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Comparison of two habitat modeling approaches for the determination of the ecological flow

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Abstract: Over the past decades, severe environmental problems have been caused by the inefficient water resources management by humans; in rivers, diversions, dam constructions and water abstractions mainly for irrigation purposes lead to flow-regime alterations and threat river ecosystems mainly during the dry period when the flow is dramatically reduced. To prevent fish extinction and ensure the good ecological status of aquatic ecosystems, the EU Water Framework Directive proposes the definition of a minimum flow rate, commonly called "Ecological Flow", in rivers. In this study, we compare two different approaches for the determination of the Ecological Flow in Sperchios river, Central Greece, for the case of Squalius vardarensis which is the most important species inhabiting this river. The first approach is the Hydraulic-Habitat model PHABSIM which is an easy-to-use engineering tool utilizing one-dimensional calculations both for hydraulic and habitat modeling. We define Ecological Flow via the calculation of the Weighted Usable Area of the river as a function of discharge. The second approach is an integrated two-dimensional Hydraulic-Habitat model which was developed in the National Technical University of Athens in cooperation with the Technical University of Munich and the Hellenic Centre for Marine Research; this model is a combination of the hydrodynamic model TELEMAC-2D and a habitat model. The results of the two methods are in reasonable agreement; however, the two-dimensional calculations offer higher accuracy and reliability but require much more detailed input data and computational time compared to the one-dimensional method.

Key words: Ecological flow, Habitat Modeling, PHABSIM, Telemac-2D, Sperchios river

1. INTRODUCTION

Severe environmental issues have arisen over the past decades due to over-exploitation and inefficient management of water resources. In rivers, diversions, dam constructions and water abstractions lead to flow-regime alterations threatening river ecosystems, mainly during the dry period when the flow is dramatically reduced. To prevent fish extinction and ensure the good ecological status of aquatic ecosystems, the EU Water Framework Directive proposes the definition of a minimum flow rate, commonly called "Ecological Flow". Several methodologies for the definition of Ecological Flow exist; these can be divided into (1) Hydrological, (2) Hydraulic-Habitat and (3) Holistic (Tharme, 2003; Petts, 2009; Linnansaari et al., 2012). Hydraulic-Habitat simulation is one the most accurate and easy-to-apply methodologies, combining hydraulic calculations with biological models.

In this work, we apply the Hydraulic-Habitat simulation by employing the one-dimensional (1D) model PHABSIM to calculate the Ecological flow for Sperchios River, Greece. The results are compared against preliminary results of the modeling approach of Stamou et al. (2017) who applied a two-dimensional (2D) Hydraulic-Habitat model which was a combination of the hydrodynamic model TELEMAC-2D and a habitat model which they developed in the National Technical University of Athens in cooperation with the Technical University of Munich and the Hellenic Centre for Marine Research.

2. CALCULATIONS

2.1 Study area and data

The Sperchios River is located in Central Greece and is characterized by a Mediterranean climate with low flows in the summer and high flows in late autumn, winter and spring. It flows through an area of former wetlands which have been reclaimed for agricultural uses and finally discharges into Maliakos Gulf. Subsequently, its water is used primarily for irrigation purposes via local water abstractions; these abstractions lead to severe reduction of its flow, especially during the summer, and thus cause detrimental effects on river ecosystem. For this reason, the definition of Ecological flow for this river is considered to be critical.

For the calculation of Ecological flow for Sperchios River we exploited the data from Stamou et al. (2017) who selected a 200 m long river reach at location Loutra Ypatis (see Figure 1) based on the intense upstream water abstractions for irrigation. They initially conducted a detailed topographic survey to obtain the geomorphology of the reach and the flood plain. In this reach, they selected 5 cross-sections in order to take water depth and flow velocity measurements using a propeller current meter. Moreover, they characterized the bed material, which was predominantly pebbles and cobbles, to divide the reach into two segments; the 75 m long upstream part was characterized by the presence of clay accumulated at the banks of the river, while in the downstream segment the slope was steeper, silt was washed out and heavier cobbles were distributed evenly throughout the bottom of the river (Stamou et al., 2017). Manning coefficient (n) was estimated next; for the upstream and downstream parts n was taken equal to 0.028 and 0.032, respectively. Stamou et al. (2017) used these data in the first part of their model, i.e. in the calibration, verification and application of the hydrodynamic model TELEMAC-2D.

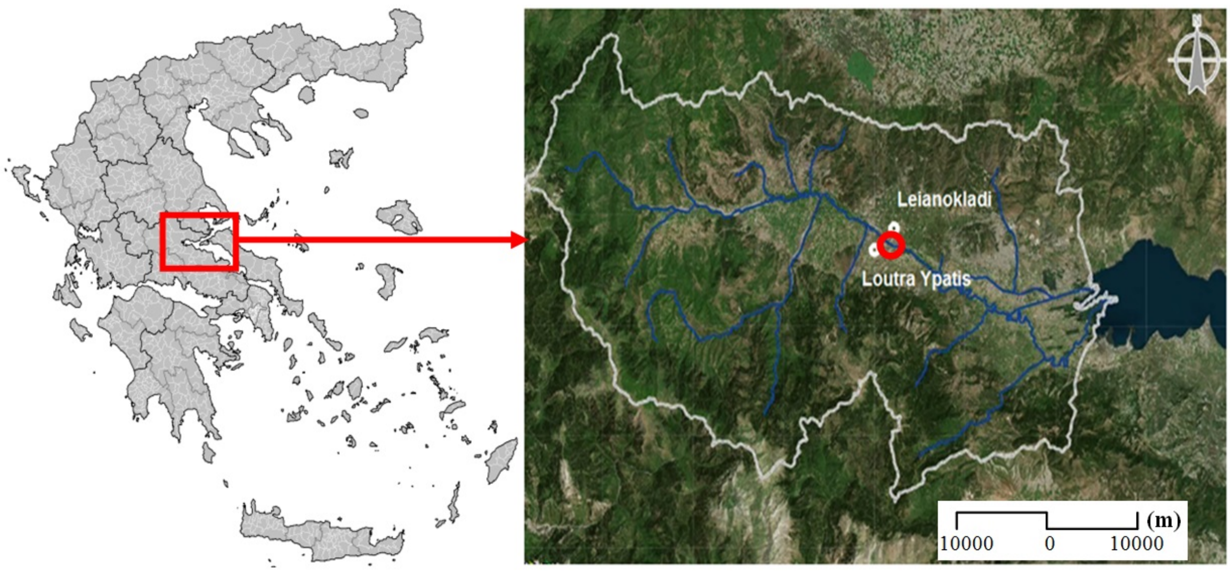

Figure 1. The study area

For the application of their habitat model, Stamou et al. (2017) detected the most important fish species in Sperchios river, i.e. the *Squalius vardarensis* or the commonly called Chub. Two size classes were examined, i.e. the small sized (<10 cm) and large sized Chub (>10 cm). They developed the Habitat Suitability Curves (HSCs) for water depth (D) and mean velocity (V), which are shown in Figure 2, based on international standards (Heggenes and Saltveit, 1990; Martínez-Capel et al., 2009) and literature (Bovee et al., 1986; Brosse and Lek, 2000; Fukuda et al., 2011).

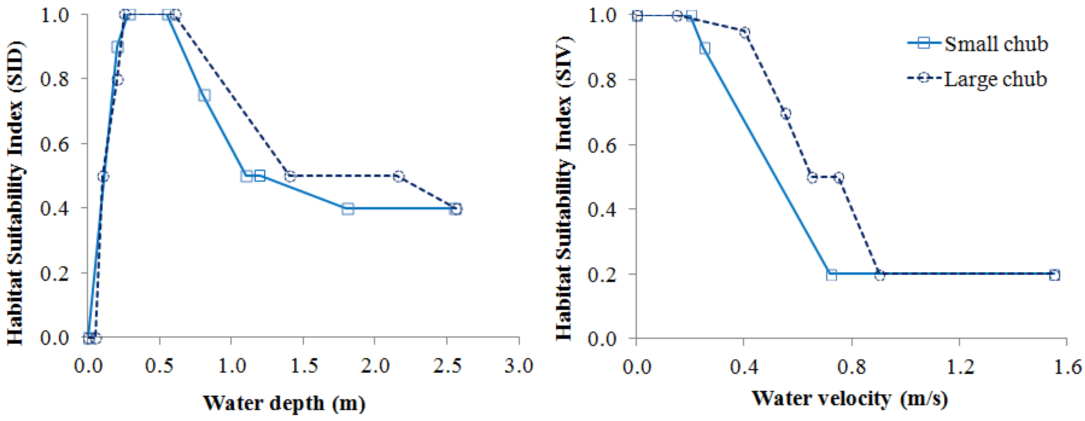

Figure 2. Habitat Suitability Curves for water depth and mean velocity by Stamou et al. (2017)

2.2 Application and results of the Hydraulic-Habitat models

PHABSIM, which is applied in the present study, is a 1D Physical Habitat Simulation that includes two sub-models: a hydraulic model and a habitat model. In this model, the study area is divided into a number of cross sections, for which the available data field is large enough, whereas each cross section is divided into a number of smaller cells; each cell is characterised by its index (i) and area (Ai). For each cell the Velocity (V_i), Water Depth (D_i), Channel Index (CI_i) and bed profile data are defined as inputs (Stamou, 2015). Thus, for the application of PHABSIM we divided the chosen river reach into 5 cross sections exploiting the geometric and hydraulic data available by Stamou et al. (2017); these cross sections were CS0 (x=0.0 m), CS50 (x=50.0 m), CS154 (x=154.0 m), CS163 (x=163.0 m) and CS197 (x=197.0 m), where CS0 is the most upstream cross section.

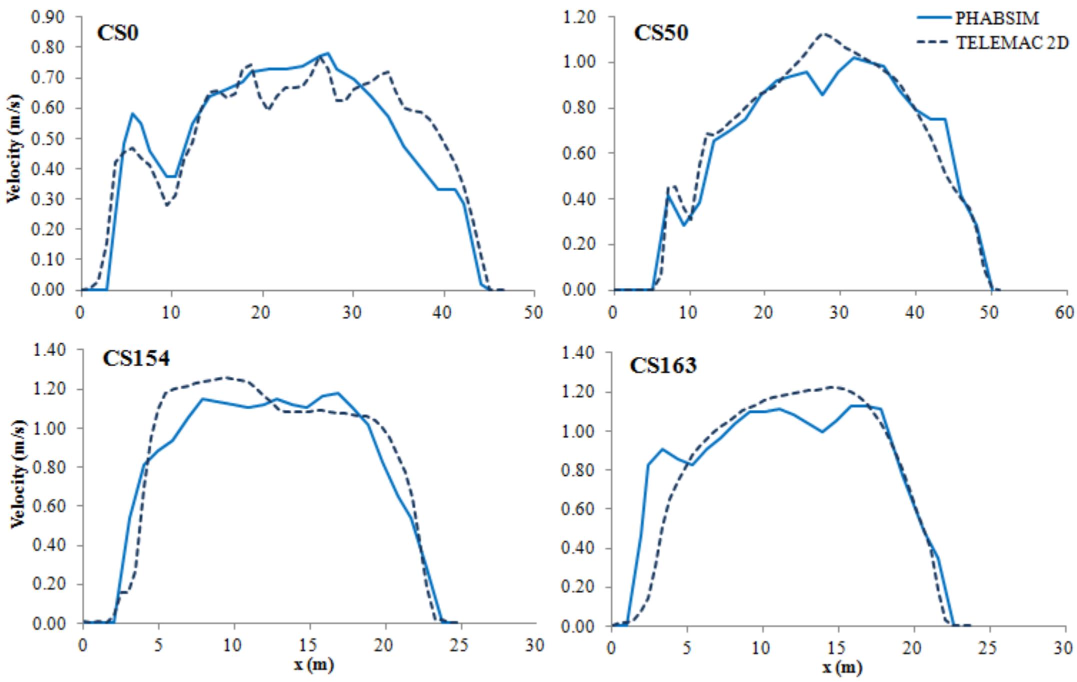

Figure 3. Velocity calculations by PHABSIM and TELEMAC-2D (Stamou et al., 2017) for Q=8.10 m^3/s

Based on the study of Stamou et al. (2017), we initially calibrated the hydraulic model for a discharge equal to Q=8.10 m^3/s to define the Stage-Discharge Curves that would be used next for the calculation of Water Depth for each cross section. Hydraulic calculations were performed for the discharge scenarios used by Stamou et al. (2017), i.e. for Q=0.3, 0.5, 0.9, 1.8, 6.3, 8.1 and 10.0

m^3/s. Velocity profiles for each cross section were calculated using Manning equation; the comparison between the results by the 1D model PHABSIM and TELEMAC-2D (Stamou et al., 2017) shows very good agreement, as shown in Figure 3. It is noted that Stamou et al. (2017) constructed a 2D computational grid based on the spatial coordinates and elevations from 1255 points of the river reach and the flood plain, which they obtained during their topographic survey; the same grid was used in the application of the hydrodynamic and the habitat model.

After conducting the hydraulic calculations, we applied the habitat modeling part for the two size classes of Chub, using the HSCs shown in Figure 2; in order to estimate the Ecological flow, we calculated the so-called Weighted Usable Area (WUA) for each class and discharge scenario, which expresses the amount of in-stream habitat. Based on similar studies (Jowett and Davey, 2007; Lambert and Hanson, 1989) and the study of Stamou et al. (2017), for the calculation of WUA we neglected the effect of substrate and took the effect of water depth and mean velocity into account. Moreover, since in PHABSIM for the calculation of WUA along the examined river reach a weight is assigned to each chosen cross section, we performed a sensitivity analysis on its effect on the results; this weight is called Upstream WF (Upstream Weighting Factor). Figures 4 and 5 show the results of WUA by PHABSIM for various Upstream WF scenarios, compared against the preliminary results of the Hydraulic-Habitat model by Stamou et al. (2017).

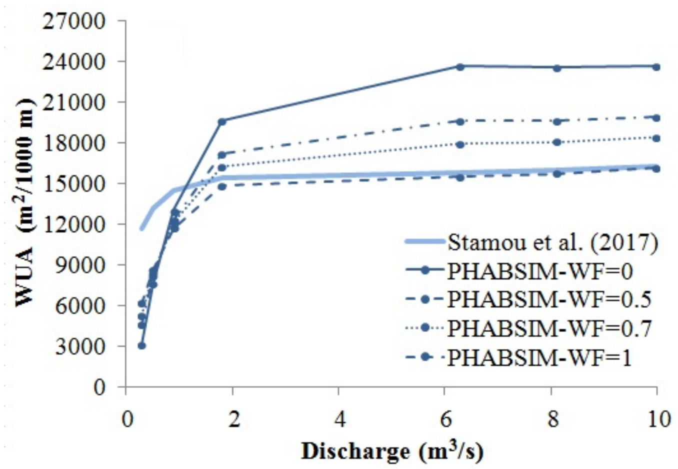

Figure 4. Variation of WUA with discharge and the Upstream WF for the Small Chub

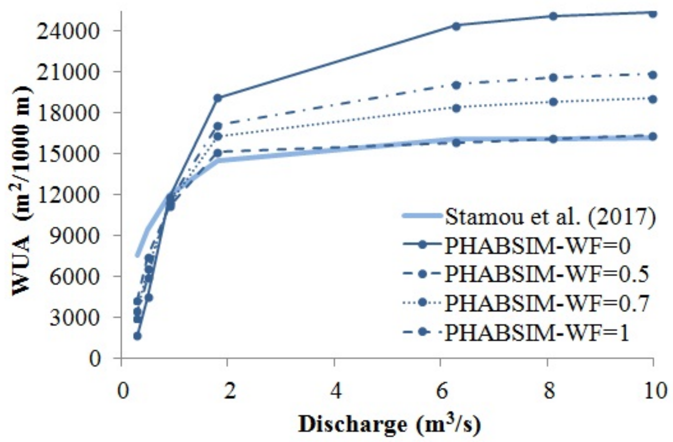

Figure 5. Variation of WUA with discharge and the Upstream WF for the Large Chub

3. DISCUSSION AND CONCLUSIONS

PHABSIM is a useful and easy-to-use engineering tool, demanding limited input data and offering very small computational times whereas the application of a 2D Hydraulic-Habitat model, like the one developed by Stamou et al. (2017), requires much more detailed inputs and computational time. 2D calculations offer much more accuracy since the study area is thoroughly examined being divided into a large number of cells whereas in the 1D model it is divided into a discrete number of cross sections which are examined independently; a weight chosen by the Hydraulic Engineer is assigned to each cross section to calculate the WUA along the study area. However, based on the results of Figures 4 and 5, we conclude that the results of WUA by PHABSIM are very sensitive to the effect of this weight, i.e. the Upstream WF, taken into account. Only for Upstream WF=1 we notice very good agreement with the 2D calculations of Stamou et al. (2017). Finally, we conclude that the minimum flow rate that needs to be ensured, i.e. the Ecological Flow, for Sperchios river is the 2 m^3/s both for the Small and the Large Chub; this is in accordance with the preliminary results of the modeling approach by Stamou et al. (2017).

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