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SENSITIVITY ANALYSIS OF THE HYDROMORPHOLOGICAL INDEX OF DIVERSITY USING NUMERICAL GENERATED DATA

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ABSTRACT

River restoration has become a priority goal in many countries. The interest in rivers as valuable habitats for floral and faunal diversity and as an ecosystem with important functions has increased. For evaluating the structural changes from a river restoration project, quantitative methods are needed to support engineers and resource managers in decision making. The Hydromorphological Index of Diversity (HMID) is a metric using the statistical values of flow depths and flow velocities measured at several points at multiple cross-sections of a river reach. For restoration project planning, however, numerical models often are applied offering a rapid calculation of flow depth and flow velocity for multiple variants of a study reach.This is a case study of a 2-km meandering residual flow stretch in the Sarine River in Switzerland downstream of a dam with a constant discharge of 2.5 m^3/s. In this river, flow depths and flow velocities are measured at 27 cross-sections. Further, a numerical model is created to generate flow depths and flow velocities using BASEMENT.The roughness of the numerical model is first estimated based on grain characteristics. The model is then calibrated. Analyses show that HMID changes substantially between the values generated with the physically feasible roughness and the calibrated roughness value. It turns out to be less profound for higher discharges. Analysis of the influence of extreme values then shows a strong dependence of the HMID on them. Therefore, extreme values from numerical models may have significantly lesser weight due to the large sample size compared to field measured data, where only the values of 27 cross-sections are taken into account.

Keywords: Morphology; indices; restoration; numerical modelling; habitat diversity.

1 INTRODUCTION

In Europe, river training is an essential measure mainly for flood protection, navigation and agricultural land gain purposes. Rivers are used as energy sources, with high-head power plants in the Alps and run-of-the-river power plants in lowland areas. Overall, rivers contribute much to the development of Europe and its welfare. River constructions, on the other side, also have negative effects on the environment. Therefore, authorities launched projects to enhance ecological conditions for in-stream organisms in the last decades. In the densely populated Switzerland, for example, hydropower accounts for 56% of the total electricity production (SFOE, 2015). According to the Swiss federal office of Environment, more than 15,000 km of the river network is categorized as strongly modified or artificial. In order to classify the natural state of a river, a solid method is needed. Commonly used methods, such as the Rapid Bio assessment Protocol based on visual observations, are sensitive to the person responsible for the survey. Especially in large countries, where each province has its responsible people for rivers, an objective tool is needed in order to compare classifications and reveal where priority for a restoration project should be given. The Hydromorphological Index of Diversity (Gostner et al., 2013) could serve as such a tool and will be the focus of the analysis in this conference paper.

1.1 Site description

This study was carried out on the Sarine River in Switzerland. The Sarine has its origin in the western Swiss Alps and drains into the Aare, a tributary of the Rhine. Due to its steep slope of 1.4%, it is subjected to multiple hydropower plants. Its regime is highly modified due to artificial lakes, dams and power houses. The study site is situated downstream of Gruyère lake and consists of a ca. 2-km long residual flow reach. It is a meandering river with a constant residual discharge of 2.5 m^3/s in winter and 3.5 m^3/s in summer. The study site has a bed-rock alluvial river bed and a large variety of river channel structures, such as multiple gravel bars, islands and riffle-pool sequences. Due to its large canyon-like incision – it is more than 100 m lower than the local surroundings – it is less affected by human built structures and at some areas the alluvial forest is flooded during high flows. An illustration of the study site is given in Figure 1, flow direction from south to north.

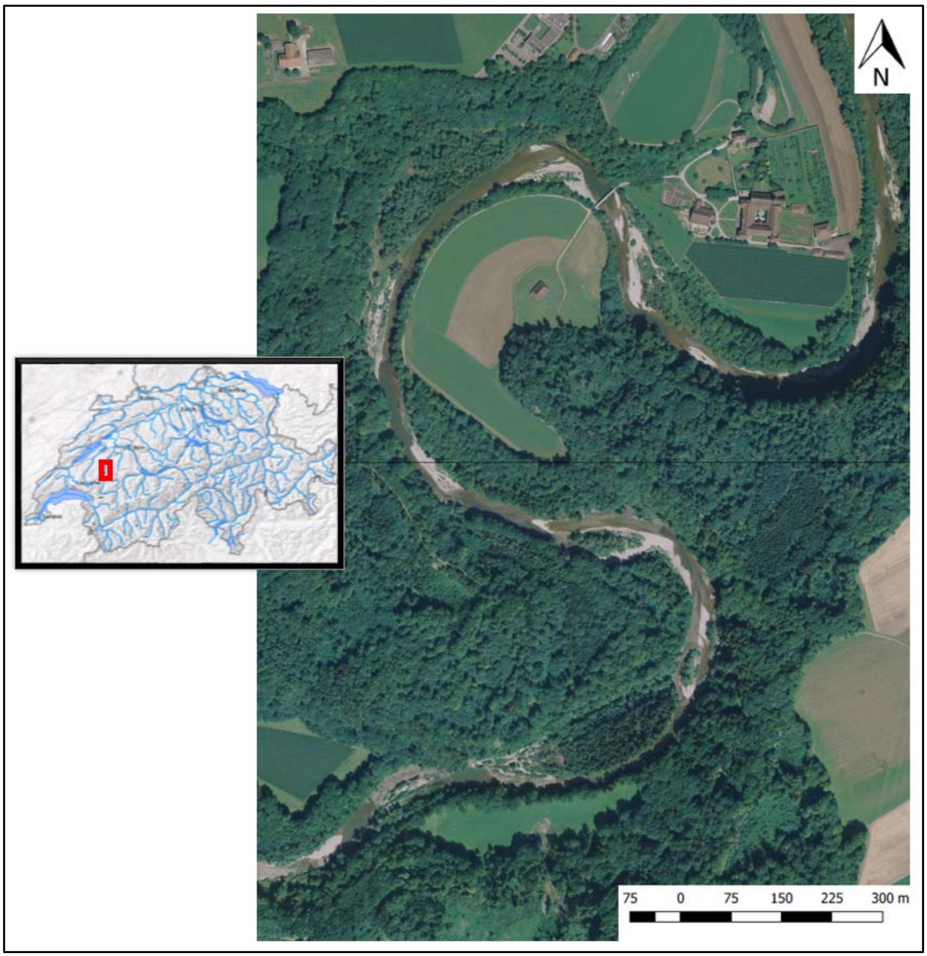

Figure 1: The study site in the Sarine upstream of Fribourg in the western part of Switzerland. The flow direction is from south to north

2 METHODS

2.1 The hydromorphological index of diversity (HMID)

The HMID is an index used to classify the habitat diversity in a river reach and was developed by Gostner et al. (2013). It is based on the coefficient of variation (CV) of the flow velocity and flow depth measured in a series of cross-sections in the river reach of interest, see Eq. [1]. The scale varies from: a channelized or heavily altered site, with uniform cross-sections and minor geomorphic patches (HMID < 5) to a reference site with fully developed spatial dynamics and full range of hydraulic habitats (HMID > 9). If the HMID lies between these two values (5 < HMID < 9), the study site shows limited variability to near natural morphology. Patterns of intact natural state are not developed in this class.

$$HMID_{Site}=\prod_i (1+CV_i)^2 = \left(1+\frac{\sigma_h}{\mu_h}\right)^2 \cdot \left(1+\frac{\sigma_v}{\mu_v}\right)^2 \quad [1]$$

where,

CV=coefficient of variation [-]
μ=mean value[m] or [m/s]
σ=standard deviation [m] or [m/s]

Gostner et al. (2013) also showed that the CV of different other variables, e.g. CV of substrate or Thalweg diversity, correlate with the CV of flow velocity. Therefore, flow depth and flow velocity variation can be considered to represent the main factors that define the shape of a river accurately. In order to keep the objectivity and the representability of the method, the distances between cross-sections measured in the river

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need to be constant as well as the distance between the measurement points in a cross-section, as illustrated in Figure 2.

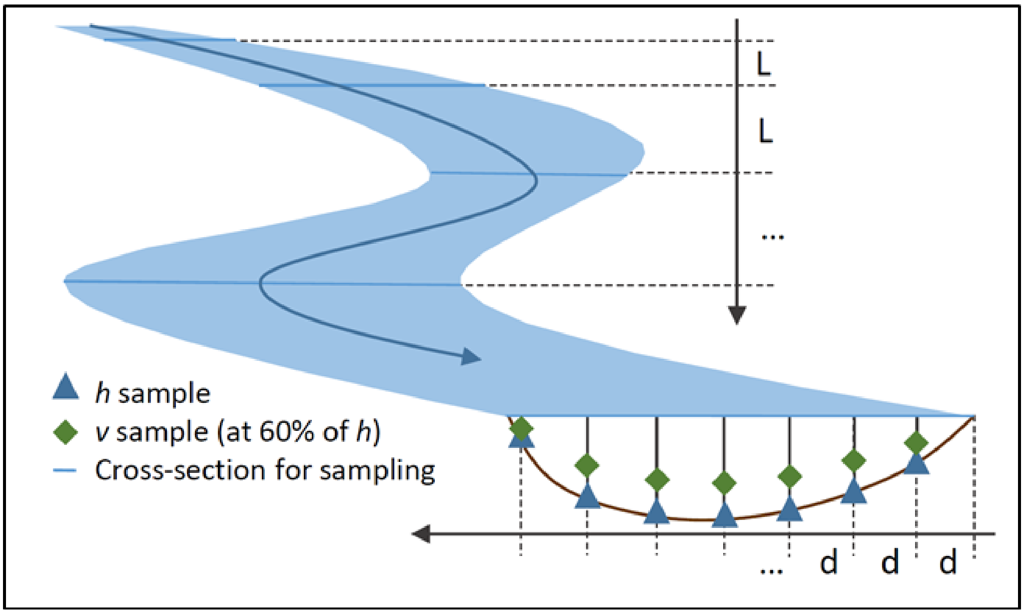

Figure 2: Sampling procedure for the variables *h* (flow depth) and *v* (flow velocity) used to calculate the HMID. It is important that the distances *L* and *d* remain constant

2.2 Measurement instruments

Flow depth was measured with a simple double meter attached to a global navigation satellite system (GPS). The GPS was a TOPCONHiPer Lite connected to the local mobile phone network using a SIM card for higher precision, resulting in a spatial precision, both vertically and horizontally,less than 2 cm. The positioning data obtained was then used for the Numerical model construction (see chapter 2.3). Flow velocity was obtained with a handheld velocimeter (SonTek FLOWTRACKER®). Where the water was too deep, an acoustic Doppler current profiler (ADCP, SonTek RIVERSURVEYOR®) was used to measure both flow depth and flow velocity. Figure 3 shows the tools used to determine flow velocity.

Figure 3: Tools used to measure flow velocity: on the left side SonTek RIVERSURVEYOR®, and on the right side the SonTek FLOWTRACKER®. Images were taken in the Sarine River, Switzerland.

2.3 Numerical model description

The use of numerical models has facilitated river restoration planning substantially. The HMID can be easily applied using a numerical model wherefore the influence of a restoration measure on habitat diversity can be quantified. A numerical 2D model of the study site was built in BASEMENT (Faeh et al., 2006) in order to simulate flow depth and flow velocity. The digital elevation model for the simulation consisted of data from two different sources. The terrestrial elevation came from a LiDAR flight and the in-river data came from 27 cross-sections that were measured at regular distances of 80 m, as described in section 2.1 using a GNSS. A linear interpolation between the cross-sections was done, before the DEM was generated, using the software SMS from AQUAVEO. The minimum distance between nodes was 2 m.

2.4 Grain size distribution (GSD)

Grain size properties were determined with 18 line-samplings (Fehr, 1987). In addition, two photos were analyzed using BASEGRAIN (Detert &Weitbrecht, 2012). The d_{90} varied from 9.1 to 13.0 cm, with an average of 11.3 cm. According to the Manning-Strickler velocity law (Eq. [2]), flow velocity and flow depth depend on the roughness.

$$v=K\cdot\sqrt{J}\cdot R_h^{2/3} \qquad [2]$$

where,

K=Strickler roughness value $\left[m^{1/3}/s\right]$
K is the inverse of the Manning roughness n
J=energy slope[-]
R_h=hydraulic radius [m]

The roughness, on the other hand, depends on grain properties, and in alpine gravel-bed rivers can be calculated using Eq. [3] (Strickler, 1923).

$$K=\frac{21.1}{\sqrt[6]{d_{90}}} \qquad [3]$$

where,

K=Strickler roughness value $\left[m^{1/3}/s\right]$
K is the inverse of the Manning roughness n
d_m=mean diameter[m]

Based on Eq. [3], a Strickler value of 30.4 $m^{1/3}/s$ is obtained.

2.5 Analyses

With the data available, the influence of roughness on the HMID was calculated. For computational reasons, only the Manning-Strickler velocity law was applied.

- In the first step, the numerical model was calibrated. Therefore, the Strickler value was changed until the sum of the absolute differences in flow depth in the cross-sections was minimal (difference between $h_{simulated}$ and $h_{measured}$).
- Further, the HMIDs were calculated for the values between the physically reasonable roughness and the roughness value determined through the calibration. For comparison, the same procedure was also done for a higher discharge.
- Since there is a difference between the HMID determined by the model and the field data, the influence of extreme values (flow depth and flow velocity) was analyzed. Therefore, the same amount of extreme values (max and min) from both variables was removed and the performance of the HMID was observed. For example, for 4% of the removed extreme values, the highest and lowest 1% of the values from flow depth and flow velocity were removed from the data series.

3 RESULTS

3.1 Calibration result of the numerical model

For calibration, the difference between the simulated and the measured flow depths in the 27 cross-sections were measured. The resulting maximum and mean of the absolute differences in flow depth for the different scenarios are displayed in Table 1.

Table 1. The maximum and mean difference of the absolute differences in flow depth measured with the different Strickler values at a discharge of 2.5 m^3/s.

K [$m^{1/3}/s$]	MAX DIFFERENCE [m]	MEAN DIFFERENCE [m]
30.4	0.45	0.20
28	0.45	0.19
16	0.41	0.12
14	0.39	0.11
12	0.38	0.09
10	0.35	0.09

3.2 HMID dependence on the Strickler value

The influence of the different calibration values on the HMID was calculated: first on the measured discharge of 2.5m^3/s and for comparison also for a higher discharge of 100 m^3/s. For the 100 m^3/s floods, only the gravel banks but not the floodplain were assessed. Bankfull discharge was estimated around 150 m^3/s. Figure 4 shows that HMID highly depends on the roughness applied in the numerical model. With a Strickler value of 30.4 $m^{1/3}/s$, the HMID achieves a value of more than 12 for a discharge of 2.5 m^3/s,which corresponds to a hydromorphological reference site. The best fitting result from the calibration, HMID = 8.4, indicates a limited variability. To compare, the HMID calculated with the data from the field survey, resulted in HMID = 9.4. At 100 m^3/s, the influence on the HMID was significantly less.

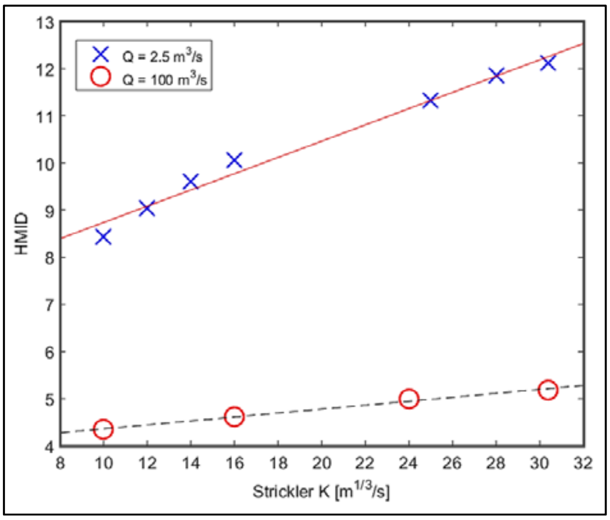

Figure 4: The HMID dependence on the Strickler value for two different discharges

3.3 Influence of extreme values on the HMID

For a Strickler value K = 10 $m^{1/3}/s$ and a discharge Q = 2.5 m^3/s, extreme values were continuously removed. Figure 5 shows that HMID decreases exponentially when extreme values are removed. The 5% highest extreme values made the HMID drop by almost 25%.

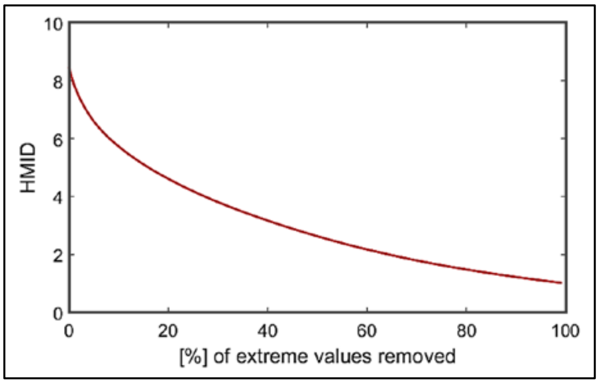

Figure 5: The influence of extreme values on the HMID at a discharge of 2.5m^3/s and a Strickler value of 10 $m^{1/3}/s$.

4 CONCLUSIONS

The results clearly show that an accurate calibration of a numerical 2D model in order to calculate the HMID is necessary. A Strickler value of 10 $m^{1/3}/s$ shows the best results of the tested Strickler values. However, this value does not represent the physical conditions found in the river reach. This low representation may be explained with the research done by Millar (1999), who indicated that bed forms such as pool-riffles sequences, pebble clustering and bars – bedforms found in the Sarine - may significantly influence the roughness of the river bed. The low submergence ratio with a discharge of 2.5 m^3/s brings out this effect even more and macro-roughness may cause its influence. Berchtold (2015) concluded that the calibration of a 2D model results in half or more than the physically expected Strickler values while doing experiments with BASEMENT. Therefore, the flow law of Chézy might be more appropriate for a 2D flow simulation, but if this is also true for the HMID needs to be proven. The importance of extreme values on the HMID is evident. This might therefore be the driving factor why the field measured HMID is higher than the model generated value (9.4 from the field data and 8.4 from the numerical flow data). Since the numerical model has almost 23,000 nodes while the field data consists of only about 700 data points, a reduced impact of extreme values may result. Different mesh resolutions and cell selection methods in future investigations may help in minimizing this difference.

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