INVESTIGATING RIVER WETTED HABITAT SENSITIVITY TO FLOW CHANGE

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This project aimed to improve the understanding of the response of river wetted habitat (represented by wetted perimeter WP) to change in flow (Q) in order to support ecological status and potential assessment in UK rivers impacted by abstraction/flow regulation, which is of high relevance to dam and hydropower scheme design. The analysis relied on a pool of >1,000 UK sites with good quality hydraulic data. A method to assess objectively WP sensitivity to Q was developed, which models WP as a function of Q in a consistent manner, then identifies three different sensitivity zones and corresponding flow thresholds mathematically (ranging from high sensitivity occurring at lower flows, medium sensitivity, and low sensitivity at higher flows). The study then investigated if wetted habitat sensitivity patterns could be related to catchment/river reach types. For c. two thirds of sites, WP was found highly sensitive to flow change at Q_{95} (5th percentile) or below, suggesting generic environmental flow values can mask variations in hydraulic sensitivity; there was no site featuring low WP sensitivity below Q_{95}. Regarding typology, statistically significant patterns between sensitivity thresholds/ slopes and river types based on key catchment descriptors (area, altitude, permeability) were found; WP tend to be more sensitive to Q at higher flows for sites associated with smaller, lower elevation, and/or lower permeability catchments; sites with larger, higher elevation, and/or lower permeability catchments may feature sharper differences between sensitivity zones.

1 INTRODUCTION

River discharge and ecological health are indirectly related, with individual species and/or communities responding directly to physical variables, which are themselves controlled by discharge (e.g. flow velocity, wetted habitat, depth, stream power). Discharge data are generally easier to collect and more widely available so that flow is commonly used as a master variable to assess ecological status or, for heavily modified water bodies, ecological potential by UK environment agencies. To ensure using discharge provides robust evidence to ecological classification, it is necessary to understand better the relationship between flow and the physical variables which influence river ecology directly.

This study aimed to: (i) improve the understanding of the relationship between river wetted habitat and discharge in order to support ecological status and potential assessment in rivers impacted by abstraction/flow regulation (highly relevant to dam and hydropower scheme design/operation); (ii) define and develop methods to calculate (metric(s) representing wetted habitat consistent with the existing scientific and grey literature; sensitivity zones for the response of wetted habitat to change in river discharge); (iii) apply these methods to existing UK river hydraulic and flow data in order to evaluate the distribution of sensitivity zones, and their associated thresholds, against discharge, to investigate if wetted habitat sensitivity to discharge can be related to catchment/river reach types.

Beyond the present study region, such an approach, based on ecohydraulics (i.e. wetted habitat metrics) \and providing a quantifiable link between hydrology and ecology, is high relevant to evaluating how dams and hydropower generation impact ecology and ecosystem services downstream, and, in turn, to identifying which dam design and operation practices are most effective at maintaining ecosystem functioning.

2 DATA AND METHODS

Current scientific papers and grey literature (e.g. official EU and UK documents) on the use of hydraulic habitat in environmental flow setting were reviewed (Edwards and Laizé, 2017). Hydraulic data were sourced from various UK statutory agencies (Environment Agency for RAPHSA 1 and 2 datasets; Scottish Environment Protection Agency for SEPA dataset) bringing a theoretical maximum of c. 7,000 sites with UK-wide geographical coverage; after thorough quality-control, 1057 sites were retained (Figure 1). Combining the literature review findings and data availability, it was decided to use wetted perimeter (WP) to represented river wetted habitat in this study.

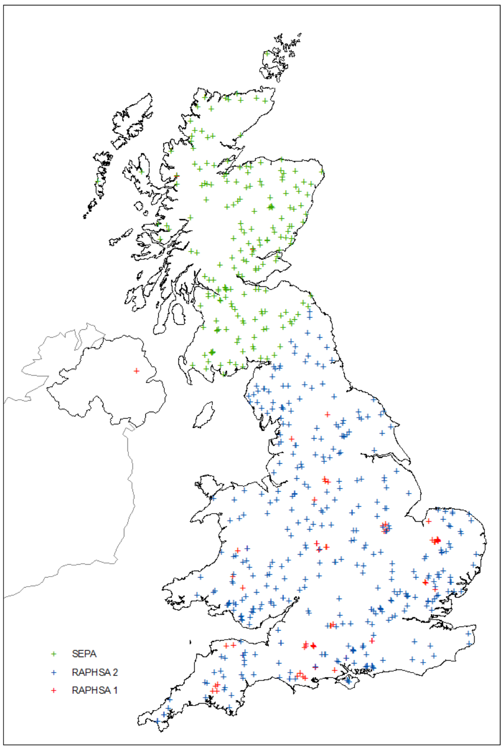

Figure 1. Selected sites and their data source.

Several approaches were developed to identify automatically and consistently WP flow sensitivity (Laizé and Edwards, 2017). The retained method first models WP as a function of discharge (Q) in a consistent manner, then identifies three sensitivity zones (high/medium/low) and corresponding flow thresholds mathematically (Figure 2). First, the maximum curvature point is calculated and its tangent to the WP curve derived. Then, tangents at the extreme ends of the WP curve are derived and the intersection points between tangents identified. Last, the intersection points are projected on the WP curve (red + and X on Figure 2); these are the points splitting the WP curve into high sensitivity zone (left-hand side, low flow end of regime), medium sensitivity zone ("bend" of the curve), slopes), and low sensitivity zone (right-hand side, high flow end of regime).

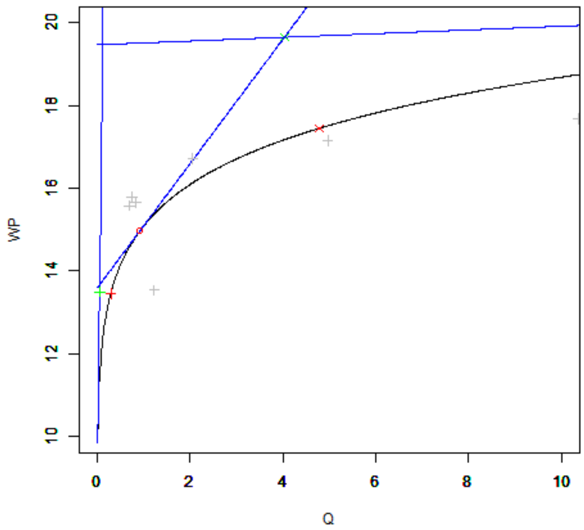

Figure 2. Example of WP vs Q curve automated partionining (maximum curvature point (red circle) and its tangent (oblique blue line); intersection points between tangents at extremes of WP cruve and maximum curvature tangent (green + and X); break points on WP curve, i.e. closest to green points (red + and red X).

Flow thresholds are expressed as exceedance flows (e.g. Q_{95} is the flow exceeded 95% of the time). In addition, sensitivity slopes were derived for each zone (approximated as the linear slopes between break points). Key catchment characteristics, capturing size, wetness, elevation, and permeability, were derived at those sites. For each sensitivity threshold, the analysis assessed the number of sites vs exceedance flows (distribution statistics, histograms, and cumulative distribution plots were generated). Sensitivity classes were statistically tested (ANOVA and Tukey's HSD) for potential relationships with catchment/river types based on key catchment characteristics (all sites), and based on hydro-morphological types (Scottish sites only due to data availability). Project sites and data were checked to ensure they were reasonably representative of UK rivers by using four key catchment descriptors; results split per country were also satisfactorily compared to overall UK results.

3 RESULTS

3.1 Sensitivity thresholds

The analysis of the number of sites vs exceedance flows showed that for c. two thirds of sites, WP is highly sensitive to flow change at Q_{95} (5th percentile) or below (Figure 3), suggesting generic environmental flow values can mask variations in hydraulic sensitivity; there is no site featuring low WP sensitivity below Q_{95} (Table 1).

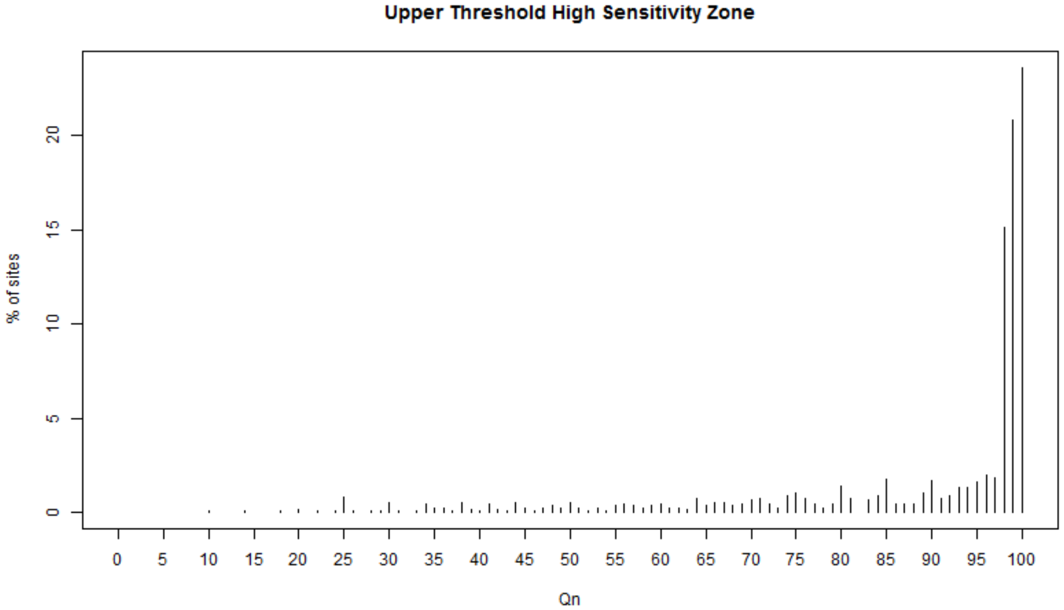

Figure 3. Distribution of exceedance flows (Qn), expressed as percentage of total number of sites, corresponding to flow threshold between high and medium zones at each site (i.e. low flow end of regime).

Table 1. Summary of results.

Threshold	Minimum Q_n	% of Sites <=Qn					Maximum Q_n
		5	25	50	75	95	
Upper threshold of high sensitivity	Q_{100}	Q_{100}	Q_{99}	Q_{98}	Q_{84}	Q_{41}	Q_{10}
Lower threshold of low sensitivity	Q_{95}	Q_{63}	Q_{40}	Q_{24}	Q_{9}	Q_{1}	Q_{1}

3.2 Typology pattern

Statistically significant patterns between sensitivity thresholds/ slopes and river types based on key catchment descriptors (area, altitude, permeability) were found. The wetted habitat at sites associated with catchments having smaller area, lower altitude, and/or lower permeability tend to be more sensitive to discharge at higher flows than for other types of site (Table 2).

Table 2. Flow thresholds summary statistics per catchment type.

Threshold	Area	Median	Elevation	Median	Permeability	Median
High sensitivity	Smaller	Q_{57}	Lower	Q_{98}	Impermeable	Q_{92}
	Larger	Q_{99}	Higher	Q_{99}	Permeable	Q_{98}
Low sensitivity	Smaller	Q_{8}	Lower	Q_{20}	Impermeable	Q_{18}
	Larger	Q_{35}	Higher	Q_{29}	Permeable	Q_{30}

Regarding sensitivity slopes, the still significant but much weaker pattern is a contrast between types (lower altitude, smaller size, higher permeability) tending to feature milder high sensitivity slopes and steeper medium and low sensitivity slopes (i.e. mild bend in wetted perimeter curve) vs types (medium altitude, larger size, lower permeability) featuring steeper high sensitivity and milder medium and low sensitivity slopes (i.e. sharp bend in wetted perimeter curve); see Figure 4.

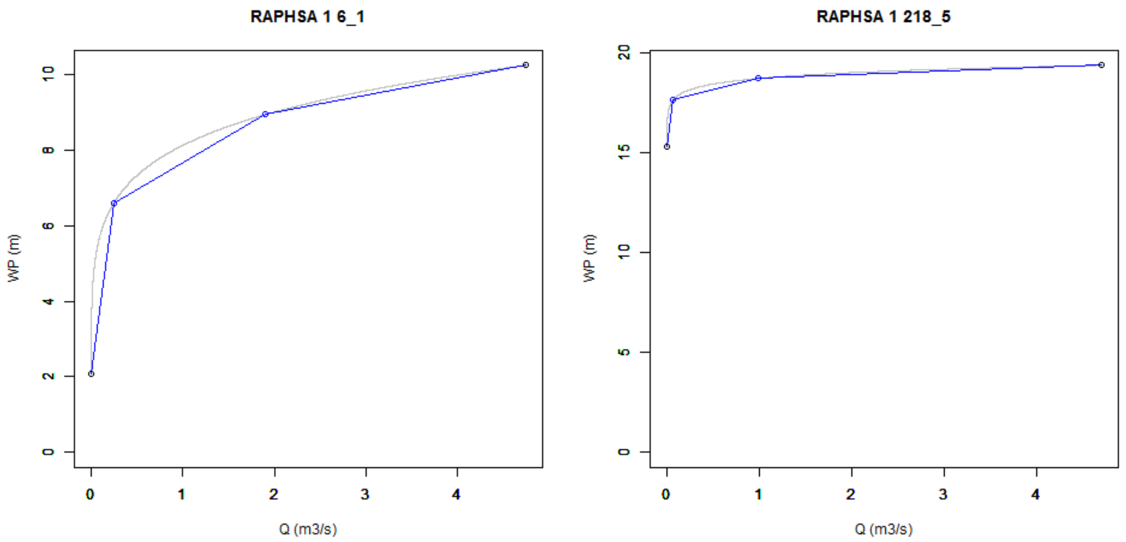

Figure 4. WP sensitivity zones for low altitude (left) and medium altitude (right) sites; modelled WP (grey line), approximated sensitivity slopes (blue line), thresholds (blue circles).

4 CONCLUSIONS

This study improved the understanding of hydraulic behaviour in channels by considering a pool of >1000 UK sites. It developed a method for objectively assessing the sensitivity of wetted habitat (as represented by WP) to discharge by modelling WP as function of discharge in a consistent manner, then identifying the different sensitivity zones and thresholds mathematically.

The study showed that wetted habitat is highly sensitive to flow at Q_{95} or below for a majority of sites (c. two thirds), suggesting generic environmental flow thresholds can mask site variations, while there is no site with low sensitivity thresholds below Q_{95}.

Some statistically significant patterns were found linking sensitivity thresholds/ slopes and river types (based on catchment area, altitude, and permeability). Sites with smaller, lower elevation, and/or less permeable catchments tend to be more sensitive at higher flows. Regarding sensitivity slopes, there is a contrast between lower altitude, smaller size, higher permeability types (milder high sensitivity slopes and steeper medium and low sensitivity slopes, and medium altitude, larger size, lower permeability types (steeper high sensitivity and milder medium and low sensitivity slopes).

The method applied here for the UK can be adapted worldwide. Because it relates hydrology and ecology via a simple physical variable (i.e. hydraulic metric characterizing river wetted habitat), it has potentially high relevance to on-going research aiming to quantify the impact of dams on river ecology and to optimize dam design and operating rule within an integrated water-energy-food-environment model (e.g. FutureDAMS project).

5 REFERENCES

Edwards FK, Laizé CLR. 2017. Investigating the sensitivity of river wetted habitat to changes in flow. Objective 1: literature review. Science Report CREW CRW2016 -06. 33pp.

Laizé CLR, Edwards FK. 2017. Investigating the sensitivity of river wetted habitat to changes in flow. Objective 3: Identification and analysis of wetted habitat sensitivity thresholds. Science Report CREW CRW2016 -06. 49pp.

6 ACKNOWLEDGMENTS

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