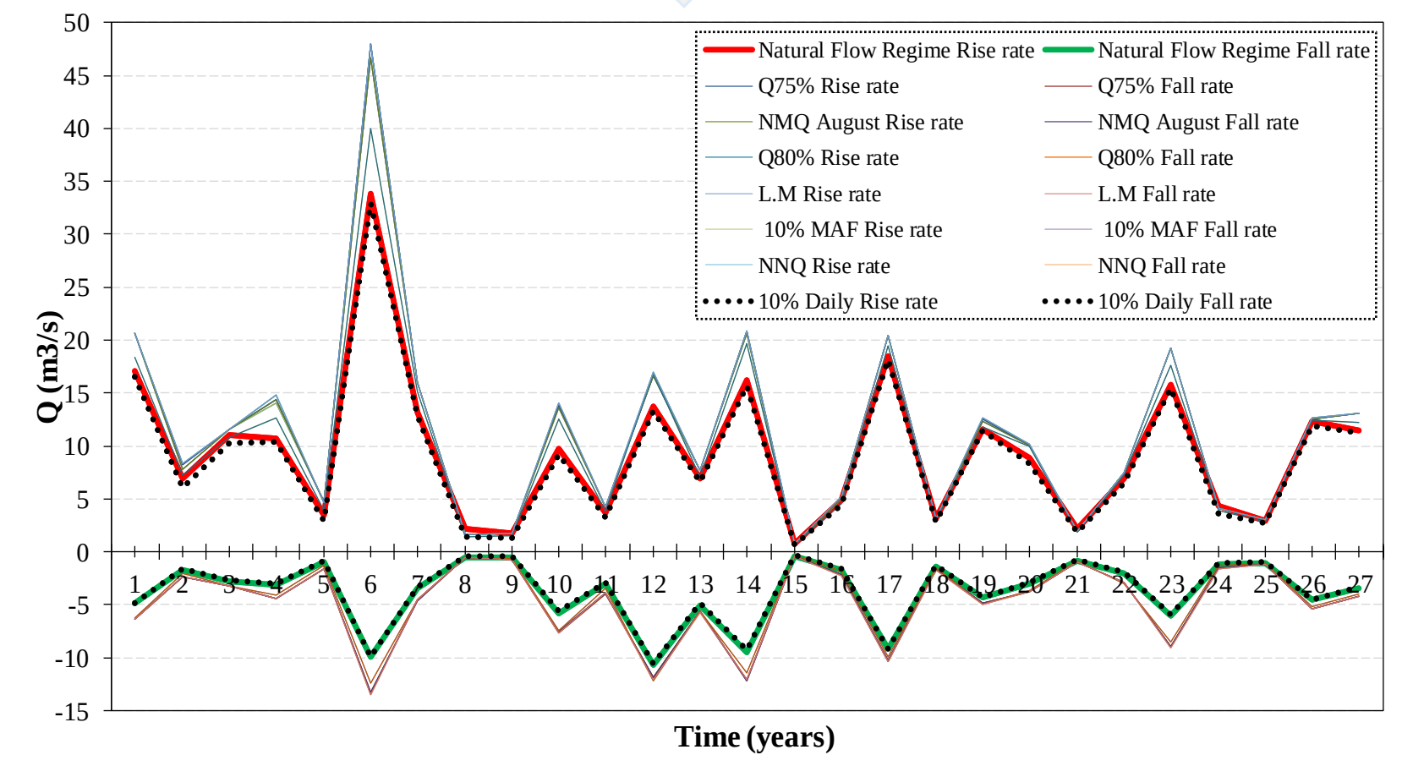


Fig.4 Inter-annual rise and fall rate for natural and altered flow regime, 10% daily is the only method that provides a rate of change similar to that of natural regime. This is a very important component, since high rate of changes may wash-out and strand of aquatic species

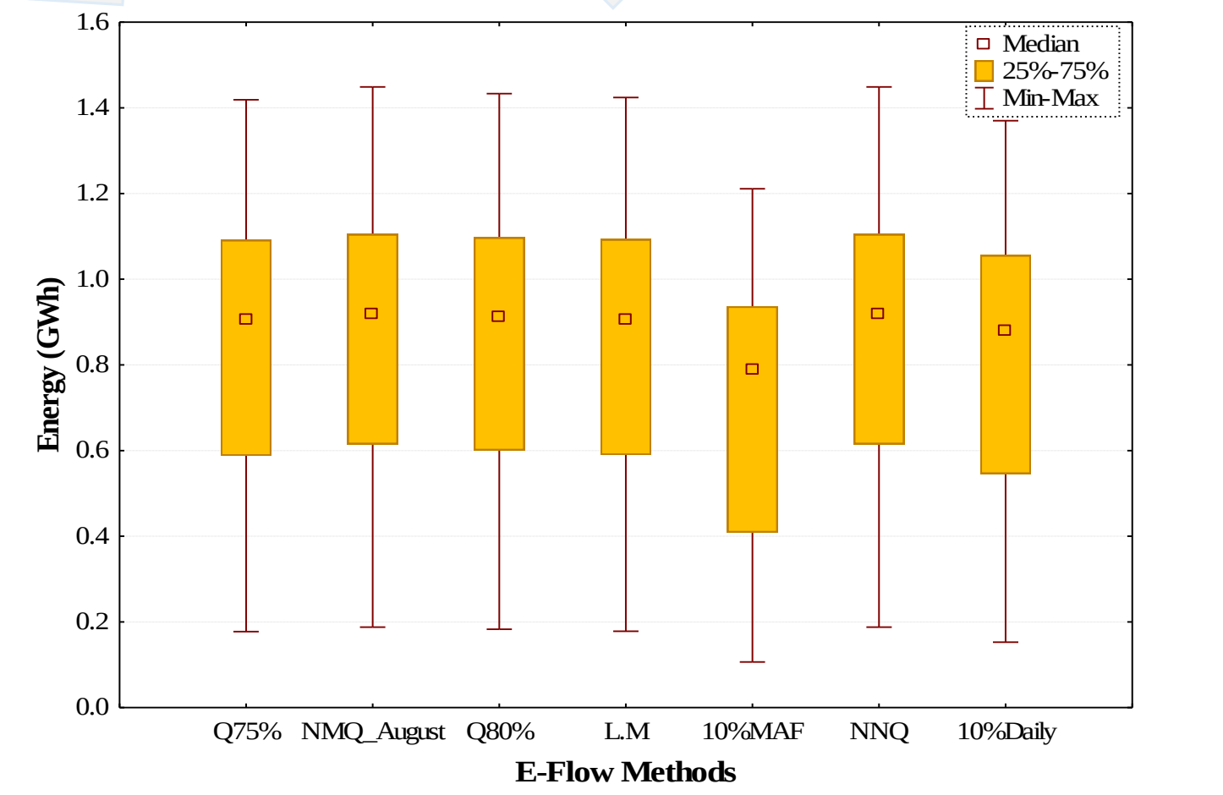


Fig.7 Inter-annual energy generation expressed as percentile of 25 and 75%, median and min, max. 10% MAF provide relatively low energy generation while NNQ shows a slight difference with the other methods except 10% MAF

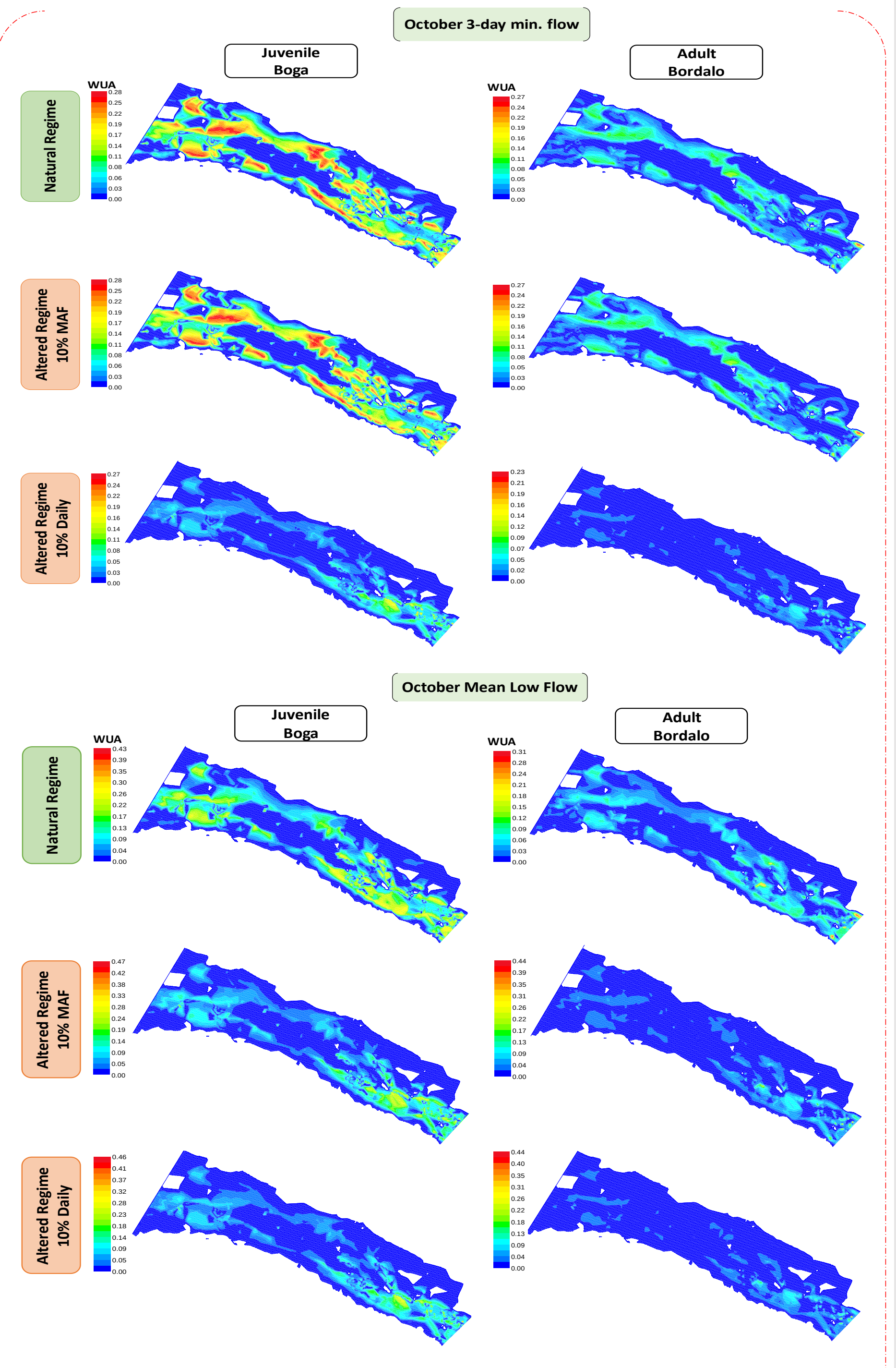
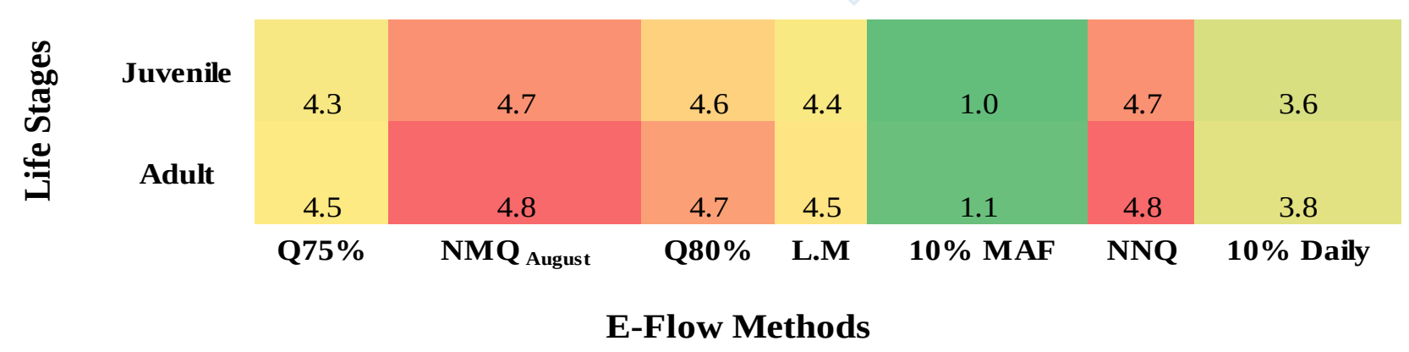


Fig.8 Scenarios with highest Weighted Usable Area (WUA) for 3-day min flow (above) and mean low flow in October (fish sampling month) (below). considering all fish species, 10 %MAF and 10% Daily provide highest WUA



Life Stages	Q75%	NMQ$_{August}$	Q80%	L.M	10% MAF	NNQ	10% Daily
Juvenile	4.3	4.7	4.6	4.4	1.0	4.7	3.6
Adult	4.5	4.8	4.7	4.5	1.1	4.8	3.8

E-Flow Methods

Fig.9 Habitat Alteration Index due to flow alteration considering all fish species, two life stages, 10% MAF shows lowest degree of alteration, followed by 10% Daily

5 Conclusions

- **Reliability**- The six of the tested EFMs are not fully reliable, with failure rates of 24.9, 12.6, 18.4, 23.9, 44.8 and 12.6 % respectively, 10% Daily is the only fully reliable method, with 0% failure.
- **Flow Regime** - 10% Daily method is the only method which provides a rate of change (rise rate/fall rate) as the natural flow regime, by maintaining natural flow regime components.
- **Flow Allocation** - In terms of quantity, all methods allocate almost similar flow discharges as e-flow, except 10% MAF which provides slightly higher flow, but not a significant difference.
- **Energy Generation** -10 % MAF provides relatively low energy generation, while six other methods provides similar energy generation amount.
- **Habitat Alteration** - 10 % MAF and 10% Daily show the highest performance related to **WUA** and the lowest **HAI$_Q$**, 10 % MAF has performance similar to the natural flow regime.
- **Life Stage Sensitivity** – Regarding **WUA** and the lowest **HAI$_Q$**, adult fish are slightly more sensitive to flow alteration than juveniles; this is due to their positioning preference in the riverbed.

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