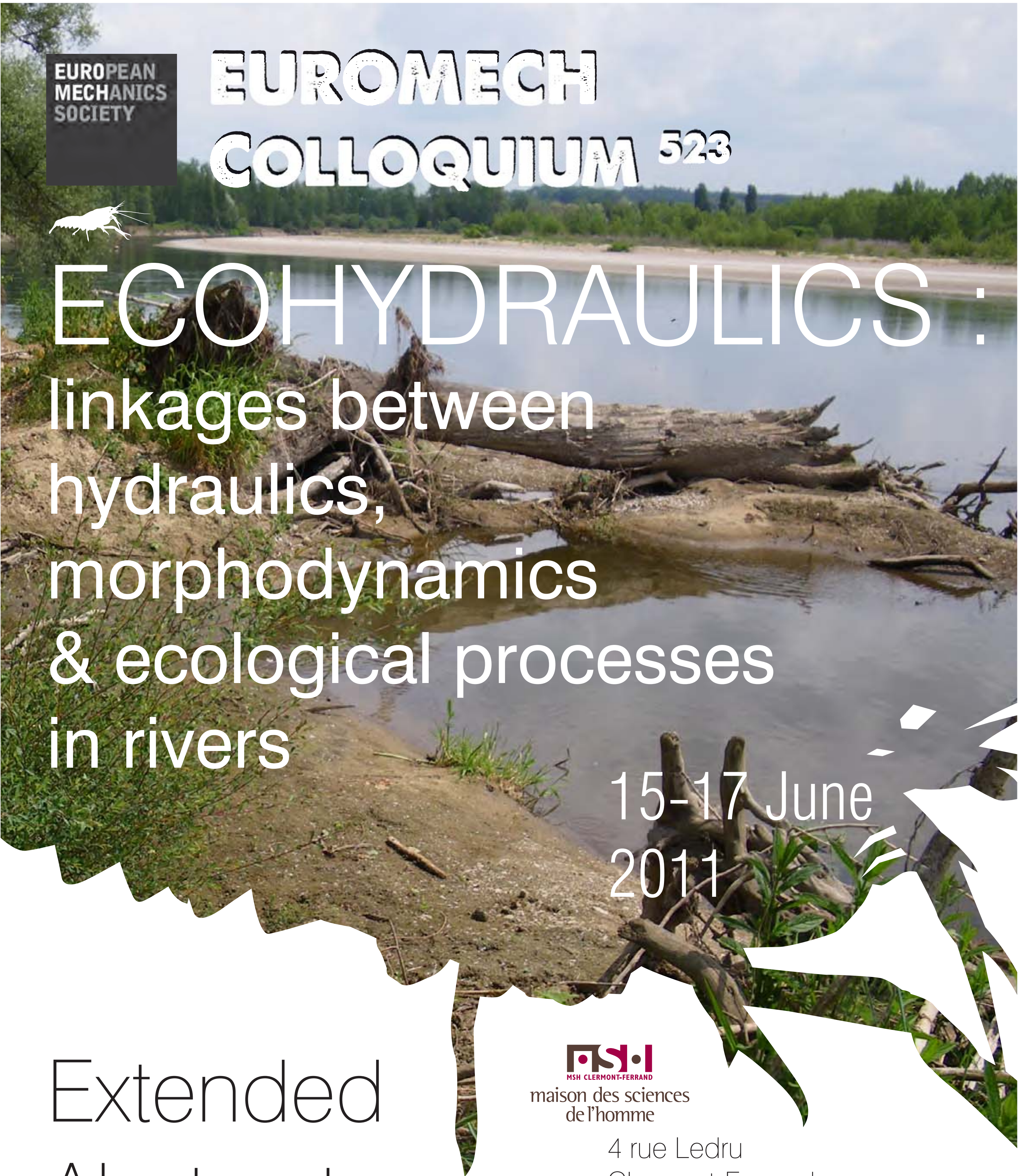

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ECOHYDRAULICS : linkages between hydraulics, morphodynamics & ecological processes in rivers

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Extended Abstracts

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Modelling the spatial distribution and temporal dynamics of Mediterranean riparian vegetation in a reach of the Mijares River (Spain)

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ABSTRACT. In Mediterranean environments, the riparian vegetation is adapted to semiarid conditions, being the limiting factors basically three: water availability, flow regime and flood regime. In order to set up an available tool for modelling riparian vegetation dynamics in Mediterranean semiarid environments, the RIPFLOW model was calibrated. The calibration was made by the expertise trial and error of the sub-models' parameters, with comparison of the observed and the simulated vegetation in the last year. The model was considered well calibrated, obtaining maximum values of correctly classified instances (71.86% of the simulated cells) and a good coefficient of agreement, Cohen's *Kappa* (k = 0.56 ± 0.0079, 95 % confidence limit). This opens the way to future applications, in order to integrate the riparian vegetation into water management issues.

Keywords: *Riparian vegetation, semiarid, modelling, calibration, RIPFLOW.*

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1. Introduction

The riparian vegetation exerts an important influence on sediment retention processes (Hupp & Rinaldi, 2010), has an essential role in water quality control (Medici *et al.*, 2010) and favours a complex distribution of habitats along the river (Naiman *et al.*, 2005). Its distribution depends on the morphology and the hydrological regime of the stream. Frequently, the riparian species are adapted to the variant conditions of the river dynamics. When the fluvial characteristics are modified, these plant species are susceptible to be replaced by terrestrials, favouring less bio-diverse environments, worse water quality and more exposed river beds; definitely leading to a poor or bad ecological status.

The main objective of this work was to set up an available tool for modelling riparian vegetation dynamic distribution in Mediterranean semiarid environments. Once the RIPFLOW model was selected (Francés *et al.*, 2010), the efforts were focused on its calibration in a representative reach of the Mijares River (Spain).

2. The RIPFLOW model

The RIPFLOW model simulates the dynamic riparian vegetation distribution, establishing its succession or retrogression in response to physical parameters. It has demonstrated to be a very useful tool in different hydrological conditions across Europe (Francés *et al.*, 2010).

The model consists of five successive sub-models called *recruitment*, *shear stress*, *flood duration*, *soil moisture* and *succession progression*.

Recruitment establishes the pioneer areas where the recruitment may occur, considering changes in morphology, scour disturbances and water table elevations. *Shear stress* evaluates the effect of maximum yearly shear stress on vegetation. To each vegetation type, a threshold value (SSlim) was assigned, so when the disturbance is higher the vegetation is considered to be removed. *Flood duration* includes the retrogression caused by physiological stress, considering succession phase, stand age and impact severity. *Soil moisture* analyzes the water abundance or scarcity in the soil, by means of Evapotranspiration Index (ETidx) calculations (Morales & Francés, 2009). The vegetation performance is established by upper and lower ETidx limits. Finally, *succession progression* evaluates if any stand is old enough to become a different succession series.

Requirements

The RIPFLOW model requires ESRI™ ArcGis9.2® with spatial analyst extension, Python version 2.4, and Microsoft.NET Framework 4. The RibAV model software needs to be installed externally to allow the correct functioning of the *soil moisture* sub-model. Several topographical and hydrological inputs are required to allow the model operation. Most of the hydrological inputs required a previous hydraulic modelling. In addition, a database is required for each year representative input maps definition, which must have equal grid extension and pixel size.

3. Study site description

The site (539 m long, 850 masl) is in the Mijares River, near to the village of Mora de Rubielos (Teruel). Eleven ºC is the average annual temperature, 500 mm the average annual precipitation and 0.894 m^3/s the mean annual discharge. It was selected by its natural dynamism, free from flow regulation, its variety of vegetation succession phases and stands' age, and its proximity to a gauging station with long time series. The study area was delimited considering the flood with recurrence interval of 100 years (approx. 860 masl).

3.1. Observed vegetation and succession phases

The vegetation survey was accomplished once 2009 ended. Before, patches were delineated upon aerial photos, and then surveyed and characterized in the field; soil sampling and vegetation characterization were assessed. The age of each patch was estimated

applying growth curves (defined for the species in the site) to the key species in the patch.
Two parallel and interconnected succession series were identified on the site: woodland and reed. Patches were classified into succession phases according to the species, age and development stage of the plants. Only one initial (IP) and one pioneer phase (PP) were defined as the colonization stage for both series. In both succession series, herbs phase (HP) is followed by the shrubs phase (SP). The shrubs phase within reed series (SP*) can progress to the woodland series after ten years. After any shrubs phase, vegetation can progress to the early successional woodland (ES) and the established forest (EF). Finally, under stable conditions the riparian and terrestrial species can dominate together in the mature stage (MF). When disturbances take place, retrogressions to earlier phases may occur.

3.2. Soil types parameters

The terrain elevation was used to stratify the soil survey sampling. From each sample (30-60 cm soil depth), the percentages of gravel, sand, silt, clay and organic matter were estimated. These characteristics were introduced in the "Soil Water Characteristics" model (Saxton & Rawls, 2006), which provided for each soil type the following parameters: soil moisture at field capacity, porosity, saturated hydraulic conductivity, bubble pressure, and porosity index. The soil types map allowed the selection of the corresponding set of parameters in each cell, during the *soil moisture* simulations.

3.3. Hydro-meteorological data

Monitoring networks of different institutions (AEMET, CEDEX and IVIA) supplied valid data for the soil moisture sub-model variables: precipitation (P), potential evapotranspiration (ET_0) and river discharge (Q).
Data from the nearest stations were adjusted daily to the site location for the period 1968-2009. Seven stations (AEMET) were used to interpolate precipitation by inverse distance weighting (β=2). Temperature data came from the meteorological station of Sarrión (AEMET) and corrected for elevation. We used the estimated values of ET_0 by Penman-Monteith equation (IVIA) in the station of Planes; the accuracy of such estimations was tested by several authors. Such values were the reference to calibrate in-site the simplified Hargreaves equation (Samani, 2000), using a correction factor of 0.001887. The mean daily flow was available in the station of Sarrión (CEDEX), 550 m downstream of the study site. The watershed area is very similar and there are no tributaries or springs between them, therefore no correction was necessary.

4. Hydraulic simulations

Influence zones, water table elevations (WTE) and shear stresses (SS) were obtained by performing 2D hydraulic simulations with the Guad-2D software (InclamSoft). GUAD-2D is a finite volume based two-dimensional model for the numerical simulation of transient flows over irregular topography, under the shallow water equations hypothesis (Murillo *et al.*, 2008).
Besides the digital elevation model, a Manning roughness shape was defined as input according to Cowan estimation procedure, considering both grain size and vegetation features along the reach. Boundary conditions corresponded, upstream, to a flat hydrograph for each simulated flow (20 flows ranging 0-650 m^3/s) and downstream to critical flow regime. Results demonstrated that the last downstream section of the studied reach was upstream far enough from the end of the model to not be affected by this boundary condition.

4.1. Aquatic, bank and floodplain zones

Three areas were deducted to analyze the influence of flow magnitude and frequency on the riparian vegetation. The aquatic zone (AZ) corresponded to the river channel area under the base flow for driest conditions (0.2 m^3/s). The bank zone (BZ) was immediately adjacent to AZ and just below the bankfull level (wetted areas between 0.2 and 5 m^3/s). Finally, over the bankfull level, the floodplain zone (FZ) was the least disturbed area, with a higher presence of older succession phases.

4.2. Water table elevation

The water depths were obtained for each simulated flow. Then WTE of the river wet main channel zone were interpolated to represent ground water levels under dry banks along each side of the river. Ground water level was considered horizontal under the banks. Interpolations from water depths were done assigning, by the Thiessen proximity algorithm, the nearest water elevation of the wet channel zone to its nearest dry bank zone, up to model boundaries. The result was the WTE shape for each reference flow of the simulated set.

4.3. Shear stress

According to water depths and velocities obtained from hydraulic simulations, SS were deducted. The bed shear velocity u* is defined as $u^* = \sqrt{gR_H I}$, where R_H is the hydraulic radius, g the gravity acceleration and I the energy slope. Besides, $v = C\sqrt{R_H I}$, where v is the flow velocity and C the Chézy roughness coefficient. Thus, both expressions combined lead to $v\sqrt{g} = Cu^*$. Chézy and Manning (n) coefficients are related by the well-known expression $C = 1.49n^{-1}R_H^{1/6}$. Moreover, for shallow water flows, the hydraulic radius (R_H) can be approximated by the flow depth (y), so, the relationship between v and u* is given by $u^* = 2.102 v \cdot n \cdot v^{-1/6}$. Finally, bed SS are evaluated as $\tau = \rho \cdot u^{*2}$ where ρ is the water density. Velocity and water depth shapes were previously obtained with hydraulic simulations, and Manning roughness shapes were those used as parameters of the hydraulic model.

5. Calibration methodology

The model was calibrated considering a time period of 42 years (1968-2009) and the observed vegetation as starting condition. The calibration process required iteratively variations of the different sub-model parameters values and comparisons between the last simulated year vegetation and the observed vegetation maps.

5.1. Hydraulic maps selection

Each year representative base flow elevation and flood duration maps selection was set through flow frequency analysis, excess curves and percentile values, considering five year types: very wet, wet, medium, dry and very dry. The SS maps specification took into account the maximum monthly instantaneous flow of each year. Finally, the soil moisture sub-model made an interpolation between the higher and lower nearest WTE maps to establish the more accurate WTE for the daily flow value.

5.2. Tools for performance evaluation: confusion matrix and Cohen's Kappa

In order to evaluate the calibration results quality two useful tools were selected: the confusion matrix, which is a visualization tool where the columns represent the number of units simulated for each category while the rows represent the observed values; and the Cohen's *Kappa* (Cohen, 1960), a coefficient of agreement which takes into account the chance agreement effect.

6. Calibration results

The final confusion matrix (Table 1) showed a very satisfactory calibration result with maximum values in the main diagonal (71.86%); and a very good distinction between terrestrial and riparian vegetation (93.64% terrestrial vegetation successfully simulated; 98.80% riparian units simulated as riparian vegetation).

The Cohen's *Kappa* value of 0.56 ± 0.0079 (95% confidence limit), confirmed that the outcome was successfully compared to the real vegetation distribution. Based on these results, the model was considered to be well calibrated and ready to be applied in hydro-meteorological scenarios.

Table 1. Confusion matrix. Observed vegetation in rows; simulated vegetation in columns.

Phases	IP	PP	HP	HP*	SP	SP*	ES	EF	MS	UF
IP	**145**	19	611	29	153	3	131	55	105	0
PP	196	**181**	36	13	38	5	36	1	4	17
HP	243	14	**551**	13	163	3	128	36	98	29
HP*	0	0	0	**0**	0	0	0	0	0	0
SP	335	30	197	19	**931**	12	130	34	164	45
SP*	179	23	75	17	349	**25**	66	81	455	7
ES	313	47	23	16	84	13	**1255**	156	757	59
EF	389	28	22	45	97	22	5	**1112**	229	62
MS	496	12	12	4	78	12	27	13	**750**	4
UF	304	76	41	32	637	46	37	60	205	**17678**

* Reed succession series

6.2. Model parameters

The model parameters (Table 2) included the SSlim, which were considered to be higher in older succession phases; and the ETidx upper and lower limits, which were set considering the required plant's effort to evolve into a more advanced succession stage, and the maintenance minimum value respectively.

Table 2. RIPFLOW model parameters.

Phases	SSlim [N/m^2]	ETidx upper limit [ ]	ETidx lower limit [ ]
IP	95	0.5	0.15
PP-HP-HP*	100	0.6	0.4
SP-SP*	150	0.85	0.35
ES-EF-MS	200	0.95	0.15
UF	500	0.95	0.05

* Reed succession series

6.3. Vegetation dynamic distribution

The results showed enough variability through the 42 years period, to be considered realistic. During flood or drought events, an important area of the riparian vegetation was removed by the model.

The model simulated correctly the vegetation community presence (Fig. 1) and distribution, showing riparian bands near the stream and terrestrial vegetation in further zones (Fig. 2).

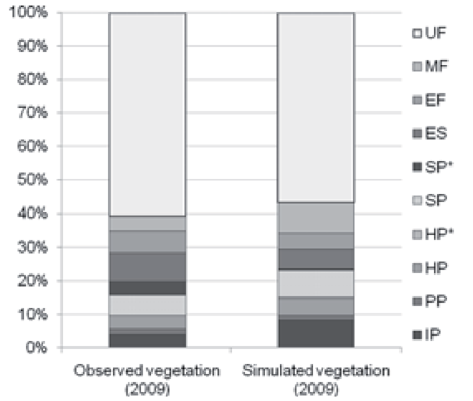

Figure 1. Comparison between observed and simulated vegetation stages for year 2009.

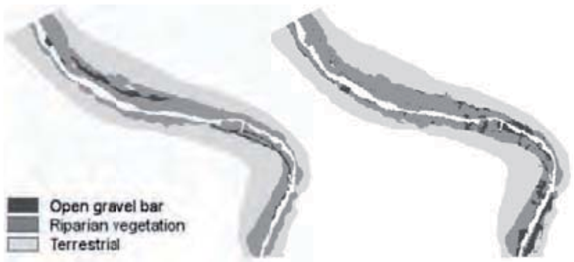

Figure 2. Riparian and terrestrial vegetation distribution observed in field in 2009 (left) and simulated with the RIPFLOW model in 2009 (right).

7. Conclusions

The RIPFLOW model was well calibrated with high values of correctly classified instances (71.86 % of the simulated cells) and a good *kappa* value (0.56 ± 0.0079, 95 % confidence limit), being capable of simulating the vegetation community presence and distribution, and showing an excellent distinction between riparian and terrestrial bands.

The RIPFLOW model is now available for several hydrological, morphological and climate scenarios analyses in the Terde reach, or in reaches with similar characteristics. This work was funded by the RIPFLOW project (Era-Net IWRM Funding Initiative; Spanish MEC CGL2008-03076-E/BTE), and SCARCE project (CONSOLIDER-Ingenio, CSD2009-00065).

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