RIPFLOW PROJECT

Research Report No [ ]
Riparian vegetation modelling for the assessment of environmental flow regimes and climate change impacts within the WFD

submitted [February 2011]

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Natacha Amorsi
Office International de l'Eau
15 Rue Edouard Chamberland
87065 Limoges Cedex FRANCE
Tel : 33 (0) 555 11 47 88
Fax : 33 (0) 555 11 47 48

Prepared by the Joint Project Consortium consisting of | **Funded by**

Universidad Politecnica de Valencia (Spain)	**MEC (ES)**
Eb&p Umweltbüro GmbH (Austria)	**BMLFUW (AT)**
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Summary for Decision-Makers

It is recent the necessity of developing new management tools to allow the Member States to achieve the good ecological status of the river related ecosystems required by the Water Framework Directive. The riparian ecosystems are fundamental for the equilibrium maintenance in the aquatic ecosystems so important efforts in their preservation must be done.

In Europe, the most relevant impacts to the riparian ecosystems are directly related to dam operations, river stabilization and exploitation of the river resources. It is indispensable to take into account several regulation scenarios, in order to find out the potential affections over the riparian zones before managing these areas (conservation and restoration plans, determination of affected areas, etc.). The Water Framework Directive justifies this necessity, establishing that one of the objectives must be to improve the aquatic ecosystems.

Actually not only the water regulation can affect the riparian ecosystems. Other important threats are the effects of climate change. This implies that the design and management of water systems should consider different climate change scenarios to mitigate the possible effects of climate change, instead of using the records obtained in the past hydrological conditions.

Mathematical models bring us the possibility of gaining insight on the replicated ecosystem and to forecast effects deriving on the variation of the ecosystem driving forces (Perona *et al.,* 2009). On these premises, the work carried on in this project, and more specifically the implementation of a dynamic vegetation model, which takes into account the major components of the floodplain ecosystem, is a valid basis for assessing impacts and management measures on riparian ecosystems.

Key objectives of the project

Three general goals have been covered in this project. The first one was the development of a flexible dynamic model of riparian habitats and vegetation to be easily applied in a wide range of conditions across Europe. Two important key elements of this model were the soil-moisture sub-model (to consider the effect of low flows or droughts) and the succession sub-model (to consider the effect of floods).The result is a friendly use software that will help the water managers in making decisions to achieve the natural recovery and the improvement of the ecological status of the riparian vegetation, in the context of the European Union directives.

A second objective of the project has been to identify and to apply cost-effective methods for the acquisition of biological information needed to calibrate the model in most regions of the European Union.

The last key objectives were to allow the model application to the case studies of three European countries by its calibration, and to analyze several representative disturbed flow and climate change scenarios in the study sites in order to show the capabilities of the model. It has to be considered that these analyses could be taken as reference by the end users as example of how the results should be exposed and interpreted.

The RIPFLOW model

The RIPFLOW model has demonstrated to be a very useful tool in riparian vegetation distribution in space and time. This model has been applied to several scenarios analysis with satisfactory results that shown coherent tendencies in the riparian vegetation evolution.

The model incorporates the essential riparian ecosystem driving forces and the key parameters related with the behaviour of riparian ecosystems. The model assumes that vegetation development depends by the functional relationship between hydrology, physical processes, climate and vegetation communities. In the model conceptualization, physical processes are represented by height over mean water, shear stress and flood duration while the link to the climate is mainly represented by the soil moisture, which considers also temperature. These factors allow the successful establishment and development of the vegetation or its retrogression to the initial stage.

The model concept has been divided in two main components. The first component, static, provides an initial landscape while the second component, dynamic, simulates the vegetation succession or retrogression in space and time.

Model components summary	
Model Component	**Explanation**
Static Component	Defines the starting vegetation cover types and minimum age of the vegetation in the study area. ▪ Minimum age spatial extent of each cover type is rule based. ▪ The component calculates habitat conditions and latter it reclassifies these conditions to typical vegetation cover types. ▪ Component output is meant to be used as input for the dynamic component.
Dynamic Component	Evaluates the evolution and spatial distribution of floodplain vegetation in regard of yearly base flow level (Mediterranean climate) or spring mean water level (Alpine climate), shear stress, flood duration, hydro-meteorological inputs and morphology. Additional driving variable is the time. The component simulates the effects of these driving forces on the vegetation community. The rules on which the model is based can be briefly described as follows. ▪ Yearly base flow influences the recruitment and the scour disturbance applied to seedlings. ▪ Shear stress, when enough strong causes disruption of the vegetation and consequent retrogression of the stands to primary stage (gravel). ▪ Flood duration causes physiological stress to the root system and, according to submersion duration, it can lead to total or partial retrogression. ▪ Hydro-meteorological factors deem the vegetation evapotranspiration and consequent vegetation wealth level. If no one of these effects is enough strong to retrogress the vegetation, time leads the stands toward more mature stages, until the climax would be reached. Furthermore the model verifies, at each run, whether the morphology of the study area has changed from the previous run (simulated year) morphology. It has to be underline that the model does not calculate morphology evolution. The morphology for the simulated year is provided as input; the model only recognizes the eventual change and applies to it the model rules. The model it is mainly rule based though it makes also use of parameters based on expert knowledge. Driving forces are applied in atomistic fashion: effects of each driving force are computed in sequence, synergetic effects are therefore neglected. In addition, the model adopts a Boolean approach and relies on hard thresholds. The model is defined dynamic for two reasons. First, it takes different base flow, shear stress, flood duration and morphology data for each simulated year. Second, the output landscape, resulting from a simulation, is output for the next model's run.

The second component, dynamic, is further divided in modules, namely: recruitment, shear stress, flood duration and soil moisture. The dynamic part is addressed as dynamic because it takes different inputs for each simulated year and because the outputs of each model run is fed again to the model as input for the next iteration.

Dynamic component modules summary	
Module	**Explanation**
Recruitment	Evaluates where occurs recruitment, where pioneer stages are retrogressed to gravel due to scour disturbance and toward which succession series the oldest pioneer stands are driven. Driving variable of the sub model is the height over mean water. In addition, the sub model checks eventual changes of the bank zone and/or in the river bed morphology. Particularly if the bank zone changes and/or the river bed are turned to bank zone, floodplain zone or vice versa. The bank zone and morphology for each simulated year are provided as input; that means the model does not calculates morphologic changes, it only recognize these, eventual, changes. Where river bed is turned to bank or floodplain zone, model assumes these "new land" is gravel.
Shear Stress	Evaluates the effect of maximum yearly shear stress on vegetation community. Vegetation shear stress resistance is set according to vegetation stand age class. When shear stress is higher than vegetation age class resistance the stand is retrogressed to "gravel" cover type. Before starting the shear stress effect evaluation, one year is added to the successions age. This operation simulates the year step in the overall succession-retrogression model. Ages are divided in classes, according to these classes each stand is reclassified to its shear stress resistance (expert knowledge based parameter). The successions, thus reclassified are compared with the shear stress map of the year. ▪ Where the yearly shear stress is greater or equal to the resistance, succession age is set to zero ("gravel minimum age"). ▪ Where the resistance is greater than the yearly shear stress, the age of the stand remains the same.
Flood Duration	Evaluates the effect of flood duration stress (physiological stress) on vegetation community. Vegetation flood duration resistance is set according to vegetation stand age class. When physiological stress is longer than vegetation age class resistance the stand is retrogressed.
Soil Moisture	Water abundance or scarcity in the soil is assessed calculating the Evapotranspiration Index (ETidx) which is computed as the ration between the Actual Evapotranspiration (ETR) and the Potential Evapotranspiration (ETP) of each vegetation type. The ETidx ranges between 0 and 1 (although the internal calculations consider that comprises between 0 and 100) . ▪ ETidx values close to 1 indicates a good or excellent moisture status in the soil, hence suitable conditions for the vegetation growth. ▪ On the other hand, ETidx values approaching 0, indicate a poor soil moisture condition, therefore unfavorable conditions for the vegetation development. ▪ Intermediate values are assumed to slow down the vegetation growth.

With this conceptualization the model allows a wide applicability of the developed tool and the exploitation of its results by either scientific, policymakers or stakeholders audiences. The model outputs are in fact both, spatial (maps) and tabular. These two formats allow immediate visualization, therefore suitable also for non-trained or non scientific personnel, and statistical treatment of the results, which is indeed an interpretation approach more close to the technical and scientific methodology.

Ultimately, the model applicability ranges from the planning and optimization of river restoration measures to the forecasting the development of floodplain vegetation in response of changing environmental conditions.

The considered scenarios

The RIPFLOW project team decided to consider three scenarios for each selected location. One representative water management scenario of each area within each country, and two climate change scenarios taking into account the two most realistic possible futures in an optimistic and a pessimistic ways at each case study.

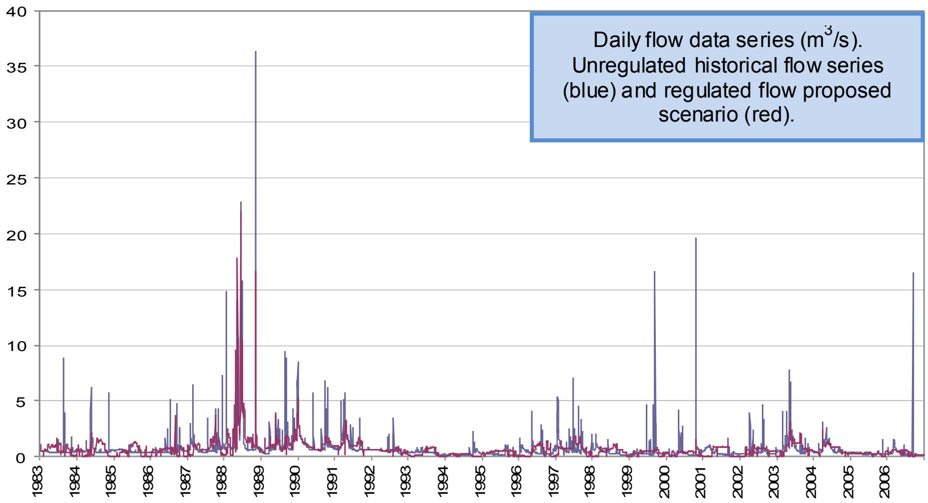
The water management scenarios. In Europe, the most relevant impacts to the riparian ecosystems are directly bound to dam operations, river stabilization and exploitation of the river resources. While in the Austrian study site important river stabilization necessities had determined the in-stream bars scenarios selection, in Mediterranean regions, water is a scarce resource and analyses of flow regulation scenarios were considered more interesting.

- **Spanish flow regulation scenarios:**

The Spanish partner selected two different water management scenarios.

The first one considered a flow regulation scenario which took as reference the Arenós dam regulation regime between 1988 and 2006. The definition of the regulation scenario considered the following expression:

$ST_{ij} = SA_{ij} \cdot \frac{ET_j}{EA_j}$	Where: STij, is the regulated flow in Terde (day i, year j) SAij, is the regulated flow in Arenós (day i, year j) ETj, is the global contribution in Terde (year j) EAj, is the global contribution in Arenós (year j)



Daily flow data series (m^3/s). Unregulated historical flow series (blue) and regulated flow proposed scenario (red).

The second one was a minimum environmental flow scenario, created with data provided by the Jucar River Basin authority and the historical data in the study site. Given the minimum environmental flow in Mijares-Terde (0.203 m^3/s), correspondent to the month of minimum monthly average (September), the environmental all over the year should follow a monthly pattern of variability similar to the natural flow regime. The environmental flow for each month (except September, minimum) was calculated as the product of the minimum and a variability factor (VF), as described below.

$Q_{eco} = Q_{\min} \cdot VF_i$	$VF_i = \sqrt{\frac{Q_i}{Q_{\min}}}$	Were: Qi is the average natural monthly flow (m^3/s) Qmin is 0.203 m^3/s

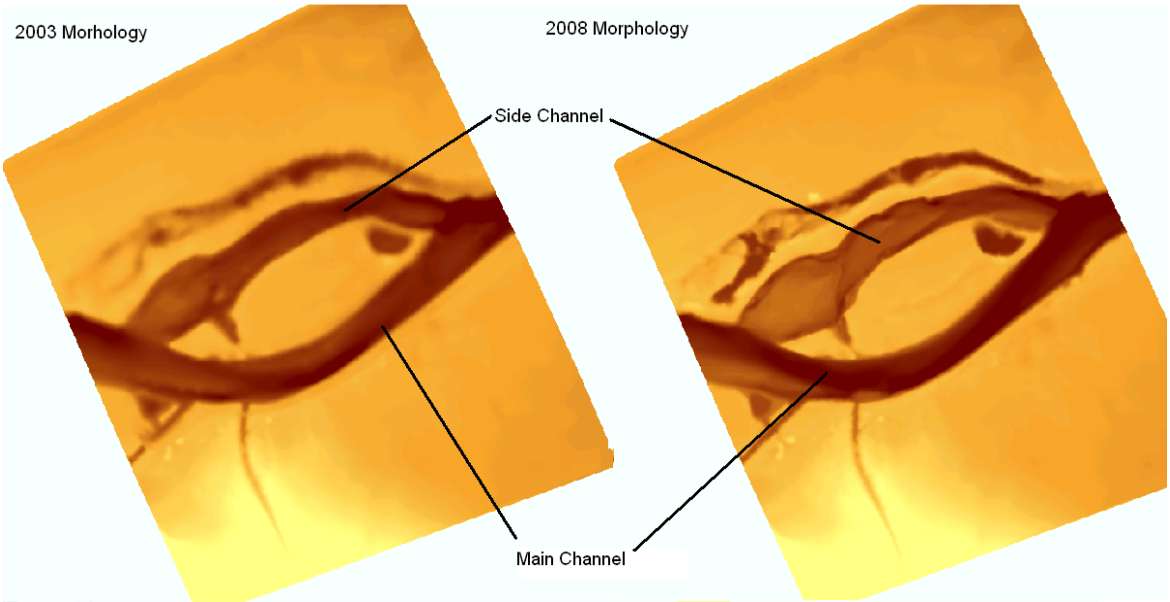
Minimum ecological flows for each year in Terde reach (Mijares River, Spain) for the 1988 – 2009 time period and year type definition for this scenario

	Natural flow			Minimum ecological flow		
Year	Average Flow (m^3/s)	Variation coefficient	Year type	Average Flow (m^3/s)	Variation coefficient	Year type
1988	2.071	1.62	Very wet	0.234	0.10	Very dry
1989	1.135	1.08	Wet	0.234	0.10	Very dry
1990	1.097	0.74	Wet	0.234	0.10	Very dry
1991	1.058	0.83	Wet	0.234	0.10	Very dry
1992	0.504	0.48	Medium	0.234	0.10	Very dry
1993	0.354	0.42	Very dry	0.222	0.17	Very dry
1994	0.241	0.92	Very dry	0.168	0.25	Very dry
1995	0.238	0.74	Very dry	0.183	0.22	Very dry
1996	0.474	1.00	Dry	0.229	0.13	Very dry
1997	0.841	0.97	Medium	0.234	0.10	Very dry
1998	0.420	0.72	Dry	0.222	0.17	Very dry
1999	0.388	2.50	Very dry	0.214	0.15	Very dry
2000	0.445	2.59	Dry	0.205	0.22	Very dry
2001	0.370	0.66	Very dry	0.218	0.17	Very dry
2002	0.431	1.02	Dry	0.225	0.11	Very dry
2003	0.848	0.92	Medium	0.234	0.10	Very dry
2004	0.665	0.68	Medium	0.234	0.10	Very dry
2005	0.247	0.39	Very dry	0.213	0.13	Very dry
2006	0.328	2.68	Very dry	0.190	0.31	Very dry
2007	0.440	1.34	Dry	0.199	0.22	Very dry
2008	0.505	0.91	Medium	0.224	0.11	Very dry
2009	0.597	2.21	Medium	0.233	0.11	Very dry

- **Austrian in-stream bars scenarios:**

Two scenario alternatives have been performed to find out the effect of channel geometry on habitats for riparian vegetation. "Small In-Stream Bars" alternative has been run using as a basis for the hydraulic and vegetation model the morphology measured in 2003. "Large In-Stream Bars" alternative has been run using the morphology measured in 2008. The two morphologies differ for the side channel width, depth and morphology of the in-stream bars. Compared to the 2008 morphology, the morphology measured in 2003 has a narrower and deep side channel while the in stream bars are smaller and less high.

Morphologies applied in the Austrian river management scenarios



2003	2008
Maximum side channel water depth : 1.8m Average depth: 0.66m Maximum width: 70m (aprox.)	Maximum side channel water depth : 2.1m Average depth: 0.25m Maximum width: 90m (aprox.)

* Water depth measures refer to the mean discharge, which is approximately of 125 m^3/s, measured between May and June

The climate change scenarios.

The optimistic and pessimistic climate change scenarios analysis for each specific study case have considered the variations expected for the climate model with best performance in the country of origin, being applied when possible regional scenarios. In order to allow a certain degree of comparability among the results of each project partner, the climate model scenarios reference period was the same for all partners, named as no change scenario. Finally, the selected scenarios were:

- **Spanish climate change scenarios:**
  - No change: historic reference period between 1960 and 1990
  - Optimistic: model HadCM3-PROMES, scenario SRES B2, time reference 2070-2100
  - Pessimistic: model HadCM3-PROMES, scenario SRES A2, time reference 2070-2100
- **Austrian climate change scenarios:**
  - No change: historic reference period between 1960 and 1990
  - Optimistic: model GCM ECHAM5, scenario SRES A1B, time reference: 2070-2100
  - Pessimistic: model GCM ECHAM5, scenario SRES A2, time reference: 2070-2100
- **Portuguese climate change scenarios:**
  - No change: historic reference period between 1960 and 1990

- Optimistic: model HadCM3, scenario SRES B2, time reference 2070-2100
- Pessimistic: model HadCM3, scenario SRES A2, time reference 2070-2100

To obtain the hydrological future variations at the local scale, some additional hydraulic simulations were necessary, considering the precipitation and temperature data series related to each scenario. Both, the meteorological and the hydrological variations expected by the scenarios have been considered at a monthly temporal scale.

The field data survey and processing

The calibration of the model in temperate (Austria) and Mediterranean (Spain and Portugal) conditions demanded the acquisition of field data in both kinds of environments to use them as inputs. The data quality in this phase of the project was considered particularly important, as it would condition the quality of the results. Prior to this, one important task was the selection of the study site. It had to satisfy several requirements, such as easy accessibility, long time series of flow records and meteorological data, good ecological status, natural dynamism (biogeomorphic processes), and natural variety of vegetation types, succession phases and stand ages.

All the countries tried to follow a similar schedule to complete all the necessary data, however, some small modifications were introduce in some cases in relation to the use of historic information. However, especial efforts were made to use comparable techniques. For example, in order to compare the results across the different teams, the plant dominant types were classified with a common standard, based on the concept of succession phases. The classification in phases was made according to the species and development stage of the plants. The choice of this method is very suitable in this international context where a species-to-species comparison can be hardly performed, especially when comparing Alpine and Mediterranean vegetation.

Regarding the sites' selection, for the data collection (vegetation, topographic and hydrology surveys) it is very important the selection of the natural or near-natural reference site. This selection is conditioning the assessment of model parameters and the comprehension of the riparian processes during the natural succession and retrogression. Besides, when the model is applied to a regulated river, the natural reference must be a site with characteristics comparable to the regulated one, so that the natural relationships occurring in the riparian ecosystem can be studied in the natural reference site and transferred to the regulated one.

Different inputs have been necessary to account for the main factors affecting the establishment and development of the riparian woody vegetation. These inputs can be explained as follows:

- **Topographic data:** it was necessary to create digital elevation models (DEM). Only one DEM can be used if the river morphology is very stable (Spanish case), but if more than one are available, or if the river morphology changes significantly after a big flood, it would be advisable to use different DEMs (Austrian case). In the Spanish case, the DEM was completed with topographic cross-sections within the river channel (transversal lines to the main flow). It was also useful to register the hydraulic changes and the longitudinal profile of the water surface along the study site. The quality of the DEM is very important, because it is also an input in the hydraulic modelling process; the quality of the DEM determines the accuracy of the hydraulic model, the final capacity of the input maps and results to describe explicitly the study site, and therefore it condition the whole work flow and the final discussion of results. At this stage, it was decided the topographic datum to be used in the different samplings.

- **Hydrological data:** it was necessary to gather all the hydrometeorological information to characterize the flow regime in each site, and to create maps for different hydrologic and hydraulic variables. For this task, it was necessary to get data from different monitoring networks of national and regional institutions for each study site. In the cases were the soil moisture (ETidx) sub-model was applied, several variables such as Temperature, Precipitation, Potential Evapotranspiration and river discharge were necessary.

- **Hydraulic modelling:** The water surface elevation was recorded (accomplishing topography and hydrometry) in order to calibrate the 2-D hydraulic model selected in each country. It is advisable to repeat the survey at different flow stages, being very important the availability of water levels for high flows of some magnitude/s; the quality and reliability of the rating curves and the hydraulic model depend very much on the data of water surface elevation when the water covers the floodplain (recorded with benchmarks during the flood, or with other techniques such as videos, etc.). Several discharge classes (based on the most typical flows in each site) were modelled. The raster maps were created for different hydraulic variables to be included into the Dynamic Vegetation Model: water table elevation, shear stress and flood duration. As different recruitment rules were applied to the bank and floodplain zones, raster maps for these zones were created.

- **Soil survey:** soil samples were taken in those study sites where the soil conditions were determinant for the vegetation establishment (Spanish and Portuguese cases). Soil samples covered the lateral and transversal gradient of the river. For each sample, texture and organic matter content were obtained. From the laboratory results, specific soil parameters were assigned to each habitat patch and pixel of the map.

- **Vegetation survey:** the vegetation patches were defined as homogeneous units with a similar elevation, soil and vegetation characteristics. They were, firstly, delineated over aerial photographs, and secondly, checked and surveyed in the field. For each patch, were recorded general information (date, location, plant functional type, and a first guess of the succession series and succession phase), soil parameters (cover percentage of substrate types, soil moisture, etc.), hydrological parameters (height above water table, distance to water-edge, etc.) and vegetation characterization (survey of the different vegetation layers, dominant species and measurements of diameter and height for age estimation).

- **Vegetation data processing:** growth functions of indicator species (e.g. poplar, willow shrubs) were developed to estimate the age of every patch. Vegetation data were processed and the succession series and phases (and their characteristics, interconnections and succession-retrogression pathways) were defined for each country. A map of observed vegetation was created (that would be use as reference to compare the performance of the model after the calibration process). In the Austrian case, vegetation maps of different years were available. It is very important that the selected sites include natural or reference sites, where the rules for vegetation succession and retrogression, as well as the natural processes in the riparian habitats, can be reliably identified in the natural status.

- **Expert rules:** they were defined to be implemented in the *starting condition submodel.* In this case, the key aspect was to define the more typical age intervals (minimum and maximum age) and elevation ranges (above base flow) where every succession phase appears. In the case of the Spanish site, also expert rules were created to represent the retrogression paths due to flood duration by means of 4 classes of different intensity of disturbance, depending on how many days per year a portion of the study site were submerged.

The model implementation

The steps to prepare the application of the model followed a defined line which begun with the gathering of the input data for the model. As it has been mentioned before, the input data have been gathered with slightly different methodologies by each project partner according to the in-house resources, budget and technical possibilities. Before applying the model to the different scenarios, the model was calibrated by each partner in its study site with the aid of statistical means.

Inputs definition

With the field data and the explained analyses, it is necessary to make the inputs of the model in the specific format, with coherent criteria for all the information. For example, the hydrological classes of years are flexible, because the user can define 3 classes (dry, medium, wet year), 5 classes, etc. However, it is important that all the maps and analyses are coherent with these classes, in all the information generated in a study site.

Regarding the maps format, it is very important that all the maps must be generated with the same grid extension and pixel size (in each study site, one mask for maps creation in ArcGIS was selected). The selected size has to accomplish a balance between accuracy in the vegetation mapping and time consumption during the calibration process.

The inputs for the calibration process in each study site were:

- Vegetation succession map (observed vegetation at the end of the calibration process).
- Riverine zones map (aquatic, bank and floodplain zone). The same map is constant across all the simulations. One important remark is that the mean annual flow was considered as the reference low flow in the Alpine site, and the base flow was the low flow reference in the Mediterranean sites (Spain and Portugal), where the difference between mean and base flow is very relevant.
- Digital elevation model (topography). The same map is used across all the simulations.
- Hydrological classes of years (period used for calibration) into year types depending on the annual average flow. The types were very dry, dry, medium, wet and very wet. A characteristic discharge was associated to each year type. For each year, the mean discharge value was replaced with the mean discharge class arithmetically more close to the real value.
- Water table elevation raster for each year type.
- Flood duration raster for each year type.
- Raster maps of shear stress (the maximum daily flow observed for each year during the calibration period was considered, and the corresponding shear stress reference flow was assigned).

Calibration process

The model calibration required the iteratively variations of the different sub-models parameters values. In order to evaluate the quality of the calibration results we compared two raster files, last year simulated vegetation and observed field vegetation. This comparison was developed by two useful tools, the confusion matrix and the coefficient of agreement, *kappa* (Cohen, 1960).

The confusion matrix is a visualization tool where the columns represent the number of units simulated for each category while the rows represent the real or observed values. In this case, the units are the cells from the vegetation raster file and the categories are the different phases of the succession lines. For each simulation point must exist an observed and a simulated succession phase. The confusion matrix is created by adding a unit value in the corresponding row and column when each simulated point is compared to the observed phase. The calibration of the model objective is to make the main diagonal values as higher as possible; reducing to minimum the other values specially those further from it.

Example of confusion matrix (Terde in Mijares River, Spain)

	Confusion matrix									
	IP-SD	PP-RH	WD-HP-RH	WD-SP-RJ	WD-ES-RA	WD-EF-RA	WD-MS-RA	WD-UF-TV	RE-HP-RH	RE-SP-RH
IP-SD	441	175	143	50	41	68	18	0	50	239
PP-RH	427	23	1	0	2	1	0	17	37	19
WD-HP-RH	429	10	413	35	54	68	44	27	34	163
WD-SP-RJ	1072	23	23	278	64	42	71	45	41	233
WD-ES-RA	665	30	23	16	615	468	608	59	49	189
WD-EF-RA	410	15	5	1	1	1083	247	62	87	83
WD-MS-RA	336	3	10	6	2	12	1010	4	15	16
WD-UF-TV	918	61	23	44	5	46	136	17721	71	82
RE-HP-RH	0	0	0	0	0	0	0	0	0	0
RE-SP-RH	481	34	74	28	46	235	36	7	30	303

To complement the confusion matrix results, the coefficient of agreement, *kappa* (Cohen, 1960), was calculated as the measure of agreement corrected the effect of chance. The maximum value of *kappa* (*k*) is 1, perfect agreement when all cases fall on the main diagonal of the confusion matrix and the other cells are empty. When *k* is very high, greater than 0.8, it is considered that the disagreements are the result of marginal discrepancies. By convention, *kappa* results are classified as following.

- 0.4 < *kappa* > 0.6 → acceptable
- 0.6 < *kappa* > 0.8 → good
- 0.8 < *kappa* > 1.0 → excellent

$$k = \frac{\sum f_0 - \sum f_e}{n - \sum f_e}$$

Where:
Σfo is the sum of the frequencies observed in the main diagonal
Σfe is the sum of the expected frequencies on the main diagonal. Each fe is calculated as the product of total number of simulated points and total number of observed points for each succession phase, divided by the total number simulation points.
n is the total number of simulation points

In addition to the *k* coefficient, the outcome of the relative area balance performed with focus on the bank zone was considered for the Austrian study site.

Relative area balance comparison between the observed and simulated vegetation. *Obs.: *Observer Vegetation; **Sim.: Simulated Vegetation								
Year	***Map***	***IP***	***PP***	***HP***	***PSP***	***SP***	***ESWP***	***Tot.***
2003	*Obs.	98.70%	0.0%	0.0%	0.0%	0.0%	1.30%	100.0%
	**Sim.	100%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
2005	*Obs.	39.0%	24.9%	1.2%	33.6%	0.0%	1.4%	100.0%
	**Sim.	71.6%	0.0%	9.3%	19.1%	0.0%	0.0%	100.0%
2007	*Obs.	17.8%	53.0%	0.4%	10.8%	3.5%	14.6%	100.0%
	**Sim.	61.5%	11.4%	4.3%	0.0%	6.3%	16.5%	100.0%
2008	*Obs.	24.8%	23.0%	8.4%	27.7%	8.5%	7.6%	100.0%
	**Sim.	9.2%	52.3%	7.6%	8.2%	6.3%	16.5%	100.0%
2009	*Obs.	14.6%	14.4%	17.5%	1.2%	44.7%	7.7%	100.0%
	**Sim.	29.0%	0.0%	8.3%	32.0%	14.3%	16.5%	100.0%
2010	*Obs.	9.9%	0.0%	4.4%	53.7%	0.0%	32.1%	100.0%
	**Sim.	12.8%	5.2%	10.3%	17.5%	16.1%	38.1%	100.0%

An example of RIPFLOW model calibrated parameters, corresponding to the calibration developed for the study site in Spain, is shown in the next tables.

Plant functional types	**ETidx sub-model vegetation parameters**								
	Zr (m)	**Ze** (m)	**Zsat** (m)	**Ri** ( )	**Rj** ( )	**CRT** (mm.Mpa^{-1}.h^{-1})	**Pwp** (KPa)	**Pcrit** (KPa)	**Cov** ( )
RH	1.25	0.7	-0.9	0.7	0.9	0.97	1500	500	0.7
RJ	1.3	0.8	-0.3	0.7	0.3	0.97	1500	350	0.7
RA	3.2	0.8	-0.3	0.7	0.3	0.97	1500	125	0.8
TV	1.9	1.6	1.6	1	0	0.97	1500	95	0.8

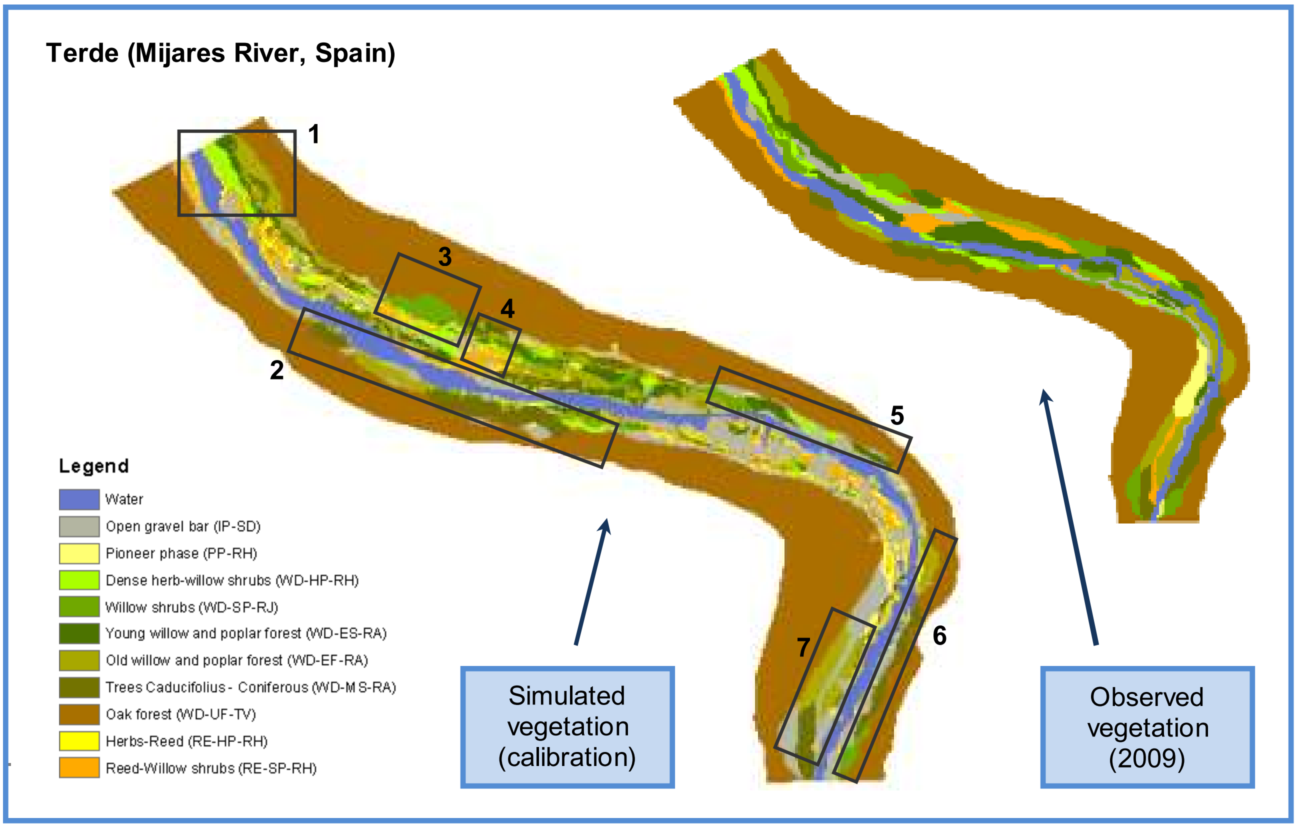
Calibration parameters values for Terde reach in Mijares River (Spain) corresponding to the recruitment sub-model (1), shear stress sub-model (2), flood duration sub-model (3), succession to woodland sub-model (4) ETidx sub-model limits (5).

	Parameter	Value	Units
1	HBFL for Floodplain Recruitment Dry	> 7	meters
	HBFL for Woodland Recruitment Zone	0.6 – 3	meters
	HBFL for Scour Disturbance Zone	< -5 and > 7	meters
	Pioneer zone	≤ 3	years
2	Critical Shear Stress of Woodland	12 (IP-SD) 22 (PP-RH) 24 (WD-HP-RH) 26 (WD-SP-RJ) 26 (WD-ES-RA) 27 (WD-EF-RA) 30 (WD-MS-RA) 30 (WD-UF-TV)	$N.m^{-2}$
	Critical Shear Stress of Reed	12 (IP-SD) 22 (PP-RH) 23 (RE-HP-RH) 24 (RE-SP-RH)	$N.m^{-2}$
3	Flood Strong Impacts	240 – 366	days
	Flood Moderate Impacts	150 – 239	days
	Flood Low Impacts	90 – 149	days
	No flood impacts	0 – 89	days
4	Succession Reed to Woodland	< 10	years
5	Woodland upper ETidx limit	0.85 (IP-SD, PP-RH, WD-HP-RH) 0.90 (WD-SP-RJ, WD-ES-RA) 0.95 (WD-EF-RA, WD-MS-RA, WD-UF-TV)	-
	Woodland lower ETidx limit	0.40 (IP-SD, PP-RH, WD-HP-RH, WD-SP-RJ, WD-ES-RA) 0.30 (WD-EF-RA, WD-MS-RA) 0.20 (WD-UF-TV)	-
	Reed upper ETidx limit	0.80 (IP-SD, PP-RH, RE-HP-RH) 0.95 (RE-SP-RH)	-
	Reed lower ETidx limit	0.50 (IP-SD, PP-RH, RE-HP-RH) 0.70 (RE-SP-RH)	-

Calibration results

In Mediterranean environments the model was calibrated with satisfying results, being excellent the distinction capacity between riparian and terrestrial vegetation distribution.

For example, the kappa value obtained with the calibration proposed for Terde reach in the Mijares River (Spain) is 0.7127 ± 0.0067 (95% confidence limit) or 0.7127 ± 0.0089 (99% confidence limit). This result was considered as very good taking into account that the number of points for each succession phase were not always similar and that some of those phases were barely observed in field.



Calibration accuracy of the model reached different Kappa values for each partner at the sub model's calibration process, with divergent results suggesting research is still needed on succession phase's definition and model parameters characterization.

	Model accuracy (k)	
	RIPFLOW model (without ETidx sub model)	RIPFLOW model (with ETidx sub model)
Spain	-	0.72
Austria	0.4	-
Portugal	0.48	0.24

However, the good results achieved in some cases demonstrate that with a high-quality calibration developmental process the RIPFLOW model can reproduce correctly the fluvial dynamics exerted on riparian patches and its resilience response with an adequate quality.

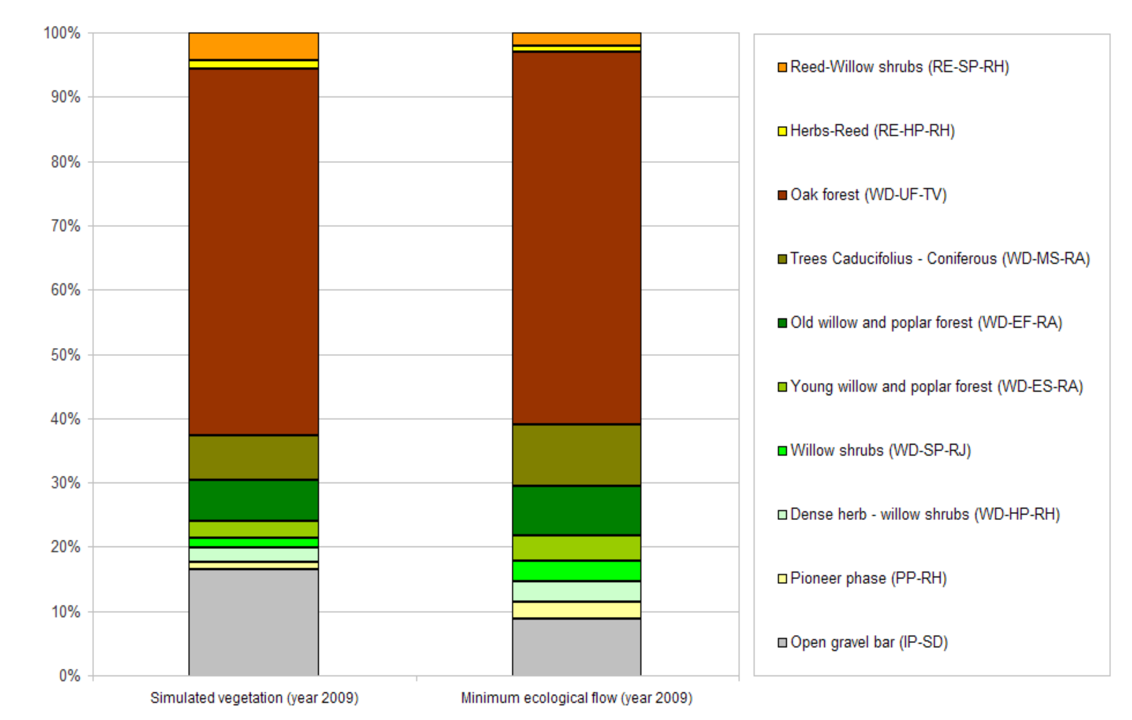
Discussion of results

Flow management scenario example: Spanish minimum environmental flow

The minimum ecological flow scenario constrained the flow passing through the stream to minimum required values. In this case, the shear stress suffered by the riparian vegetation is directly reduced almost removing it completely. These scenario results were compared to the natural flow regime between 1988 and 2009. The differences between scenarios were important.

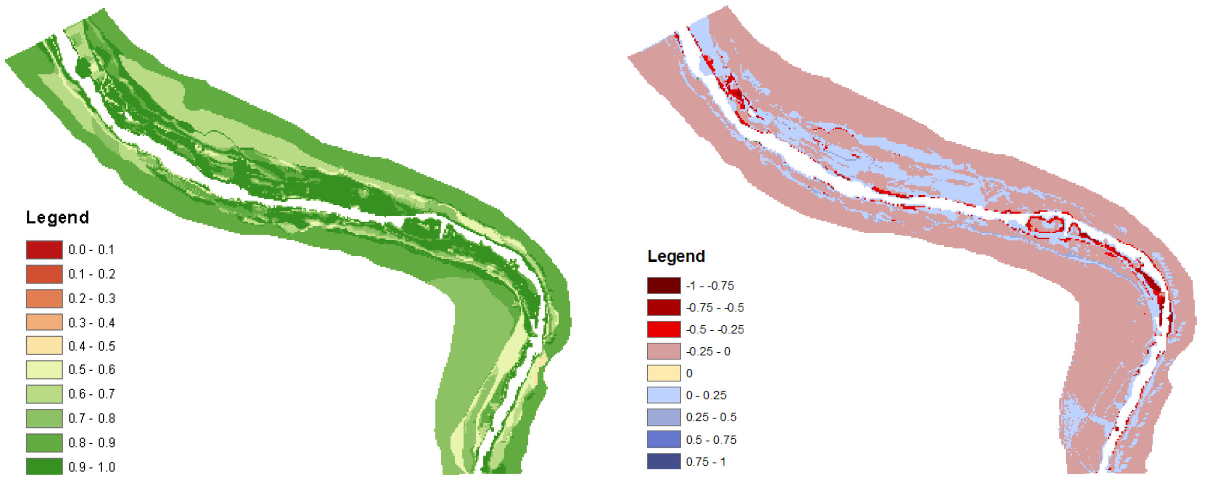
The resultant balance comparison for the last year simulation showed a reduction of the gravel bars presence (IP-SD) in the minimum environmental flow scenario. The presence of gravel bars is an evidence of high flows, which have enough shear capacity to remove the existent vegetation. The other succession phase's presences were more abundant in the minimum ecological flow scenario than in the historical data, except the reed shrubs phase (RE-SP-RH) which was considerably lower. This seems to indicate that the reed succession line can be considerably disfavoured and the biodiversity in riparian areas could be affected by the establishment of minimum environmental flow regimes.

Balance comparison between natural flow scenario (simulated vegetation with historical hydrometeorological data) and minimum ecological scenario during year 2009, in Terde reach (Mijares River, Spain)

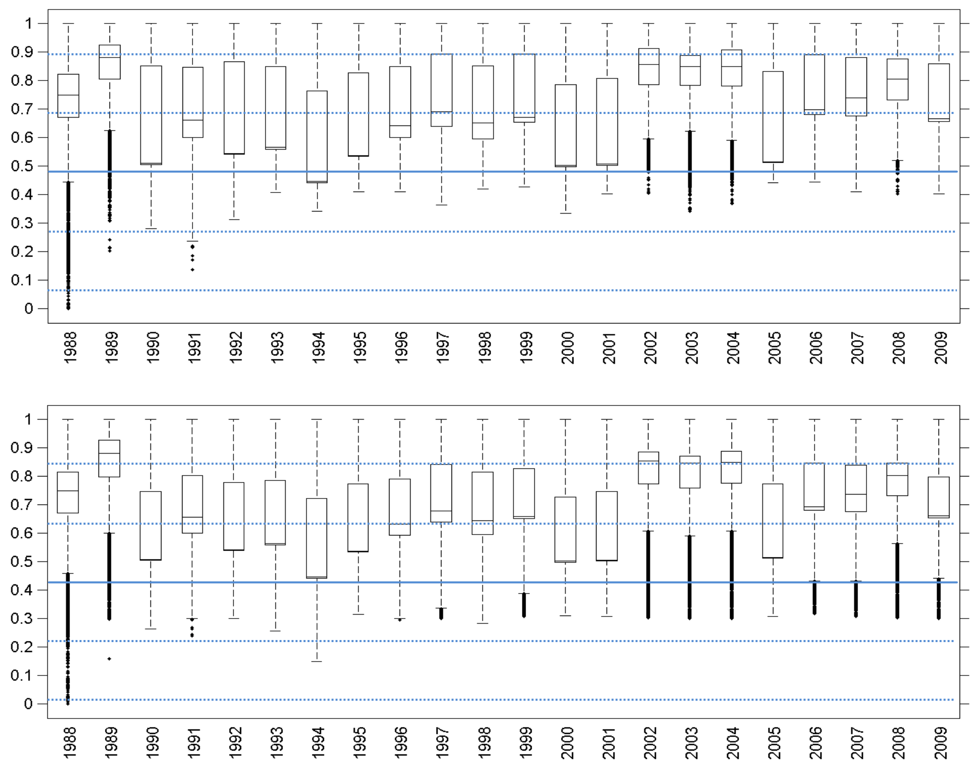


Analyzing the ETidx, under this scenario assumption, some differences were observed in the comparison of a medium year results. A large proportion of the area suffered a decrease of ETidx in the minimum ecological scenario. On the contrary, some riparias areas located near to the aquatic zone increased their ETidx values in the environmental scenario analysis. The environmental flow scenario maintains an approximately constant minimum flow and this fact support high evapotranspiration rates in some specific areas.

ETidx map simulated for year 2008 in natural regime flow (left) and differences observed for the same year in the minimum ecological flow scenario (right) in Terde reach (Mijares River, Spain). Areas in red represent lower ETidx and areas in blue show higher ETidx values observed in the minimum ecological flow scenario



ETidx box plots for natural flow scenario (above) and minimum ecological flow scenario (below) in Terde reach (Mijares River, Spain) for the 1988 – 2009 period



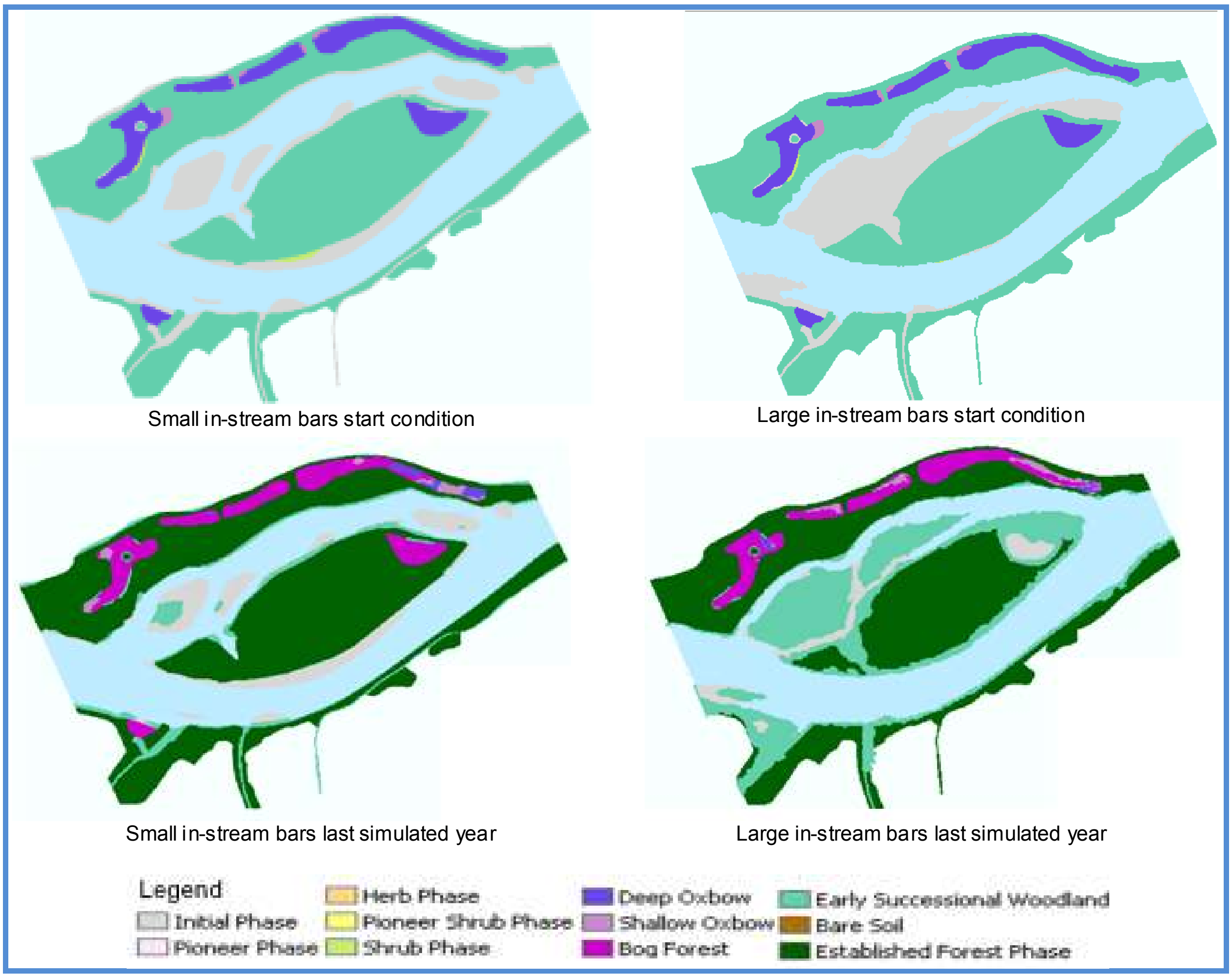
Decision makers should take into account that the vegetation evolution takes place very slowly especially in advances stages of the succession. It is important not only to consider a long enough time period to show consistent scenario effects, but the potential long term effects if the tendencies shown are maintained. The water managers should take into account that although the riparian ecosystem evolution seems to be favoured with minimum ecological flow establishment, no retrogressions finally cause that the terrestrial vegetation replaces the riparian one.

Morphology management scenario example: Austrian In-stream bars alternatives

Under a management perspective, the model can be applied to evaluate the possible outcome of different management strategies (McLain & Lee, 1996). In the presented work, the different strategies were represented by two cases (large and narrow in-stream islands). Nonetheless, this study case application can be extended to include more complex and more structured solutions.

The results interpretation of these two alternatives must take in to account the lack of modelled sediment transport (leading to bed erosion and aggradation) and bank erosion and bank accretion (controlling channel width), which play a big role in the shaping of the riverine vegetation community (Bendix & Hupp, 2000; Edwards *et al*., 1999).

In both river management alternatives, the final picture portrays a static, artificial system with no habitat shift. Under the ecological point of view the lack of habitat shift has a negative effect on the ecological functions of the river corridor because there is a depletion of habitats which can host different species types and their different life stages.



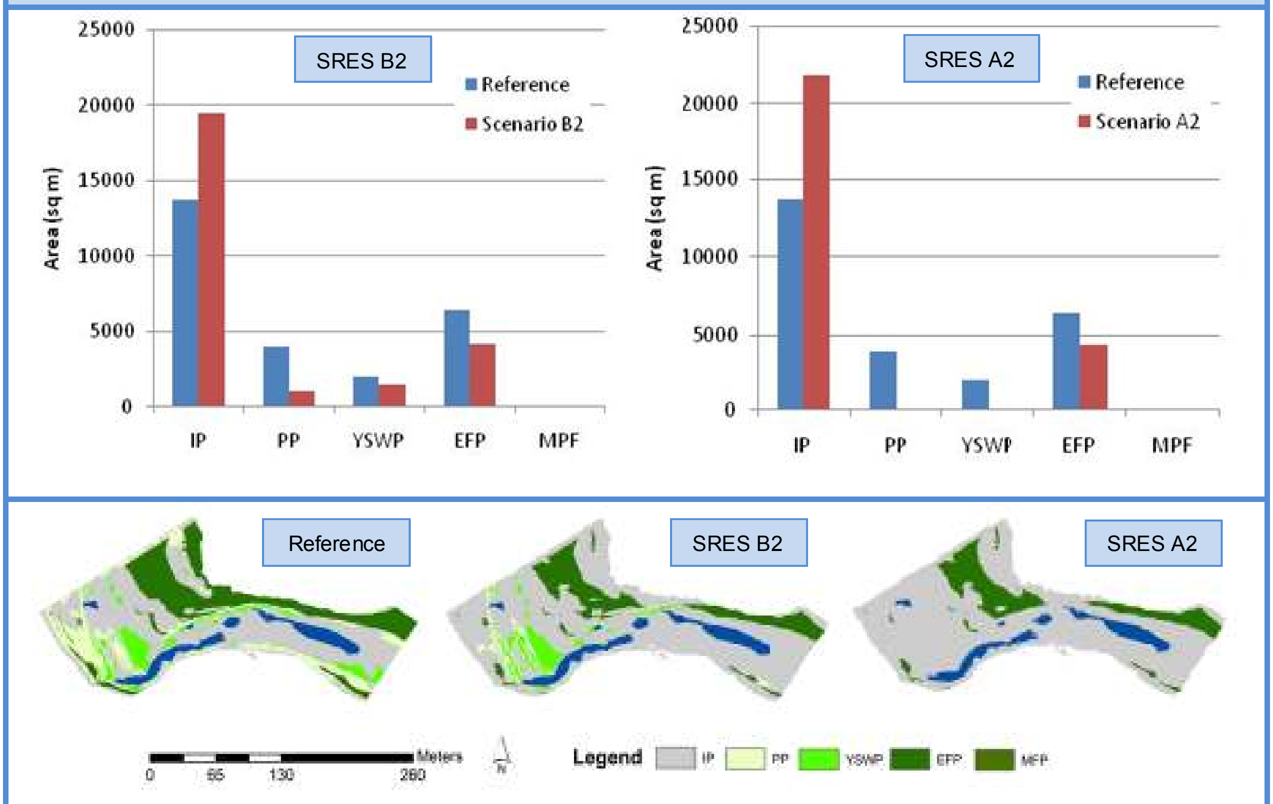
However, the two alternatives strongly differ in the paths that lead to their results. While alternative “small in-stream bars” reaches the static condition with very monotonic steps, in the alternative “large in-stream bars”, the phase transitions are more dynamic.

Climatic change scenarios example: Portuguese optimistic/pessimistic projections for 2070-2100

In the Portuguese study case, climate change effects were more extreme than in the other study cases and resulted almost in the disappearance of the pioneer and juvenile riparian patches due to recruitment cannot proceed. In addition to this, a reduction e to winter flows and summer dryness. These results were coherent in both scenarios (optimistic SRES B2/pessimistic SRES A2) showing a river channel widening with substantial decrease of the early succession phases, leading to species lost, aging of the remaining riparian vegetation and spreading of upland forest inwards the river.

A common factor in the two climate change scenarios, which have been simulated, is the reduction of the peak discharges, also for the extreme events. This reduced flood magnitude would have also a direct impact on the magnitude of the sediment/erosion processes and consequently on the recycling and recruitment of vegetation. This trend was more pronounced in the worst scenario, suggesting that extreme climatic change will promote the disappearance of pioneer or young succession stages of the riparian woodlands in Mediterranean rivers.

Portuguese optimistic/pessimistic projections for 2070-2100



In other countries, although there were important differences between scenarios results, they were lower as expected in spite of the great variations between hydrological inputs of each scenario definition all over the simulation periods.

Conclusions

The great potential of the model given by its capability to visualize and quantify the changes occurring both at spatial and temporal scale on the riparian ecosystems, in response to hydraulic driven variables such as the discharge. The time series map which is produced at the end of each simulation is in fact of easy interpretation and immediate exploitation also for non expert users, such as policy makers or generic stakeholders, who can be involved in water allocation conflicts or administration of river restoration funding. The model demonstrates its potential to evaluate the possible outcome of different management strategies as the establishment of large/narrow in-stream islands, also when the impacts on the floodplain ecosystem involves flow regulation or the design of environmental flows regimes aimed at sustaining an ecological status compliant with the Water Framework Directive. In last instance, the possibilities afforded by the model are the decision support that allows the visualization and quantification of different alternatives, thus reducing the uncertainties in the matter of river management unstructured problem.

Further point of the model strength is its applicability to riparian ecosystems located in different climates and therefore subject to different hydrological regimes. Trans-regional applicability of the model is given by two factors, which concern the model conceptualization and in second place the model architectural implementation. The model concept formalization of the floodplain processes accounts for the riparian general components, which are found in most of the temperate riparian ecosystems in spite of their specific regional position. On the other hand, the modular architecture of the model allows setting up the different model components to fit the specific requirements of the modelled riparian ecosystem (i.e. neglecting soil moisture or flood duration components where they are not relevant).

The model can manage information at small and medium scale (river segments from hundreds of meters to some kilometers), with input generation from different sources (e.g. total station, GPS, digital imagery), and furthermore, with different time periods, from some years to decades. It is possible to start the model and to calibrate with several benchmarks in time, but it is also possible to generate a generic starting condition in a study site (derived from field data processing).

Taking into account those considerations, the main conclusions extracted during this project are the following:

1. The RIPFLOW model simulates **riparian vegetation distribution in space and time**.

2. The model application is flexible and **adaptable to different regions**.

3. Before the model can be used in any other study case different from which are presented in this report, the users will need to implement a **first phase of field data survey** (hydrology, vegetation and soil).

4. During the development of the field data, the **quality of the DEM** is very important, because its quality determines the accuracy of the hydraulic model and the input maps.

5. Once the model is set up for a specific reach, it **allows a wide range of scenarios analyses**, expanding the range of possibilities **to make the better decision**.

6. The **hydrological inputs** must be reviewed and redefined in order to be **coherent with the scenario** that is going to be analyzed. In some cases, morphological inputs or soil data information should be modified too.

7. **The analyses of climate change scenarios** for each specific **study case** must consider the variations expected for the **climate model** (or group of models) with the **best performance** in the country of origin, being very advisable to apply **regionalization techniques**.

8. After each model iteration, a **vegetation cover map** and an **evapotranspiration index map** (raster format) are generated, allowing the final user to perform **spatial analyses** and give **summary data for decision support**.

9. The interpretation of the results must take into account the **lack of a sediment transport sub-model**.

10. Policy makers should take into account that the **vegetation evolution takes place very slowly** especially in advanced stages of the succession:

    - It is important not only to consider a **time period** long enough to show consistent scenario effects, but also to check if the trends of potential **long term effects** are maintained or stable.

    - **Not always more advanced stages** of a riparian succession **indicate a better environmental performance** (i.e. Avoid flood events in dam regulation or minimum environmental flow scenarios favours the replacement of the riparian vegetation by the terrestrial one).

11. **RIPFLOW is a reach scale model**. For watershed scale decision support an upscaling methodology should be developed.

Contents

1 Introduction

The EU-Water Framework Directive (WFD) classification scheme for ecological status and water quality includes five status categories: high, good, moderate, poor and bad. The general objective of the WFD is to achieve “good status” for all surface waters by 2015; this means both “good ecological status” and “good chemical status”. The reference status is given by “undisturbed” conditions showing no or only “very minor” human impacts. The environmental objectives set in the WFD shall ensure the long-term protection and the sustainable use of the water resources and shall prevent further deterioration, with a wide range of benefits and socio-economic gains for this and coming generations. In this view, the “Common Implementation Strategy for the WFD” (CIS) explicitly mentions the mitigation of impacts from climate change and security of water supplies as a benefit of the WFD objectives, e.g. by forward planning in river basin management, water demand and supply management and mitigation of flood and drought events (CIS, 2005).

The European river districts with more heavily modified water bodies are located in the Czech Republic, Netherlands and England with a share of 60-100%. River districts with very low human impact (less than 5% heavily modified and artificial water bodies) are to be found in Ireland, Scandinavia and the Iberian Peninsula, being Spain and Portugal partners in this project. In Austria, 20-40% of all water bodies of the Danube river district are heavily modified or artificial. While some river districts in Spain show a rather low impact of human influence (5-20%), others contain up to 60% of heavily modified or artificial water bodies (DG Environment, 2007). River districts in Austria mainly suffer from impacts related to river regulations (levees, channel modification) and the operation of hydroelectric power plants. In Spain and Portugal, dam operation and irrigation demand are the major human influences on river systems. In this context, it is obvious that intensive restoration efforts are required to achieve a good ecological status of European river systems until 2015, and dam operation rules have an important role in the accomplishment of the WFD goals.

Regarding climate change, the latest IPCC report on the issue says “From new estimates …it is extremely likely that human activities have exerted a substantial net warming influence on climate since 1750” (IPCC, 2007). It also mentions that “changes in surface temperature extremes are consistent with warming of the climate” and “increases have occurred in the number of heavy precipitation events”. As far as regional projections of precipitation patterns are concerned, the IPCC has found that “Precipitation is *likely* to increase in most sub polar and polar regions. The increase is considered especially robust and *very likely* to occur, in annual precipitation in most of northern Europe, Canada, the northeast USA and the Arctic, and in winter precipitation in northern Asia and the Tibetan Plateau”.

Until now, it seems clear, that the Alps are particularly sensitive to climate change. Recent warming has been roughly three times the global average. Climate models predict significant changes in the next decades, including a reduction in snow cover at low altitudes, receding glaciers and melting permafrost at higher altitudes. Furthermore, sharp shifts in temperatures and extreme precipitations are predicted (www.climchalp.org). In the Alpine region, detailed research on likely effects of climate change on natural disasters is currently performed, for instance in the frame of a project INTERREG III (www.climchalp.org), the CIRCLE (http://www.circle-era.net/) research initiative, StartClim (http://www.austroclim.at/ index.php?id=40) and GLORIA (http://www.gloria.ac.at/). As a consequence of the changes in the precipitation regimes, discharge parameters of river systems are expected to change as follows:

I. Extreme events (flooding, drought) are likely to become more frequent and more intense

II. Sedimentation dynamics can be expected to change because of enhanced erosion in the
III. course of extreme climate events (mudflows, landslides, runoff)
IV. Seasonal discharge patterns are likely to change
V. Total flows might change if overall yearly precipitation changes.

In the context of the Iberian Peninsula (Portugal & Spain), Mediterranean-type regions experience limited water availability during part of the year. On the other hand, the hydrological variability of Mediterranean-type regions profoundly determines the life forms and life cycles of aquatic organisms, as well as ecological processes (Gasith & Resh, 1999).

For 6000 years, the humankind overcame water shortage by water storage in reservoirs, water abstraction from ground and surface sources and water transfers (Davies *et al.*, 1994). While in temperate European rivers, physical anthropogenic disturbance usually refers to river profile modifications, in Mediterranean ecosystems the water quantity-dependent nature of human pressures results in less predictable, antagonistic or cumulative effects. These effects have been taking place for centuries, though intensified mid-last century onwards with the up-scale of engineering expertise and materials.

The apparent tolerance of native riparian species to naturally harsh and humidity constrained environments may have actively masked such pressures, e.g. distinguishing between fortuitous series of natural low-flow years and the downstream water decrease through damming. Till now, flow requirement settings in Iberia have been mostly based on concept of habitat availability of aquatic organisms such as fish (Oliveira *et al.,* 2004; Santos *et al.,* 2004). However, a more holistic and ecosystem-based approach is needed, one which will integrate the responses of both aquatic communities and the river corridor within a hydrological framework (Arthington *et al.,* 2006). Riparian ecosystems are shaped by hydrological rhythms and in this project we propose to use them as surrogate of the river ecosystem's flow requirements in Iberia.

Recently, the European Community has reviewed climate change in Europe and its implication to water management (Eisenberg, 2005), including a non-uniform increase of global precipitation and extreme events, and a temperature rise up to 5.8ºC. Climate change scenarios in Portugal using high resolution models indicate an increase in diurnal temperature range, a dramatic increase in the number of days per year with temperatures over 35ºC, reductions in yearly mean precipitation and in the duration of the rainy season, but an increase in winter precipitation due to heavy daily events (Santos *et al.,* 2002). Riparian ecosystems provide a natural biological sentinel for these dramatic changes, acuter at higher latitudes. In order to generate climate change scenarios, regional projections based on downscaling of global change models are progressing in Europe. These scenarios will be used in this project for the simulation of long term effects. The main project where such scenarios are being developed is the ENSEMBLES project (http:// grupos.unican.es/ai/meteo/ensembles/), which is responsible of constructing probabilistic high-resolution regional climate scenarios using dynamical and statistical downscaling methods (www.ecmwf.int/research/EU_projects/ENSEMBLES /downscaling/index.html).

Past researchers have demonstrated that experimental flooding is an effective method to restore some degraded riparian ecosystems, e.g., recruitment of riparian vegetation (Rood *et al.*, 2005), continuation of the nutrient cycle (Ellis *et al.*, 1999), and the establishment of sand bars and sediment management (Stevens *et al.*, 2001). In this method, high water volume available during wet years is released in such a way that is compatible with seed dispersal and establishment criteria of cottonwood seedlings. This practice is now widely accepted for promoting the recovery of riparian cottonwood forests. The ramping flood (experimental peak flood) helped to regenerate extensive numbers of cottonwoods and willows along the river, which was previously deprived of reach and resulted in improvements to the river and floodplain ecosystem (Rood *et al.*, 2005). Ellis *et al.,* (1999) concluded that even limited managed flooding is very effective to increase the decay rate of leaf and woody debris, suggesting an increase in nutrient cycles, thus helping restoration of at least partial ecosystem function.

Most restorations undertaken so far have used a simple empirical relationship or undisturbed sites as references to provide a basis for the restoration, but it does not reflect a clear reason why certain restoration design is best to use. One of the greatest challenges to make progress in the riparian ecosystem restoration is to understand physical and ecological processes of a system, interaction, and feedback within these processes. It is equally important to recognize the specific disturbances that have altered a system. Jorde (2002) pointed out the importance of addressing complex linkages between physical processes and biotic interactions in research and the development of restoration projects over larger spatial and temporal scales in the future. For management purposes, Goodwin & Hardy (1999) emphasized the importance of a framework for a systematic analysis of river ecosystems.

During recent decades, several models were constructed to facilitate prediction of changes in vegetation species as a consequence of altered hydrological regime. These models were used to increase the understanding of complex riparian systems and their interactions. The simulation of ecosystems has taken place since the rapid development of analog and digital computers in the 1950s and early 1960s. According to Wiegert (1975), the earliest applications of the concept of simulating dynamic ecosystems using computers was Odum (1960), who utilized an analog device, and Garfinkel (1962), who used a digital computer. During recent years, a variety of ecological models have evolved to address changes in vegetation species as consequence of changes in environmental variables and hydrological alterations (e.g., Baptist, 2005; Botkin *et al.*, 1972; Braatne *et al.*, 2002; Franz & Bazzaz, 1977; Glenz, 2005; Hooke *et al.*, 2005; Mahoney & Rood, 1998; Murphy *et al.*, 2006; Pearlstine *et al.*, 1985; Phipps, 1979). Most of these models are based on functional relationship between river hydrology and vegetation species or communities.

Chapin & Beschta (2002) stated that periodic flooding is an important parameter for the establishment and growth of riparian vegetation communities, and that there should be functional relationships between flood hydrology and riparian vegetation communities; however, this relationship may differ depending on regional climate conditions. Flooding frequency, duration, and disturbance are the most important variables governing riparian vegetation communities (Gergel *et al.*, 2002).

Baptist (2005) developed a rule based dynamic floodplain vegetation model capable of coupling with 1-D (water surface elevation) and 2-D (flow velocity) hydrodynamic models. The model consists of a hydraulic module, sedimentation module, and vegetation module that interface with each other. The model considers that the succession of vegetation is a function of inundation duration, land use, grazing intensity, and sedimentation rates. The model result showed that the proposed plan results in diverse floodplain vegetations similar to the historical reference. The results of this study still need to be considered with care, since the modeling is based on very simplified assumptions of complex natural processes. Baptist (2005) considered the sedimentation rate as the only parameter for retrogression of vegetation. The results of this model show also, that the inclusion of mechanical stress (shear stress) would result in a more realistic outcome.

It is very important to understand riparian forest dynamics and its driving processes in river restoration projects and decision-making processes. From this point of view, Glenz (2005) developed a coupled model RIFOD (RIparian FOrest Dynamics) of ecological and hydraulic processes to simulate riparian forest dynamics for Central European conditions. The ecological (vegetation) model consists of four modules that are interfaced with one another and coupled with the hydraulic model. Regarding the flooding stress, the model considers both physiological and mechanical stresses. The main model outputs are biomass, number of individuals per area, and shrub species at different height classes. One of the main limitations of this model is the lack of real data to compare with the model results. The model results are evaluated by comparing the results from models developed in other studies. Such a model-model comparison does not allow for quantitatively comparing the species-specific proportion of biomass, the number of individuals, or other variables. The model is limited to applications in widened fluvial corridors with stable geomorphology (lowland rivers). However, from the scientific point of view, the model is able to simulate patterns and processes in riparian areas and to illustrate ecological concepts and hypothesis related to the riparian ecosystem. There are still considerable uncertainties in the equations used to simulate plant growth, plant recruitment, and environmental stress factors etc.

In the last decade, other models were focused on water quality. For example, the Riparian Ecosystem Management Model (REMM, http://www.cpes.peachnet.edu/ remmwww/remm/remmoldwww/default.htm), that is a computer simulation model of riparian forest buffer systems. It is one of the most complex mathematical models developed to simulate hydrology, carbon and nutrient cycling, and plant growth processes in riparian forest systems on a daily time step (Lowrance *et al.,* 1998). However, many different parameters are necessary for its use. REMM mimics the three zone conceptual model of a riparian system and allows the user to define vegetation types for each zone. Some of the principles and processes modeled in REMM were used as background in the design of a soil moisture model that is being developed by Partner 1 called RibAV (TETIS2 project, http://www.proyectosh2o.upc.es/) that will become a part of RIPFLOW.

The European COST action 626 was dedicated to the “modelling in aquatic ecosystems”, it ended in 2007. One of the results was the definition of the state-of-the-art in methods and modelling of riverine habitats and the definition of research needs (http://folk.ntnu.no/borsanyi/eamn-web/index.htm/). The eb&p Umweltbüro (Partner 2) was also a partner in that project. One objective was to develop integrated methods and models for assessing the interactions between aquatic flora and fauna and riverine habitats, however the riparian vegetation models were not finally generated (Kerle et *al.*, 2005) respectively the result of the vegetation models was not satisfying (Baptist & De Jong, 2005).

FLOBAR2 is dedicated to riparian ecosystem processes, with the aim of addressing knowledge-gaps in present scientific understanding of river-floodplain biological and physical processes. The final report (http://www.geog.cam.ac.uk/research/projects/flobar2/reports/final/) shows different aspects of how floodplain forests work, the principle threats to these ecosystems, ways of restoring them and the policy and institutional contexts within which their restoration might take place. The final recommendations focused in the understanding of the processes that take place in the floodplain, but it was not created a tool for decision making in water management. However, all the information generated in FLOBAR2 will be important in the analysis of the European and national framework (WP2) of this project and also in the model conceptualization.

Also related to European rivers, the FLOODsite project (http://www.floodsite.net/), with a large consortium, is dedicated to generate strategies of integrated flood management. However, the riparian vegetation was not directly considered, although it has an important influence on hydraulics during extreme floods. Therefore, the development of the RIPFLOW model in this project can be very helpful for the management of floodplain to avoid disastrous effects of extreme hydrological events in the future. Finally, another European project ending in 2009, will evaluate the impacts of global change on European Freshwater Ecosystems (Euro-limpacs, http://www.eurolimpacs.ucl.ac.uk/). It is not an objective to develop environmental flow assessments, and the riparian vegetation is not among their objectives, but one of the tasks is to generate climate change scenarios, which has been useful in the development of the RIPFLOW project.

Nowadays, very few studies have considered the riparian vegetation in environmental flow assessments, because most of these studies have used physical habitat simulation based on fish or sometimes invertebrates (Tharme, 2003), and still the practitioner do not have the biological information and the dynamic succession models necessary for an accurate assessment. In Spain, all the studies for environmental flow assessments, in the last decade, have been based exclusively on fish microhabitat data (Martínez-Capel *et al.,* 2007; Ferrer *et al.,* 2007; Hernández *et al.,* 2007).

The RIPFLOW project provides a dynamic riparian vegetation distribution model that can be employed as a technique to understand and manage the impacts of altered hydrology (flow rates and volumes) on the riparian ecosystem structure. In addition, this tool has demonstrated to be very useful in the assessment of acceptable ecological flow regimes of rivers. Finally, the RIPFLOW model can support decision-making and policy development in extreme events (both floods and droughts) related to the riparian forest management.

2 Objectives

Within the framework of the problem and the previous and ongoing main European related projects described above, two general goals have been covered in this project: the development of a dynamic riparian model and its application to the case studies of 3 European countries.

2.1 Development of a dynamic riparian model

The specific objectives in this first general goal have been:

I. To develop a flexible dynamic model of riparian habitats and vegetation to be easily applied in a wide range of conditions across Europe, from humid regions of Austria to Mediterranean conditions. Two important key elements of this model were the soil-moisture sub-model (to consider the effect of low flows or droughts) and the succession sub-model (to consider the effect of floods).
II. To create a software to run such model (it has been called as this project: RIPFLOW), in a user-friendly interface, with easy data input and management, and the clear and necessary outputs to give decision support in the implementation of the WFD by the water managers and also consultancy companies working on environmental flow assessments and river restoration.
III. To identify and to apply cost-effective methods for the acquisition of biological information needed to calibrate the model in most regions of the European Union.

2.2 Application to project case studies

The specific objectives in this second general goal have been:

I. To calibrate the model in nearly totally undisturbed conditions.
II. To help water managers in the learning and the starting point for the practical application of the results in the water management of the case studies (exploitation in national context), to be potentially used in the corresponding River Basins Plans
III. To identify scientific based guidelines for assessing the impacts of altered hydrology on riparian vegetation, due to climate change or dam operation rules, considering extreme hydrological events like droughts and floods (trans-national context)
IV. To analyze several representative disturbed flow and climate change scenarios in the study sites in order to show the capabilities of the model. In addition, these analyses could be taken as reference by the end users as example of how the results should be exposed and interpreted.

3 Methodology

In order to fulfil the objectives of the project the overall process can be summarized in five steps. First the model development, second the establishment and set up of representative altered flow and climate change scenarios, third the field survey and the acquisition of the scientific base data, fourth the model implementation with the calibration in the selected study sites and fifth the model application to the scenarios analysis.

3.1 The RIPFLOW model development

The first step consisted in the acquisition of the necessary information to define a model concept able to fit both the Mediterranean and Alpine riparian ecosystem rivers. The conceptualization was followed by the model implementation and testing.

The definition of the RIPFLOW model comprised the following tasks:

I. **Definition of the main physical parameters that determine the riparian vegetation distribution in space and time.** The model was designed to simulate the vegetation succession or retrogression in response of those physical parameters (shear stress, flood duration, recruitment areas and evapotranspiration parameters).

II. **Definition of the main questions for water management.** The model RIPFLOW allow the simulation of different climate scenarios, relevant dam operation schemes and their effects on the riparian forest. RIPFLOW consider the role of minimum flows and also floods in the maintenance of riparian forest and its recruitment.

III. **Definition of RIPFLOW information flow.** The outputs (data files in different formats, tables, charts, etc.) have been defined for a friendly and clear presentation of results for the water managers (flow characteristics, vegetation types, critical values, thresholds, etc.) in a friendly interface. It has been also crucial to select the data format for inputs in order to allow the incorporation of information from dam operation schemes, from climate change scenarios and from other tools of water management outputs. This definition of information flow has been conditioned to the economical optimization of field work methods. This aspect was considered important to get a reliable sub-model and answer the main questions at an affordable cost (coherent with our budget).

IV. **Definition of the model conceptualization and structure.** The riparian vegetation sub-model and the whole model RIPFLOW is dynamic, because it is necessary to consider long-term changes of the driving parameters in the riparian system, as well as the changes in physical conditions, habitats and vegetation succession. In order to handle the complexities of the system, a vegetation model has been built by the use of sub-models. The most important components of riparian ecosystem models are: hydraulic and hydrological processes, which drive geomorphologic processes (sedimentation, erosion) and soil moisture (groundwater, soil conditions), feeding back on hydrology. All three act on riparian vegetation (interactions of plants, succession and disruption as well as disturbance of plant communities). Of course, these in turn shape processes in the hydrological and the geomorphologic system component, e.g. if vegetation growth changes roughness values that reduce flow velocity, leading to higher sedimentation rates which in turn change soil conditions and hence the soil-specific vegetation. The partners discussed about the basic structure, based on their experience in the application of hydrologic, hydraulic, physical habitat and riparian vegetation models. The basic structure for the dynamic riparian ecosystem model was set as shown in the following figure (Figure 3.1). The most important model input parameters are discharge, bed load and climatic data. Important model variables are topography, roughness, shear stress, soil moisture and growth velocity.

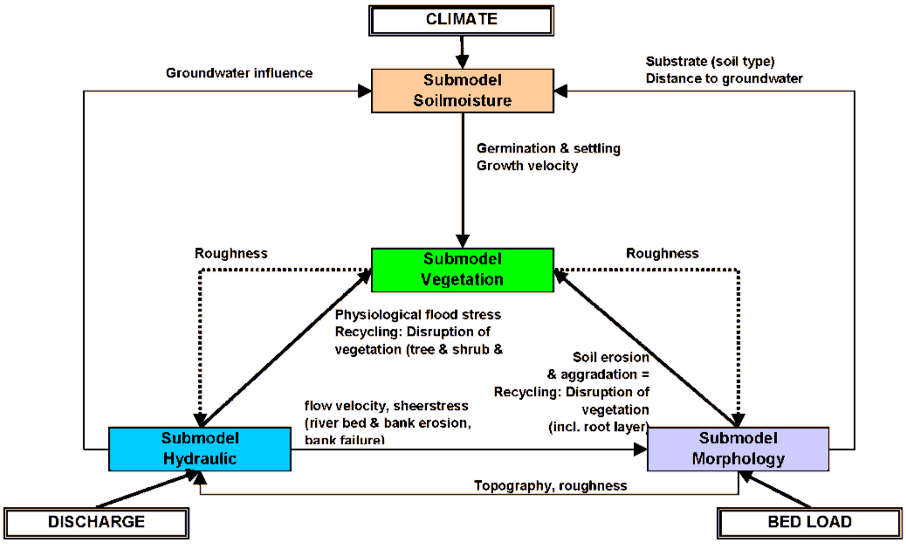


Figure 3.1. Basic structure for the dynamic riparian ecosystem model

V. **Programming of the model.** In the programming, the main works consisted in physical and ecological processes definition. It was necessary the development of the hydraulic, morphology and soil sub-models, which outputs were necessary inputs in the vegetation sub-model. The final outputs of RIPFLOW are both analytical and graphical results. A part of the graphical results are obtained in analyses developed in ArcGis 9.2®. (ArcMap model builder, application using Python and ArcScene for 3D visualization). The linkage between sub-models (soil, hydraulic, morphology and vegetation in ArcGis 9.2) work automatically, and the whole model is based on yearly step iterations. For each model iteration is generated a vegetation cover map (raster format). Maps can be then grouped to produce a 3D animation which displays the evolution of the system over the simulated years. Using the discharge data for each year, it was also possible to build an animated chart of the landscape along the years of study. Maps outputs can be also used to perform spatial analyses and give summary data for decision support.

3.2 Scenarios definition

Comparison of scenarios is one of the major tools that can help the decision makers. In this stage, the aim is both to describe the current status and to generate different scenarios (i.e. different “pictures” of future development). These scenarios serve as an input to the riparian vegetation model, representing both the nowadays situation and possible future conditions for natural and affected rivers. This part of the project comprised the following previous tasks:

I. **Review and description of the most relevant impacts.** There have been considered the most relevant impacts (e.g. canalisation, dam operation, land use, irrigation, ...) in the European rivers and more specifically in the countries of the three partners..

II. **Gathering climate information and climate change scenarios.** Defining representative climate change scenarios for the regions where the study sites will be located, in the three countries.

III. **Making a pre-selection of natural and altered study sites.** In the selection have been considered sites with different expectations about potential climate change impacts; in the pre-selection of altered study sites (with regulated flow regime) we considered different dam operation schemes.

IV. **Selection of natural sites for the biological data survey.** This selection has been based on the pre-selection (III) eco-region, river ecotypes and water bodies classified for the implementation of the WFD in each river basin. We selected sites in natural or nearly undisturbed conditions. Indexes of ecological status developed in each country have been considered, as well as the reference sites and hydrological reserves included in ecological studies and listed by the water administration in the WFD implementation documents.

V. **Selection of case studies with altered flow regime.** They have different dam operation schemes or water management objectives, in the 3 countries.

VI. **Hydrological flow regime.** The flow regime was analysed based on data from flow gauging stations. A special attention have been paid to the recurrence period and the hydraulic conditions associated with the floods, therefore flood risk maps and associated studies were important inputs in the study (i.e., Francés *et al*., 2001). The hydrological modelling was needed in order to asses properly the different flow regime scenarios due to hydrological changes, human intervention and/or climate change.

VII. **Selection and generation of specific scenarios for each study case.** Each partner based in the previous points generated two representative climate change scenarios, one pessimistic and one optimistic, one disturbed flow scenario (i.e. dam regulation, channelization), and one environmental flow scenario.

3.3 Field data survey and processing

The field data acquisition and processing is an indispensable task in this project. The partners experience in the methods and different tools applied in vegetation surveys, allowed the evaluation and selection of the most cost-effective techniques to reach the project goals. Finally the procurement of the field data included the following tasks:

I. **Hydraulic and biological survey in natural river sites.** In order to obtain hydraulic models in each natural site, hydrometry surveys took place in a segment of each site, and also the topography to have explicit data of the spatial distribution of the riparian plants. Basically, two types of surveys have been done:

i. *Hydrometry for hydraulic & habitat modelling (1Dim).* In each study site a number of transects have been located in order to make the surveys of hydrometry, habitats and vegetation patches. Transects were selected to represent the hydraulic and habitat diversity, as well as the longitudinal profile of the water surface along the study site. Surveys have been done with 2 or 3 different flow rates during the hydrologic year, so that we could calculate rating curves afterwards (water elevation-flow rate).

ii. *Characterizing habitat patches & vegetation.* In each of the natural study sites we made a survey with the “line intercept method” (FIREMON, 2003), along the transects mentioned before. In the transects have been identified and geo-referenced the most representative habitat patches and the vegetation present (trees, shrubs, forbs and herbs). There has been a core sampling in the trees and shrubs in order to get the age and calculate growth curves. The soil has been also sampled, in order to estimate the development of the soil, frequency of flow disturbances and depth of productive soil.

II. **Biological data processing in natural rivers.** The biological data have been analyzed in order to get the parameters and information necessary for the model calibration in natural sites. From the hydrometry data, we obtained the rating curves (water elevation-flow rate) in each transect, with the software RHYHABSIM (Jowett, 1989). The flow time series have been transformed into water elevation time series and the statistical analyses will be based on these data. Based on the series, we analyzed the relationships between each succession stage (in a certain habitat type) and the hydrological characteristics of the river reach. Habitat conditions were characterized in terms of flood frequency, erosion/sedimentation processes and elevation above water table. Vegetation was characterized in terms of elevation above water level and above river thalweg, mean and maximum age of trees, height, diameter (at the base and breast height), mean estimated density and coverage. From the data obtained in the field, it was calculated the percentage of presence for the riparian vegetation species, the representative succession series and the habitat conditions where each stage (phase) of the succession occurs. From the age data (trees and shrubs) were calculated the growth curves (age-diameter, age-diameter-height relationships) and the estimated number of years that each succession phase can last approximately in a region. This is essential information for the dynamic riparian vegetation sub-model within RIPFLOW.

III. **Hydraulic and biological survey in altered river sites.** In order to create and calibrate the hydraulic sub-model in the case studies with altered flow regime, hydrometry surveys took place in a segment of each site. The vegetation survey in these cases was design to balance the necessary accuracy for the model, the economy and the easy application of the methods, in order to make it easy to apply in any other European river. The representative habitats (defined in the data processing of natural sites) and the species present were recorded, in order to define the “present condition”.

3.4 Model implementation: Calibration

It has been necessary to calibrate the model in ecologically different river ecotypes and ecoregions, in order to cover a wide range of riparian ecological conditions in Europe. The case studies were located in Austria, Spain and Portugal.

The selection of the natural (or at least as much natural as possible) river site was required to infer the parameters values for the model. We considered the limitations in the application of the model to regulated rivers, having selected a natural reference site with comparable characteristics to the regulated one so the natural relationships occurring in the riparian ecosystem could be studied in the natural reference site and transferred to the regulated one.

The model calibration required the iteratively variations of the different sub-models parameters values. In order to evaluate the quality of the calibration results we compared two raster files, last year simulated vegetation and observed field vegetation. This comparison was developed by two useful tools, the confusion matrix and the coefficient of agreement, kappa (Cohen, 1960).

3.5 Model application to the scenarios analysis

Finally the model was used to simulate the climate change impact scenarios both in regulated and natural reference sites, as well as some disturbed flow scenarios and environmental flow scenarios. Once the scenarios were available and the model had been calibrated, it was applied to the case studies in the following steps:

I. **Model simulations in the case studies.** In the selected cases of the 3 countries, we simulated the long term effects on the riparian vegetation of different scenarios (i.e. dam operation rules, change of land use, recruitment of the riparian vegetation in Natura 2000 areas) combined with climate change scenarios.

II. **Analysis of riparian vegetation dynamics and evapotranspiration index evolution**. The partners give some examples about the kind of results that will be obtained from the RIPFLOW simulations (site-specific). The results were discussed and represented in such a way that its interpretation is accessible to water managers, even without an excessive knowledge about the internal operation of the model.

III. **Proposal of general water management recommendations.** The analysis of the previous results produced as expected a proposal of general water management recommendations and site-specific environmental flow regimes considerations. These considerations and recommendations are included in chapter 8 within the scenarios analysis results description.

4 RIPFLOW model

4.1 Introduction

The RIPFLOW model development requirements encompass the implementation of a software tool which incorporates the main key parameters and behaviour of riparian ecosystems. Such key factors had to include the essential riparian ecosystem driving forces and vegetation responses which are generally found in temperate climate. This requirement is particularly relevant in order to allow a wide applicability of the developed tool. Second requirement was tailored on the model outputs which had to be suitable to fulfil the need of scientific, policymakers and stakeholders audiences.

4.2 Development of RIPFLOW Model

Within this package the objective is the implementation of a floodplain model capable of simulate the distribution of floodplain vegetation in space and time. The model simulates the vegetation succession or retrogression in response of physical parameters. Herein, the model is quoted with the name of RIPFLOW. Beside the scientific value of the RIPFLOW, its application must find also practical use to tackle water management issues.

To comply with the objectives, the first step was to frame what is the problem domain to which the model should be applied and in second instance what are the main question to which the model results shall answer. The problem domain definition leads to a model concept which, has been then architected in its structure and specified in its execution flow and the input data standards.

4.2.1 Definition of Main Questions for Water Managers

The RIPFFLOW model can be used to answer the following questions:

- Planning and optimizing restoration measures on rivers: the measures should be suitable and ensure a long term effect of the ecological improvement. By using the model it can be simulated, how the vegetation will influence the further development of the restoration side.
- Forecasting the development of floodplain and riparian vegetation, especially in nature protected areas. From the model's result also further development of the conservation status of FFH-Habitats on rivers can be derived.

4.2.2 Definition of Model Conceptualization and Structure

The objective of this task was the formulation of a model concept able to fulfil the project objective. The model concept assumes that vegetation development depends by the functional relationship between hydrology, physical processes, climate, riparian ecosystems and vegetation communities. In the model conceptualization, physical processes are represented by height over mean water, shear stress and flood duration while the link to the climate is represented by the soil moisture. These factors allow the successful establishment and development of the vegetation or its retrogression to the initial stage. On these premises, the model concept has been divided in two main components (Figure 4.1). The first, static, component provides an initial landscape against which the second, dynamic, component simulates the vegetation succession or retrogression in space and time.

The dynamic component is further divided in modules, namely: recruitment, shear stress, flood duration and soil moisture.

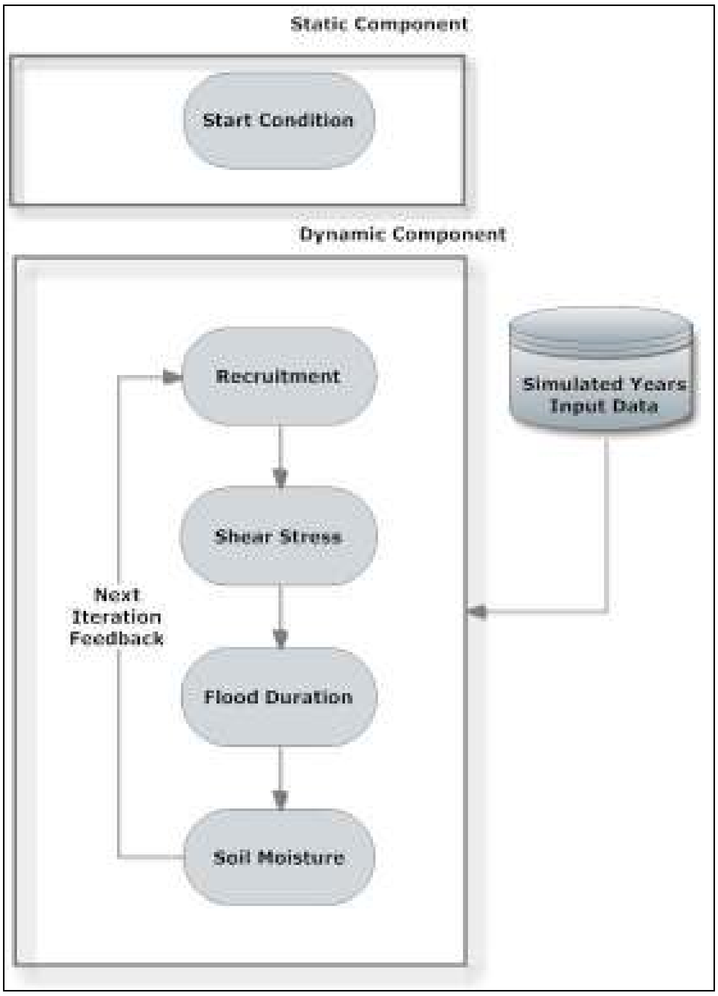


Figure 4.1. Model structure

The model concept is organized in two parts, the static, start condition component and the dynamic component. This latter is further sub divided in execution modules whose execution flow is depicted in

Figure 4.2. The dynamic part is addressed as dynamic because it takes different inputs for each simulated year and because the outputs of each model run is fed again to the model as input for the next iteration.

4.2.3 Definition of RIPFLOW Information Flow

The objective of this task is the definition of data standards and data passing procedures to harmonize the information flow within the dynamic component.

The main issue tackled within this task was due to the overall structure of the dynamic vegetation component which was intended to be partially implemented exploiting the ArcGis model builder (ESRI ™) geoprocessing framework and partially implemented as a Microsoft .Net 3.5 based stand alone application.

The first part simulates the floodplain vegetation recruitment and response to physical disturbances such shear stress and flood duration (light blue box in Figure 4.2). The second part of the model (light brown box in Figure 4.2) simulates the response of the floodplain vegetation to the variation of the soil moisture content.

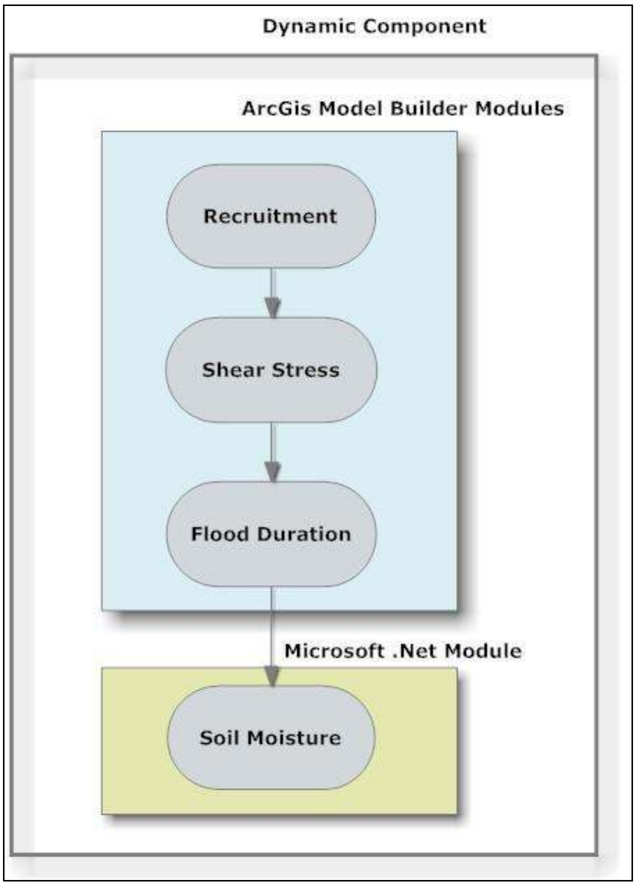


Figure 4.2. Dynamic component structure

The dynamic vegetation model for its calculation and storage of the results makes use of ESRI ™ raster grid inputs while the soil moisture model makes use of ESRI ™ ASCII files. These data formats, although supplied from the same vendor, are not fully compatible. In order tackle the discrepancy in the data structure it has been added to the overall model architecture a connector feature whose scope is the run time conversion of the ESRI grids in ASCII files and vice versa so that the data passing between the vegetation and the soil moisture model is enabled. The connector leverages the COM protocol to allow the communication between the vegetation and the soil moisture model.

4.2.4 Start Condition Component

Static start condition component (Figure 4.3) is static and predicts the different habitats based on height over mean water level (HOMW), topographic elevation as well as three different zones and assigns specific vegetation type for each habitat. Main purpose of this component is to predict potential natural vegetation (PNV) community and to use as starting conditions for dynamic floodplain component.

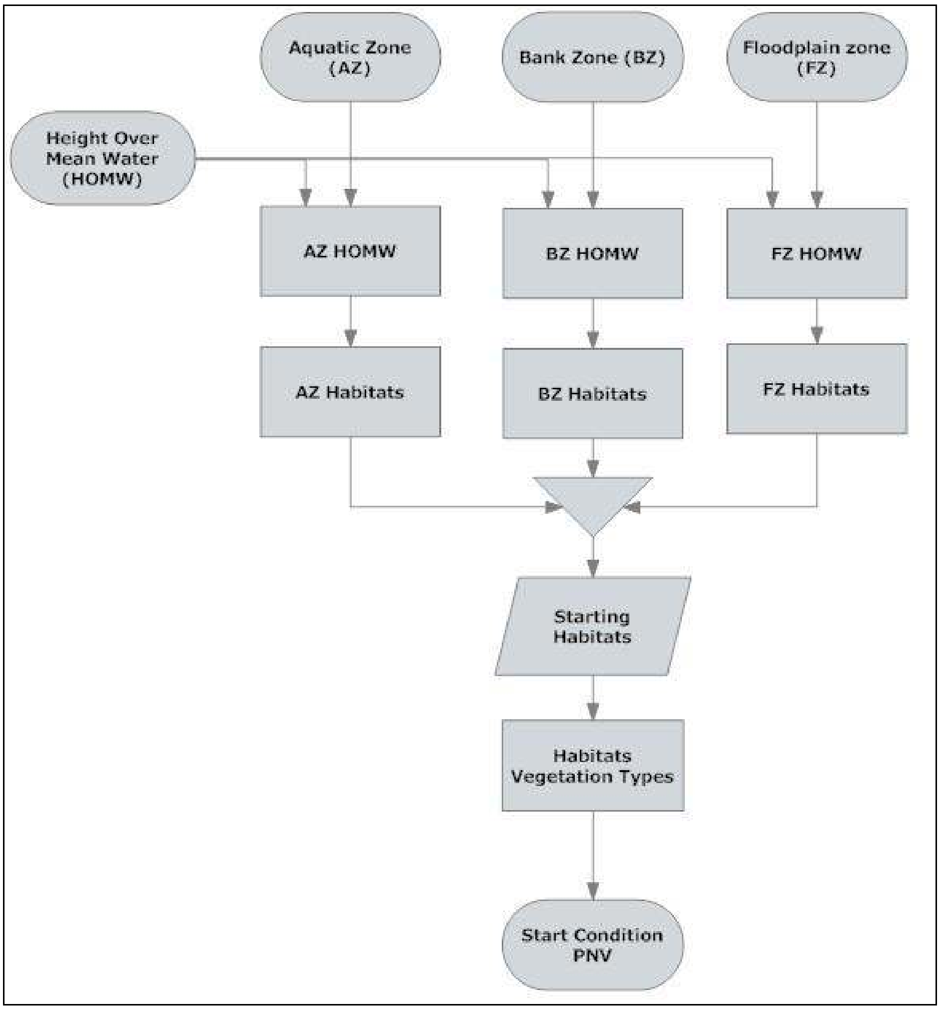


Figure 4.3. Start condition component concept

4.2.5 Dynamic Component

4.2.5.1 Recruitment Module

Recruitment module defines the potential recruitment area and possibility to occur scour disturbances based on influences of hydraulic and topographic factors. The sub-model performs according to "Recruitment box model" which defines the band above the river stage that facilitate successful establishment of riparian woodland seedlings. Initial phase is only an area where recruitment takes place and it follows succession towards pioneer phase after a year. Existing pioneer vegetation follow succession towards shrub phase of willow series or herb phase of reed series after reaching maximum age based on recruitment band (vertical) as well as different zones (horizontal). Woodland succession takes place only in the BZ and within a specific band above HBFL (e.g., 0.6 – 2.0 m). Below this band and within BZ pioneer is destroyed and turn into initial phase from scour disturbances. In another circumstance, if existing vegetations are older than age of pioneer, it will survive by scour disturbances since those communities assumed to be strong enough to resist the disturbances. Wetland community "Deep marsh" can process succession towards pioneer vegetation (e.g. HBFL>0.3) or vice versa if required condition is fulfiled (e.g. 0.3<HBFL).

Beside the hydraulic effects, recruitment sub-model considers changes in river topography. When topography changes areas of the bank zone can turn in aquatic zone and vice versa. The same principle applies to flood plain and bank zone or floodplain and aquatic zone.

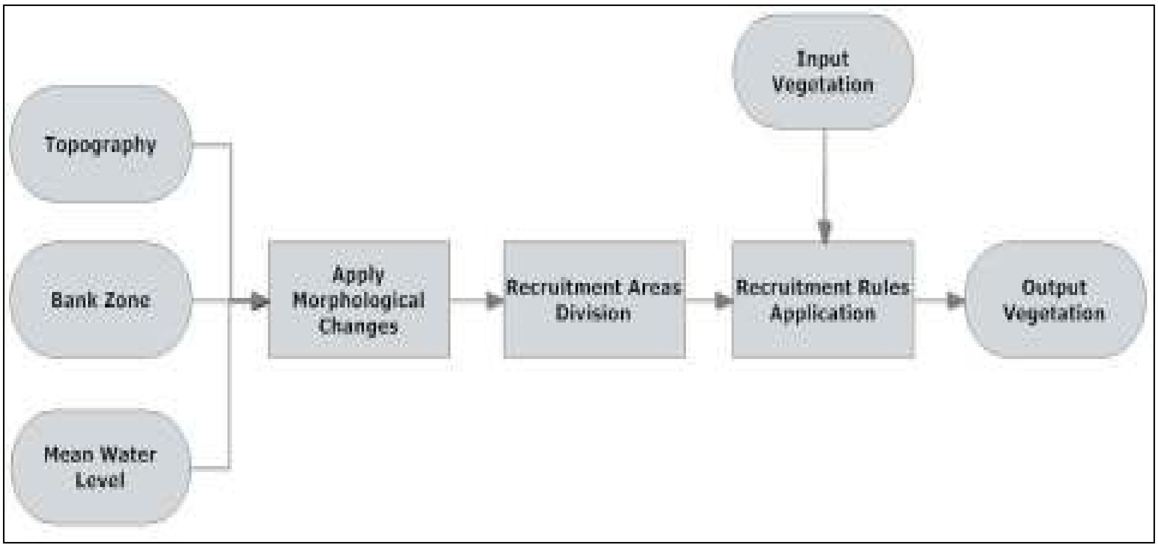


Figure 4.4. Recruitment module

4.2.5.2 Shear Stress Module

Shear stress is defined as force per unit area applied by water along the bottom surface. Critical shear stress can be used as an indicator of surface erosion. It is the maximum shear stress that can be applied at the surface without erosion or sediment transport and is a function of particle diameter.

A combination of local water depth and shear stress is one of the most important combinations of physical parameters that drives erosion and deposition of sediment on floodplains, and therefore, is responsible for floodplain geomorphic processes.

The module (
Figure 4.5) considers, if any existing vegetation is destroyed by shear stress, it will turn into initial phase. Likewise, wetland community turns back into deep marsh. Vegetation is destroyed when the shear stress at any location is higher than critical shear stress for any vegetation community. Critical value for shear stress for each vegetation community is different and assigned based on the vegetation age which is optimized again during calibration process.

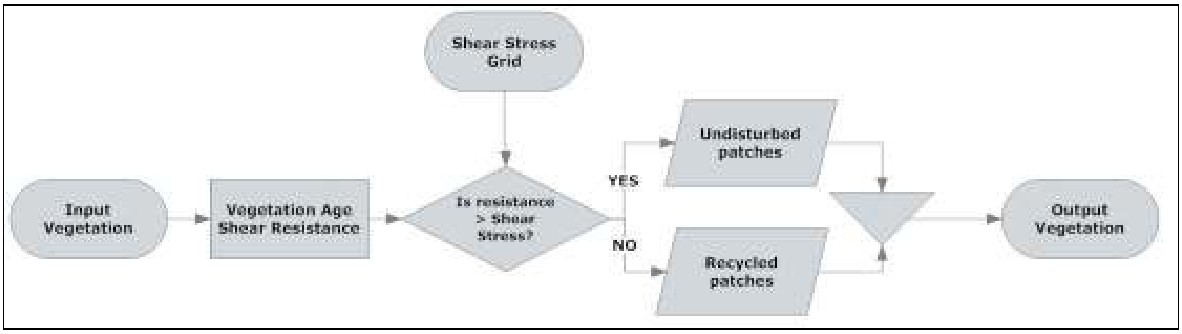


Figure 4.5 Shear stress module concept

4.2.5.3 Flood Duration Module

Flood duration is the amount of time a floodplain area is inundated during a season or a year. Flood duration kills vegetation by anaerobic effects. Anaerobic effects are probably most important in the environment where floodwater remains for a long time. Long flood duration (indicator for physiological stress) kills vegetation which is associated with oxygen depletion in the root zone. It is considered that the vegetation will go back to another community if duration of flood is longer than critical value. Intensity of disturbance of flood duration is classified into high, medium, and low classes depending on number of days flooded during vegetation period.

A new vegetation community after the retrogression by flood duration depends on intensity of disturbance and existing community. In order to survive, even the most flood-tolerant species need to be flood free for at least 55-60 percent of vegetation season. The model concept is depicted in Figure 4.6.

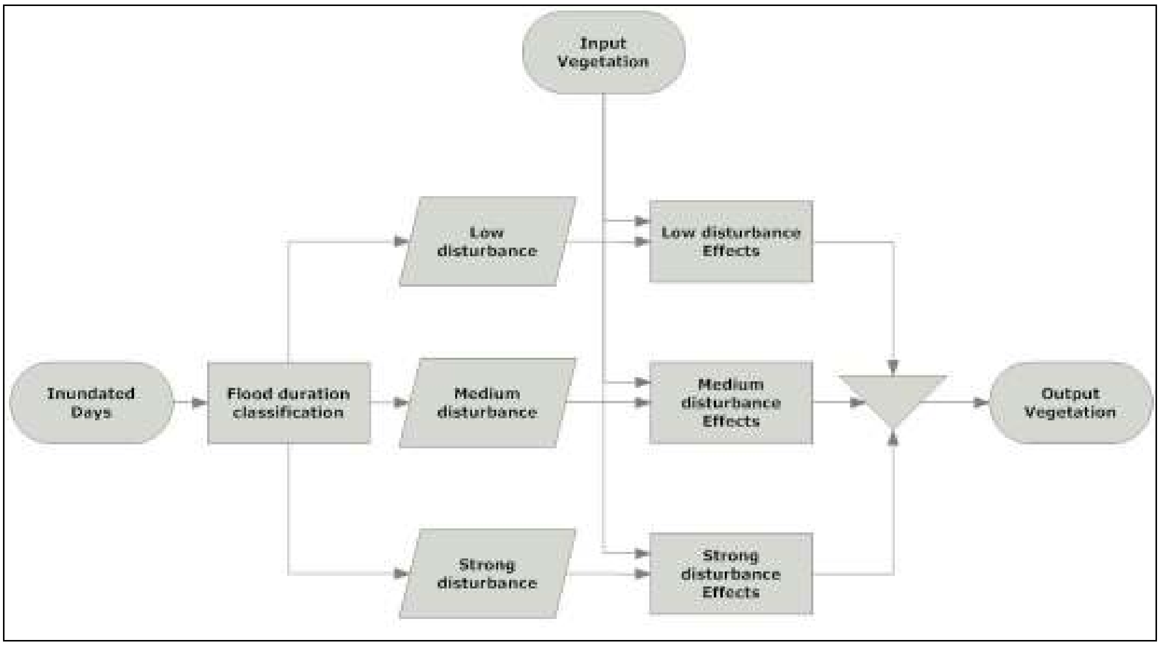


Figure 4.6 Flood duration module concept

4.3 Soil moisture sub-model

Soil moisture is a limiting factor for the vegetation growth and wealth. It depends on soil characteristics, topography, ground water level, precipitations and type of vegetation cover. The lack or scarcity of soil moisture in the soil can lead the vegetation to death or stress. Water abundance or scarcity in the soil is assessed through the use of the Evapotranspiration Index (ETidx) which is computed as the ratio between the Actual Evapotranspiration (ETR) and the Potential Evapotranspiration (ETP) of each vegetation type. The ETidx ranges between 0 and 1 (although the limits definition and internal calculations consider that ETidx ranges between 0 and 100). ETidx values close to 1 indicates a good or excellent moisture status in the soil, hence suitable conditions for the vegetation growth. On the other hand, ETidx values approaching 0, indicate a poor soil moisture condition, therefore unfavorable conditions for the vegetation development. Intermediate values are assumed to slow down the vegetation growth.

4.3.1 General Diagram

In this model the studied portion of the soil is represented as a tank filled with a porous material. The tank contains water that in our model represents the “Soil Moisture (H)”. The quantity of the soil moisture is measured by its elevation in millimeters, because only the vertical dimension is taken into account. The vertical moisture has a daily variation, so the model will calculate this moisture for all the daily intervals of the simulation. In the following figure (Figure 4.8) the flows and processes simulated by the model are shown:

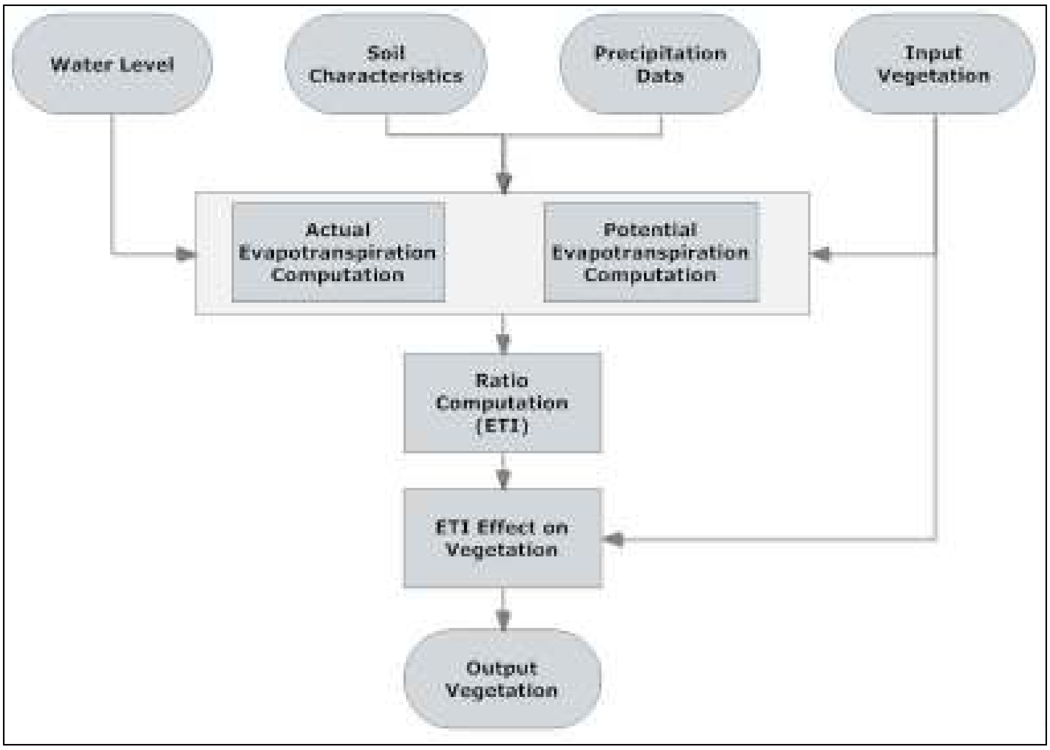


Figure 4.7 Soil moisture module concept

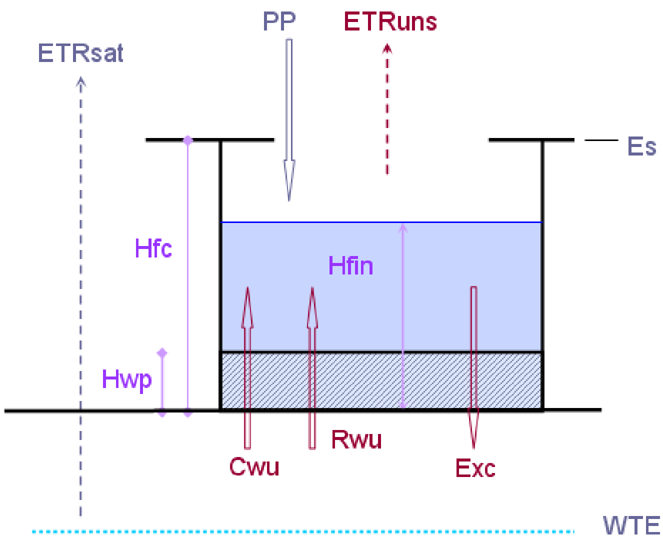


Figure 4.8. Conceptual diagram of the RibAV model which corresponds to the soil moisture sub-model (Where: *ETRsat* and *ETRuns* are the actual evapotranspiration from the saturated zone and the unsaturated zone respectively, *PP* is the daily precipitation, *WTE* is the water table elevation, *ES* is the soil surface elevation, *Hfc* is the field capacity equivalent water, *Hwp* is the permanent wilting point equivalent water, *Hfin* is the end of the day soil moisture, Cwu, is the capillary water rise, *RWU* is the root water rise and the *Exc* is the excess water .

4.3.2 Vertical limits of the conceptual tank

The vertical limits of the conceptual tank are defined by the following water quantities, which are measured in millimeters.

- **Hfc:** Field capacity equivalent water. It is the maximum quantity of water that the soil can retain without damaging the plants due to anaerobiosis.
- **Hwp:** Permanent wilting point equivalent water. It is the quantity of moisture in the soil for which the plants cannot extract more water and they lose their turgor.
- **Hfin:** End of the day soil moisture. It is the quantity of water that the tank has when it ends each daily simulation interval.

4.3.3 Relevant Elevation Values

The model takes into account the following elevations (or absolute depths), which are measured in meters above sea level:

- **Wte:** Water Table Elevation. It is the elevation at which the limit between the unsaturated and saturated parts of the soil is located for a given day.
- **Czr:** Root Depth Elevation. It is the maximum elevation at which the roots can extract water from the water table.
- **Cze:** Effective Root Depth Elevation. It is the maximum elevation in which the roots can extract water and evapotranspirate from the unsaturated part of the soil.
- **Czsat:** Extinction for Saturation Root Depth Elevation. It is the maximum elevation in which the roots can tolerate saturated soil without being damaged due to root asphyxia. In some cases this level may be higher than the soil surface elevation.
- **Es:** Soil Surface Elevation. It is obtained from a Digital Elevation Model, and represents the elevation where the separation between the aerial and subterranean parts of the plant is located.

4.3.4 Modelling of the Flows

The input and output model flow and processes are measured in millimeters and are the following:

- **PP:** Daily Precipitation. It is the daily precipitation measured and weighted from the meteorological stations, which are in the study sites' surroundings.
- **Rwu:** Root Water Rise. It is the vertical nocturnal transference of water from the more moist to the more dry parts of the soil, produced by the plant's roots. The equation is obtained by the REMM models (Ryel *et al.*, 2002).
- **Cwu:** Capillary Water Rise. It is produced by the capillary force that is exerted by the soil pores to the water molecules. This capillary attraction is caused by the surface tension from the liquids that are representative in the small diameter ducts. This process is described by the Richards(1931) equation.
- **Exc:** Excess Water. The excess water is the main output flow from the tank and represents the water that is lost by runoff or by percolation, due to the tank's limited storing capacity.

4.3.5 Modelling of the Evapotranspiration Processes

The evapotranspiration (ET) is the process from the water cycle, in which the liquid water is returned to the atmosphere in the water-vapor state. The following model's variables are related to the ET process:

- **ETP:** Daily Potential Evapotranspiration. The ETP is only influenced by the meteorological conditions and points to the maximum water quantity that a plant can evapotranspirate, assuming optimal conditions.
- **ETRtot:** Actual Total Evapotranspiration. It is the water that a plant uses in some certain environmental conditions and for a certain physiological state.
- **ETRuns:** Actual Evapotranspiration from the Unsaturated Zone. It is the ET that takes place in the soil's portion that is above the water table, being its pores unsaturated at that moment.
- **ETRsat:** Actual Evapotranspiration from the Saturated Zone. It is the ET that takes place in the soil's portion that is beneath the water table, being its pores saturated with water at that moment.
- **ETindex:** Evapotranspiration index: After each yearly period all the ETRtot daily values are summed. The daily ETP values are also summed for each yearly period. The ETindex is then obtained from the quotient between the yearly ETRtot and the yearly ETP. The resultant yearly ETindex has values between 0 and 1. The higher the values (and closer to 1), the less vegetation is affected by the water stress.

4.4 Programming Of The Model

Within this task, the objective was to put in place the concepts and structures defined in the tasks 4.2 and 4.3. Due to the distributed nature of the project team, the model coding has been carried with the aid on-line development tools which allowed the effective communication and code exchange between the model developers.

The vegetation model coding has been implemented exploiting the ESRI™ geoprocessing framework enhanced with the development of custom components coded with Python 2.4 scripting language. The soil moisture model has been instead implemented using the Microsoft Visual Basic .Net programming language. The coupling of the two model components has been made possible by leveraging the COM protocol. A technology that allows the communication among software based on strictly defied data structures, functions and interfaces. In order to allow the use of the soil moisture model from the ESRI™ platform, in the soil moisture source code it has been implemented a COM interface which exposed the functionalities of the soil moisture model. The interface implementation is callable within Python scripts which supplies the data required by the soil moisture model and collects its outputs.

The vegetation and soil moisture model coupling has been successfully implemented, however, the solution presents several limitations to the overall model usability. To overcome such constraints, it has been put under development a new version of the vegetation model, coded in C# programming language and far more compatible with the current implementation of the soil moisture model. The C# version is currently under testing and its release is expected within a short time but due to time constraints will not be applied to this project.

5 Scenarios

5.1 Introduction

In Europe the most relevant impacts to the riparian ecosystems are directly bound to dam operations, river stabilization and exploitation of the river resources. Herein is reported a list with the major impacts for the Austrian-Alpine region:

- Channelization (Bank protection)
- Cut off of sidearm
- Dams for bed consolidation
- Water extraction
- Dams for impoundment
- Beat out of the riverbed
- Taper of spatial water extension
- Reservoir (upstream)
- Uprooting of floodplain forests
- Bed consolidation
- Levee in the floodplain zone
- Hydropeaking
- Impoundment
- Flushing
- Excavation
- Extraction of ground water
- Deforestation of riparian woods

In the Mediterranean region, water is a scarce resource and there is a high water demand for agricultural and urban purposes. The balance between available water resources and demand is very tight. In Spain, to meet this demand, the obtaining of about half of the available resources come from groundwater reservoirs while the other half depends considerably on the regulation of surface water resources. The traditional agricultural land uses, with huge demand, have an important role in the management of the water resources. In recent years, urban uses and hydropower have been gaining importance too. These variations in water supplies, the increasing water demand for human uses and considering the characteristic scarcity of resources, makes indispensable to take into account several regulation scenarios, in order to find out the potential affections over the riparian zones before managing these areas (conservation and restoration plans, determination of affected areas, etc.). The Water Framework Directive justifies this necessity, establishing that one of the objectives must be to improve the aquatic ecosystems.

Actually not only the water regulation can affect the riparian ecosystems. Other important threats are the effects of climate change. The Intergovernmental Panel on Climate Change (IPCC) has recently pointed out that, although previsions have still high uncertainty associated, the Mediterranean is one of the most susceptible regions to potential climate change impacts (IPCC, 2007). This fact implies that the design and management of water systems should consider different scenarios, instead of using the records obtained in the past hydrological conditions, to mitigate the possible effects of climate change.

In this context, the RIPFLOW project team decided to consider three scenarios for each selected location. One representative regulation scenario of each area within each country, and two climatic change scenarios taking into account the two most realistic possible futures in an optimistic and a pessimistic ways.

In order to simulate the impacts of climate change on the floodplain vegetation, within the team it has been agreed the selection of three feasible climate change scenarios, namely: no change, pessimistic and optimistic. Each team member selected the climate model and the climate model scenario with the best performance in the country of origin.

Austrian Climate Change Scenarios:

- No changes: historic reference period between 1960 and 1990
- Optimistic: model GCM ECHAM5, scenario SRES A1B, time reference: 2070-2100
- Pessimistic: model GCM ECHAM5, scenario SRES A2, time reference: 2070-2100

Portuguese Climate Change Scenarios:

- No Change: historic reference period between 1960 and 1990
- Optimistic: model HadCM3, scenario SRES B2, time reference 2070-2100
- Pessimistic: model HadCM3, scenario SRES A2, time reference 2070-2100

Spanish Climate Change Scenarios:

- No changes: historic reference period between 1960 and 1990
- Optimistic: model HadCM3-PROMES, scenario SRES B2, time reference 2070-2100
- Pessimistic: model HadCM3-PROMES, scenario SRES A2, time reference 2070-2100

In order to allow a certain degree of comparability among the results of each project partner, the climate model scenarios reference period is the same for all partners.

5.2 Spain

5.2.1 Spanish Natural Reference Study Site

The selected study site for the Spanish case is located in the Jucar River Basin District (Figure 5.1), with a characteristic semi-arid environment. This River Basin District has a tight balance between an important scarcity of available water resources and a high water demand. The natural reference reach is called Terde, along the Mijares River, which is free from regulation and channelization.

The reach length is 539 meters. It is located in the Teruel province, between the two villages Sarrión and Mora de Rubielos. The soil granulometry is coarse. The riparian area can be considered continuous and connected with the terrestrial forest areas. The main riparian woody species are *Salix eleagnos*, *Salix purpurea* and *Populus nigra*.

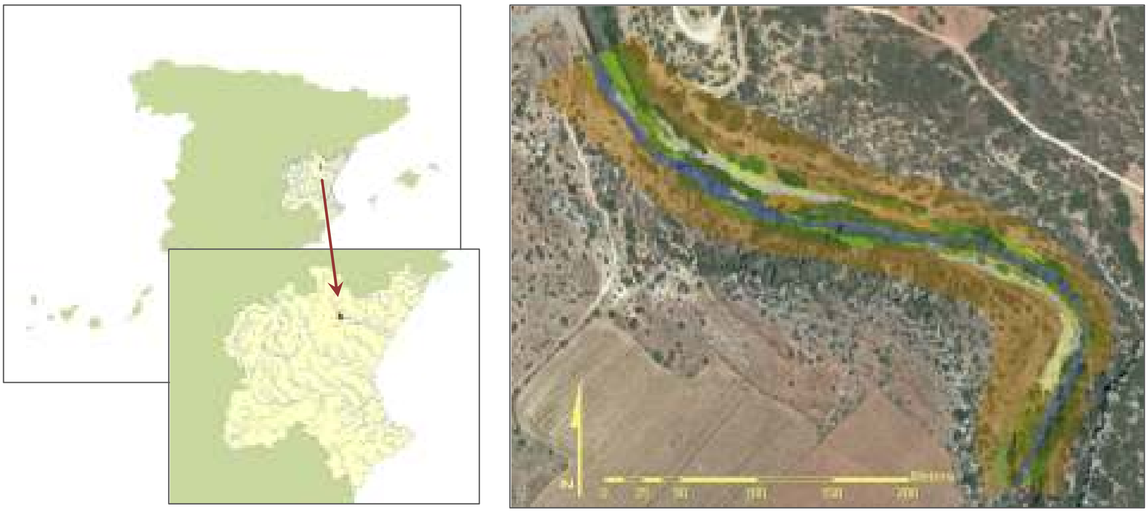


Figure 5.1. Spanish natural reference site, Terde reach in the Mijares River.

5.2.2 Spanish flow regulation scenario

The preparation of the flow regulation scenario selected for Spanish case took as reference the Arenós dam regulation between 1988 and 2006 (available data within the calibrated period). The Arenós reservoir, with a maximum capacity of 130 Hm^3, is located in the Mijares River downstream of the Terde reach, between two villages Montanejos and La Puebla de Arenoso in Castellón, Spain (Figure 5.2). The dam construction occurred between 1970 and 1977 in order to supply the agricultural demands from almost 30.000 Ha of productive arable land in La Plana de Castellón.

The definition of the regulation scenario considered the following expression:

$$ST_{ij} = SA_{ij} \cdot \frac{ET_j}{EA_j} \qquad (1.)$$

Where:

STij, is the regulated flow in Terde (day i, year j)
SAij, is the regulated flow in Arenós (day i, year j)
ETj, is the global contribution in Terde (year j)
EAj, is the global contribution in Arenós (year j)

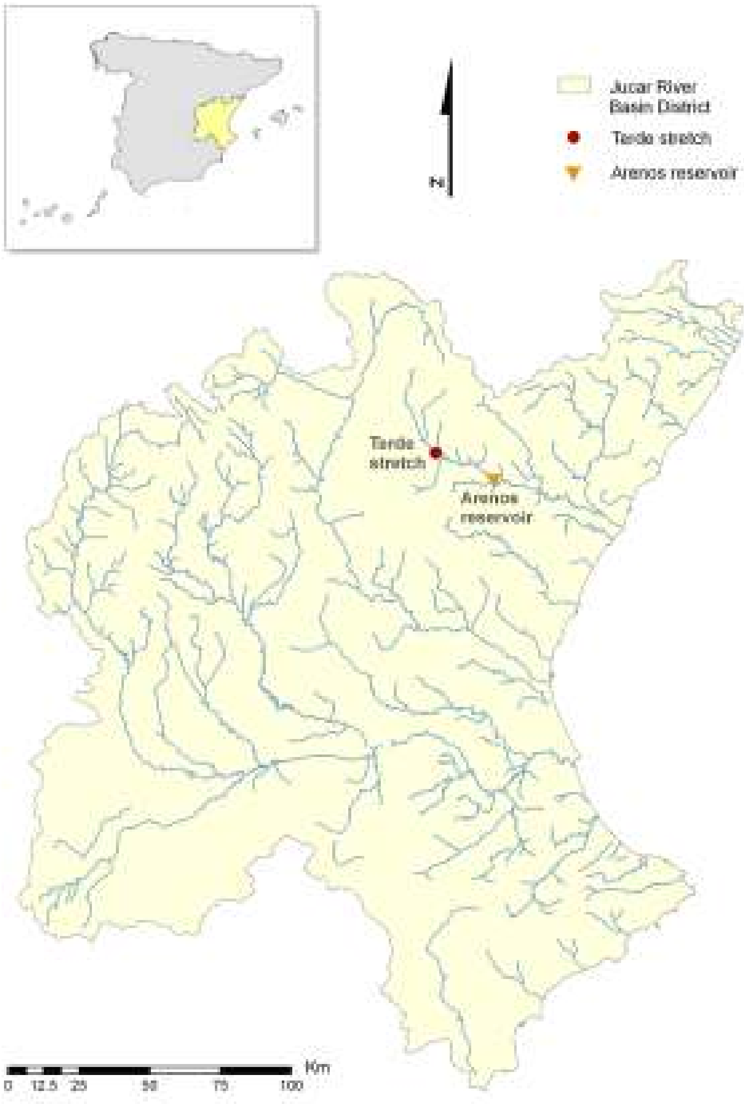


Figure 5.2. Situation map of Terde reach and Arenós reservoir, in the Mijares River within the Jucar River Basin District, Spain.

The establishment of the regulated daily flow in Terde considered the regulated daily flow in Arenós and the ratio between the global contribution in Terde and the global contribution in Arenós (inflow to the reservoir) for each j year (Table 5.1).

Table 5.1. Global inflow contribution to the theoretical Terde reservoir (ETj), the Arenós reservoir (EAj), and the ratio between them, for each j year.

Global contribution (year j)			
Hydrologic year (oct – sep)	Etj (Hm^3)	Eaj (Hm^3)	ETj / EAj
1987-1988	64.473	203.668	0.317
1988-1989	32.524	230.559	0.141
1989-1990	36.794	306.148	0.120
1990-1991	38.585	197.126	0.196
1991-1992	18.619	174.097	0.107
1992-1993	12.114	153.969	0.079
1993-1994	5.139	132.025	0.039
1994-1995	10.257	96.496	0.106
1995-1996	13.657	83.258	0.164
1996-1997	25.223	139.164	0.181
1997-1998	15.678	143.663	0.109
1998-1999	11.330	112.717	0.101
1999-2000	10.370	95.516	0.109
2000-2001	15.940	94.083	0.169
2001-2002	12.707	84.149	0.151
2002-2003	24.972	196.852	0.127
2003-2004	22.421	190.629	0.118
2004-2005	8.905	148.449	0.060
2005-2006	11.024	121.878	0.090
2006-2007	13.491	90.028	0.150

The theoretical flow regulation in Terde reach implies a considerable variation of flow regime compared with the historical natural flow data.

Although taking into account hydrologic year values of global contributions and ratio between them was considered the better option, the RIPFLOW model requires a natural year time step and the RibAV model (soil moisture sub-model) needs a daily temporal scale. That is why the final calculations for runoff data were done considering the correspondent hydrologic year values for each day of the theoretical series in the daily scale and then we did an aggregation for natural years obtaining the mean flow values for each year.

Each year in the regulation scenario was classified by different categories of year type (Table 5.2). Several limits calculated previously for the natural regime were established to make the decision of which type would represent better each year hydrologic characteristics. Therefore, those years with an average daily flow below the 10 percentile were considered as very dry years, those between the 10 percentile and the first quartile as dry years, between the first quartile and the third one as medium years, those with an average daily flow between the third quartile and the 90 percentile as dry years and finally those over the 90 percentile as very dry years.

Table 5.2. Hydrologic representative statistics and year types for the comparison of the historic unregulated regime and the theoretical regulated regime in Terde reach.

	Unregulated flow			Theoretical regulated flow		
Year	Average Flow (m^3/s)	Variation coefficient	Year type	Average Flow (m^3/s)	Variation coefficient	Year type
1988	2.071	1.62	Very wet	2.043	1.21	Very wet
1989	1.135	1.08	Wet	1.123	0.53	Wet
1990	1.097	0.74	Wet	1.103	0.56	Wet
1991	1.058	0.83	Wet	1.079	0.46	Wet
1992	0.504	0.48	Medium	0.530	0.28	Medium
1993	0.354	0.42	Very dry	0.305	1.05	Very dry
1994	0.241	0.92	Very dry	0.156	0.71	Very dry
1995	0.238	0.74	Very dry	0.390	0.44	Very dry
1996	0.474	1.00	Dry	0.483	0.96	Dry
1997	0.841	0.97	Medium	0.751	0.65	Medium
1998	0.420	0.72	Dry	0.504	0.61	Medium
1999	0.388	2.50	Very dry	0.342	0.60	Very dry
2000	0.445	2.59	Dry	0.338	0.58	Very dry
2001	0.370	0.66	Very dry	0.437	0.90	Dry
2002	0.431	1.02	Dry	0.497	0.60	Dry
2003	0.848	0.92	Medium	0.825	0.67	Medium
2004	0.665	0.68	Medium	0.635	0.62	Medium
2005	0.247	0.39	Very dry	0.267	0.44	Very dry
2006	0.328	2.68	Very dry	0.326	0.67	Very dry

While in natural regime the global average daily flow was 0.623 m^3/s (CV = 1.63), the regulated regime increased slightly this value to 0.630 m^3/s (CV = 1.19). Moreover, in Mediterranean natural environments, hydrology has a very strong seasonal component characterized by low flows during summer season and possible extreme flows in autumn (Figure 5.3). That is why the monthly averaged values would be more representative to analyze the effect of regulation over the stream.

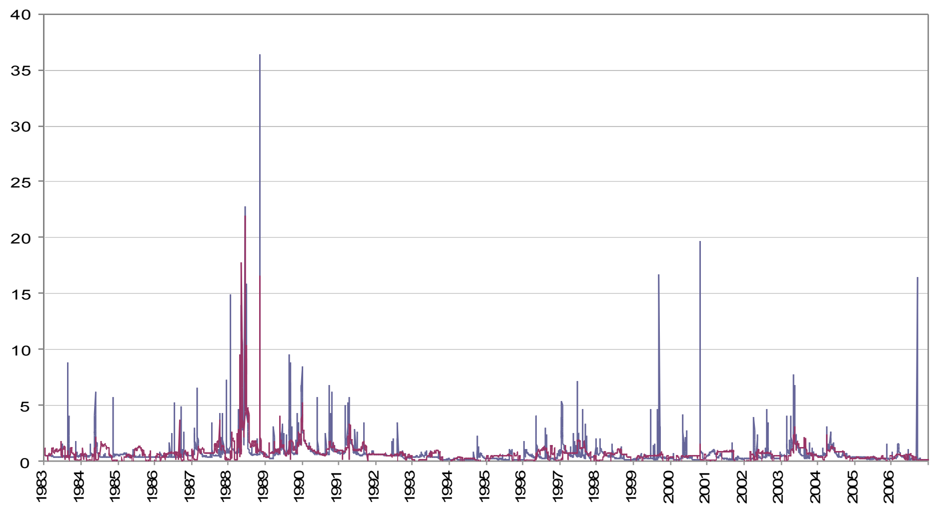


Figure 5.3. Unregulated historical flow series in Terde (blue) and regulated flow proposed scenario (red) for this reach.

Although the model considers yearly steps, it takes into account this seasonal effect through the evapotranspiration sub-model. This sub-model, analyzes the daily evapotranspiration index, which is directly affected by the daily flow regime (Figure 5.4, Figure 5.5).

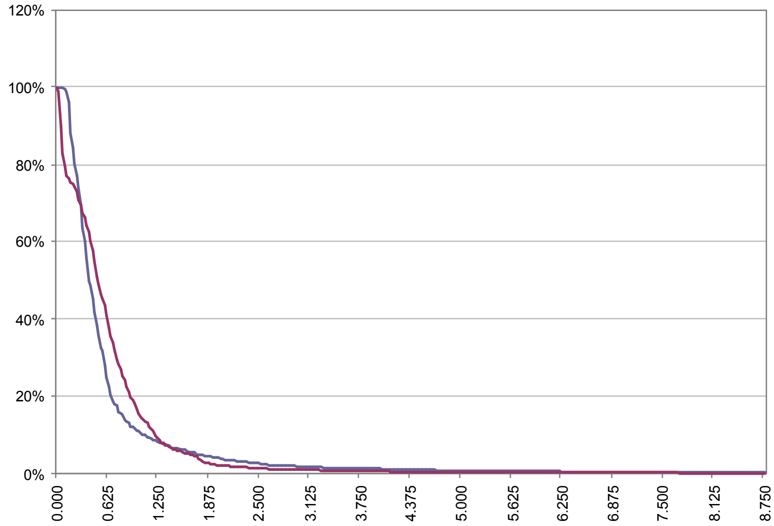


Figure 5.4. Flow exceedance curves (%) for unregulated historical flow series in Terde (blue) and Regulated flow scenario (red) in m^3/s.

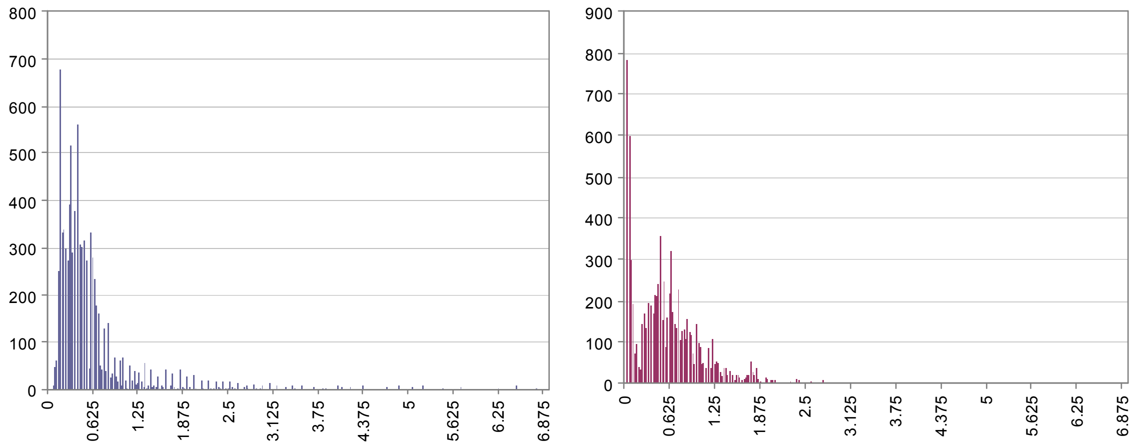


Figure 5.5. Frequencies in number of days for unregulated historical flow series in Terde (blue) and theoretical regulated flow scenario (red) in m^3/s.

In addition, the flow regulation by a theoretical dam reduces considerably the yearly peak flow, which affects directly the shear stress suffered by the riparian vegetation of the reach. To include this effect we decided to analyze the maximum flow for each type of year and change the associated shear stress reference input according to the new situation (Table 5.3).

Table 5.3. Maximum flows for each year and the associated shear stress flow, in the unregulated historical data series and in the theoretical regulated flow scenario.

	Unregulated flow		Theoretical regulated flow	
Year	Maximum Flow (m^3/s)	Shear stress ref. flow (m^3/s)	Maximum Flow (m^3/s)	Shear stress ref. flow (m^3/s)
1988	36.4	40	21.97	20
1989	9.5	10	4.03	5
1990	6.8	10	5.29	5
1991	5.7	5	3.29	5
1992	3.5	5	0.87	1
1993	1.0	1	0.91	1
1994	2.3	2.5	0.41	0.5
1995	1.1	1	0.81	1
1996	4.1	5	1.38	1
1997	7.1	10	1.86	2.5
1998	2.0	2.5	1.07	1
1999	16.7	20	0.88	1
2000	19.7	20	1.51	1
2001	1.6	1	0.99	1
2002	4.7	5	1.09	1
2003	7.8	10	3.08	2.5
2004	3.2	2.5	2.36	2.5
2005	1.6	1	0.48	0.5
2006	16.5	20	0.66	0.5

All these considerations seem to be enough to anticipate a result of simulated succession phases of riparian series enough different from the unregulated scenario. If this becomes true, the model will demonstrate to be useful in other situations of regulation effects over riparian vegetation needed analysis.

5.2.3 Spanish minimum environmental flow scenario

The environmental flow scenario was created with data provided by the Jucar River Basin authority and the hydrological data produced in this project for the scenario of “no change”. The starting point was the minimum environmental flow; this value was proposed by the water administration of the Jucar River Basin, based on studies of physical habitat simulation (financed by MARM, 2010). The minimum environmental flow met the requirement of the legal norm for hydrological planning of the Spanish Government; this norm tells that the minimum value must be within the range of flows corresponding to the 50 and 80% of the maximum Weighted Usable Area (WUA, in Spain named as HPU) that can be calculated by the physical habitat simulation system (Bovee *et al.,* 1998). This study funded by the Spanish Government was done in a reach downstream our study site, near the town of Olba, with coordinates UTM (30N): X=698711.836, Y=4444432.041. The target species were the same in the site of Mijares-Terde, the Iberian chub (*Squalius pyrenaicus*), brown trout (*Salmo trutta fario*) and Mediterranean barbel (*Barbus guiranois*); their habitat suitability curves (at microhabitat scale) were generated in specific studies for the Jucar and Tagus River basins (Martínez-Capel *et al.,* 2007; Martínez-Capel *et al.,* 2009) financed by the Jucar River Basin authority (belonging to the MARM, Ministry with the responsibilities of Environment).

Given that the watershed area in the cited study is larger than in Mijares-Terde, the minimum environmental flow in Olba (0.4 m^3/s), was corrected in direct proportion to the watershed area. Given this minimum flow in Mijares-Terde (0.203 m^3/s), correspondent to the month of minimum monthly average (September), the environmental flow in every other month should follow a pattern of variability similar to the natural flow regime. For this reason, the environmental flow for each month (except September, minimum) was calculated as the product of the minimum and a variability factor.

$$Q_{eco} = Q_{\min} \cdot VF_i \qquad (2.)$$

This variability factor (VF_i) was calculated from the natural flow regime (monthly data), as the squared root of the ratio of each monthly average to the minimum monthly average flow.

$$VF_i = \sqrt{\frac{Q_i}{Q_{\min}}} \qquad (3.)$$

Were:
Qi is the average natural monthly flow (m^3/s)
Qmin is 0.203 m^3/s

The natural flow regime and the environmental flow regime are indicated in the figure below (Figure 5.6).

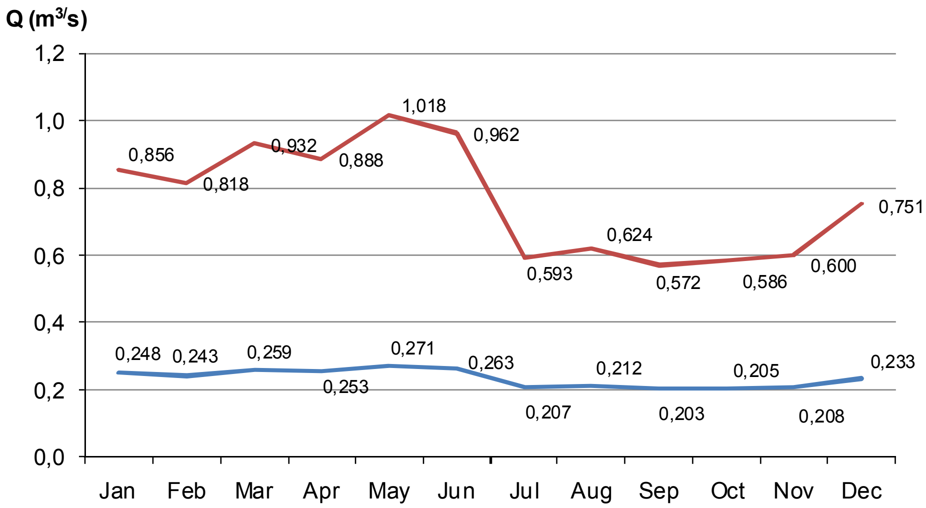


Figure 5.6. Comparison of the environmental (blue) and natural flow regime (red) for a normal year in the Mijares-Terde.

It had been considered that if the natural daily flow is lower than Qeco then the natural daily flow is considered as the flow which goes through the reach. On the contrary, if the natural daily flow is higher than Qeco then Qeco is kept considering that the excess is totally consumed by hypothetical demands.

Taking into account all that considerations the inputs definition for this scenario was set as described below (Table 5.4,

Table 5.5).

Table 5.4. Minimum ecological flows for each year in Terde reach (Mijares River, Spain) for the 1988 – 2009 time period and year type definition for this scenario.

	Natural flow			Minimum ecological flow		
Year	Average Flow (m^3/s)	Variation coefficient	Year type	Average Flow (m^3/s)	Variation coefficient	Year type
1988	2.071	1.62	Very wet	0.234	0.10	Very dry
1989	1.135	1.08	Wet	0.234	0.10	Very dry
1990	1.097	0.74	Wet	0.234	0.10	Very dry
1991	1.058	0.83	Wet	0.234	0.10	Very dry
1992	0.504	0.48	Medium	0.234	0.10	Very dry
1993	0.354	0.42	Very dry	0.222	0.17	Very dry
1994	0.241	0.92	Very dry	0.168	0.25	Very dry
1995	0.238	0.74	Very dry	0.183	0.22	Very dry
1996	0.474	1.00	Dry	0.229	0.13	Very dry
1997	0.841	0.97	Medium	0.234	0.10	Very dry
1998	0.420	0.72	Dry	0.222	0.17	Very dry
1999	0.388	2.50	Very dry	0.214	0.15	Very dry
2000	0.445	2.59	Dry	0.205	0.22	Very dry
2001	0.370	0.66	Very dry	0.218	0.17	Very dry
2002	0.431	1.02	Dry	0.225	0.11	Very dry
2003	0.848	0.92	Medium	0.234	0.10	Very dry
2004	0.665	0.68	Medium	0.234	0.10	Very dry
2005	0.247	0.39	Very dry	0.213	0.13	Very dry
2006	0.328	2.68	Very dry	0.190	0.31	Very dry
2007	0.440	1.34	Dry	0.199	0.22	Very dry
2008	0.505	0.91	Medium	0.224	0.11	Very dry
2009	0.597	2.21	Medium	0.233	0.11	Very dry

Table 5.5. Maximum flows and associated shear stress reference flows for each year of the minimum ecological flow scenario in Terde reach (Mijares River, Spain), 1988 – 2009 time period.

	Natural flow		Minimum ecological flow	
Year	Maximum Flow (m^3/s)	Shear stress ref. flow (m^3/s)	Maximum Flow (m^3/s)	Shear stress ref. flow (m^3/s)
1988	36.4	40	0.27	0.2
1989	9.5	10	0.27	0.2
1990	6.8	10	0.27	0.2
1991	5.7	5	0.27	0.2
1992	3.5	5	0.27	0.2
1993	1.0	1	0.27	0.2
1994	2.3	2.5	0.23	0.2
1995	1.1	1	0.26	0.2
1996	4.1	5	0.27	0.2
1997	7.1	10	0.27	0.2
1998	2.0	2.5	0.27	0.2
1999	16.7	20	0.27	0.2
2000	19.7	20	0.27	0.2
2001	1.6	1	0.27	0.2
2002	4.7	5	0.27	0.2
2003	7.8	10	0.27	0.2
2004	3.2	2.5	0.27	0.2
2005	1.6	1	0.26	0.2
2006	16.5	20	0.27	0.2

2007	3.8	5	0.27	0.2
2008	3.6	5	0.27	0.2
2009	24.6	20	0.27	0.2

5.2.4 Spanish climate change scenarios

The selection of the climate change scenarios satisfied the previous requirements established for all partners. The selected emission scenarios, defined by the Intergovernmental Panel on Climate Change, were SRES A2 as the pessimistic one and SRES B2 as the optimistic one, both for the same 2070-2100 period (IPCC, 2007). The analysis of those scenarios required the comparison with the reference period results (1960-1990).

As decided, the climate change model was selected taking into account which one provided the best results for each country. In Spanish case of study, it was the Hadley Centre Global Climate Model (HadCM3) from the United Kingdom as boundary conditions, regionalized with the PROMES regional climate model from Spain (MOMAC, 1993) with 50 Km resolution.

In the climate change process some climate characteristics, as precipitation and temperature, varies over time allowing the systematization through the monthly statistics. This makes possible to adapt historical data to the new climate conditions for each period, provided the monthly statistics (constant and independent on time). Thus, for the adjustment of series with the scenarios characteristics, we modified the reference period data in order to obtain coincident statistics with each scenario. By a spatial interpolation, we obtained the local scenarios statistics for the reach. Then we increased additively the temperature series (max, min, average) from the reference period for each scenario. With these new series we obtained the potential evapotranspiration scenarios (Figure 5.7) using the Hargreaves method described in the FAO Irrigation and drainage paper 56 (Allen *et al.,* 1998).

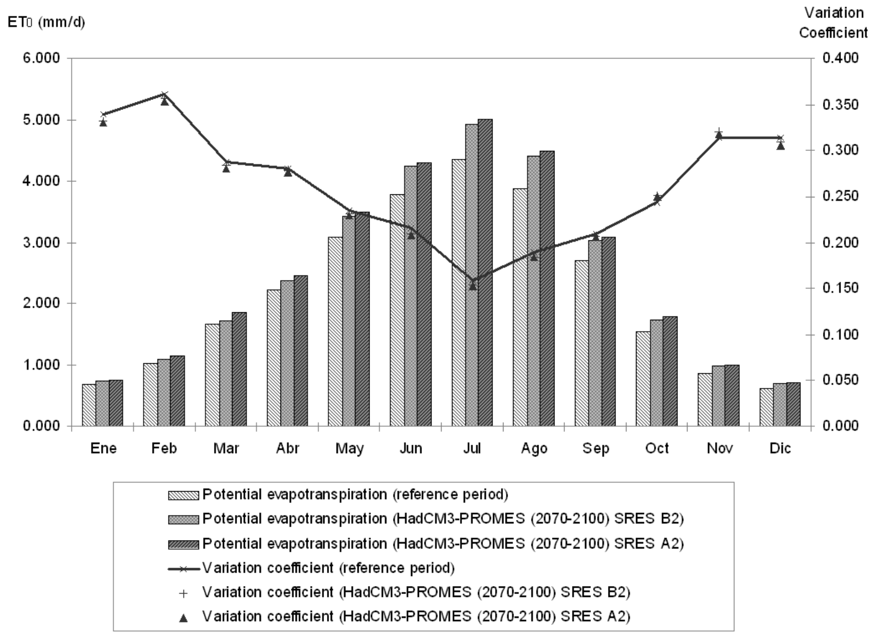


Figure 5.7. Potential evapotranspiration monthly average values and variation coefficients for the reference period and selected scenarios, HadCM3-PROMES (2070-2100) SRES B2 and SRES A2.

The temperature increase will be higher during summer period and it will cause higher increases of potential evapotranspiration during this season showing a more marked seasonality (Figure 5.8).

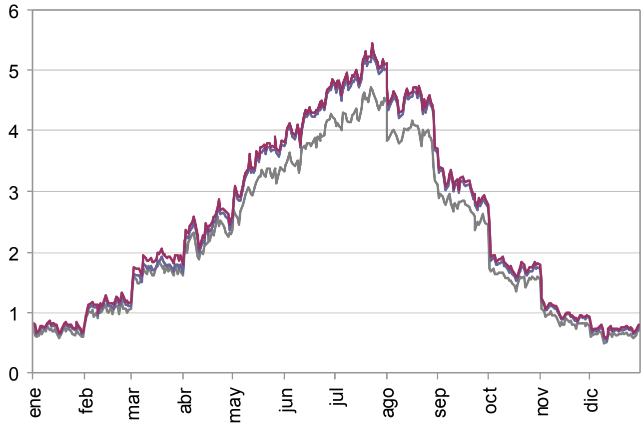


Figure 5.8. Potential evapotranspiration daily average values for the reference period (grey) and selected scenarios, HadCM3-PROMES (2070-2100) SRES B2 (blue) and SRES A2 (red).

The procurement of precipitation data for each scenario needed the multiplicatively modification of the reference period series. To conserve the statistics of each scenario, we obtained calibrated monthly factors and we affected the series with them. It is remarkable that not all of the variations predicted are decreases of precipitation, this justify the necessity of using monthly time scale to obtain the climate change scenarios.

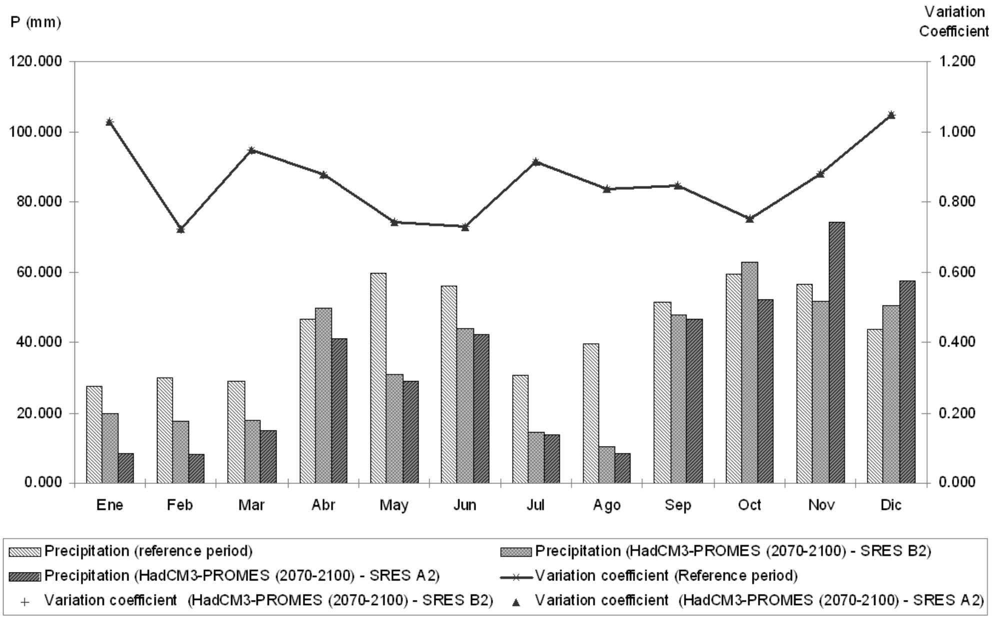


Figure 5.9. Precipitation monthly average values and variation coefficients for the reference period and selected scenarios, HadCM3-PROMES (2070-2100) SRES B2 and SRES A2.

While temperatures increase in both scenarios all over the year, the expected precipitations patterns are more variable and it is not possible to expect a generalized increase or decrease of them in any scenario.

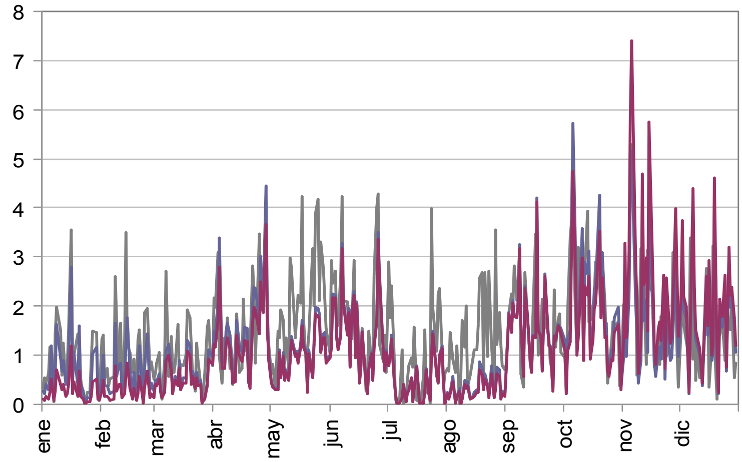


Figure 5.10. Precipitation daily average values for the reference period (grey) and selected scenarios, HadCM3-PROMES (2070-2100) SRES B2 (blue) and SRES A2 (red).

In order to obtain the hydrology scenarios, we considered the monthly percentage variations of incoming flows to Arenós reservoir, obtained by the PATRICAL precipitation - runoff model, from a previous work from the department (Hernández, 2007). Considering those variations as reference, we optimized new multiplicative factors, used to affect the daily reference period series for each flow scenario (Figure 5.11).

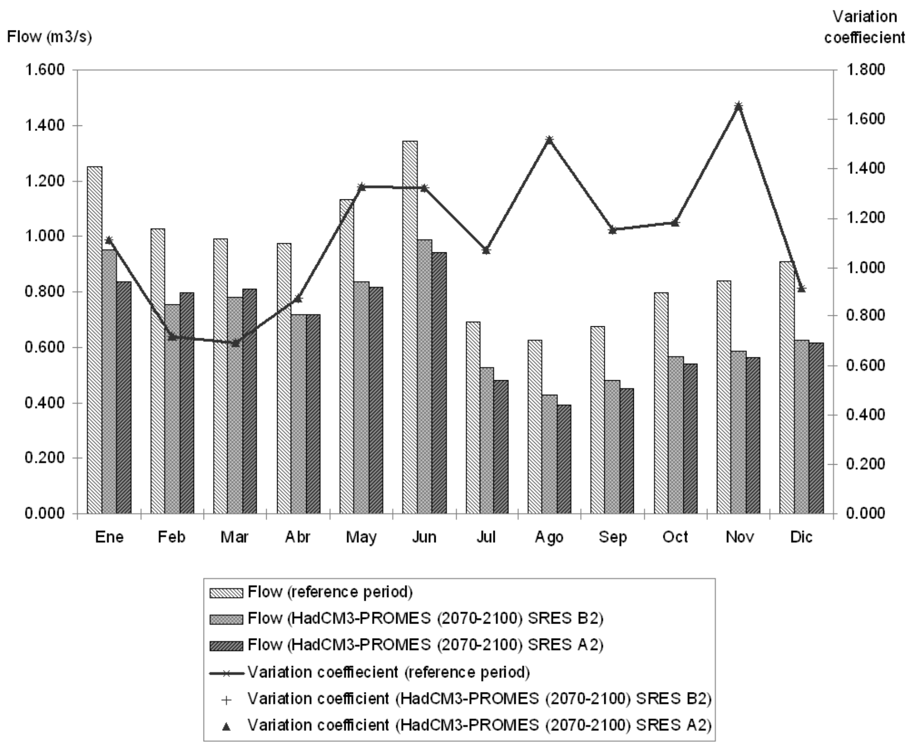


Figure 5.11. Monthly average flow values and variation coefficients for the reference period and selected scenarios, HadCM3-PROMES (2070-2100) SRES B2 and SRES A2.

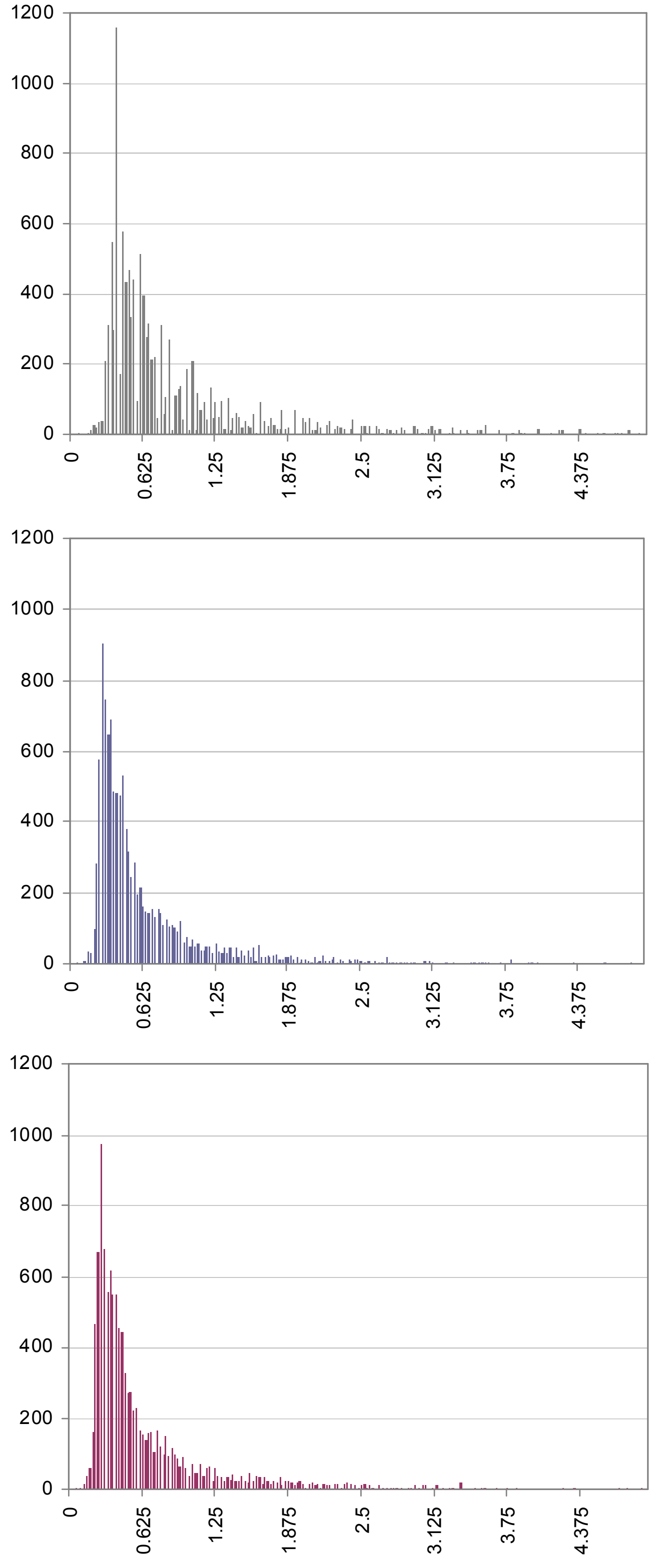


Figure 5.12. Frequencies (number of days) of flows in m^3/s, for the reference period (grey) and selected scenarios, HadCM3-PROMES (2070-2100) SRES B2 (blue) and SRES A2 (red).

The frequency analysis (Figure 5.12) showed that, compared to the reference period, both scenarios have higher frequencies at low flows while the ordinary avenues are less frequent. Both scenarios expected to reduce the higher flows too so, while in the reference period the maximum flow is 36.40 m^3/s, in the SRES B2 and A2 scenarios these maximum flows expected are 15.47 m^3/s and 14.06 m^3/s respectively.

Once the daily data was obtained the yearly inputs were defined as following (Table 5.6).

Table 5.6. Reference period and climate change scenarios. Definition of hydrological yearly inputs for Terde stretch (Mijares River, Spain).

Reference period			SRES B2 (optimistic)			SRES A2 (pessimistic)	
Year	Average Flow (m^3/s)	Year type	Year	Average Flow (m^3/s)	Year type	Average Flow (m^3/s)	Year type
1960	1.531	Very wet	2070	1.128	Wet	1.084	Wet
1961	0.937	Medium	2071	0.689	Medium	0.664	Medium
1962	1.444	Very wet	2072	1.047	Wet	1.005	Medium
1963	1.336	Wet	2073	0.983	Medium	0.959	Medium
1964	0.870	Medium	2074	0.639	Medium	0.619	Medium
1965	0.909	Medium	2075	0.671	Medium	0.657	Medium
1966	0.958	Medium	2076	0.704	Medium	0.672	Medium
1967	0.515	Medium	2077	0.375	Very dry	0.364	Very dry
1968	0.893	Medium	2078	0.645	Medium	0.625	Medium
1969	1.212	Wet	2079	0.886	Medium	0.857	Medium
1970	0.893	Medium	2080	0.665	Medium	0.630	Medium
1971	0.991	Medium	2081	0.725	Medium	0.701	Medium
1972	1.548	Very wet	2082	1.136	Wet	1.101	Wet
1973	0.856	Medium	2083	0.626	Medium	0.601	Medium
1974	1.017	Medium	2084	0.752	Medium	0.737	Medium
1975	0.596	Medium	2085	0.434	Dry	0.418	Dry
1976	1.023	Medium	2086	0.742	Medium	0.715	Medium
1977	1.347	Wet	2087	0.997	Medium	0.955	Medium
1978	0.799	Medium	2088	0.590	Medium	0.577	Medium
1979	0.633	Medium	2089	0.459	Dry	0.443	Dry
1980	0.572	Medium	2090	0.420	Dry	0.406	Dry
1981	0.442	Dry	2091	0.322	Very dry	0.309	Very dry
1982	0.637	Medium	2092	0.458	Dry	0.440	Dry
1983	0.473	Dry	2093	0.343	Very dry	0.328	Very dry
1984	0.618	Medium	2094	0.451	Dry	0.436	Dry
1985	0.422	Dry	2095	0.310	Very dry	0.301	Very dry
1986	0.503	Dry	2096	0.365	Very dry	0.352	Very dry
1987	0.789	Medium	2097	0.574	Medium	0.562	Medium
1988	2.071	Very wet	2098	1.524	Very wet	1.461	Very wet
1989	1.135	Wet	2099	0.803	Medium	0.769	Medium
1990	1.097	Wet	2100	0.812	Medium	0.778	Medium

Considering the maximum flow established for each year and scenario or period, the shear stress inputs were selected as described below (Table 5.7).

Table 5.7. Shear stress input definition for the reference period and the climate change scenarios in Terde reach (Mijares River, Spain).

Reference period			SRES B2 (optimistic)			SRES A2 (pessimistic)	
Year	Maximum Flow (m^3/s)	Shear stress ref. flow (m^3/s)	Year	Maximum Flow (m^3/s)	Shear stress ref. flow (m^3/s)	Maximum Flow (m^3/s)	Shear stress ref. flow (m^3/s)
1960	7.7	10	2070	5.8	5	5.1	5
1961	4.3	5	2071	3.0	2.5	2.8	2.5
1962	13.5	10	2072	10.0	10	9.7	10
1963	4.6	5	2073	3.3	5	3.3	5
1964	7.7	10	2074	5.6	5	5.3	5
1965	3.4	2.5	2075	2.7	2.5	2.8	2.5
1966	8.0	10	2076	6.1	5	5.3	5
1967	8.0	10	2077	5.6	5	5.4	5
1968	22.5	20	2078	15.5	20	14.1	10
1969	5.5	5	2079	4.1	5	4.1	5
1970	7.1	5	2080	5.4	5	4.8	5
1971	11.2	10	2081	8.3	10	8.1	10
1972	9.3	10	2082	6.6	5	6.2	5
1973	8.8	10	2083	6.4	5	6.1	5
1974	7.8	10	2084	5.7	5	5.7	5
1975	6.8	5	2085	5.0	5	4.9	5
1976	8.4	10	2086	6.4	5	5.9	5
1977	14.4	10	2087	10.7	10	10.4	10
1978	4.2	5	2088	3.1	2.5	3.0	2.5
1979	8.1	10	2089	5.8	5	5.4	5
1980	2.5	2.5	2090	1.8	2.5	1.8	2.5
1981	5.7	5	2091	3.9	5	3.6	5
1982	11.7	10	2092	8.3	10	7.9	10
1983	8.8	10	2093	6.1	5	5.5	5
1984	6.2	5	2094	4.6	5	4.5	5
1985	1.1	1	2095	0.8	1	0.7	0.5
1986	5.2	5	2096	4.0	5	3.6	5
1987	7.3	5	2097	5.0	5	5.0	5
1988	36.4	40	2098	25.4	20	24.4	20
1989	9.5	10	2099	6.5	5	5.9	5
1990	6.8	5	2100	4.8	5	4.6	5

5.3 Austria

For the Austrian study case it has been performed a set of five simulations. First simulation replicated the riparian ecosystem during the time span 1960-1990, second and third simulations referred to two possible river management strategies based on the river morphology control, last two simulate the effects of climate change on the floodplain vegetation.

The reference simulation objective was to provide base data to assess the different scenarios performance in respect to the natural reference base line. The river management scenario have been performed to find out the effect of channel geometry on habitats for riparian vegetation. Finally the two climate change scenarios objectives where to investigate the possible effects on the floodplain vegetation given by discharge variations induced by climate change.

The base data for the simulation of the climate change impact scenarios on the floodplain vegetation of the Upper Drau where represented by the time series discharge data measured at the Sachsenburg gauging station. The reference period span the years 1960-1990. The measures refer to daily values which have been processed to yield the maximum yearly value and the mean discharge value during the floodplain vegetation recruitment period (April-July).

5.3.1 Austrian Natural Reference Study Site

The Austrian study site is located at the river Upper Drau, next to the village Kleblach, that is about 18 km east of Spittal an der Drau (Figure 5.13). This river section has been restored 8 years ago within a LIFE-project. Over a length of app. 700 m the channelized river has been widened and a side channel has been restored.

Figure 5.13. Location of Austrian natural reference study site, Obere Drau, Carinthia

In
Figure 5.14 and
Figure 5.15 are depicted the maximum yearly and the mean spring discharges for each year of the reference period (1960-1990); the base data of these charts are listed in Table 5.8. These base data where transformed to include the effect of climate change on the Upper Drau discharge.

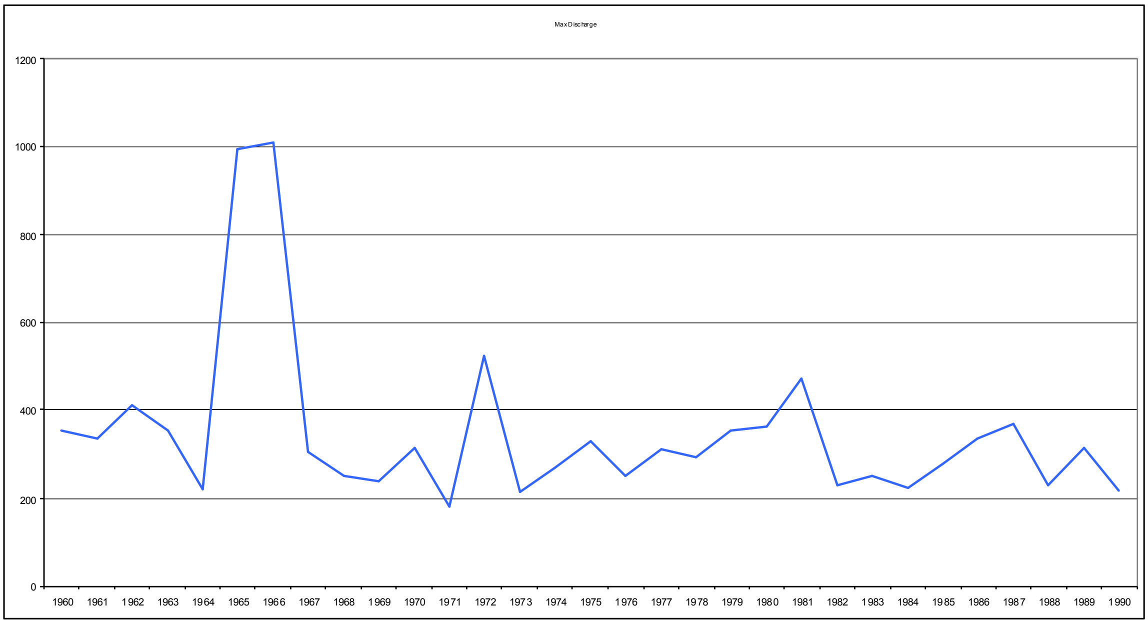


Figure 5.14. Maximum yearly discharges (m^3/s) of the reference period 1960-1990

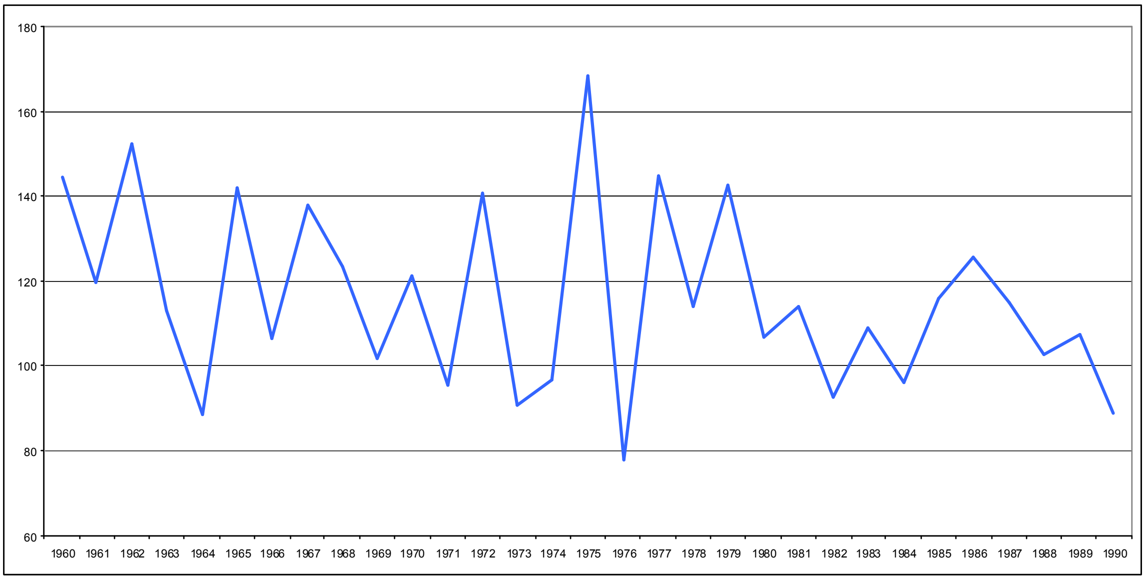


Figure 5.15. Yearly mean spring discharge of the reference period 1960-1990

Table 5.8. Mean spring discharges and maximum year discharges for the reference period 1960-1990

Year	*Mean Discharge (m^3/s)*	*Max Discharge (m^3/s)*
1960	144	355
1961	120	334
1962	152	410
1963	113	355
1964	89	220
1965	142	994
1966	106	1010
1967	138	306
1968	123	249
1969	102	236
1970	121	314
1971	95	179
1972	141	521
1973	91	214
1974	96	267
1975	168	330
1976	78	251
1977	145	312
1978	114	292
1979	143	352
1980	107	364
1981	114	471
1982	93	228
1983	109	249
1984	96	224
1985	116	277
1986	126	336
1987	115	368
1988	103	228
1989	107	316
1990	89	216

5.3.2 Austria River Management Scenario

Two scenario alternatives have been performed to find out the effect of channel geometry on habitats for riparian vegetation. “Small In-Stream Bars” alternative has been run using as a basis for the hydraulic and vegetation model the morphology measured in 2003 (Figure 5.16). “Large In-Stream Bars” alternative has been run using the morphology measured in 2008 (Figure 5.16).

The two morphologies differ for the side channel width, depth and morphology of the in-stream bars. Compared to the 2008 morphology, the morphology measured in 2003 has a more narrow and deep side channel while the in stream bars are smaller and less high (Forman et al. in preparation).

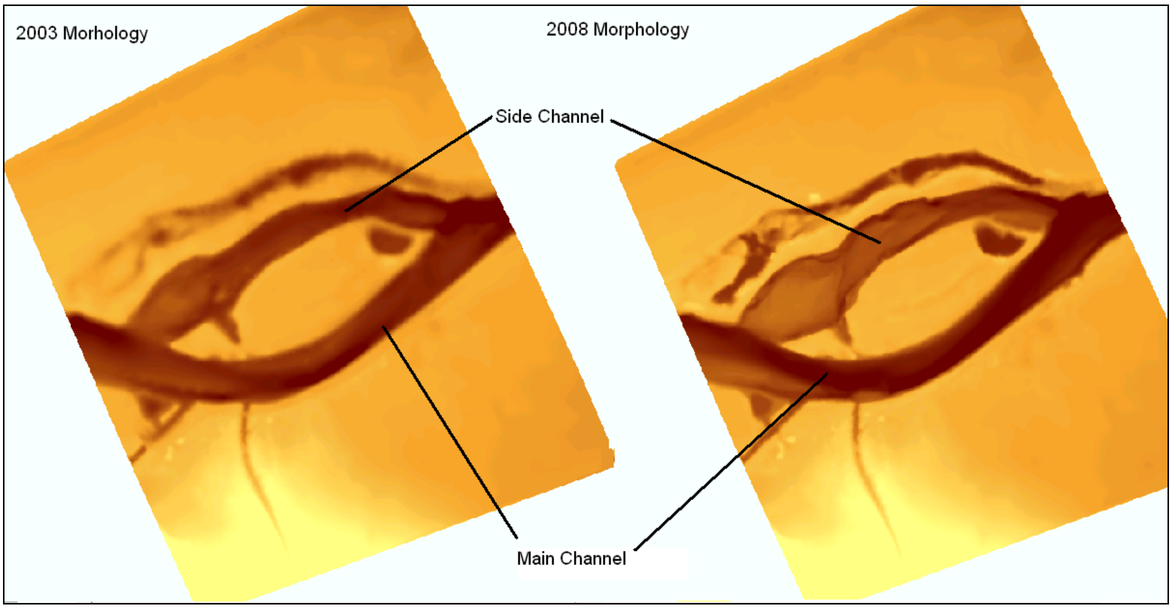


Figure 5.16. Morphologies applied in the river management scenarios

“Small In-Stream Bars” alternative morphology has a maximum side channel water depth of 1.8m, and average depth of 0.66m and a maximum width of approximately 70m. “Large In-Stream Bars” alternative has instead a maximum water depth of 2.1m and average depth of 0.25m and a maximum width of approximately 90m. Water depths measures refer to the mean discharge, which is approximately of 125 m^3/s, measured between May and June.

In both alternatives all the other boundary conditions where the same: the starting condition in the bank zone completely occupied by initial phase (Figure 5.17), simulated time of 60 years and the hydraulic inputs based on the last 60 years (1951-2010) hydrograph.

Yet, for both alternatives the used elevation models have been kept constant, it has been therefore assumed that, during the simulated period, there was no sediment transport or lateral erosion. The results of both alternatives have been analyzed focusing on the side channel bank zone.

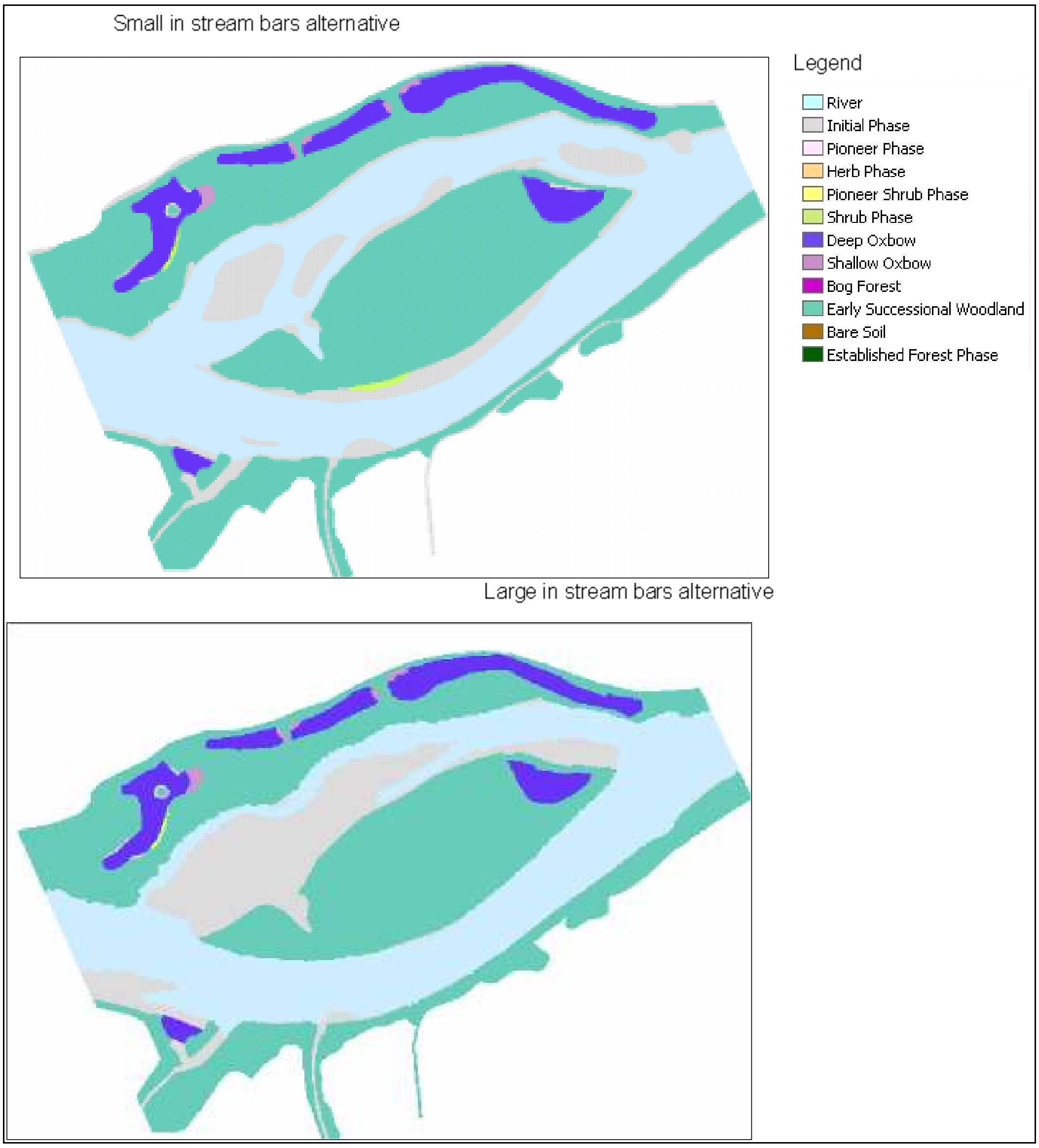


Figure 5.17. Starting condition of the two river management alternatives

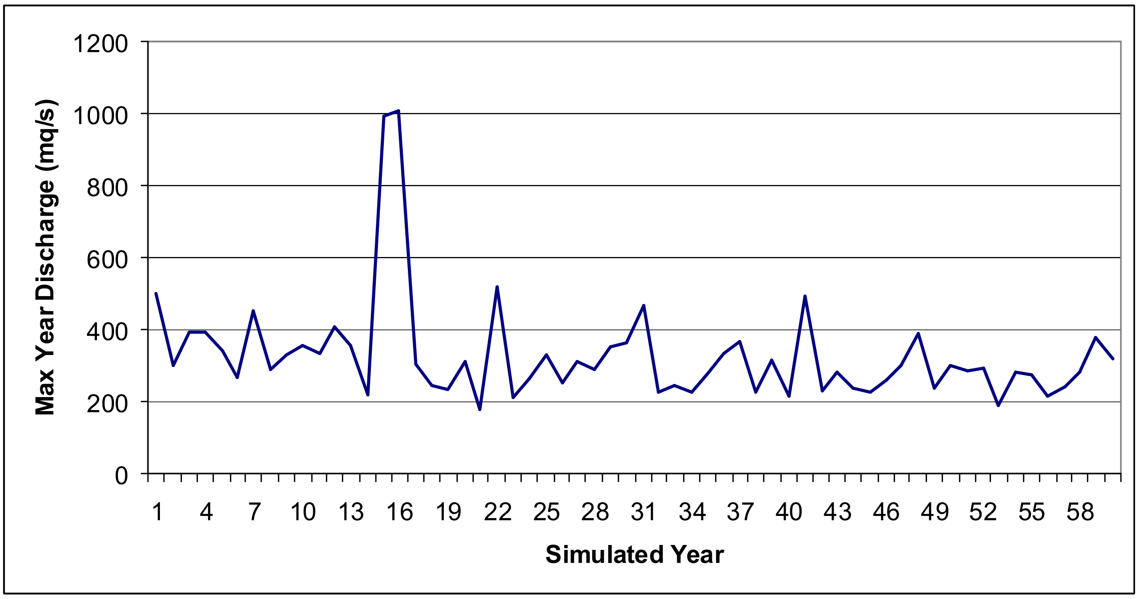


Figure 5.18. Maximum discharges (m^3/s) of the river management simulated alternatives

5.3.3 Austria River climate change scenarios

Two climate change scenarios have been selected to evaluate the potential consequence of climate change on the floodplain vegetation of the Upper Drau. The two scenarios reflect different intensities of the climate change severity and are called after these severities likelihood, namely: SRES B1: Optimistic and SRES A1: Pessimistic scenarios.

The two scenarios where based on climatic models (Stanzel & Nachtnebel, 2010). Pessimistic and Optimistic scenarios differ for the ground assumptions about the human induced climate impact in regard to its economical and social development. The time period for which the climate change impact has been estimated was the spanned by the years 2070 and 2100. In order to yield the variations on the reference period maximum and spring mean discharges it has been applied a percentage variation (Table 5.10) which has been calculated on the basis of Table 5.9 Such data are the result of (Stanzel & Nachtnebel, 2010). These data are graphically represented by the chart in Figure 5.19.

The figures in Table 5.10 refer to the percentage increase or decrease of discharge, for each month, in the two climate change scenarios.

Table 5.9. Discharge values for the reference period and the climate change scenarios

Month	*Reference Period*	*SRES B1 (Optimistic)*	*Sres A2 (Pessimistic)*
1	111.49	139.54	160.61
2	125.75	171.07	175.44
3	192.92	227.28	207.32
4	301.37	359.42	356.81
5	465.14	461.76	470.29
6	502.78	460.97	438.90
7	422.91	369.11	340.17
8	325.84	280.36	262.70
9	264.64	240.91	208.68
10	222.22	204.81	186.07
11	207.37	222.52	218.63
12	140.11	163.87	180.60

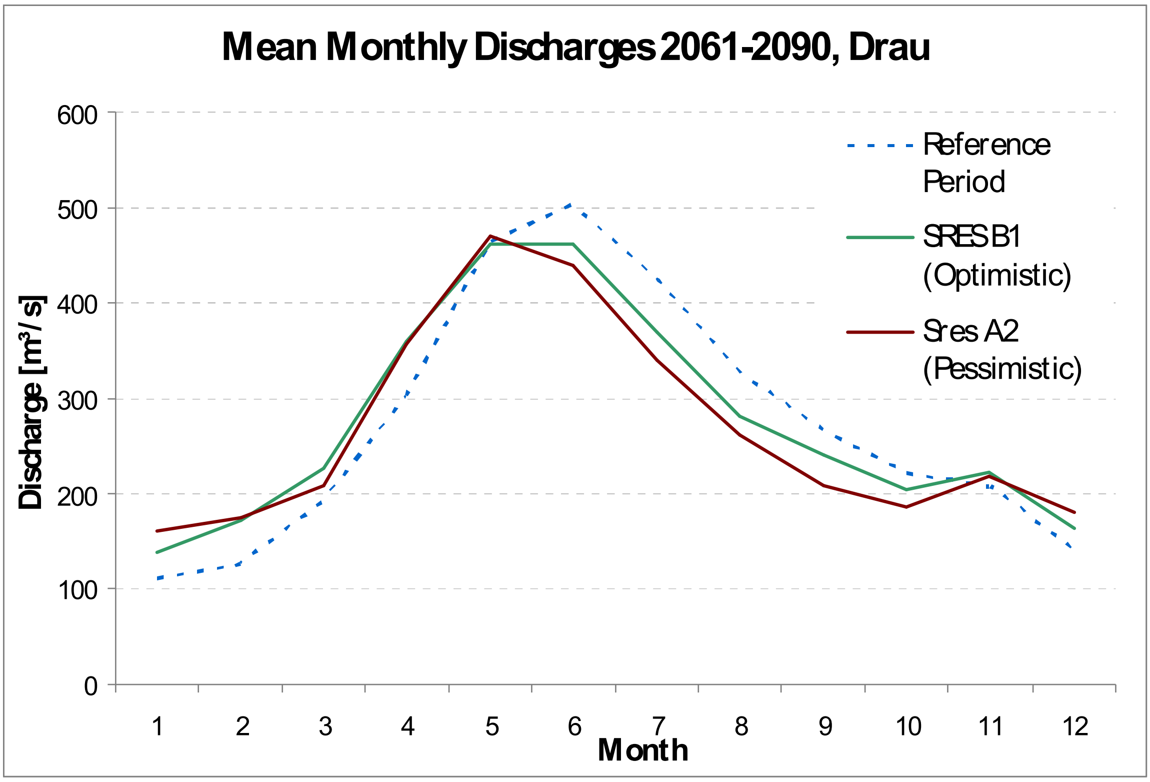


Figure 5.19. Mean monthly discharges for the reference period and the climate change scenarios

In Figure 5.19 are compared the typical hydrographs, for the mean monthly discharge, at the River Drau. The blue dotted line represents the mean discharge in the reference period. In this time span, the discharge gradually increases from January to June-July, when it reaches the year maximum. After this peak, the mean discharge decreases until reaching a plateau in the fall months (October and November) and then decreasing again. The climate change scenarios follow a similar increase-decrease patter, but the winter mean discharge is higher than in the reference period, maximum discharge is reached in the early spring its value is lower than in the reference period. On the other hand, during summer, the mean flows of the climate change scenarios are lower than in the reference period.

Table 5.10. Discharge percentage variations on the reference period discharge

Month	*Change (%) SRES A2 (Pessimistic)*	*Change (%) SRES B1 (Optimistic)*
01	44%	25%
02	40%	36%
03	7%	18%
04	18%	19%
05	1%	-1%
06	-13%	-8%
07	-20%	-13%
08	-19%	-14%
09	-21%	-9%
10	-16%	-8%
11	5%	7%
12	29%	17%

In order to yield the maximum and mean spring discharge values for each scenario, the variations in Table 5.10 have been applied to the values in Table 5.8.

The application of the maximum discharge variation of each climate change scenario yield the results listed in Table 5.11.

The application of the spring means variations in to the values in Table 5.10. yield the results listed in Table 5.13. In order to yield these values, the climate change discharge percentage variation of each recruitment month has been applied to the correspondent reference period month. The mean discharge values thus yield have been averaged to obtain the yearly spring mean. In Table 5.13 is reported an example of such procedure, for the first simulated year.

Table 5.11. Maximum discharge values obtained for each scenario

Year	*Optimistic Max Discharge (m^3/s)*	*Pessimistic Max Discharge (m^3/s)*
2070	334	334
2071	307	294
2072	377	361
2073	327	312
2074	202	194
2075	867	759
2076	884	789
2077	282	269
2078	229	219
2079	236	236
2080	289	276
2081	179	179
2082	479	458
2083	214	214
2084	238	216
2085	304	290
2086	219	192
2087	287	275
2088	265	253
2089	332	332
2090	331	314
2091	421	396
2092	210	201
2093	249	249
2094	222	222
2095	255	244
2096	336	336
2097	329	298
2098	204	185
2099	282	256
2100	193	175

Table 5.12. Example of mean spring discharge calculation for the first reference and climate change scenarios year. The discharges of the spring months of the reference period have been multiplied for the climate change discharge variation. The single month discharges have been then averaged to yield a single indicator value.

Year/month	*Ref. Mean value*	*Optimistic B1 Change (%)*	*Pessimistic A2 Change (%)*	*B1 Mean value*	*A2 Mean value*	*Climate Change Year Scenario*
1960/04	61	19%	18%	72	72	2070
1960/05	154	-1%	1%	153	156	2070
1960/06	201	-8%	-13%	184	175	2070
1960/07	162	-13%	-20%	141	130	2070
Average	**144**			**138**	**133**	

Table 5.13. Spring (recruitment time) mean discharge values for each climate change scenario

Year	Optimistic Mean Spring Discharge (m^3/s)	Pessimistic Mean Spring Discharge (m^3/s)
2070	139	133
2071	115	110
2072	145	138
2073	108	103
2074	84	81
2075	134	127
2076	101	97
2077	132	126
2078	119	115
2079	99	95
2080	114	108
2081	92	89
2082	133	127
2083	86	82
2084	92	87
2085	162	155
2086	75	72
2087	140	135
2088	108	103
2089	136	130
2090	101	96
2091	109	104
2092	88	84
2093	104	99
2094	91	87
2095	110	106
2096	122	119
2097	108	103
2098	98	94
2099	102	97
2100	85	81

5.4 Portugal

5.4.1 Portuguese Natural Reference Study Site

The Portuguese natural reference study site lies along the Odelouca river, with 511 Km^2 of watershed extension and a stream length of 92 Km (Figure 5.20). This water body is a typical Mediterranean river with winter flash-floods and dry bed in Summer (Figure 5.21). The study site is located near the village of Ribeira and it has been selected due to the absence of flow regulation upstream, near natural conditions in terms of human presence and naturalness of the riparian vegetation.

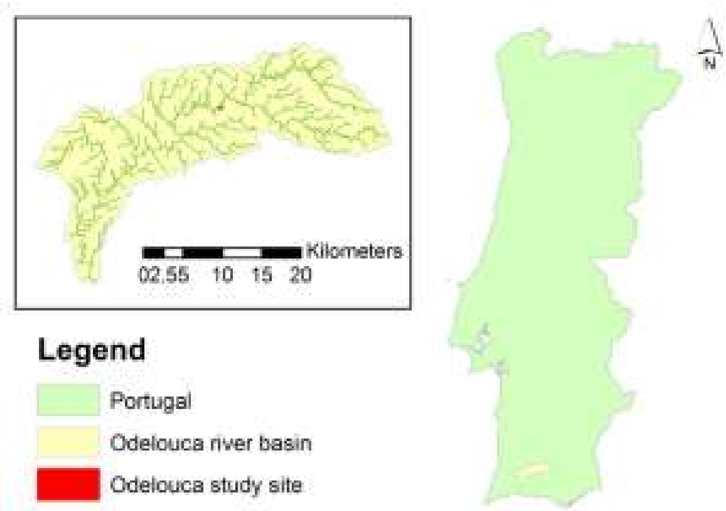


Figure 5.20. Portuguese natural reference study site location at Odelouca river basin (Algarve region).

Figure 5.21. Odelouca river at the study site. On the left side, an image of the low summer flow (August), and on the right side the winter mean water level (February).

5.4.2 Portuguese climate change scenarios

The climate change scenarios used in the Portuguese case studies are the predictions obtained from Global Circulation Model (GCM) HadCM3 (created by the Hadley Centre for Climate Prediction and Research) for Portugal (Santos *et al.*, 2002, Santos and Miranda, 2006). Out of several models tested, GCM HadCM3 and Regional Circulation Model HadRM2 have produced the results that are most consistent with Portuguese historical observations (Santos *et al.*, 2002).

The climate change scenarios considered in the vegetation modeling are SRES (Special Report on Emission Scenarios) A2 and B2. Those scenarios are selected among four families of possible future socioeconomic developments, where demographic, social, economic and technologic factors are considered. A2 scenario stands for a differentiated world with the largest population among the SRES storylines, where economic growth is uneven and the income gap between now-industrialized and developing parts of the world does not narrow. On the other side, B2 scenario considers a world with increased concern for environmental and social sustainability compared to the previous one. In this storyline high priority is given to human welfare, equality, and environmental protection. Government policies and business strategies at the national and local levels are influenced by environmentally aware citizens and the international institutions lose their importance to the local and regional ones. This scenario describes also a population growth until end of 21st century but in a slower pace than A2 scenario (IPCC, 2000).

Comparing both scenarios, A2 scenario forecasts for the Iberian Peninsula a higher quantity of greenhouse gases (GHG) released to the atmosphere than B2 scenario, so it is expected a higher increase in average global temperature in the former scenario than in the last one (Figure 5.22). More precisely, for A2 and B2 scenarios it is expected for the south of Portugal a mean annual temperature increase of 4,9 and 3,5ºC by 2100, respectively.

For Portugal, HadCM3 model foresees by 2100 a precipitation change increased in 4% in the north and a decrease of about 34% in the south for the winter precipitation in scenario A2. For the same period, in the scenario B2 it is expected to have an increase between 18 to 25% of precipitation in the same season. In summer both scenarios agree with a precipitation decrease of about 40 to 50%. In general, both scenarios agree in a high decrease of summer precipitation, being contradictory in the winter with different tendencies of precipitation change (Santos and Miranda, 2006).

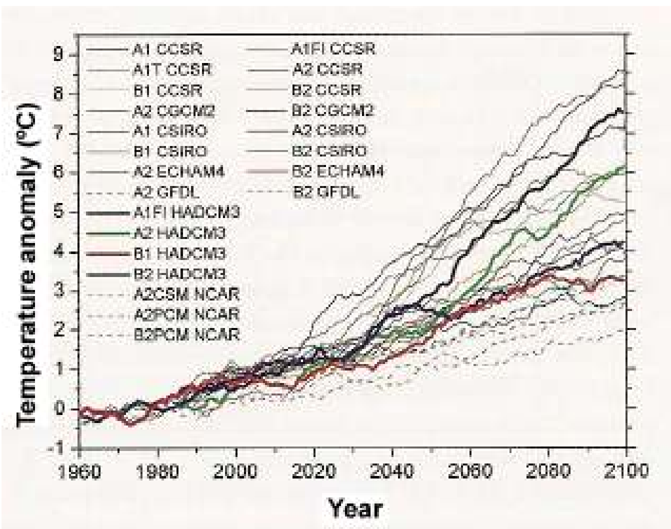


Figure 5.22. Forecasted temperature anomaly in the Iberian Peninsula according to different climate change scenarios. Source: Santos and Miranda, 2006.

HadCM3 – SRES B2 results for the Algarve region show a winter runoff increase from about 30 to 50% by 2100 whereas HadCM3 – SRES A2 expect a winter runoff decrease of about 80% for the same region. Regarding the annual ground recharge, HadCM3 – SRES B2 foresees a water table level lowering from 0% to 10% in the Algarve region and for SRES A2 scenario a 50 to 75% lowering by 2100. This may represent a reduction in the water table of up to 1m according to HadCM3 – SRES B2 and up to 13m according A2 scenario (Santos *et al*., 2002; Santos and Miranda, 2006).

Based on the results from the studies by Santos *et al*., 2002 and Santos and Miranda, 2006, two future hydrological regimes were created for input into the model. Scenarios 2 and 3 were created from HadCM3 – SRES B2 and A2 results respectively. The more optimistic Scenario 2 (HadCM3 – SRES B2) foresees a 50% increase in the intensity of winter floods, with a reduction of 1m in the water table. The more pessimistic, Scenario 3 (HadCM3 – SRES A2), expects a decrease of 60% in winter flood intensity, with a fall of about 13m in the water table. Scenario 1 (no changes) is obtained from the reference period between 1960 and 1990 (Table 5.14).

Table 5.14. Hydrologic regime considered in the vegetation modeling in different climate change scenarios.

	Scenario 1 – no changes	**Scenario 2 – Optimistic**	**Scenario 3 – Pessimistic**
Winter precipitation	1960 to 1990 period	20% increase	30% decrease
Winter runoff	1960 to 1990 period	50% increase	80% decrease
Water table elevation	1960 to 1990 period	1m decrease	13m decrease

6 Field Data

6.1 Introduction

The calibration of the model in temperate and Mediterranean conditions demanded the acquisition of field data in both kinds of environments to use them as inputs. In this section we describe how all the important data were obtained in each country.

The data quality in this phase of the project was considered particularly important as it would condition the quality of the final results.

Before the field data acquisition, one important task was the selection of the study site. Several field trips were done to the selected region of every country in order to find the best riparian area to calibrate the model. The selected place had to satisfy several requirements, such as easy accessibility, long time series of flow records and meteorological data, good ecological status, natural dynamism (geomorphological processes), and natural variety of vegetation types, succession phases and stand ages.

The different inputs have been necessary to represent in some way the main factors that affect the establishment and development of the riparian woody vegetation. These inputs can be separated in two aspects: hydrology and vegetation.

In the first, it was necessary to gather all the hydrometeorological information to characterize the flow regime in each site, and to create maps for different hydrologic and hydraulic variables, such as water table elevation, shear stress and flood duration. For this task, it was necessary to get data from different monitoring networks of national and regional institutions for each study site.

In the second aspect, the survey of the vegetation was necessary to create maps of observed vegetation, and, moreover, it was necessary to understand how succession develops in each site, and to analyze the vegetation data to define expert rules that determines the running of the dynamic vegetation model.

The three countries tried to work in sites with similar length, to map at similar scale and to work with similar pixel size. It has been important to determine the scale of work previously for all the techniques to apply, as well as the topographic datum to be used in the different samplings.

A large variety of techniques have been used for the generation of inputs, for instance different topographic techniques, hydraulic modelling, dendrocronology, soil analyses, vegetation measurements, GIS calculations, etc. All of them are explained in detail along the section.

6.2 Spain

6.2.1 Study site: Location and description

The river Mijares has its source in the Sierra de Gúdar (Teruel) at 1600 m above sea level (masl). It runs 156 km from NO to SE until the mouth in the Mediterranean Sea. The study site (539 m long) is located at 850 masl, between the villages of Sarrión and Mora de Rubielos (Teruel) (Figure 6.1). The stream flow pattern is determined by rainfall and secondly by snow, with notable intra- and inter-annual variability in the discharge, characteristic in Mediterranean watersheds; 11 ºC is the average annual temperature and 500 mm the average annual precipitation. The basin area in the site is 665 km^2 and 43 km is the river length from birth to the site. The mean annual discharge is 0.894 m^3/s and the bankfull discharge was estimated at 5 m^3/s.

Figure 6.1. Location of the Spanish natural site in the river Mijares (red circle), within the Jucar River Basin District (green area superimposed).

The site is in nearly natural conditions and free from flow regulation. It was selected because it is possible to recognize the natural dynamism, with some fluvial biogeomorphic processes in the segment, there were variety of succession phases and stand ages, and it is very near of one of the best gauging stations of the Jucar River Basin Authority.

The study area (Figure 6.2) was defined using the contour line for 860 masl, as a first reference. Besides, it was considered the line defined by the flood with a recurrence period of 100 years, which is generally recognized as the limit between the riparian and the terrestrial zone, and the study area was considerably larger. In those sections were it was possible, the terrestrial band has double width than the riparian band. In a first delineation of the site, the tributary upstream was considered, but finally it was removed from the study area because there were no flow records for the tributary. For all the grids used in the model, the pixel area was 1 m^2, (i.e. a square with 1 m long). This size was considered as the best in a balance between accuracy in the vegetation mapping and time consumption during the calibration process. All the maps were generated with the same grid extension and pixel size.

Figure 6.2. Location of the study site in the river Mijares, in the province of Teruel.

Figure 6.3. General view of the study site in the river Mijares, from upstream to downstream.

6.2.2 Hydro-meteorological data

The hydrometeorological data is necessary in the calibration and in validation of the model, and should be adjusted to the study sites' location. The hydrometeorological variables necessary as input of the RibAV model (soil moisture sub-model) are Precipitation (P), Potential Evapotranspiration (ET_0), and river discharge or flow ratio (Q). The available monitoring networks of different national and regional institutions (Banco Nacional de Datos Climatológicos de la Agencia Estatal de Meteorología, AEMET; Centro de Estudios Hidrográficos del CEDEX; Instituto Valenciano de Investigaciones Agrarias, IVIA) supplied valid data of the area for precipitation, temperature and flow, in stations near the study site. For potential evapotranspiration (ET_0) precise estimations are available, made with Penman-Monteith equation (Instituto Valenciano de Investigaciones Agrarias, IVIA) which accuracy was tested by different authors (Allen, 2000; Irmak *et al.,* 2002; Kashyap & Panda, 2001). Such values of ET_0 were the reference to calibrate the estimations in the study site with the Hargreaves equation (Hargreaves & Samani 1985; Allen *et al*., 1998; Samani, 2000); this equation provides a simpler and accurate estimation, with a smaller number of parameters which is based on temperature data.

6.2.2.1 Precipitation

The daily records of precipitation were obtained from the national meteorological agency of Spain (AEMET); from those data, an interpolation was applied to translate those data to the exact location of the model. The inverse distance weighting (IDW) was the method selected, with a coefficient of 2 (therefore, the square of the distance). Given that the number of records was enough to make the interpolation for each day of the time series, based on the group of stations around the area, it was not necessary to complete or to fill the precipitation time series; only the more reliable meteorological data of different stations were used, depending on the stations available in different time periods.

Table 6.1. Characteristics of the stations of the Spanish agency for meteorology (AEMET) that provided the data to calculate precipitation in the site of Terde, river Mijares.

Official name	Code	Elevation (masl)	Period of data (precipitation)	Province
La Puebla de Valverde	8459	1129	08/42-05/96	
Mora de Rubielos	8466	1039	03/48-11/81	
Rubielos de Mora	8470	949	03/55-12/05	
San Agustín	8473	959	04/53-09/09	Teruel
Sarrión	8463O	981	11/85-08/09	
Sarrión Comarcal	8463P	900	07/92-01/08	
Sarrión (La Escaleruela)	8464	860	03/48-11/94	

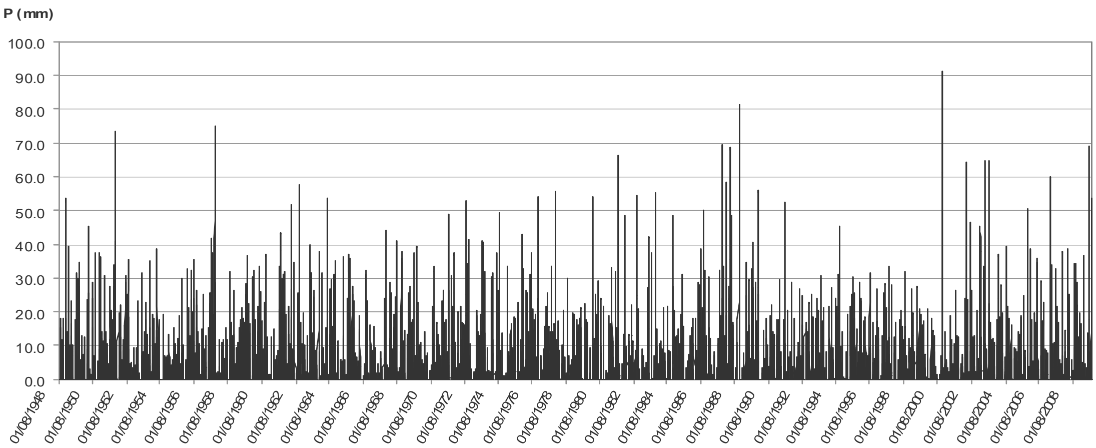


Figure 6.4. Mean daily precipitation (mm) in the site Mijares-Terde, river Mijares (1948 - 2009).

In some time periods only 1 station was available; to fill those periods of the series, a linear regression was calculated between data of that station and the interpolated data (when 3 or more stations were available), and the regression was used to obtain daily data from that single station. In some periods no data were available; then, the average daily precipitation was calculated for a whole year, day by day, and these averages were used as daily data for those periods. The stations used to obtain the data are detailed in Table 6.1, and the time series of precipitation in the site Mijares-Terde for the period August 1st, 1948, to September 30th, 2009 is plotted in Figure 6.4.

6.2.2.2 Potential Evapotranspiration

The methods were the same as for daily temperatures (mean, maximum, minimum), necessary for ET_0 determination. For temperature this correction was applied (related with altitude) in the interpolation:

$$T_0 = \sum_{j=1}^{n} w_{0j} \left[T_j + \beta \left(z_0 - z_j \right) \right] \quad (4.)$$

Where β is the ratio of temperature reduction as elevation increases. This ratio is between 5 and 8 ºC by 1000 meters above sea level (Marco, 1981) with an average of 6.5 ºC/1000m. Given the stability of this ratio, this correction was applied when a reliable calibration of this variable was not possible (due to microclimatic conditions or not having sufficient number of recording stations).

From the temperature series, interpolated at the study site, the next step was the calibration of ET_0 (mm/d). From the temperature records of a station (Planes) the correction factor of the simplified equation of Hargreaves was obtained (Hargreaves & Samani, 1985; Allen *et al.*, 1998; Samani, 2000); therefore, the ET_0 estimated was approximately the maximum ET_0 calculated by the managers of these data (IVIA) which used the equation of Penman-Monteith. This equation is scientifically recognized as one of the more precise, but needing a great amount of information, while the one of Hargreaves (Hargreaves & Samani, 1985) only need temperature and sun radiation, as follows:

$$ET_0 = 0.0135 \left(t_{med} + 17.78 \right) \cdot R_s \quad (5.)$$

Where ET_0 is the potential daily evapotranspiration (mm/d), Tmed is the mean temperature (ºC) and R_s the sun radiation (mm/d). The last variable was estimated with the equation of Samani (2000). When R_s is replaced by Samani's equation, with a coefficient of KT = 0.17, a more common expression of Hargreaves' equation is obtained (Hargreaves & Allen, 2003):

$$ET_0 = 0.0023 \left(t_{med} + 17.78 \right) \cdot R_0 \left(t_{\max} - t_{\min} \right)^{0.5} \quad (6.)$$

For minimizing the error derived from the use of the simplified expression of Hargreaves, the results were calibrated with the results of the station of Planes (IVIA) based on Penman-Monteith. For such correction, a calibration factor (FC) was used in the expression:

$$ET_0 = FC \left(t_{med} + 17.78 \right) \cdot R_0 \left(t_{\max} - t_{\min} \right)^{0.5} \quad (7.)$$

The minimum squared error was obtained with a FC = 0.001887 in Planes. Therefore, the final equation for estimation potential evapotranspiration was the following:

$$ET_0 = 0.001887 \left(t_{med} + 17.78 \right) \cdot R_0 \left(t_{\max} - t_{\min} \right)^{0.5} \quad (8.)$$

The time series of temperature were calculated in the meteorological station of Sarrión (AEMET); in periods without data, the time series was completed with a linear regression between Sarrión and other station in the area. In some periods, no station was available to relate the data (period April 1952), them the relation between river discharge and average number of days with rain for this month, calculated in the whole series, was used to estimate the parameter.

Table 6.2. Characteristics of the meteorological stations of the Spanish agency (AEMET) used for the calculations of mean daily temperature in the site Mijares-Terde, river Mijares.

Official Name	Code	Elevation (masl)	Period of data (temperature)	Province
Sarrión	8463O	981	01/86 - 07/09	Teruel
Sarrión Comarcal	8463P	900	07/92 - 01/08	

For the correction with elevation, the station of Sarrión was at 981 masl and the site at 851 masl (estimated in a DEM of 20x20 m). In the estimation of ET_0 of reference, the Hargreaves equation was applied with a correction of FC = 0,001887. The resulting data are indicated in the figure below.

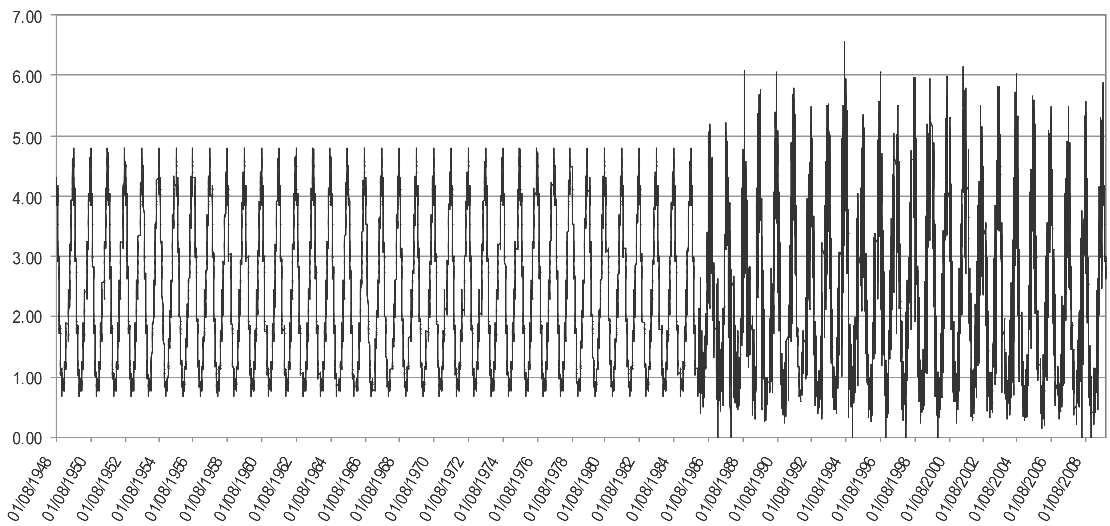


Figure 6.5. ET_0 of reference (daily data, mm/day) in the site of Terde, river Mijares (1948 - 2009).

6.2.2.3 River discharge

This variable was calculated by interpolation of the nearest gauging station. The data were corrected in proportion to the watershed area in the sites of natural flow regime, and corrected with simulations of the hydrological model PATRICAL for water yield without gauging data in the sites with altered flow regime. The gauging data comes from the station of Sarrión (CEDEX), located only 550 m downstream of the study site. The watershed area is very similar and there are no tributaries or springs between these points, therefore no correction was necessary. The characteristics of the station are listed in table.

Table 6.3. Main characteristics of the flow gauging station of Sarrión, river Mijares.

Type of data	Name	Code	Location	Year start	Year end
Gauging station	Sarrión	8030	Downstream	1945	2009

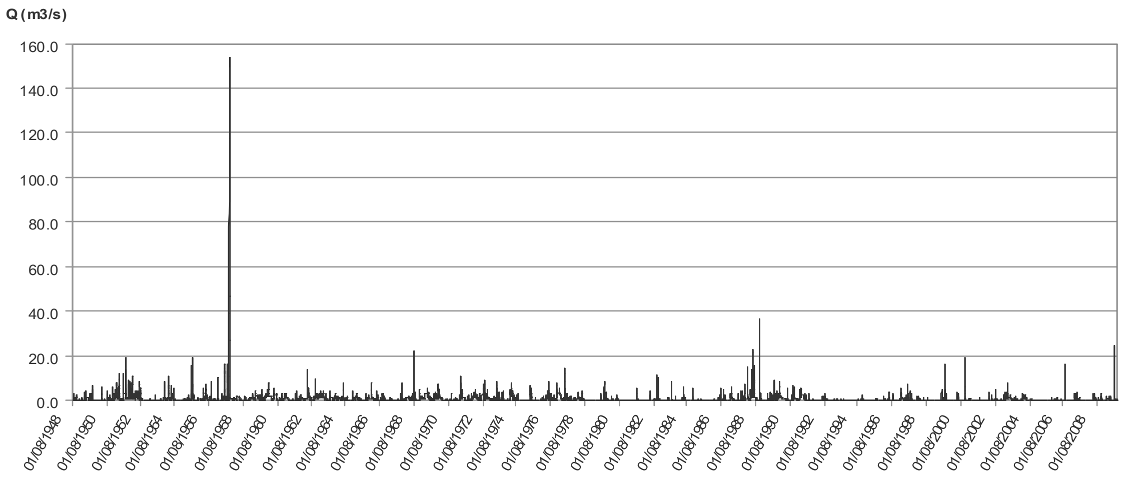


Figure 6.6. Daily river discharge (m^3/s) in the site Mijares-Terde (1948 - 2009).

The mean monthly data of river discharge are displayed in the figure; the discharge show the same pattern of the precipitation, with maximum in spring and autumn, low flows in winter and summer, and the minimum usually in July.

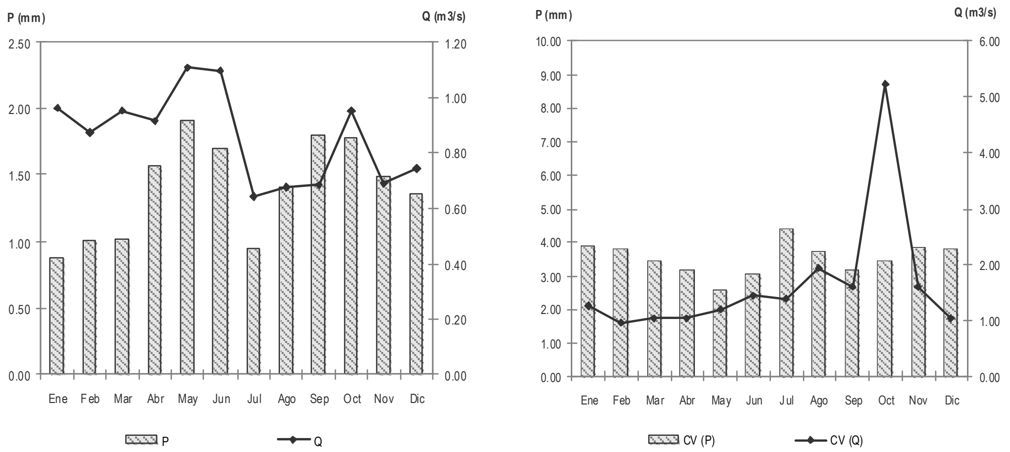


Figure 6.7. Mean monthly data of precipitation and river discharge in the river Mijares, site of Terde (1948 - 2009). Left, precipitation (mm) and river discharge (mean daily flow in m^3/s) by months. Right, coefficients of variation of the same two variables, by months.

6.2.3 Soil survey and characterization

6.2.3.1 Soil survey

The surveyors walked along the site drawing a draft of the different types of soils and writing a short description of them. After that, all the information recorded about the site was summarized and 10 points were selected to be sampled, covering the lateral and transversal gradient of the river, i.e. the points were localized in representative soil types and covering from the area near to the water edge to the upland and from upstream to downstream. Also, a draft of the soil types present in each one of the 20 cross-sections was done during the field survey. As a general rule, the samples were extracted by digging pits between 30 and 60 cm soil depth.

Figure 6.8. Example of soil sampling in the soil types 5 (left) and 8 (right).

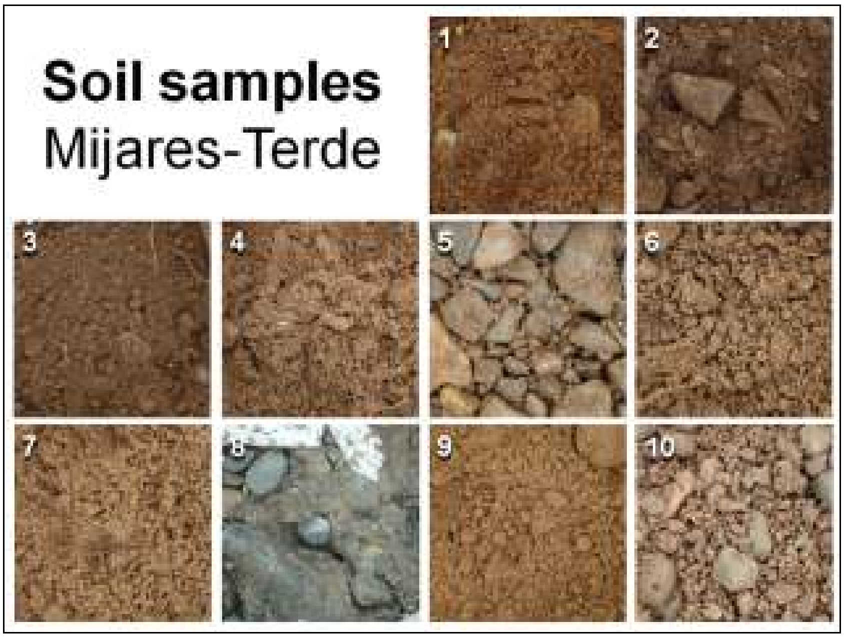


Figure 6.9. Appearance of the ten soil samples taken in the Mijares-Terde.

From the last figure (

Figure 6.9) can be easily appreciated the differences among soil samples, taking into consideration principally the differences in texture and organic matter content. One type more (soil 11) was add to the list (representing the area with bedrock soil), where no sample was extracted.

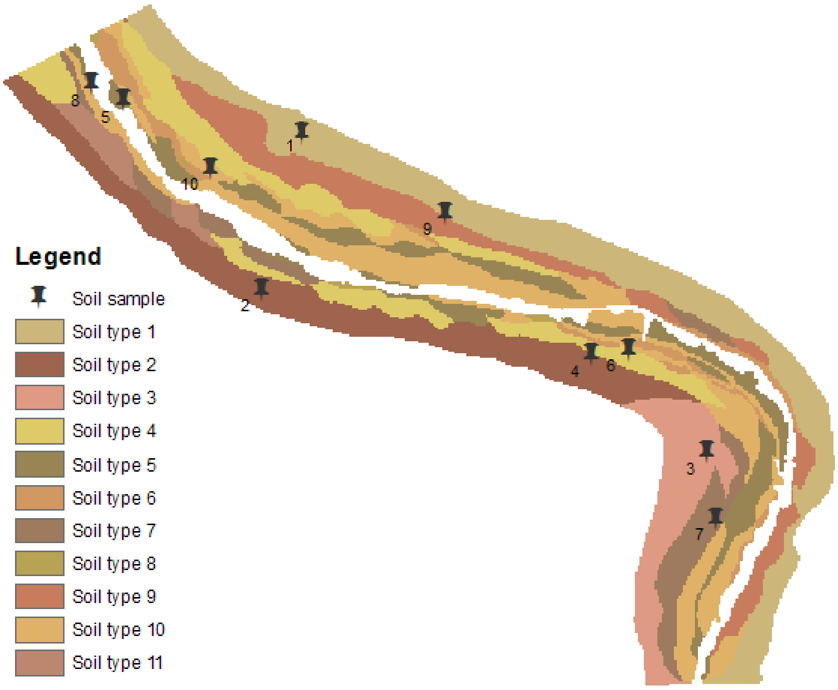


Figure 6.10. Map of soil types of the Mijares-Terde. Locations selected for soil sampling are also indicated.

6.2.3.2 Soil analysis

The samples (labelled with a code) were analysed in a specialized Soil Laboratory of the Universidad Politécnica de Valencia. From each sample, the texture and the organic matter content were obtained. A short description of every analysis is provided:

- Determination of the oxidisable organic matter content by Potassium permanganate method (UNE 103.204-93).
- Particle size analysis by sieves test (UNE 103.101-95). This granulometric analysis employs a set of sieves of different size of mesh to separate the particles with bigger size (from 100 to 0.08 mm).
- Particle size analysis by sedimentation test: Hydrometer method (UNE 103.102-95). This method was used to determine the particle size distribution of very fine materials, such as silt and clay (i.e., from 0.08 to 0.001 mm).

The results from both particle size analyses were combined, creating the figure below where can be appreciated the grain size distribution of each soil type.

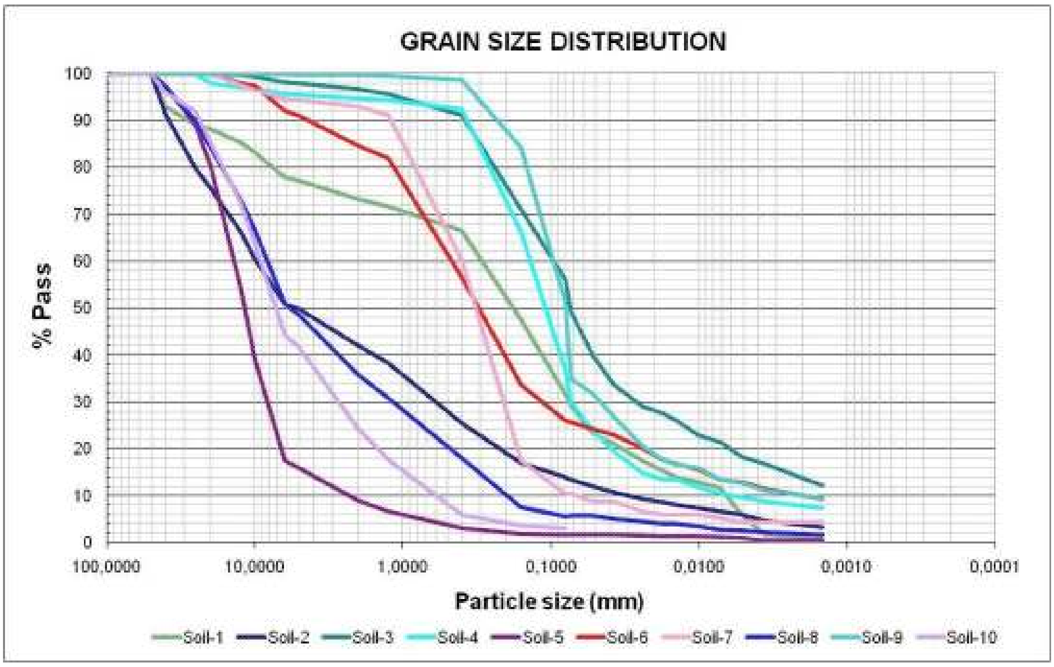


Figure 6.11. Grain size distribution of the ten soil samples in the Mijares-Terde. The graphic combine the results from the sieve and hydrometer analyses.

6.2.3.3 Soil parameters

The soil contained in the static tank of the RibAV model (soil moisture sub-model) can be saturated or non-saturated, depending on the water table elevation (WTE) at that moment. The saturated zone is beneath the water table and the non-saturated zone is above. It was necessary to describe the soil characteristics for each of the cells in which the model carries out a simulation. In this sense, from the laboratory results were extracted several basic soil parameters which were used to obtained the parameters necessary for the model. These basic parameters were:

- Percentage of gravel (particles with size > 2 mm)
- Percentage of sand (0,05 mm < size < 2 mm)
- Percentage of silt (0,002 mm < size < 0,05 mm)
- Percentage of clay (size < 0,002)
- Percentage of organic matter

Subsequently the basic parameters were introduced in the model “Soil Water Characteristics” (SWC), from Saxton *et al*., 2006. This model has been developed by the USDA (Department of Agriculture from the USA) and provides as output the water retention curves, which are defined by the following model parameters:

- **Mfc (θFC):** *Soil moisture at Field Capacity* ( ). It is the maximum moisture that a soil can retain without damaging the plants due to anaerobiosis effects. It points out to the maximum capacity of the model’s conceptual tank. It has the typical moisture value of 33 KPa.
- **Pst (Φ):** *Porosity* ( ): It is the proportion of soil volume which is occupied by voids in comparison to the solid fraction.

- **Ks:** *Saturated Hydraulic Conductivity* (mm/hr): It is the distance travelled by the water flow, by time unit, in saturated soil conditions. In non-saturated soils the conductivity is variable and time-dependent.
- **Pb (Hb):** *Bubble Pressure* (in absolute value KPa). It is the pressure exerted by the air bubbles in the zones where the soil is saturated. Although the soil is saturated, some bubbles get trapped in some places exerting a residual matrix pressure.
- **Ip (λ):** *Porosity Index* ( ): The porosity parameter, described before, only describes the void proportion compared to the solid fraction. Therefore the porosity index is also used because it describes the relative size and interconnectivity of the voids.

6.2.4 Topographic survey and Digital Elevation Model

6.2.4.1 Location of cross sections and georreferencing

Twenty transects or cross-sections (line transverse to the main flow) were defined in the study site with two main purposes, first to register the topographic conditions (section of the riverbed and the floodplain) in order to complete the digital elevation model, and second, to register the hydraulic changes and the longitudinal profile of the water surface along the study site (necessary for the hydraulic modelling).

These cross-sections were marked out with one steel rod in every river bank. When it was possible, these rods were located in the hill slopes in order to have a good view from them of a certain area and to allow us to use them without risk when high flows occurs.

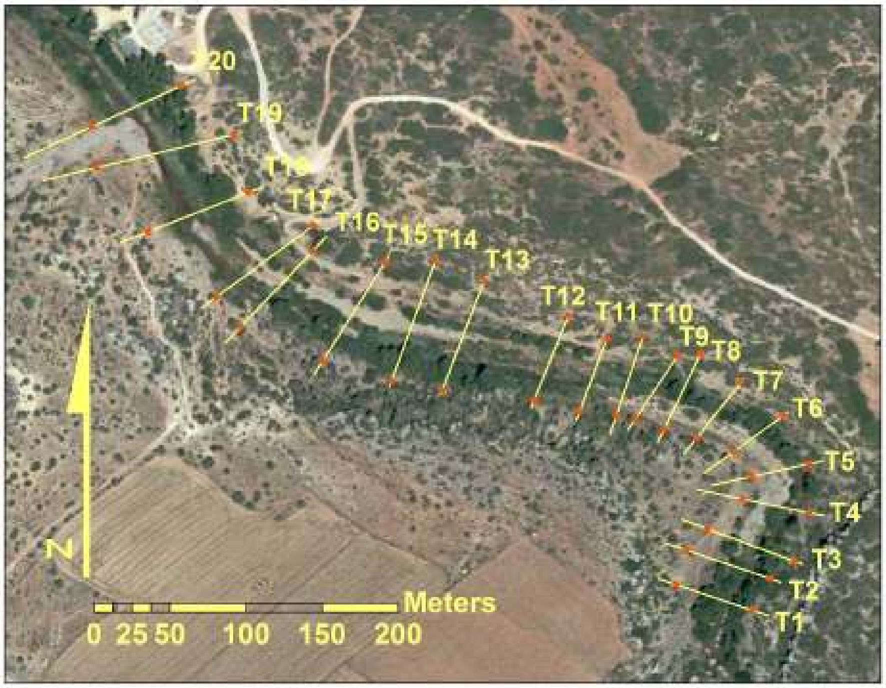


Figure 6.12. General view of the study site Mijares-Terde, including the location of the transects and steel rods (orange points).

To use the steel rods as reference in the survey, with absolute coordinates, we obtained three geodesic points (spatially distributed around the site) as a reference, provided by the Spanish Spatial Data Infrastructure (www.idee.es).

Table 6.4. Geodesic points used to provide the site with absolute coordinates.

Code	Name	Town	UTM ED50 (H 30)	Level (m)
61418	MOLINO	Sarrión	687518.530 – 4446109.330	986.20
59122	CALARIZO	Mora de Rubielos	688966.560 – 4453344.580	1012.50
61449	PILETA	Mora de Rubielos	695106.300 – 4447814.790	992.50

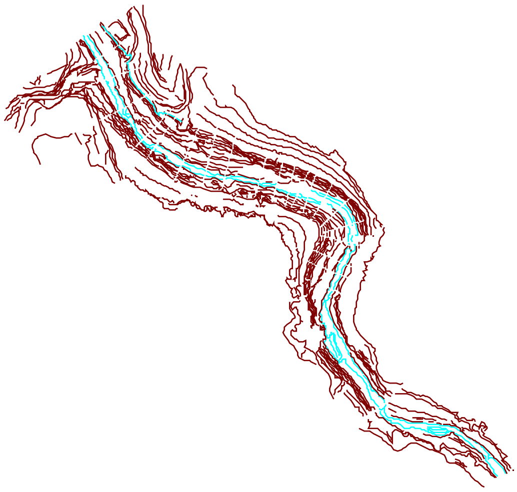
Absolute coordinates (X, Y, Z) were assigned to the top of each steel rod using a total station Leica GPS 1200 RTK (composed by two units: fixed and mobile). Previously, the 3 geodesic references were visited and introduced in the mobile controller. Once the fixed unit (base) was georeferenced (receiving data by radio), the surveyors were to the site to assign coordinates to the steel rods using the mobile GPS unit, measuring the GPS with the RTK method.

Figure 6.13. Assignation of absolute coordinates to the site. Fixed GPS unit (left) and mobile GPS unit in the Molino geodesic point (centre) and in the site Mijares-Terde (right).

The 3D quality of each measurement was obtained. The points with less quality were deleted and total station was used instead. This GPS of high precision was used in first place due to it was necessary to get good data of the rods, as they were the fix reference to evaluate the changes in water surface elevation.

6.2.4.2 Digital Elevation Model (DEM)

In order to have a proper topographic definition to develop a 2D hydraulic model, a Digital Elevation Model was built through a photogrammetric restitution. The interest area was flown on October 3rd 2009, with a Cessna T-310-R plane equipped with Ultra CAM-X cameras. The flight mean height was established at 698 m, with a longitudinal 60 m overlapping between each picture.



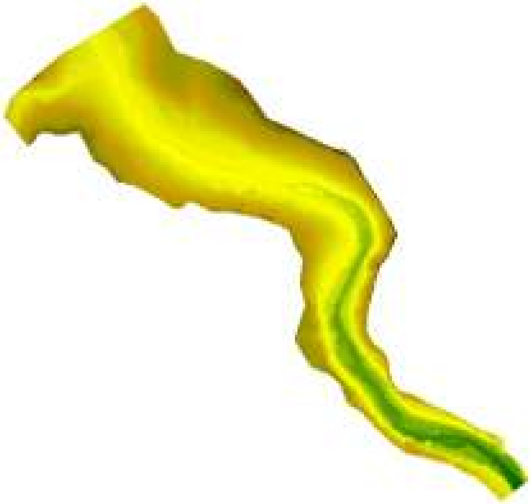


Figure 6.14. Photogrammetric restitution and digital elevation model (DEM).

6.2.5 Hydraulic survey

6.2.5.1 Water surface elevation

Together with the steel rods, also the water surface elevation was recorded in both banks of the 20 cross-sections with the mobile GPS (with RTK measuring system), in order to calibrate the hydraulic model. It was necessary to do all the work (topography and hydrometry) in a short period of time (some hours) in order to have a reliable relation between the water surface and the flow. After the survey of all the points in the sections, a direct measure of flow was done in the first cross-section downstream (direct method measuring depth and velocity). This section had excellent gauging quality (approximately permanent and uniform flow), stable substrate, no aquatic vegetation or helophytes and no turbulence.

The quality and hydraulic properties of this first cross-section were taken into consideration when the site was selected and delimited. It was important from the hydraulic modelling point of view to have permanent and uniform regime at the beginning and at the end of the site. For this reason, sections with very slow water, aquatic vegetation or high turbulence were discarded. The cross sections were located in relevant changes of the water surface profile, to allow a reliable simulation with the back step water method. The correct location of the cross sections is essential, because it must permit to calibrate the 2D hydraulic model with the water surface elevation in several points of the river profile. Only one field campaign (May 2009) was done in the Mijares-Terde to measure flow and water surface elevation in all the transects placed in the study site, for hydraulic simulation.

6.2.5.2 Hydrometry

To measure the hydraulic conditions and to estimate the flow rate, we used the area-velocity method. This method uses a classical hydraulic equation to calculate the flow (9.), in a cross section with area A. This equation is calculated approaching the integral, by means of the sum of the partial flows calculated for i virtual cells in which the transverse area is divided, i = 1, 2,…, n, of wide Δwi, average velocity V_i y depth D_i. Therefore, the flow is calculated like the formula (10.).

$$Q = \int_A V \cdot dA \qquad (9.)$$

$$Q = \sum_{i=1}^{n} V_i D_i \Delta w_i \qquad (10.)$$

The number of measurements depends on the width of the water surface and the topographical irregularity of the riverbed, and it was done to represent the topography of the cross-section. The depth Di was recorded in each cell with precision of 1 cm, with a graduated rod. The average water velocity Vi in each cell was measured in perpendicular direction to the cross section using an electromagnetic current meter of precision 0.001 m/s. The time of measuring the velocity in each cell was 15 seconds.

The number of measurements depends on the width of the water surface and the topographical irregularity of the riverbed, and it was done to represent the topography of the cross-section. The depth D_i was recorded in each cell with precision of 1 cm, with a graduated rod. The average water velocity V_i in each cell was measured in perpendicular direction to the cross section using an electromagnetic current meter of precision 0.001 m/s. The time of measuring the velocity in each cell was 15 seconds.

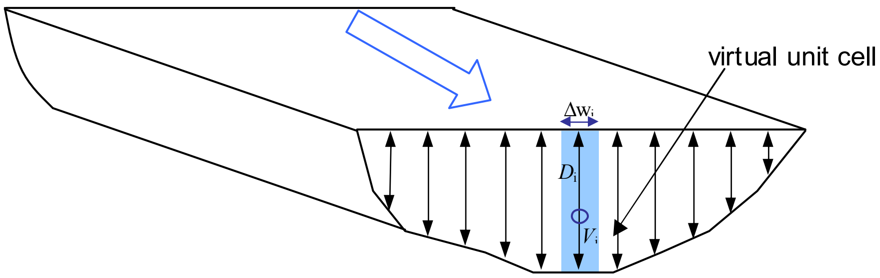


Figure 6.15. Area-velocity method to estimate the flow in a river section.

The points to measure velocity were the same when depth was measured; the number of points in the water column necessary to estimate the mean column velocity depends on the depth and other conditions that can produce an anomalous velocity profile (turbulence, coarse substrate, obstacles, etc.). In this case, the velocity was measured at 60% of the water depth (from the surface) because in general depth was smaller than 1 m. With these data, the velocity, depth and horizontal distance of the points, allowed us to calculate the flow rate with the equation described previously, which is implemented in the program of hydraulic and habitat simulation RHYHABSIM (Jowett, 1989).

6.2.6 Hydraulic modelling

6.2.6.1 Definition of aquatic, bank and floodplain zones

According to the requirements of the model, three areas were defined in the study site: aquatic zone (AZ), bank zone (BZ) and floodplain zone (FZ), based on the concept that magnitude and frequency of flooding governs the presence or absence and structure of riparian vegetation species. The criteria to define them were the following:

- **Aquatic Zone (AZ):** in the river Mijares this zone was defined as the area of the river channel under the base flow in the driest conditions for the vegetation (0.2 m^3/s).
- **Bank Zone (BZ):** is the area immediately adjacent to the AZ and just below the bankfull level, i.e. the river channel areas between 0.2 and 5 m^3/s. The vegetation living in this area is adapted to a high level of disturbance and has a short average life span.
- **Floodplain Zone (FZ):** is the least disturbed area and is localized over bankfull level. Therefore, the vegetation types tend to be more robust and well-developed.

This zone classification in the river Mijares is illustrated in the next figure. The grid had the same characteristics like the rest of them, i.e. the same grid extension, the same pixel size (1 m^2), etc.

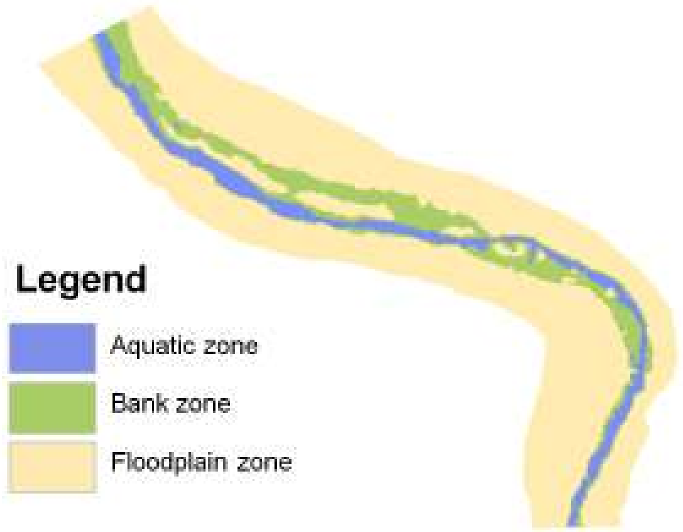


Figure 6.16. Map of river zones in the site Mijares-Terde.

6.2.6.2 Water table elevations (WTE)

Water table elevations (WTE) were obtained by performing 2D hydraulic simulations with the Guad-2D software for the following flow set: 0, 0.1, 0.2, 0.5, 1, 2.5, 5, 10, 20, 40 and 150 m^3/s. Besides the digital elevation model, the model needs, to be run, a Manning roughness shape and also hydraulic boundary conditions upstream and downstream of the river reach. Thus, the software solves the 2D shallow water equations.

Manning roughness coefficients were spatially assigned according to Cowan estimation procedure, taking into account granulometric and vegetation features along the river reach.

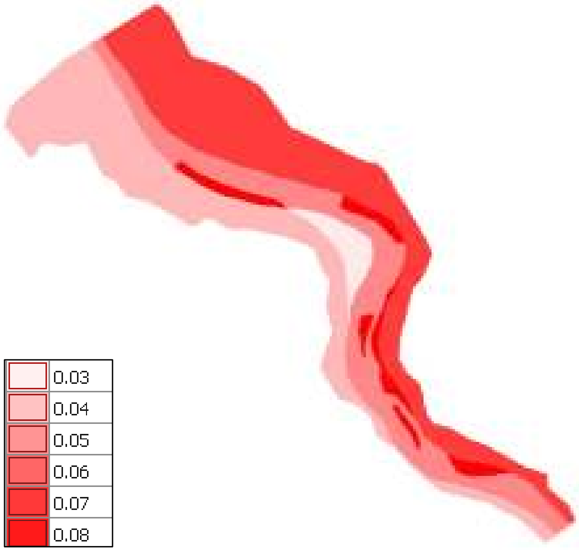


Figure 6.17. Manning roughness coefficients.

Boundary conditions correspond, upstream, to a flat hydrograph for each simulated flow and downstream to critical flow regime. The model results demonstrate that the T1 cross-section (the last one downstream of the studied reach) is upstream far enough from the end of the model to not be affected by this boundary condition.

Finally, the referred 11 simulations were performed and water depths and 2D velocities obtained for each case.

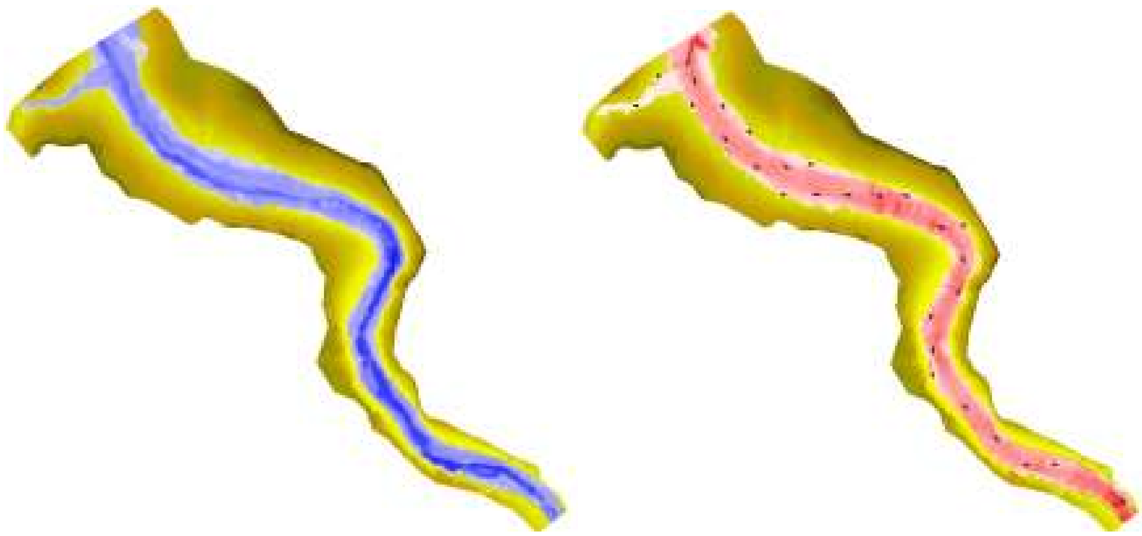


Figure 6.18. 2D Hydraulic model outputs: water depths and velocities.

Once water depths obtained for each simulated flow, water table elevations (WTE) were interpolated to represent ground water level under dry banks along each side of the river wet main channel. These interpolations were done assigning by proximity (Thiessen algorithm) the nearest water elevation of the wet channel zone to its nearest dry bank zone. The result is the water table elevation (WTE) shape set.

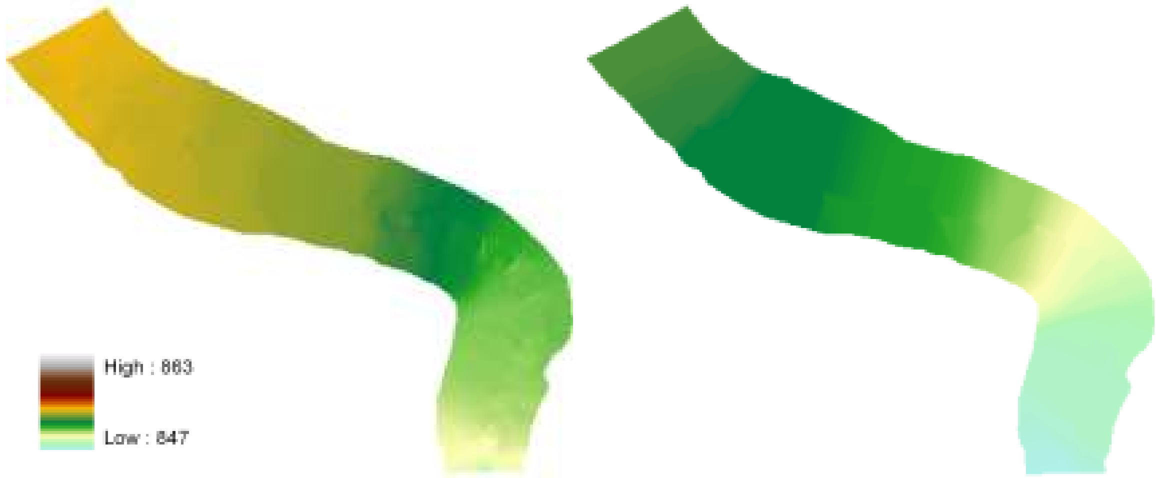


Figure 6.19. Water table elevations (WTE) for 40 m^3/s (left) and 0.1 m^3/s (right).

6.2.6.3 Shear stress (SS)

Another input needed for RIPFLOW model simulations is the shear stress (SS) produced on the river bed for each flow condition. Thus, according to water depths and velocities obtained from hydraulic simulations, shear stresses are deducted. The procedure is summarized as follows.

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. On the other hand, $v = C\sqrt{R_H I}$, where v is the flow velocity and C the Chézy roughness coefficient. Thus, combining both expressions, we obtain $\frac{v}{u^*} = \frac{C}{\sqrt{g}}$.

The Chézy coefficient and the Manning (n) one are related by the following expression:

$$C = \frac{1.49}{n} R_H{}^{1/6} \qquad (11.)$$

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:

$$u^* = 2.102 \frac{v \cdot n}{y^{1/6}} \qquad (12.)$$

Finally, bed shear stresses are evaluated as $\tau = \rho \cdot u^{*2}$ where ρ the water density. Velocity and water depth shapes were previously obtained with hydraulic simulations and Manning roughness shapes are those used as parameters of the hydraulic model.

Figure 6.20. Shear stress (SS) for 40 m^3/s (left) and 0.1 m^3/s (right).

6.2.6.4 Flood duration

The flood duration maps are one of the main inputs of the RIPFLOW v.3 model. Each year of the years of the simulation requires a map that stores in each of its cells the number of days the given cell is flooded. All the years of the simulation are reclassified into 5 different types: "very dry", "dry", "medium", "humid" and "very humid". Each of these classes is related to a CSV table that stores the approximate typical values of the daily river flows.

It is considered that a cell is flooded when the water table exceeds the elevation of the soil surface. A script in Visual Basic.net has been designed to calculate the flood duration (Figure 6.21).

This script requires the following inputs:

- An ASCII Map of the Digital Elevation Model (DEM).
- An ASCII Map Directory of the Water Table Elevation Maps for each river flow (WTE-Q).
- A CSV Table which stores the daily river flows for a given year (Qm^3/s)

The script carries out the following operations:

I. A linear interpolation is calculated between the Water Table Elevation (WTE) Maps and the Daily Flow data table, which produces a set of maps that show the WTE for each day.
II. The daily WTE maps are subtracted from the Digital Elevation Model (DEM). For each cell, if the obtained value is less than 0, then we consider that the cell is flooded during that day. Afterwards we count the total number of days that each cell is flooded.

After carrying out the previous operations the script gives the following output:

- An ASCII Map that shows the number of days in the year that each cell is flooded.

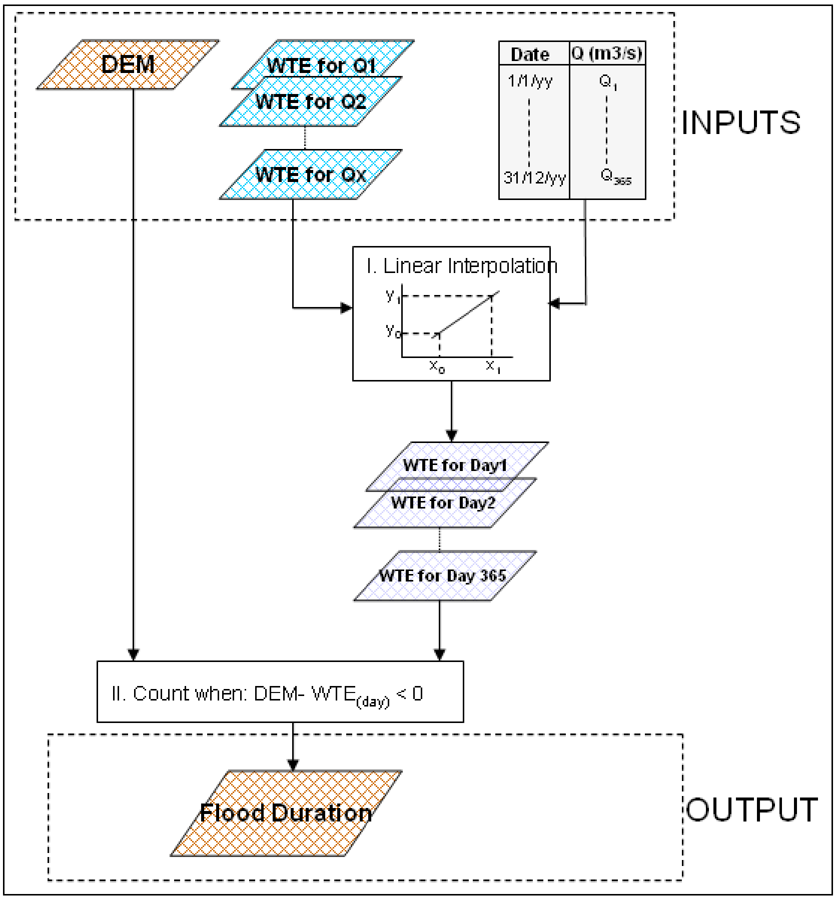


Figure 6.21. Flood Duration Script Calculation Procedure

The output flood duration maps have values between 0 and 366 (for leap years). The cells with less elevation will obviously have higher values than the cells with more elevation which are further away from the river bed (Figure 6.22).

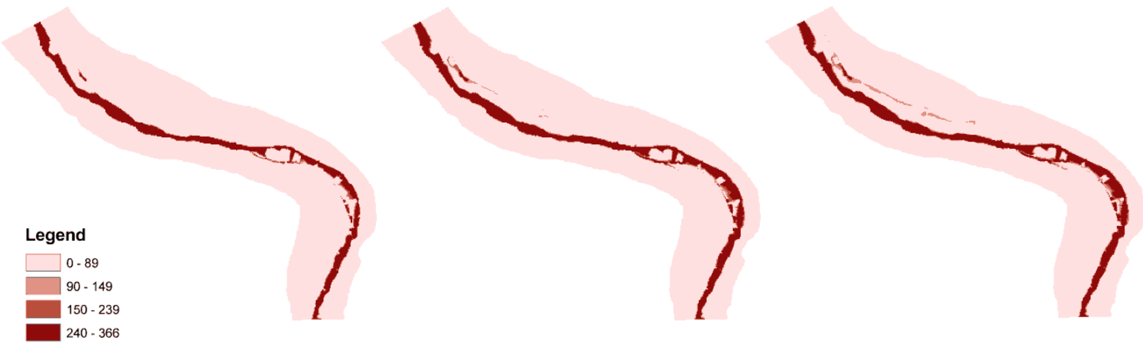


Figure 6.22. Example of output maps of flood duration.

6.2.7 Vegetation survey

Several reconnaissance walks were done in the site during spring-summer 2010, in order to draw a first draft of the vegetation patches present using printed aerial photographs (A3). The patches were delineated over the aerial photographs. Each patch was codified with a numerical code and a short description of them was also noted down. After this first general draft of the patches, they were characterized using the following field sheet.

Table 6.5. Field sheet for vegetation mapping.

VEGETATION MAPPING - RIVER MIJARES (STUDY SITE: TERDE)						CODE	
Date	Surveyors	Vegetation Type name					
X-Y GPS		**STRATUM**	**HEIGHT**	**COV %**	**DOMINANT SPECIES**		
Cross-sections		ST1 - Tree layer					
Elevation (m a.s.l.) Area (m2)		ST2 - 2nd tree layer					
Plant functional type (BS, RH, RJ, RA, TV)		ST3 - Shrub layer					
Succession (IP, PP, HP, SP, ES, EF, MS, UF)		ST4 - Herb layer					
Series (WD, RE, WE)		ST5					
Max DBH trees		**SPECIES**	**HEIGHT**	**DBH**	**DBH**	**DGL**	**DGL**
Max age trees							
SOIL PARAMETERS							
Thickness of upsoil (cm)							
% Bed rock (> 1024 mm continuous)							
% Boulders (256-1024 mm)							
% Cobbles (64-256 mm)							
% Gravel (8-64 mm)							
% Fine gravel (2-8 mm)							
% Sand (62 µm-2 mm)							
% Silt (< 62 µm)							
Organic matter							
O horizon							
A horizon (depth)							
Soil Moisture (dry, fresh, wet, sat, water)							
VEGETATION		**HYDROLOGICAL PARAMETERS**					
Herb		Height over water table (m)					
Shrub		Distance to water-edge at mean flow (m)					
Tree		Flood frequency class					
Bare bedrock		Geomorphic disturbance class					
Blank soil		Distance groundwater class (m)					

As can be seen, the field sheet consisted of several sections: general patch information, soil parameters, hydrological parameters and vegetation characterization.

Within **general patch information**, we recorded data related to the date of survey and the name of the surveyors, patch location (coordinates, cross-sections cutting the patch, elevation and area) and a first approach to the vegetation type. Elevation (i.e. average elevation of the patch above sea level in meters) and area (in m^2) were obtained after the field survey using the geo-referenced maps of the site. Also a first classification of the patch into a plant functional type, a succession series and a succession phase was noted down.

The possible categories were indicated (in a short way) in the field sheet:

- Plant Functional Type (PFT)
  - BS: bare sediment

  - RH: riparian herbs
  - RJ: riparian juveniles and small shrubs
  - RA: riparian adults trees and big shrubs
  - TV: terrestrial vegetation
  - NA: not applicable
- Succession phase
  - IP: initial phase
  - PP: pioneer phase
  - HP: herb phase
  - SH: shrub phase
  - ES: early successional woodland
  - EF: establish forest
  - MS: mature stage
  - UF: upland forest
- Succession series
  - WD: woodland series
  - RE: reed series
  - WE: wetland series

The definitions of these types are included in other sections of this report. The maximum diameter at breast height (DBH) of the vegetation was measured and an estimation of the maximum age of the trees was done; the maximum age was finally corrected with the growth curves after the field survey.

With the **soil parameters**, we recorded the characteristics of the soil surface. The cover percentage of every substrate type (according its size) was taken. The classes were bed rock, boulders, cobbles, gravel, fine gravel, sand and silt. The presence/absence of organic matter, O and A horizon was recorded in the field sheet with the option Yes/No. If the A horizon was present, an estimation of its depth was noted. Finally, in this section an estimation of the soil moisture was assigned for the entire patch, using the categories dry, fresh, wet, saturated. When several categories were present within a patch, the range of moisture was recorded, e.g. fresh-saturated.

With the **hydrological parameters,** five variables were evaluated:

- Height above water table (m). An estimation of the height of the whole patch over the water table was recorded in meters.
- Distance to water-edge at mean flow (m). The minimum and maximum distance of the patch to the water edge (aquatic zone) was measured using a measuring tape in those patches where this was possible. In the farthest patches this distance was estimated afterwards in a GIS.
- Flood frequency class (the indicator used was the flood return interval in years and a translation in the areas affected by an event of such magnitude)
  - Class 1: Very high [< 1 year]. Bank zone, every year
  - Class 2: High [1-3 years]. Bankfull, limit shrubs-trees
  - Class 3: Moderate [3-10 years]. Thin O horizon, woody debris, no A horizon
  - Class 4: Low [10-100 years]. Presence of A horizon
  - Class 5: Very low /none [> 100 years]
- Geomorphic disturbance class (the indicator used was the geomorphologic process type and intensity)
  - Class 1: Very high [< 1 year]. Intensive erosion/deposition, whole area, every year
  - Class 2: High [1-3 years]. Bankfull, limit shrubs-trees
  - Class 3: Moderate [3-10 years]. Thin O horizon, woody debris, no A horizon
  - Class 4: Low [10-100 years]. Presence of A horizon
  - Class 5: Very low /none [> 100 years]

- Distance to groundwater class
    - Class 1: Very high [> 3 m]
    - Class 2: High [1.5-3 m]
    - Class 3: Moderate [0.5-1.5 m]
    - Class 4: Low [0.1-0.5 m]
    - Class 5: Very low [0.1 m]

The **vegetation characterization** consisted of three sections, firstly an estimation of the different vegetation layers (using two approximations: the level of development and the vertical structure) and the secondly an age estimation of the patch.

Under the title of '**Vegetation**' were recorded the cover percentages of different vegetation types according their potential physiological stage. i.e., a poplar 30 cm high was classified into the tree class, not into the herb class. Also the percentage of the patch with bare soil and bedrock was recorded.

Under the title '**Stratum**' was considered the vertical structure of the patches, visually estimated in layers within each patch. The vegetation was classified into 5 different strata:

- Tree layer: tree species, canopy
- Second tree layer: tree species, sub-canopy, > ~ 6 m
- Shrub layer: shrub and tree species, ~ 1-6 m
- Herb layer: tree and shrub species < ~ 1 m and herbaceous species (herbs, graminoids, forbs and ferns)
- Climbing plants layer

For each strata/layer were recorded the cover (%), mean height (m) and dominant species. Finally, some individuals were selected for the **age estimation**. The species name, height, diameter of the stems at breast height (DBH, at 50 cm from the ground for shrubs and 130 cm for trees) and diameter of stems at ground level (DGL) were recorded to estimate the age afterwards by means of the available growth curves. Core samples were taken with the Pressler Drill in some selected individuals to complete the growth curves. Some of these procedures are illustrated below.

Figure 6.23. Different procedures during vegetation survey: DBH, DGL and height measurements (A-B-C), core samples extraction and conservation (E- F) and vegetation characterization (D-G).

6.2.8 Vegetation data processing

In this section are detailed the analysis of the field data in order to develop the growth functions of indicator species (e.g. poplar, willow shrubs) and how the patch information was processed. All this information was finally useful in the definition of the expert rules that were implemented in the model.

6.2.8.1 Growth functions

The core samples from riparian trees and shrubs were glued in wooden sticks and sanded down to increase the visibility of the growing rings. These were counted and growth curves were defined for each species, defining a relation between the diameter or height with the age. After that, the equations were applied to all the plants sampled during the field survey and an estimation of the age of the vegetation in each patch was obtained. The growth function for the *Juniperus* sp. was obtained from literature (Rozas *et al*., 2009), due to the terrestrial vegetation was measured but not cored. No functions were found for *Quercus coccifera*.

The data were completed with the samples taken in the same study site during the Ribera Project (MARM, 2009). Finally, all the information was referred to the end of the growing season of 2009, period that was considered as the end for the model simulations.

Table 6.6. Growth functions of the indicator species in the Mijares-Terde.

Specie	Growth function	Sampling size
Salix purpurea	AGE= 2,28367+2,14074*(DBH50)-0,036622*(DBH50)^2	28
Salix eleagnos	AGE = 5,05239+4,29125*log(DBH50)	46
Salix atrocinerea	AGE = (Log(DBH130)+0,565297)/0,173276	23
Salix alba	AGE = 4,33842+0,427715*(DGH)+0,242811*(HEIGHT)	22
Populus nigra	AGE = 4,65313+0,486221*(DBH130)-0,00233048*(DBH130)^2	53
Juniperus	AGE =0,2034*(DBH130)^2+3,7525*(DBH130)+5,998	-

6.2.8.2 Definition of succession series and phases

Two series were identified in the Mijares-Terde, the woodland and reed series. It was established that the colonization stage is common to both series, therefore only one initial and one pioneer phase was defined for both series. As can be seen in the figure below, after this colonization stage, both series take different paths during the transition stage. At this level differ the herb and shrub phase. Finally, the shrub phase within reed series can be integrated into the woodland series when the woody riparian shrubs can grow over the herbs and dominate the canopy of the patch. The transition stage moves toward more advanced phases and better developed and structured. At this level appear the early successional woodland and the establish forest. Finally, the riparian forest reaches the mature stage and under stable conditions riparian and terrestrial species can dominate together.

When disturbances of different kinds take place in the river, the retrogression may occur in reverse order of the succession.

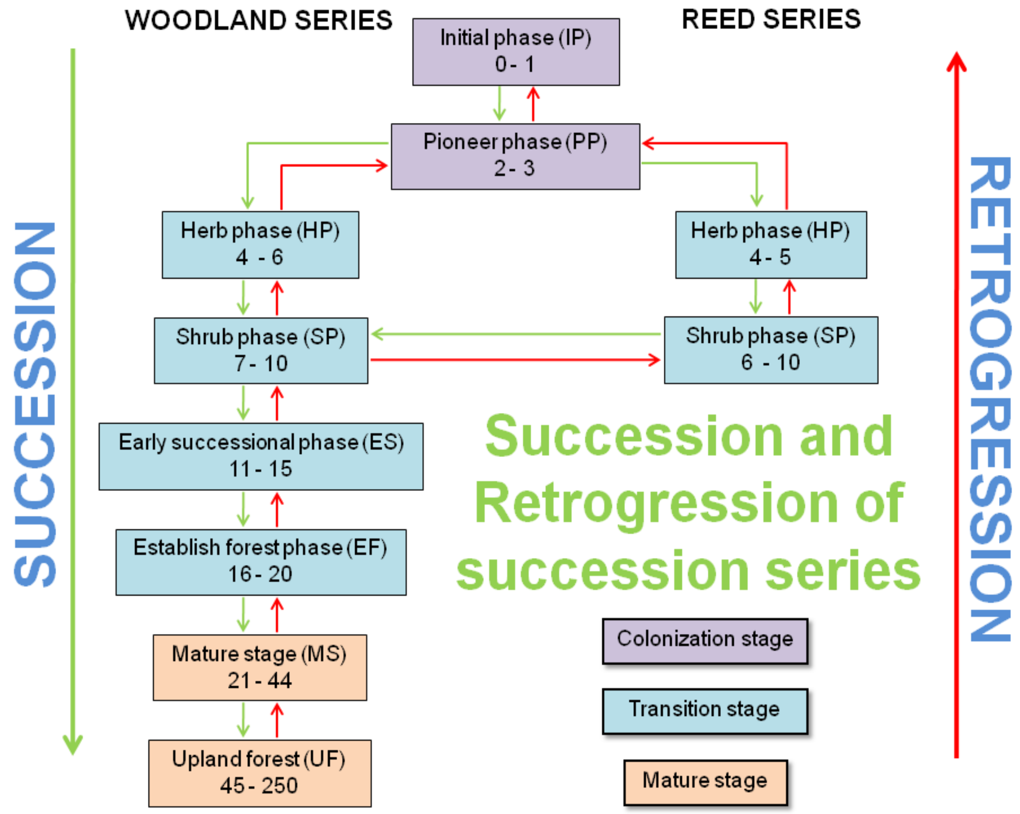


Figure 6.24. General model of succession and retrogression of phases in the Spanish study site (Mijares-Terde). The typical age range for the phases are also indicated.

The classification in phases was made according to the species and development stage of the plants.

- **Initial phase (IP):** new depositional landform (bare sediment), the groundwater table is near to surface and it has a high rate of disturbance. More or less without vegetation (less than 2-3 % cover). In the river Mijares this phase corresponds with gravel-cobble bars.
- **Pioneer phase (PP):** stage characterized by low (max. height 10-20 cm) and open vegetation (sparse), that starts to colonise and develop on newly formed or exposed substrate of low fertility, containing no remaining vegetation, no seed bank and no organic matter. Typically, it is a primary succession over sand and gravel bars after flooding. The standing biomass is very low, although the biomass production is high. The species diversity is low. The habitat conditions are crucial at this stage (enough water, light and open sediment to colonise), and the internal forces (like competition among plants) are not important. In the river Mijares this phase corresponds with young herbs and recruitment of early successional species like *Salix purpurea, Salix alba* and *Populus nigra.* These small seedlings usually cover less than 20-30% of the patch.
- **Herb phase (WD-HP):** patches colonized by annual and biannual herbs that more or less cover the entire patch (at least, cover > 30 % of the patch). In the river Mijares this phase corresponds with patches where the recruitment and the herbs can have the same height.

- **Herb phase (RE-HP):** patches colonized by herbs that cover at least 30 % of the patch area. In the river Mijares this phase corresponds with patches where reeds (especially *Phragmites australis*) are very abundant and there is little recruitment. This plant can grow very fast and usually cover the entire patch reducing the space and light for the scarce willow saplings.
- **Shrub phase (WD-SP):** the woody riparian saplings start to grow over the herbs. The standing biomass increases, the species diversity is higher and the average age increases. In the river Mijares this phase was identified when the willow species grow over the herbs and start to dominate the cover of the patch.
- **Shrub phase (RE-SP):** it occurs when some woody riparian saplings start to grow over the reeds and start to dominate the cover of the patch, shading the lower herbs. Then, a transition starts from this phase to the shrub phase into the woodland series.
- **Early successional woodland phase (WD-ES):** there is a vertical stratification by height. Some individuals are growing faster than others. The biomass of this phase is higher than in the previous one. The plant community is more persistent and complex and the species biodiversity increases. In the river Mijares this phase was identified when the *Salix alba* (tree) grows over the *Salix purpurea* and *S. eleagnos* (shrubs). At least 25% of the cover is dominated by willow trees.
- **Establish forest phase (WD-EF):** there is an initiation of understory species, normally shade tolerant species. These can be the same species as those present during the stand initiation stage but they grow slowly, creating a stand with multiple canopy layers. These patches are more stable and less disturbed. In the river Mijares this phase was identified when the *Populus nigra* (tree) reach and go above the *Salix alba* (tree). The *Salix atrocinerea* (big shrub) which started to grow also in initial phases but it is more shade tolerant starts to pass from the understory to the overstory canopy. It is common to find dead *Salix purpurea* and *eleagnos* (species that do not support the shade).
- **Mature stage (WD-MS):** it is an old growth stage. Individual trees die as a forest stand ages, opening up canopy space which is occupied by advanced regeneration in the understory. When the trees which invaded immediately following the initial disturbance die, the stand enters into an old growth condition. This is an autogenic process whereby trees regenerate and grow without the influence of external disturbances. There are living old trees and dead standing trees and diverse understory and many layers of vegetation. There is a mix of riparian trees and terrestrial trees. In this stage, long-living species will prevail, the biomass production is low but the standing biomass is high. In the river Mijares this phase was identified with the patches containing the oldest *Populus nigra* and *Salix atrocinerea* and some terrestrial trees like, *Juniperus* spp. and *Quercus* spp.
- **Upland forest (WD-UF):** terrestrial vegetation. The typical zonal vegetation in the area.

6.2.8.3 Vegetation maps

The draw of the outlined patches was traced using several overlapped transparencies (A4). They were scanned and assembled using the tool ArcScan of ArcGis 9.3 (ESRI). This tool let us also to convert the outlines into polygons. Finally, the shape of the polygons (patches) was adjusted and fixed where some small mistakes of the scanned appeared.

The vegetation map was adapted to a particular flood level, specifically the patches were defined in relation to the water surface in the driest conditions (i.e., 0.2 m^3/s as base flow). The map with the classification in vegetation types (with the corresponding phases and functional types) for the Spanish study site is portrayed in the figure below (Figure 6.25).

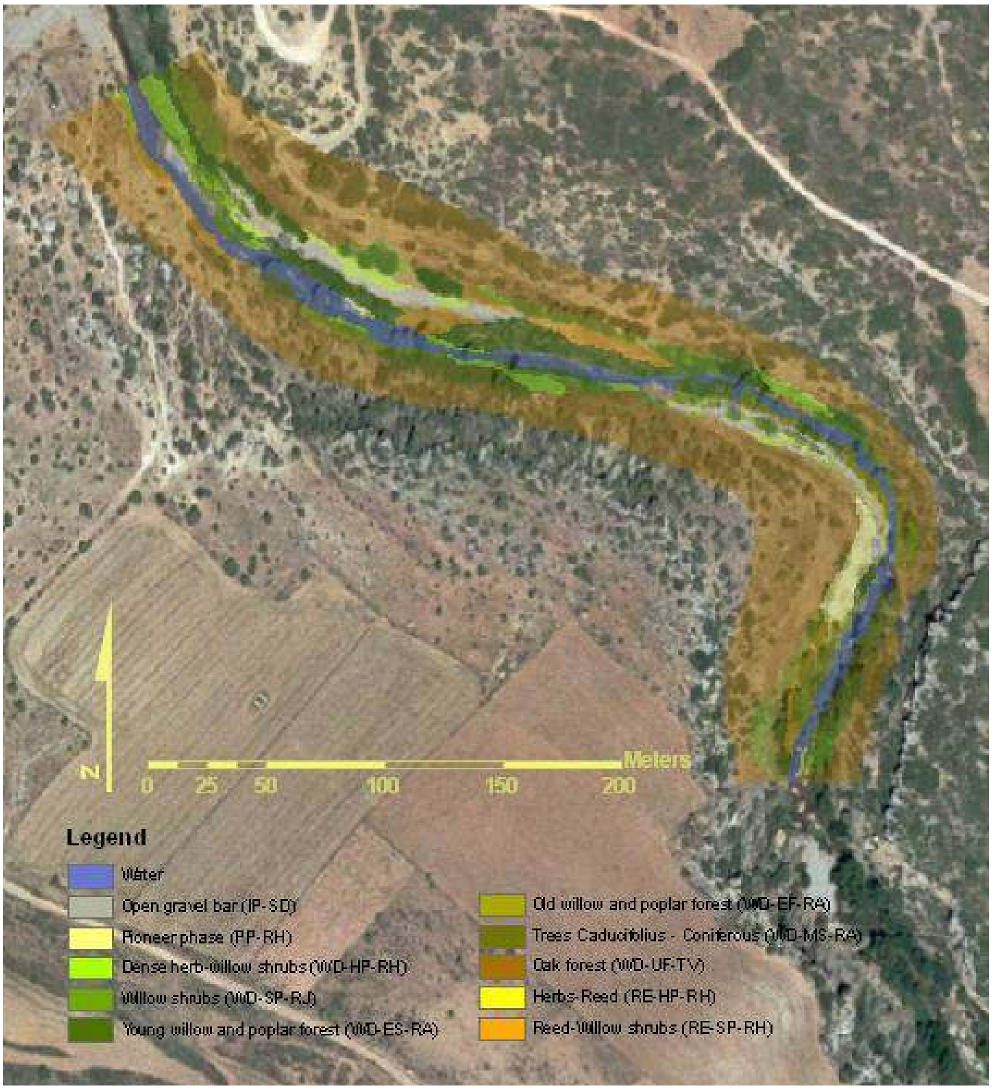


Figure 6.25. Vegetation types in the Mijares-Terde. The succession phases and plant functional types are also indicated in brackets.

6.2.8.4 Expert rules

Given the clear overlap between phases in the field, it was complicated to establish ranges of ages and height over base flow and bankfull flow, necessary for the starting condition sub-model. Gathering all the information for every patch (species samples) and comparing between phases was possible to establish some logical ranges.

6.2.8.4.1 Ages distribution and location of the vegetation in relation to base flow

In the following tables are summarized the ranges defined for the succession phases in relation to the succession velocity and height over base flow and bankfull flow.

Table 6.7. Height over base flow (HBSF), height over bankfull flow (HBNF) and succession velocity (years) for the woodland series.

Succession stages	Succession phases	Woodland series	Min. age	Max. age	HBSF (m)	HBNF (m)
Colonization stage	**Bank zone**					
	Initial phase (IP)	Open gravel bar	0	1	0 - 0.1	-
	Pioneer phase (PP)	Sparse herb-willow vegetation	2	3	0.1 - 0.2	-
Transition stage	Herb phase (HP)	Dense herb-willow shrubs	4	6	0.2 - 0.5	-
	Shrub phase (SP)	Willow shrubs	7	10	0.5 - 0.7	-
	Floodplain zone					
	Early successional woodland phase (ES)	Young willow and poplar forest	11	15	0.7 - 0.9	0 - 0.2
	Establish forest phase (EF)	Old willow and poplar forest (trees deciduous)	16	20	0.9 - 1.2	0.2 - 0.5
Mature stage	Mature stage (MS)	Trees Caducifolius - Coniferous	21	44	1.2 - 1.6	0.5 - 0.9
	Upland forest (UF)	Oak forest	45	250	> 1.6	> 0.9

Table 6.8. Height over base flow (HBSF), height over bankfull flow (HBNF) and succession velocity (years) for the reed series.

Succession stages	Succession phases	Reed series	Min. age	Max. age	HBSF (m)	HBNF (m)
Colonization stage	**Bank zone**					
	Initial phase (IP)	Open gravel bar	0	1	-1 - 0.1	-
	Pioneer phase (PP)	Sparse herb-reed	2	3	0.1 - 0.2	-
Transition stage	Herb phase (HP)	Herbs-Reed	4	5	0.2 - 0.5	-
	Shrub phase (SP)	Reed –Willow shrubs	6	10	> 0.5	-
	Transition to woodland series into the Floodplain zone					

6.2.8.4.2 Flood duration

Flood duration was estimated as the number of days per year (from 0 to 366) that water covers a floodplain area, inundating the whole root system of the vegetation. Flood duration can causes physiological stress to the plants, therefore it is one of the most frequent variables in the study of hydrological responses of riparian vegetation (Merritt *et al.,* 2009). However, in arid and semiarid regions, with natural flow regime, the flood duration can have a small relevance due to the water scarcity, and the prediction ability of this variable can be more related to its correlation with other environmental variables, such as soil moisture, depth of the groundwater table, shear stress, and also oxygen concentration in the soil (Auble *et al.,* 1994).

Intensity of disturbance of flood duration was classified into four classes (null, low, moderate and strong) depending on how many days a portion of the study site is submerged, by year. Each class is described below:

- **No impact.** It was considered that inundation duration between 0 and 89 days has no effect on the riparian vegetation. In fact, even the most flood-tolerant species need to be flooded at least 55-60 percent of vegetation season (Hall & Smith, 1955).
- **Low impact**. A flood duration between 90 and 149 days a year.
- **Moderate impact**. A flood duration between 150 and 239 days a year.
- **Strong impact**. A flood duration exceeding 240 days a year.

As a reference to define these critical values, several information sources were consulted, e.g. the response curves of hydrological variables for riparian woody species estimated in natural sites of the Jucar River Basin District (MARM, 2009). Mainly, the species considered here were *Populus nigra* and *Salix purpurea*, due to they had the largest sampling size in that aforementioned study (almost 200 vegetation units sampled).

Apart from the severity of the impact, the new community after the retrogression due to flood duration is depending on the existing community (specific succession phase), the stand age and the year type (very dry, dry, medium, wet and very wet). In the following figure is illustrated the general model of retrogression by flood duration, considering the different succession phases and the different levels of impact.

As can be seen, long flood duration (indicator for physiological stress) kills vegetation, which is usually associated with oxygen depletion in the root zone. If flood duration is longer than the critical values, it was considered that the well-developed phases (from ES to UP) will go back to the shrub phase, and the early phases (HP and SP) to pioneer phases.

These changes, known as “expert rules” in this model, were implemented into the model by changing the age of a patch (in a certain succession phase) to the minimum age of the new stage, according to the impact severity. For example, the upland forest that contains the less flood-tolerant species can regress to an earlier stage with low intensity of disturbance by flood duration. The resulting stage would be the Establish Forest (EF) where the vast majority of the species are flood-tolerant. By contrast, in the reed series the impact severity is lower and the retrogression is more gradual due to the species present in those patches are usually adapted to be submerged (e.g. *Phragmites australis*).

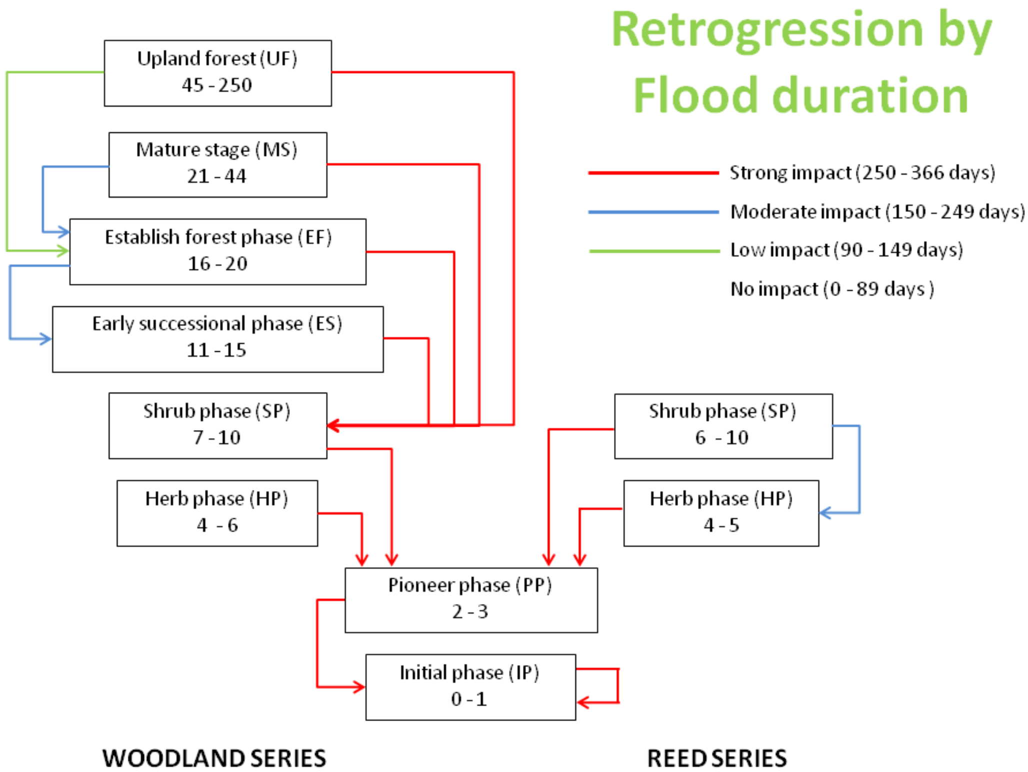


Figure 6.26. General view of the paths of retrogression due to flood duration, in the Spanish study site. The age range for every vegetation succession phase is indicated.

6.3 Austria

6.3.1 Study site location and description

The presented study case lies along the upper course of the Drau River, near the village of Lind Austria (Figure 6.27). In historic times the upper Drau was a braided river system with many side arms and gravel bars. Over the 20th century it has been canalized with consequent cutting of the side arms, loss of habitats and ultimately species decline. The site length is about 700 m, The hydrological regime of the Drau has its maximum discharge in June, while over winter discharge value are moderate with mean annual discharge of 74 m^3/s and a bankfull discharge of 320 m^3/s corresponding to one year flood recurrence interval.

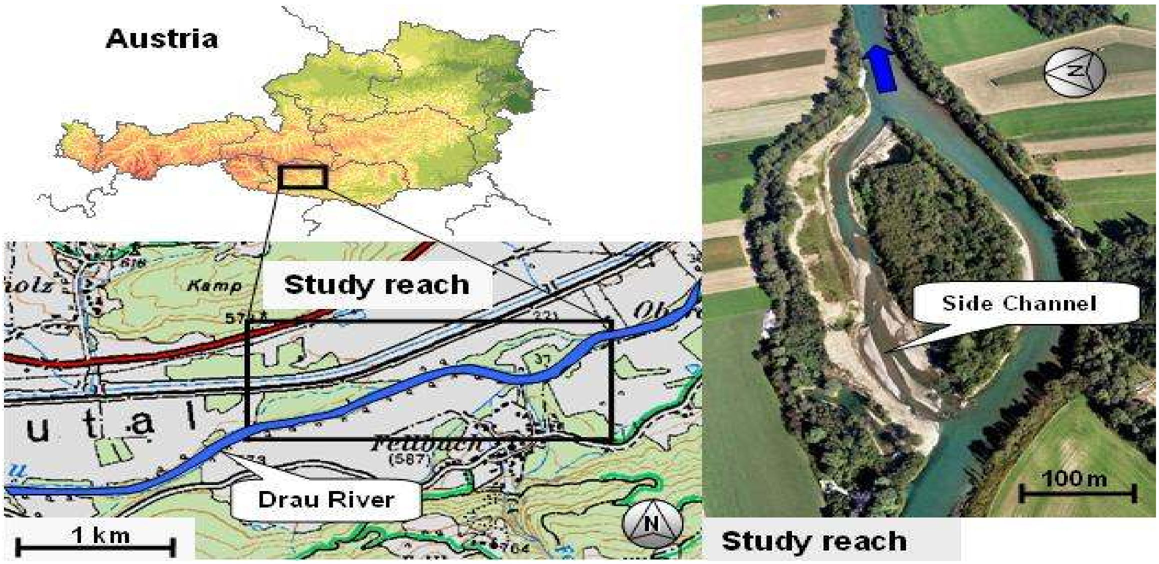


Figure 6.27. Study site location (Forman *et al.*, 2007)

Since the conclusion of the project, the site vegetation is periodically mapped. In the early post-project years, in the bank zone along the reach it has been sampled very little vegetation, consisting of tamarisk and willow pioneer shrubs (Forman *et al.,* in preparation). From 2005, it has been found pioneer vegetation, tamarisk and willow pioneer-shrubs while large parts of the bank zone where still cover by gravel and sand bars. In the following two years, the pioneer vegetation, tamarisk and willow pioneer-shrubs stands lying in the less flow-disturbed plots progressed in their growth while in the rest of the site, there was an active turnover of the vegetation among gravel, pioneer and pioneer-shrub. These processes where accompanied by progressive sedimentation in the dug (side) channel which enlarged the bars within the channel and lift their elevation above the water. In 2008 the vegetation was a mosaic of tamarisk and willow shrubs and pioneer-shrubs, pioneer vegetation and fairly large patches of gravel and sand. In the last two mapped years, 2009 and 2010, the vegetation composition was similar to 2008, however, it has been observed a reduction of the gravel and sand bars with very little vegetation turnover. In order to mitigate the negative effects of the sedimentation in the side channel, in 2009 and 2010, the project contractors sponsored the excavation of the deposited sediments.

6.3.2 Digital Elevation Models

For the Austrian study case there have been used two (Figure 6.28) digital elevation model (DEM). The first portrays the study site morphology in 2003 while the second depicts the situation in 2008. Both digital elevation models have been used also in the hydraulic inputs modelling process

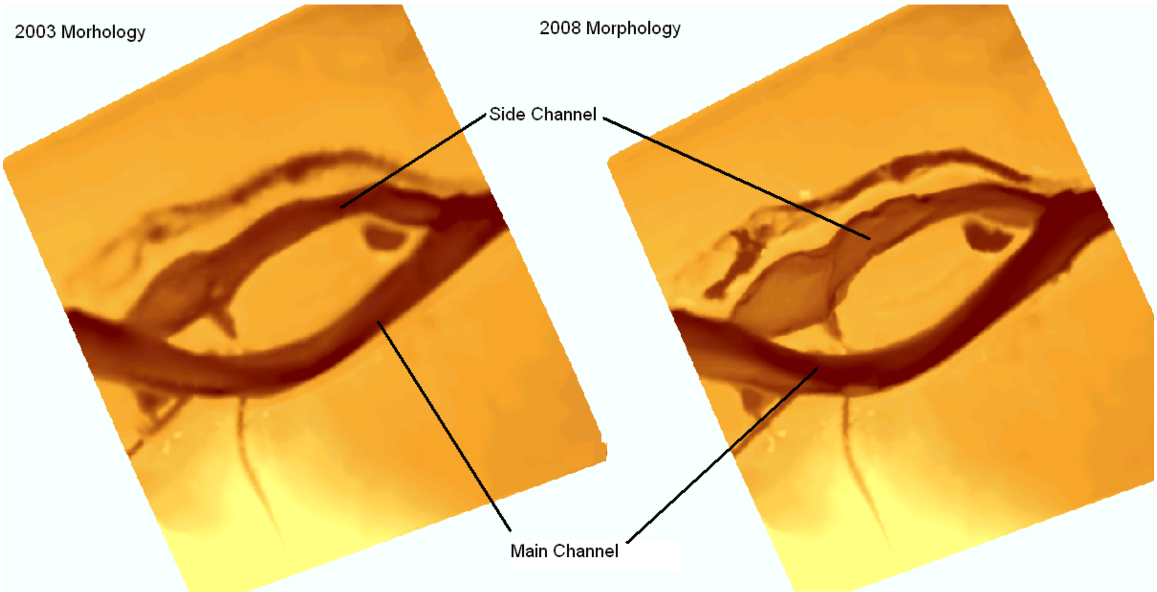


Figure 6.28 Digital Elevation Models used in the dynamic vegetation model and hydraulic modeling

Both DEM in Figure 6.28 have been used in the calibration process and, in an exclusive fashion, in the management scenario simulations. For the reference period and the climate change scenarios, only the right most (DEM 2008) has been applied.

6.3.3 Hydrological Data

In the Austrian region the typical hydrological regime is glacio-nival with the maximum discharge in the late spring season, between May and June. According to the reviewed literature about climate historic records, the trend analysis of the last decades shows a progressive reduction of the precipitations in solid form (snow) and a rose of the winter temperatures. These combined effects will lead to more abundant rains in the fall-winter season and to the reduction of the head waters glaciers. As ultimate consequence, the maximum discharge peak will switch its seasonality from the late summer to the fall-winter season, when the most of the precipitations occurs but are no longer retained at high elevations in form of snow or ice. The mutated hydrological flow regime would then be more alike the typical Mediterranean flow regime, where the maximum discharges are registered in winter and the summer flow is instead low due to the lack of precipitations and absence of water storage in the head waters glaciers.

For the application of the model to the Austrian study case the relevant hydrological data to be gathered where the maximum year discharge and the mean spring discharge. The first is relevant because directly responsible for the yearly maximum shear stress which exerts a disturbance effect on the vegetation with the consequence of renewing, by disruption, the vegetation stages. On the other hand, the mean spring discharge is relevant for the recruitment of the seedlings. Other variables bound to soil moisture or flood duration (physiological stress) have been neglected. This because, for the first, the vegetation mapping campaign and the cross comparison with the mean spring discharges, demonstrate that even in dry years, the soil conditions in the bank zone are favorable to the vegetation establishment. For the latter, physiological stress, it has been observed that even with large recurrence interval floods, the water level is negligible.

6.3.3.1 River discharge

The base discharge data for the model simulations, calibration and for the calculation of the hydraulic inputs required by the model where collected at the Sachsemburf gauging station which covers a draining basin an area of 2561.4 km2 and is located upstream, on the east side, of the study site (
Figure 6.29).

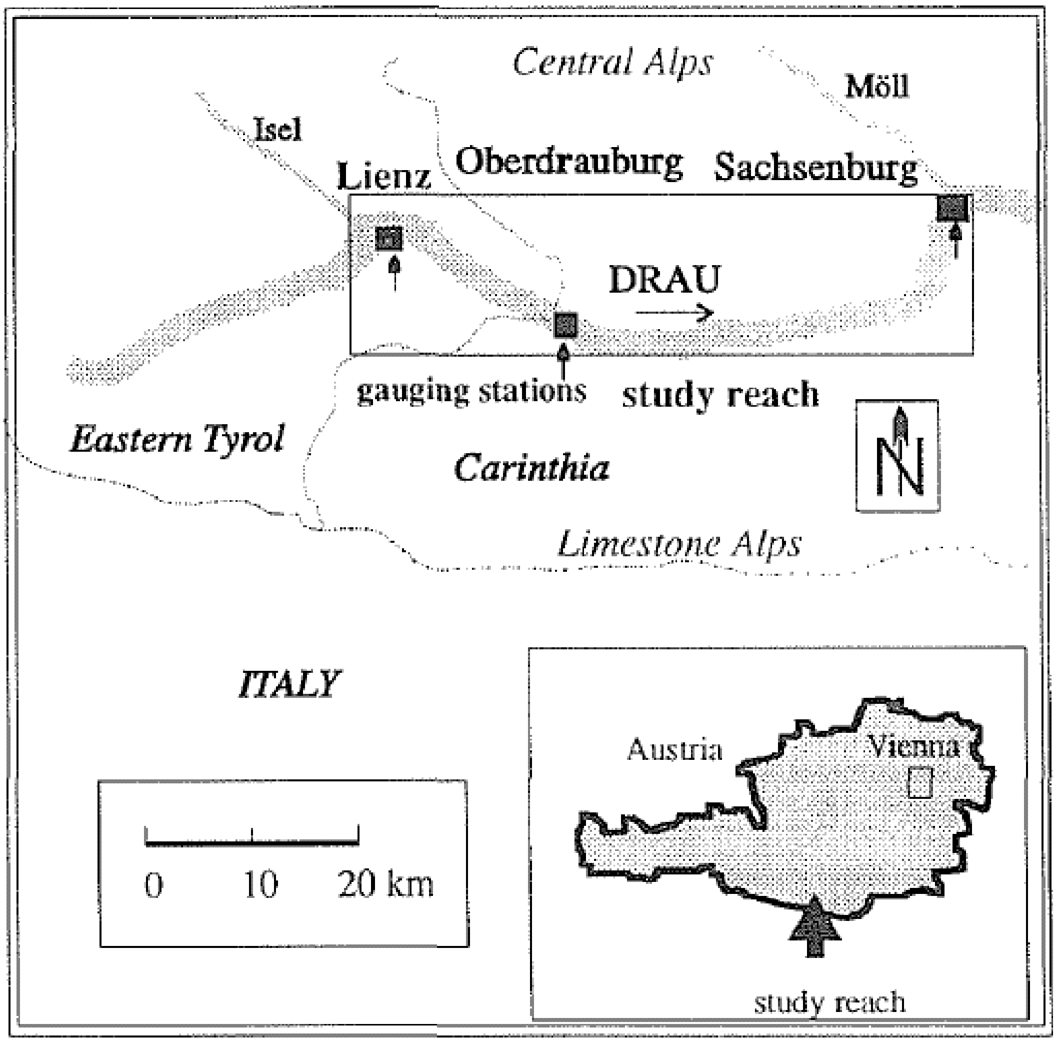


Figure 6.29 Location of the Sachsenburg gauging station (Habersack & Nachtnebel, 1994)

6.3.4 Hydraulic Modeling

The static and dynamic components of the model make use of hydraulic data which need to be simulated with the Hydraulic software. The basis for these calculation are hydrometric data such maximum yearly discharges and flood recurrence interval classes (HQ). Once these data have been collected, each project partner provide individually to the gathering-calculation of the hydraulic data required for the model.

Hydrodynamics were simulated using the two dimensional numerical flow model RSim-2D, a part of the RSim river modeling framework (Tritthart, 2005). The applied integrated hydrodynamic-numerical model is based on the Finite Element method, a triangular mesh and the Smagorinsky turbulence closure and delivers depth-averaged flow velocities. Several discharge classes between mean discharge and the discharge of a 300-year-flood were modeled. The resulting flow variables as flow velocity, water surface elevation, water depth and bed shear stress during peak flow, as well as the maximum shear stress during the entire hydrograph of corresponding flood discharge class were calculated in every computation point. The groundwater table elevation (WTE) was approximated from the calculated water surface elevation. These data were prepared as raster maps to be included into the Dynamic Vegetation Model. However, for the use in this specific study case, the hydraulic inputs required by the model where solely water depths for the two years recurrence interval flood, shear stress maps and ground water elevation tables.

6.3.4.1 Definition of aquatic, bank and floodplain zones

The dynamic vegetation model applies different recruitment rules to different locations (riverine zones) of the study site which are defined as aquatic, bank and floodplain zone. These three zones, for this study case are depicted in Figure 6.30.

- **Aquatic Zone (AZ):** was defined as the area of the study site occupied by water during mean discharge
- **Bank Zone (BZ):** was defined as the portion of the study site flooded by a two years recurrence interval flood, with the exclusion of the aquatic zone
- **Floodplain Zone (FZ):** was defined by exclusion. The area of the study site not encompassed by neither bank zone nor aquatic zone has been classified as floodplain zone.

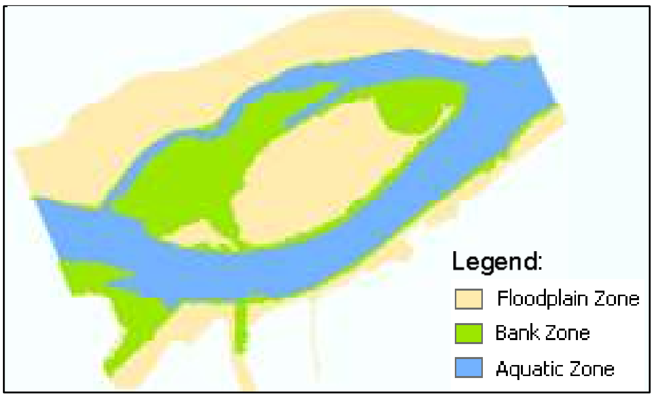


Figure 6.30. Map of river zones at the Upper Drau

6.3.4.2 Water table elevations (WTE)

For the Austrian case studies it has been considered the groundwater table, which has been yield by interpolation of the river water level measured for five discharge classes.

Table 6.9 Discharge classes used to interpolate the WTEs

Discharge (m^3/s) Class
80
100
125
140
160

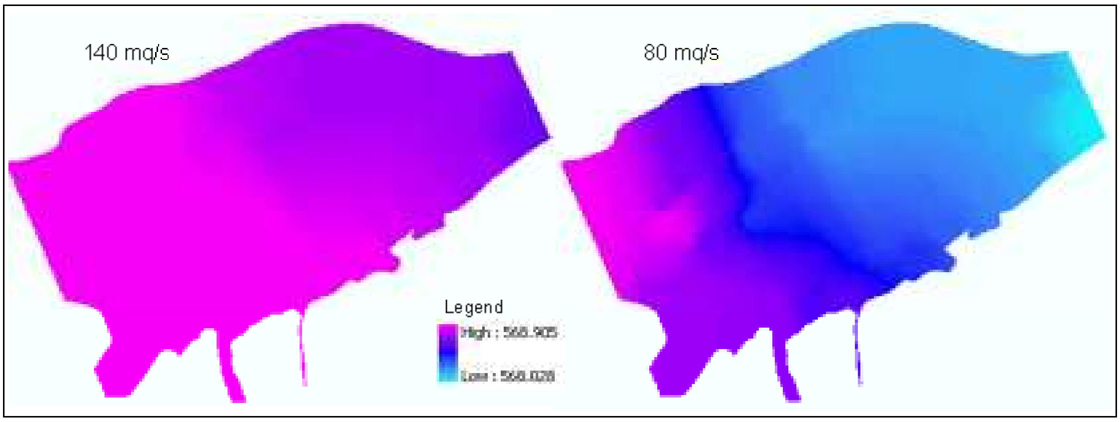


Figure 6.31 Groundwater table elevation for the 140 m^3/s (left most side) and 80 m^3/s (right most side) mean spring flow

6.3.4.3 Shear Stress

The shear stress grids where computed fort the recurrence interval discharges in Table 6.10. Several shear stress grids, yield from the hydraulic model are depicted in Figure 6.32.

Table 6.10. Recurrence interval (HQ) discharges for the Austria natural reference site.

Discharge (m^3/s)	HQ Classification
270	0.5
320	1
380	2
490	5
590	10
790	30
1050	100
1140	150

1310	300
1980	5000

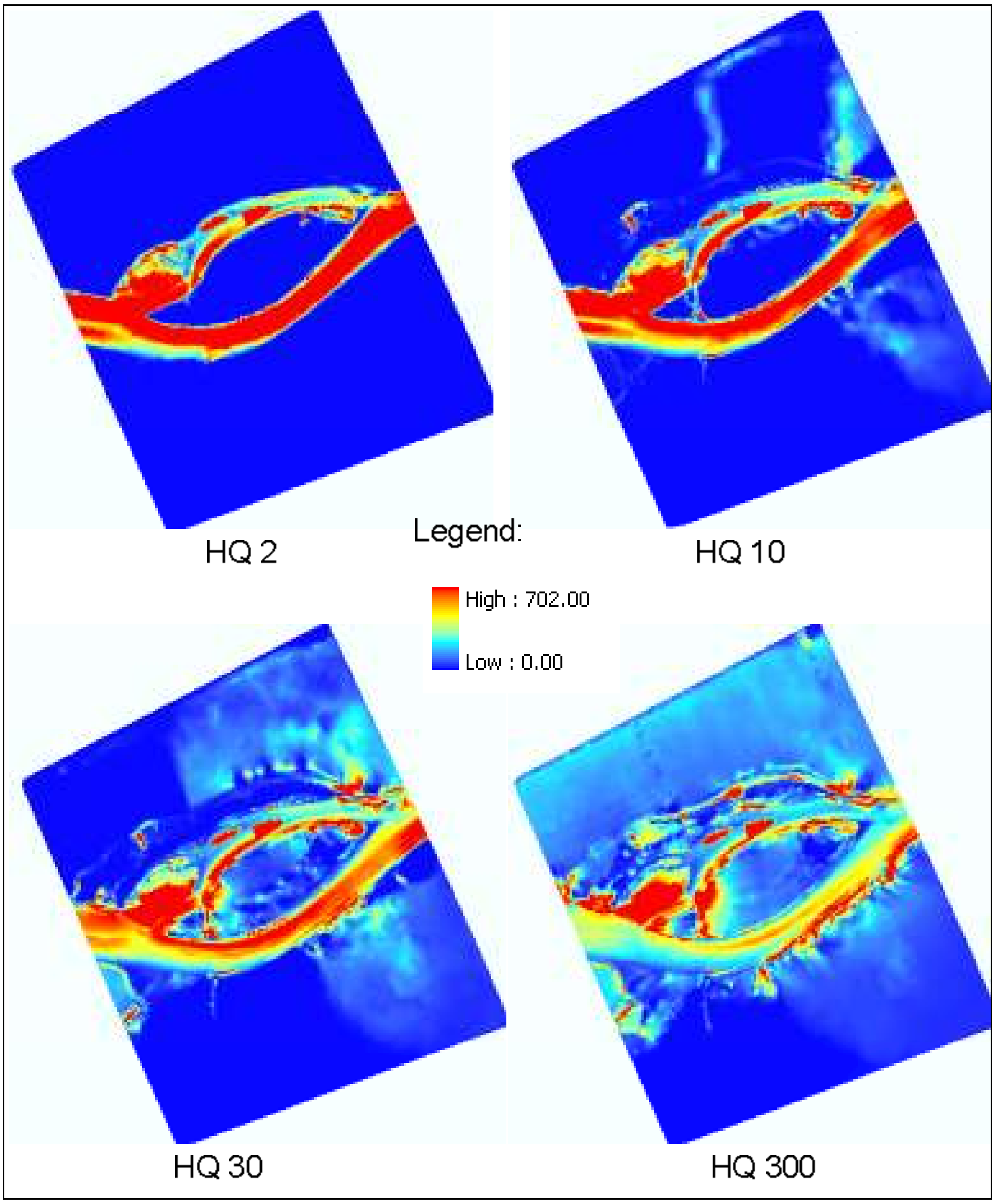


Figure 6.32. Shear stress raster grids yield from the hydraulic model from different HQ discharges.

6.3.5 Vegetation Survey

The analysis of climate change impacts on the vegetation requires a detailed picture of the current status of the plant communities along the selected study sites. In Table 6.11 is depicted an example of the plants species dominant types sampled in the Austrian natural reference site.
Figure 6.33 portrays the spatial distribution of these plant types and the other landscape features mapped in the site. The sampling method applied in the mapping campaigns conducted at the Upper Drau can be resumed as follows. The approximate edges among vegetation types patches are defined from aerial photo interpretation. These edges are sketched in polygons onto the aerial photo, the exact composition and attributes of the patches are then sampled on the field, eventually, the edges of the patch polygons are rectified and corrected during the field observations. Once the field sampling has been concluded, the attributes measured are associated with the patch polygons originally sketched. Finally these polygons are exported in shape files and are ready for further processing.

Table 6.11. Dominant vegetation species mapped in the Austrian natural reference site.

Dominant Species	Area (msq)
Vegetation-Gravel	23737.324
Pioneer Vegetation	424.761
Reed	110457.57
Calamagrostis	105732.078
Reed -Typha Minima	25230.107
Willow-Pioneer	50148.962
Tamarisk-Willow	87628.857
White-Willow	19567.28
Willow-Shrub	104792.206
Alder-Willow Shrub	21267.691
Grey-Alder	40671.5021
Spruce Forest	14491.765

The vegetation in the Austrian reference site where regularly sampled over the last seven years. The outcome of each year survey was an ESRI™ shapefile which stored the vegetation type (species) or soil cover type (i.e. human managed areas or agricultural land).

6.3.6 Vegetation data processing

In order to effectively compare the results across the different team, the plant dominant types have been classified on with a common standard which makes use of the concept of succession phases. The classification in phases is made according to the species and development stage of the plants. The choice of this method is very suitable in this international context where a species to species comparison can be hardly performed, especially when comparing Alpine vegetation with the Mediterranean. For the Austrian study case, the approximate edges among vegetation types patches are defined from aerial photo interpretation. These edges are sketched in polygons onto the aerial photo itself, the exact composition and attributes of the patches are then sampled on the field, eventually, the edges of the patch polygons are rectified and corrected during the field observations. Once the field sampling has been concluded, the attributes measured are associated with the patch polygons originally sketched. Finally these polygons are exported in shape files and are ready for further processing.

6.3.6.1 Definition of succession series and phases

The vegetation sampled along the reference site over the different years has been classified in succession series and succession phases which are temporally consecutive development stages of the vegetation. In
Figure 6.33 is portrayed the vegetation sampled in the reference site back in the year 2010. In the figure legend are listed both the vegetation and soil cover types sampled at Kleblach.

The vegetation types mapped in the study site (i.e. 2010,
Figure 6.33) have been classified in succession phases according to their development stage. The succession phases have a defined age range that is the key attribute to set the parameters values in the dynamic vegetation model. Each succession phase has been deemed to belong to a succession series. The succession series for this study site are three namely: woodland, reed and wetland series. Woodland series and reed series share the initial and pioneer phase. The woodland series has in its last phase, the climax of the ecosystem. All the succession but the Initial Phase (IP), are characterized by a typical phytosociological association. Pioneer Phase (PP) association is made up by Myricario-Chondrilletum Br.-Bl. in Volk 1939, Rumici crispi-Agrostietum stoloniferae Moor 1958 and Salici-Myricarietum Moor 1958. Herb Phase (HP) includes Calamagrostietum pseudophragmites Kopecký 1968. Pioneer Shrub Phase (PSP) and Shrub Phase (SP) are constituted by Salici-Myricarietum Moor 1958 and Salicetum triandrae Malcuit ex Noirfalise in Lebrun et al. 1955. Early successional woodland phase (ESWP) association is instead represented by the Salicetum albae Issler 1926. (Egger et. Al. in press). It has to be stressed out that for all the simulations, the focus of the analysis was on the bank zone since that in this specific case, it the most relevant to evaluate the different scenarios implications on the floodplain vegetation.

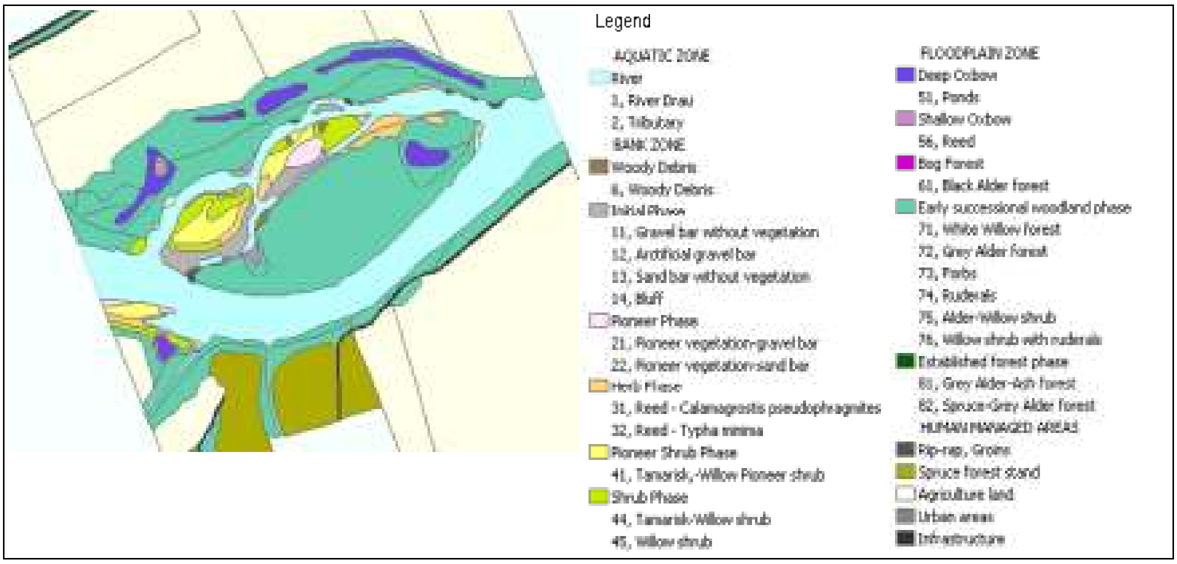


Figure 6.33 Vegetation mapped along the Austrian reference site (Kleblach) in 2010. Legend encompasses the vegetation types of each succession phase, grouped by riverine zone

Each succession phase is typically found in a specific riverine zone, either bank or floodplain.

Table 6.12 summarizes the information listed in

Figure 6.33. On the right most column, Succession Series and Phases, are listed the name of the succession phases and the succession series to whom the phase belongs. The left most column, Local Vegetation Type, stores the vegetation types or the soil cover types (portion of the site not occupied by vegetation) which belong to the phase listed on the right.

Table 6.12 Correspondence between the vegetation mapped along the Austrian natural reference study site and the succession phase into which the vegetation has been classified

Succession Series and Phases	Local Vegetation Type
BANK ZONE:	
Initial Phase (Reed & Woodland Series)	
	Gravel bar without vegetation
	Artificial gravel bar
	Sand bar without vegetation
Pioneer Phase (Reed & Woodland Series)	
	Pioneer vegetation-gravel bar
	Pioneer vegetation-sand bar
Herb Phase (Reed Series)	
	Reed - Calamagrostis pseudophragmites
	Reed – Typha minima
Pioneer Shrub Phase (Woodland Series)	
	Tamarisk,-Willow Pioneer shrub
Shrub Phase (Woodland Series)	
	Tamarisk-Willow shrub
	Willow shrub
FLOODPLAIN ZONE:	
Deep oxbow (Wetland Series)	
	Ponds
Shallow oxbow (Wetland Series)	
	Reed
Bog Forest (Wetland Series)	
	Black Alder forest
Early successional woodland phase (Woodland Series)	
	White Willow forest
	Grey Alder forest
	Forbs
Bare Soil (Woodland Series)	
	Ruderals
	Alder-Willow shrub
	Willow shrub with ruderals
Established forest phase (Woodland Series)	
	Grey Alder-Ash forest
	Spruce-Grey Alder forest

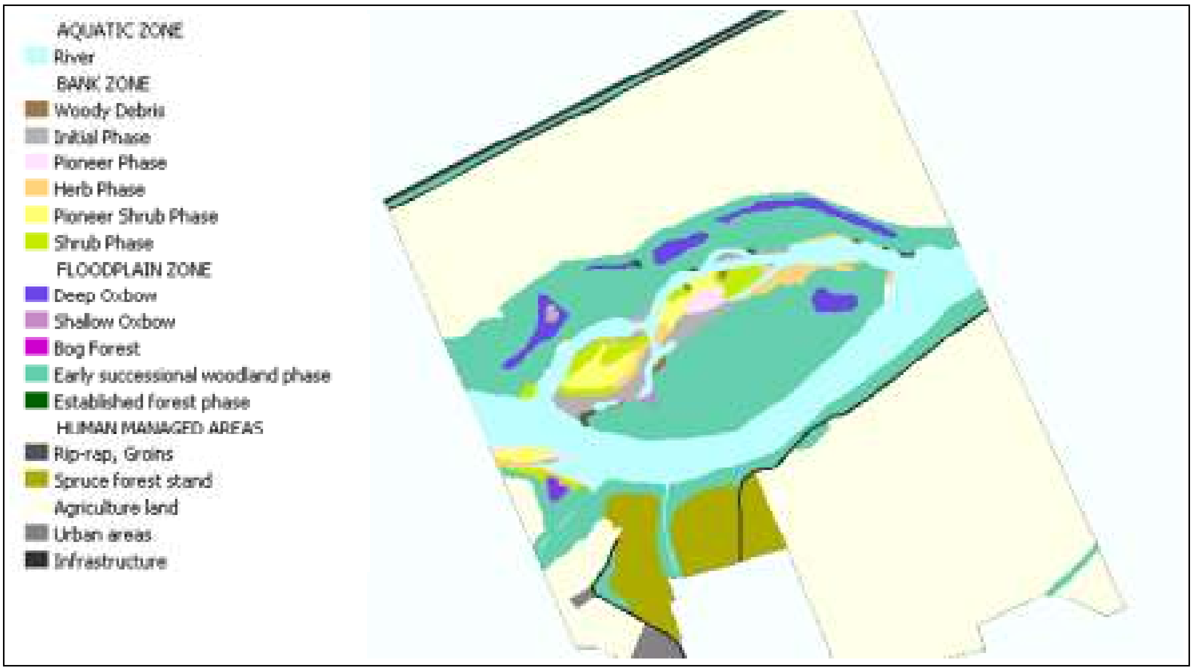


Figure 6.34 Map of the natural reference dominant vegetation types classified in succession phases

6.3.6.2 Vegetation Maps

Exploiting the information in

Table 6.12 the sampled vegetation maps have been processed to reclass the vegetation species to succession phases.

The classification in phases for the Austrian natural study site is portrayed in Figure 6.34. The data processing involved a two steps procedure. At first the shapefile resulting from the different sampling campaigns where treated to remove all the human managed areas such infrastructures or agricultural land. The removal of these land uses has been performed because, since that the dynamic vegetation model does not take into account human influences on the land use, such information in the inputs maps would not turn of any use. In a second moment, the shapefiles have been processed to rename the vegetation names according to the succession phase, in other words, it has been applied the correspondence succession phases-local vegetation type listed in

Table 6.12. Second step has been the conversion of the shapefiles in ESRI™ raster grids. All the vegetation maps data lineage has been performed with the aid of custom developed python script. The resulting vegetation raster grids are depicted in
Figure 6.35.

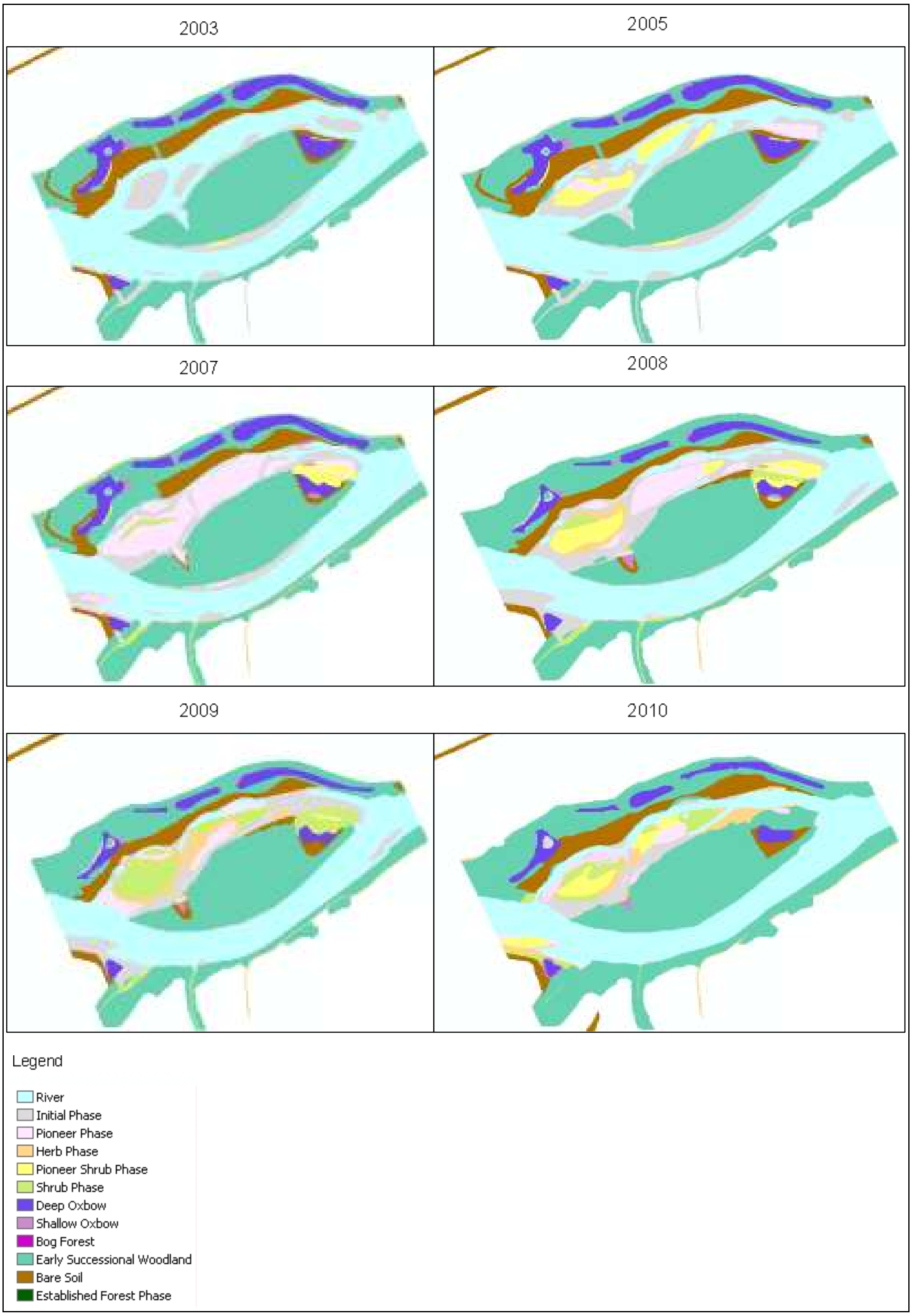


Figure 6.35 Esri raster grids of the vegetation sampled at Kleblach and classified in succession phases

6.3.6.3 Expert Rules

The expert rules required to model the Kleblach study case where mainly the age ranges of the different succession phases.

6.3.6.4 Ages distribution

The age intervals (minimum and maximum age) of the succession phases have been evaluated based on the observation of the maps (
Figure 6.35) to estimate the transition time between a succession phase and the following one. The map analysis has been aided by judgments of the technical personnel who performed the sampling campaign during the years and consequently develop hands on knowledge about the evolution of the reference site riparian ecosystem. The age span of each succession phase is listed in Table 6.13.

Table 6.13 Age span of the succession phases found along the Drau natural reference site

Phase Name-Zone	Age Range
BANK ZONE:	
Initial Phase (Reed & Woodland Series)	0 - 1
Pioneer Phase (Reed & Woodland Series)	2 - 2
Herb Phase (Reed Series)	3 - 7
Pioneer Shrub Phase (Woodland Series)	3 – 3
Shrub Phase (Woodland Series)	4 – 10
FLOODPLAIN ZONE:	
Deep oxbow (Wetland Series)	0 – 30
Shallow oxbow (Wetland Series)	30 – 50
Bog Forest (Wetland Series)	50 – 100
Early successional woodland phase (Woodland Series)	10 – 60
Bare Soil (Woodland Series)	0 – 10
Established forest phase (Woodland Series)	60 - 150

6.4 Portugal

6.4.1 Study site: Location and description

Odelouca study site is located near Ribeira village (Lat: 37º 23’ 05,00’’ N, Long: 8º 18’ 39,46’’ W) in a meandering stretch. The studied river segment is approximately 400 meters long, displaying altitude of about 132 masl and with a mean slope of 0.3% (
Figure 6.36).

In the approximately 5 ha surveyed area the existing woody riparian vegetation is composed by ashes (*Fraxinus angustifolia* Vahl), willows (*Salix salviifolia* Brot) and tamarisks (*Tamarix africana* Poir) (
Figure 6.37). These species characterize the whole Odelouca basin together with alders (*Alnus glutinosa* (L.) Gaertner) which grow in downstream reaches of the river where water availability is greater. The terrestrial vegetation located in the uplands is represented by cork oaks (*Quercus suber* L.) and holm oaks (*Quercus ilex* L. subsp. *ballota*). The river bed shows coarse soil structure and few vegetated patches while the floodplain displays much finer soil texture and much more vegetation cover.

Figure 6.36. Aerial photo of the Portuguese natural reference study site (surveyed area outlined in yellow). Source: IGP – Portuguese Geographic Institute.

Figure 6.37. Most important riparian species present in Odelouca study site. Starting from the left and clockwise: Ashes, willows and tamarisks.

6.4.2 Hydro-meteorological data

The hydrologic data used in the Odelouca study site were obtained from Monte dos Pachecos and Sapeira gauging stations, both located in same river course, respectively at 30 and 19 km downstream the study site (
Figure 6.38). The hydrological data used for Monte da Rocha study site was collected in the dam. In both Odelouca and Monte da Rocha study sites, data were obtained from the daily data available databases existing at National Water Authority website (http://snirh.pt/).
For each study site, meteorological data were obtained from the nearest meteorological stations with available precipitation and temperature daily data for an acceptable measuring period (minimum of 30 years). In the case of Odelouca the meteorological station is located in the Arade dam (Lat. 37º 14' 16,80'' N, Long. 8º 22' 30,00'' W) at 58 masl altitude and a distance of 17 km from the study site. The meteorological station used to obtain daily precipitation and temperature data for Monte da Rocha study site is located in the dam, just about 1 km from the study site.

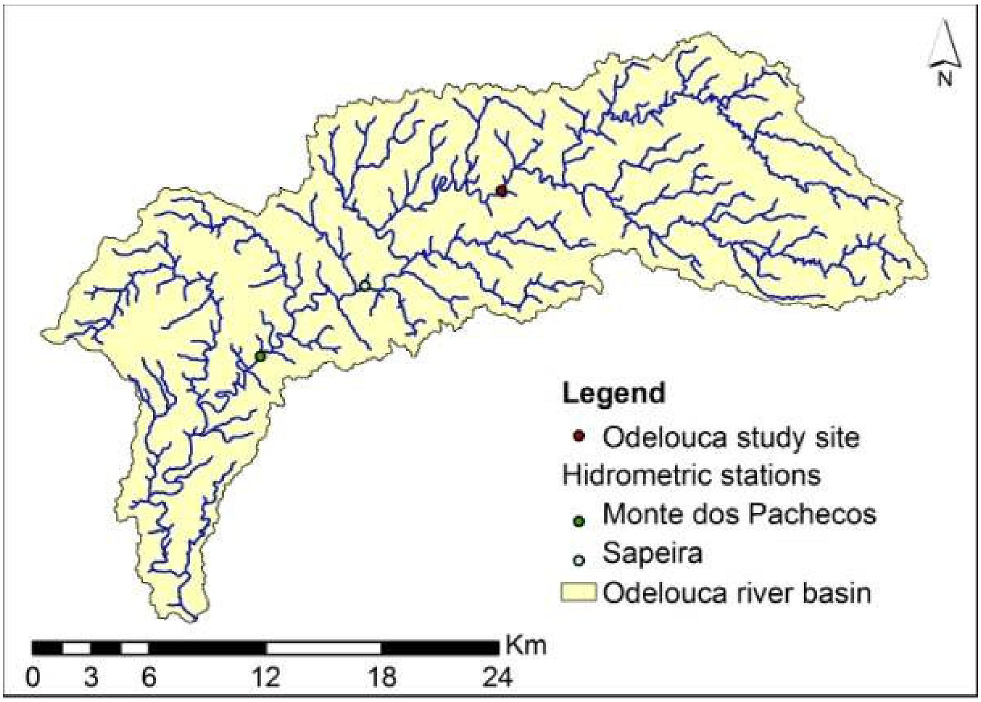


Figure 6.38. Location of the hydrometric stations and study site in the Odelouca river basin.

6.4.2.1 Precipitation

The meteorological data used for each study site was obtained from the Portuguese national system for the hydric resources information (http://snirh.pt). Data records were available for a period of near 54 years (1955 – 2009), in case of Arade dam station. Missing daily values were replaced by the mean daily precipitation of the particular month, in order to be able to fulfil the necessary modeling data periods.

In the below figure it is possible to observe the precipitation information used in the vegetation modeling for Odelouca (
Figure 6.39) study site

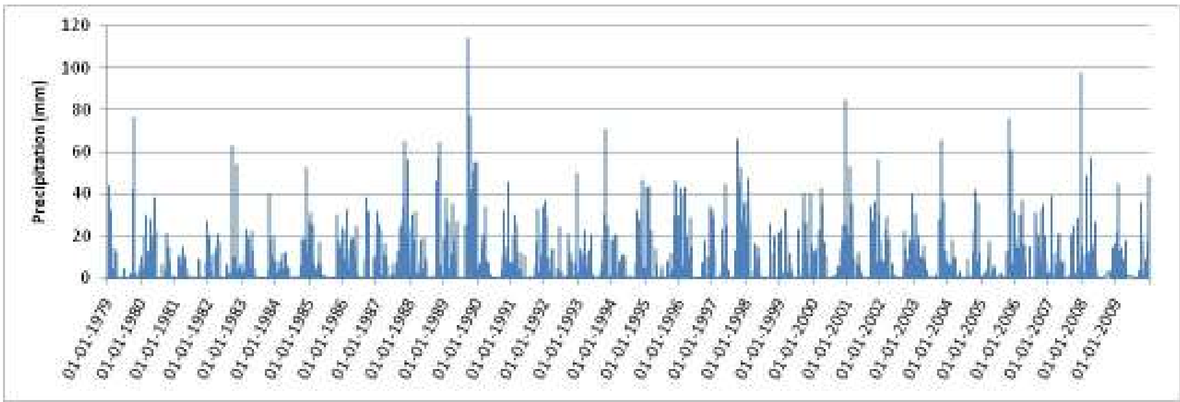


Figure 6.39. Mean daily precipitation considered in Odelouca vegetation modeling.

6.4.2.2 Potential Evapotranspiration

Potential evapotranspiration was calculated with the Hargreaves equation (Hargreaves and Allen, 2003), which needs temperature data and it is more appropriate for daily data. The equation is described below.

$$ET_0 = 0,0023 \times (t_{dmea} + 17,78) \times R_0 \times (t_{dmax} - t_{dmin})^{0.5} \quad (13.)$$

Where ET_0 is the potential evapotranspiration (mm/day), R_0 is the extraterrestrial solar radiation (mm/day) and, t_{dmea}, t_{dmax} and t_{dmin}, are the mean, maximum and minimum daily temperatures (ºC), respectively.

Some daily temperature data had to be estimated due to the occurrence of missing values. In case of existing at least one of the variables the other two where estimated considering the regression curves between those variables, using always the most powerful linear regression available (Table 6.14). In case of all variables missing it was considered de mean daily temperature for the respective month and then estimated the other two variables.

Regarding the above mentioned,
Figure 6.40 presents the mean potential evapotranspiration estimated for the study site.

Table 6.14. Regression curves used to estimate some missing daily temperature values.

	Linear regression equations	
Odelouca	$T_{max} = 1,1023 \times T_{med} + 2,5015$	R^2=0,9322
	$T_{min} = 0,8179 \times T_{med} - 2,5333$	R^2=0,8681

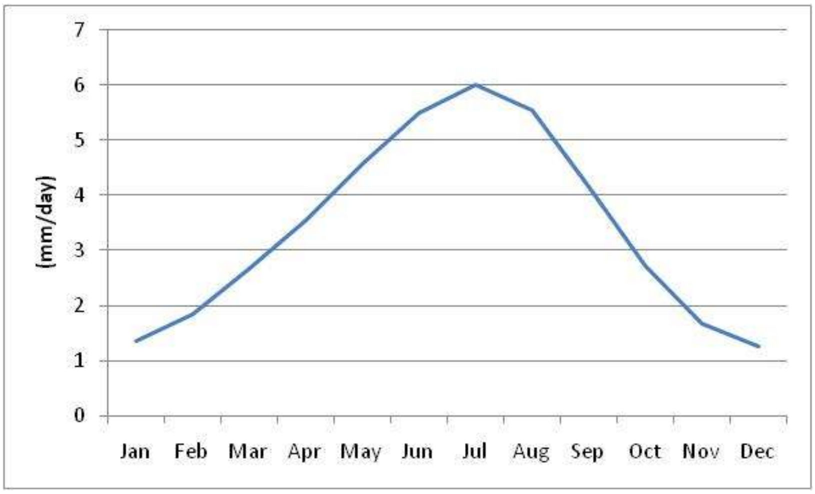


Figure 6.40. Mean potential evapotranspiration in Odelouca study site.

6.4.2.3 River discharge

The river discharge was estimated for each study site from the daily data available. At Odelouca study site annual maximum discharges were selected and their recurrence interval determined by fitting a Pearson III curve, followed by adjustment verification with a $\chi 2$ test (α=0.05). This information permitted to determine the correspondent return period of the discharges (Table 6.15). The flow estimation at the study site was obtained taking into account the drainage basins and mean annual precipitation ratio of Monte dos Pachecos gauging station and the study site (
Figure 6.41). The discharges calculated for the Odelouca study considered the below equation:

$$Q_O = Q_H \times \frac{A_O}{A_H} \times \frac{P}{P} \qquad (14.)$$

Where Q stands for flow, A for basin area and P for mean annual precipitation in the Odelouca study site (O) and hydrometric station (H) watersheds. The former equation permitted the creation of the hydrograph for the Odelouca study site, as is presented in
Figure 6.42.

Table 6.15. Return period discharges in the Odelouca study site.

Return period	Discharge (m^3/s)
$T_{1,5}$	80
T_2	122
T_3	171
T_5	225
T_{10}	290
T_{20}	351
T_{50}	427
T_{100}	483

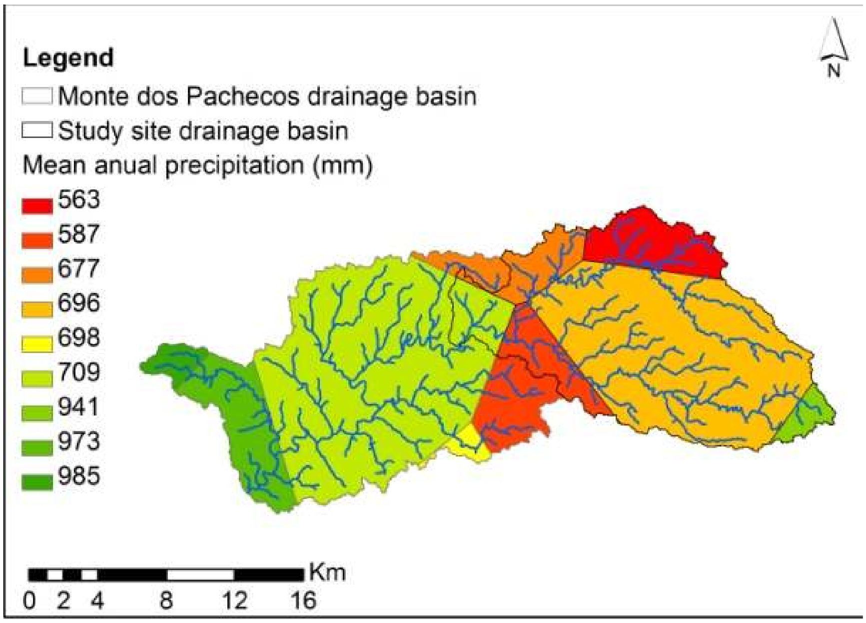


Figure 6.41. Mean annual precipitation in Monte dos Pachecos and Odelouca study site drainage basins.

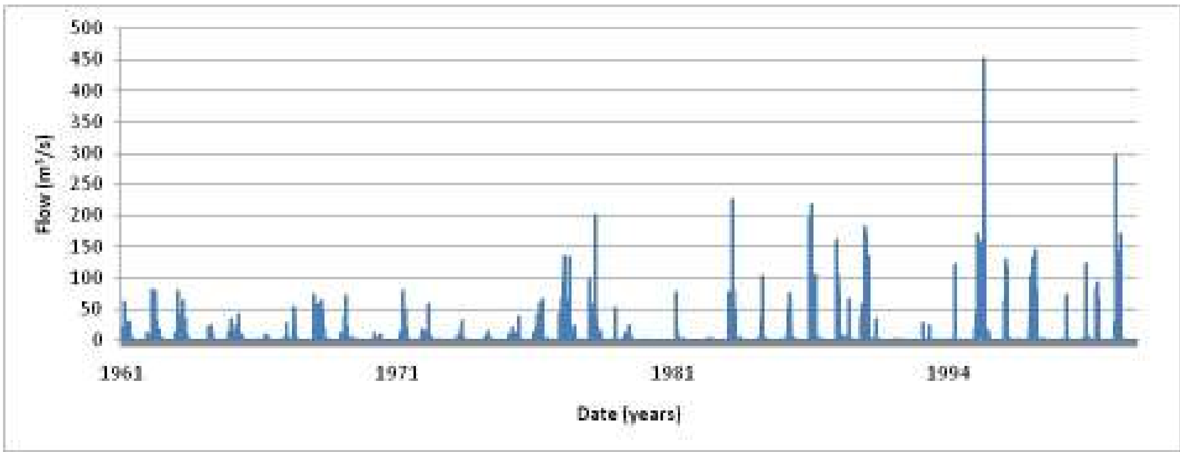


Figure 6.42. Odelouca study site hydrograph.

6.4.3 Soil survey and characterization

6.4.3.1 Soil survey

Along with the vegetation assessments, each patch soil was visually evaluated and compared among the others to be clustered in soil types. Percentage classes of soil substrates (bedrock, boulders, cobbles, pebbles, gravel, sand and fine elements) per patch were visually estimated and gathered in types by dominant class. Substrates with more than 50% of coarse elements (bedrock, boulders, cobbles, pebbles, gravel) were named coarse substrates. At the Odelouca study site, 13 soil types came out from the initial assessment, from which soil samples were collected (
Figure 6.44).

Samples were extracted from the 0-40cm depth layer with a soil corer, with retrieval of a composite sample of approximately 250cm^3 (Figure 6.43).

Figure 6.43. Soil sample collection.

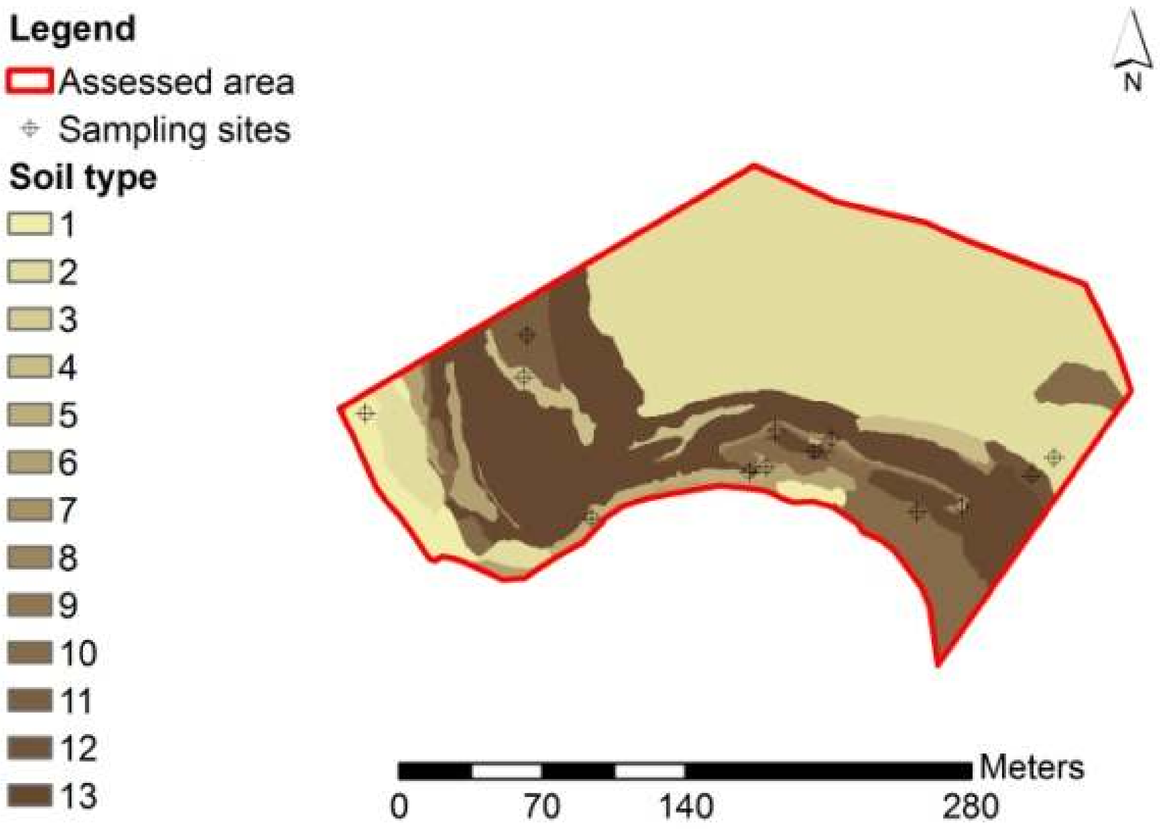


Figure 6.44. Odelouca soil types.

6.4.3.2 Soil analysis

The collected samples were analyzed in the Instituto Superior de Agronomia soil laboratory, which performed texture and organic matter content analysis (Table 6.16). The texture and organic matter results supported the soil texture classification (USDA, 1993) and soil parameters calculation, for model input.

The soil parameters calculated for each Odelouca soil types were used to compare the succession phases with a variance analysis (ANOVA).

Two main soil type groups emerged from this analysis, being the older succession phases (Established forest phase and Mature forest phase) significantly different from the younger ones (Initial phase, Pioneer phase and Young Successional Woodland phase) considering a 90% confidence interval (ANOVA $F_{(4, 77)}$=8.8750, p=0.00001) (
Figure 6.45).

The previous two succession phases groups were significantly different concerning the fine substrate percentage ($F_{(40, 259.7)}$=2.6739, p=.00000), coarse substrate percentage ($F_{(40, 259.7)}$=2.6739, p=.00000), gravel percentage ($F_{(40, 259.7)}$=2.6739, p=.00000) and saturated hydraulic conductivity ($F_{(40, 259.7)}$=2.6739, p=.00000), considering a 0.95 confidence interval (
Figure 6.46).

From all the other variables analyzed (sand percentage, clay percentage, organic matter percentage, porosity, porosity index, Hb bubble pressure and field capacity moisture) succession phases could not be differentiated.

The soil types seem to be related with the fluvial zones considered in the model, being possible to regard, for the sake of the field work performance, a fewer number of soil types, mainly corresponding to the bank and floodplain zones.

Table 6.16. Odelouca soil types analysis of texture and organic matter content.

Soil Type	Clay (%)	Lime (%)	Sand (%)	Organic Carbon (%)	Organic Matter (%)	USDA Texture
1	23	35.07	41.93	2.01	3.46	Loam
2	10.56	8.29	81.15	0.67	1.15	Loamy sand
3	13.7	17.01	69.28	1.02	1.76	Sandy loam
4	15.23	3.7	81.06	0.4	0.69	Sandy loam
5	16.2	21.22	62.57	1.73	2.98	Sandy loam
6	9.05	27.66	63.29	2.56	4.42	Sandy loam
7	10.08	10.59	79.32	0.51	0.88	Sandy loam
8	13.13	15.33	71.54	1.72	2.96	Sandy loam
9	12.03	12.03	75.95	1.67	2.88	Sandy loam
10	10.44	12.64	76.92	0.77	1.34	Sandy loam
11	10.87	13.32	75.8	0.71	1.22	Sandy loam
12	12.55	11.36	76.09	1.48	2.55	Sandy loam
13	10.31	9.36	80.32	0.54	0.78	Loamy sand

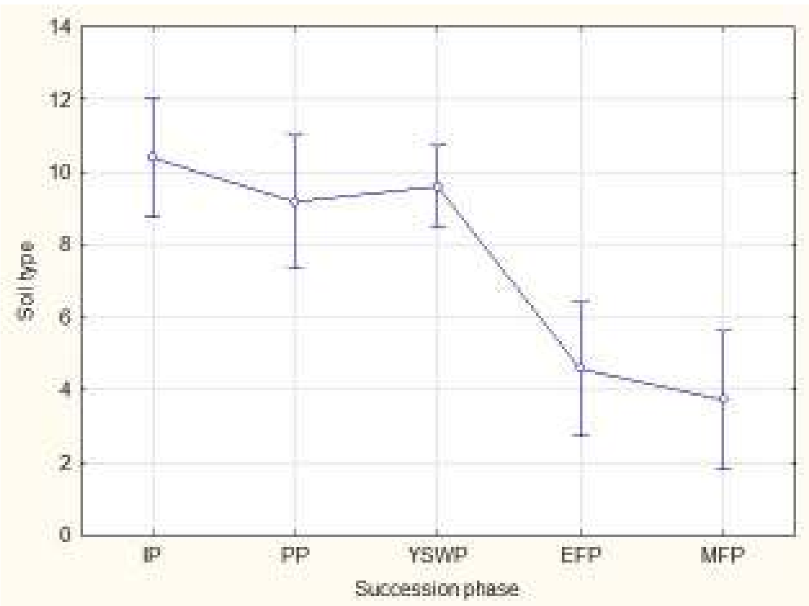


Figure 6.45. Variance analysis of soil types by succession phases (vertical bars denote 0.90 confidence intervals).

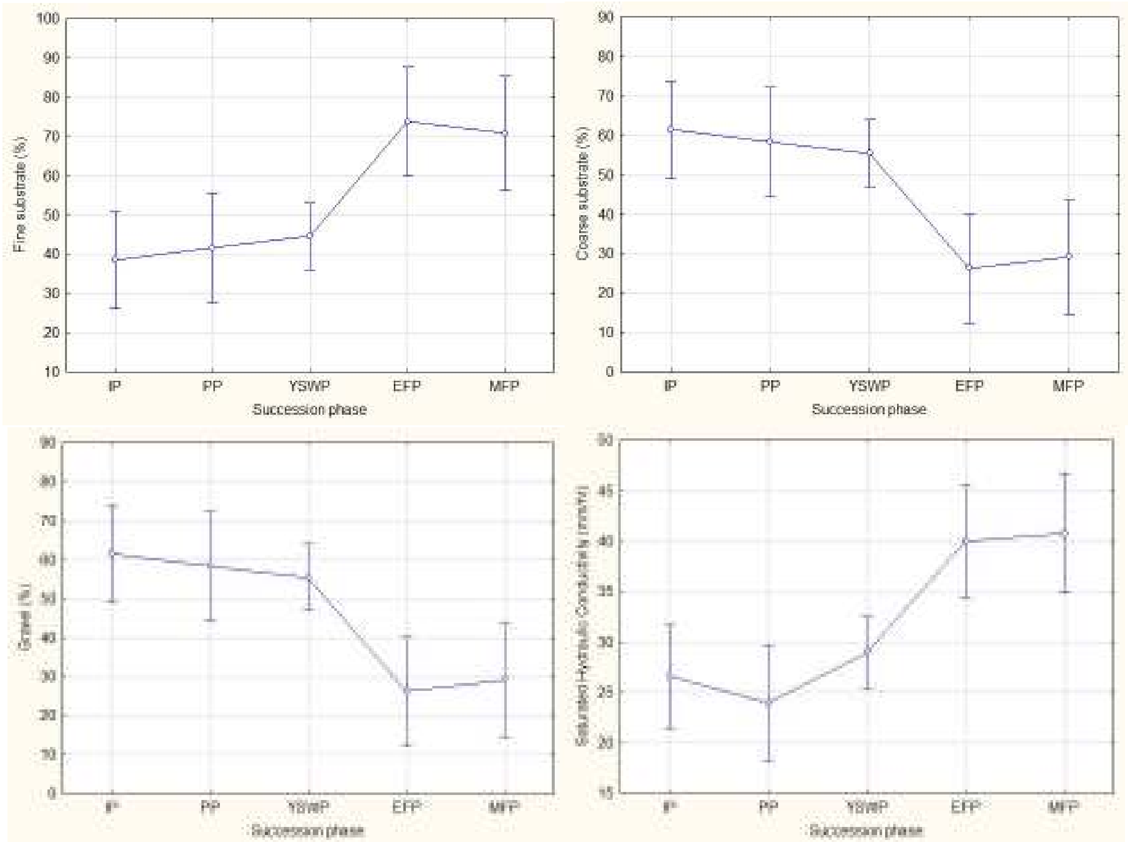


Figure 6.46. Variance analysis of fine substrate percentage, coarse substrate percentage, gravel percentage and saturated hydraulic conductivity by succession phases (vertical bars denote 0.95 confidence intervals).

6.4.3.3 Soil parameters

The soil parameters calculated for each soil type of Odelouca study site were used in the ETidx sub model and are presented in the tables below (Table 6.17).

Table 6.17. Soil parameters used in the modeling procedure (Odelouca study site).

Soil type	Porosity (%)	Porosity index	Bubble preassure (kPa)	Saturated conductivity (mm/hr)	Moisture at Field capacity	Soil description
1	48.10	0.165	3.1	15.11	30	Loam
2	41.40	0.159	0.3	45.65	13.2	Loamy sand
3	42.50	0.165	1.1	15.98	18.6	Sandy loam
4	39.70	0.122	0.5	28	15	Sandy loam
5	45.20	1.162	1.3	27.07	22.3	Sandy loam
6	0.09	0.210	0.1	50.2	21.4	Sandy loam
7	41.00	0.174	0.4	20.88	13.2	Sandy loam
8	0.04	0.158	0.6	17.71	18.6	Sandy loam
9	45.10	0.153	0.3	30.43	17.7	Sandy loam
10	41.80	0.174	0.5	31.86	14.1	Sandy loam
11	41.50	0.174	0.6	42.15	14.5	Sandy loam
12	44.20	0.147	0.4	28.34	17.7	Sandy loam
13	40.80	0.174	0.4	21.16	12.7	Loamy sand

6.4.4 Topographic survey and Digital Elevation Model

6.4.4.1 Topographic survey

The topographic survey was realized by a contractor and data was obtained using a Leica 500 GPS, composed of two double-frequency-to-real-time SR 530 RTK antennas L1 and L2 AT 502 (1cm error approximately). Elevation was recorded in altitude (masl) points, and an effort was made to register every altitude variation of 20 cm height (
Figure 6.47).

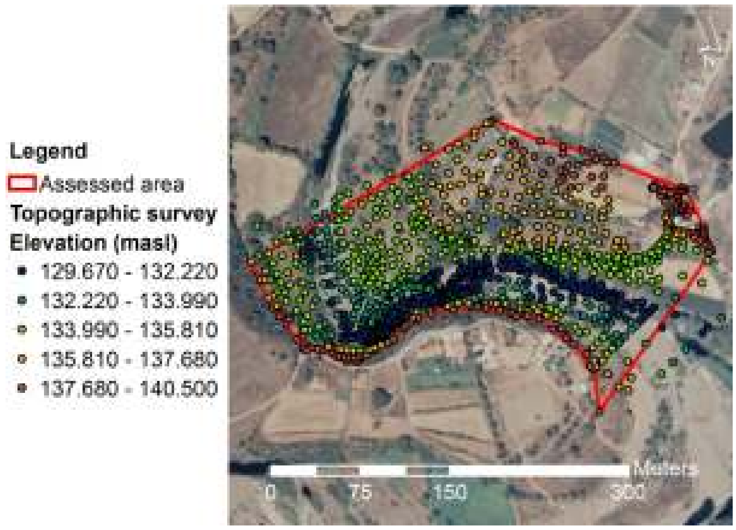


Figure 6.47. Odelouca topographic surveys.

6.4.4.2 Digital Elevation Model (DEM)

The Digital Elevation Model was created from the topographic survey data recorded in the study sites (Figure 6.48). ESRI® ArcGis™ 9.2 software was used to perform the TIN (Triangular Irregular Networks) creation and posterior raster transformation (0.5m cell size).

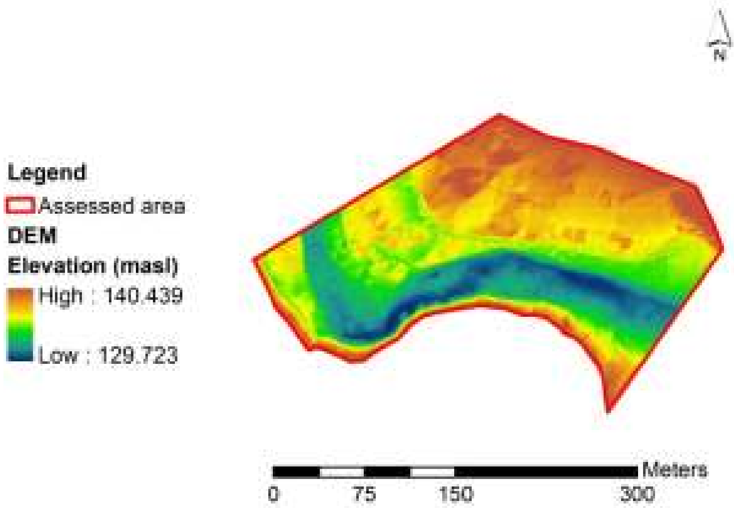


Figure 6.48. Digital Elevation Model of Odelouca.

6.4.5 Hydraulic survey

6.4.5.1 Water surface elevation

The water surface elevation information is needed for the hydraulic 2D modeling. With regard to this parameter, its values were estimated using HEC-RAS 4.0 model (Brunner, 2008), as it was not possible to measure it for the correspondent discharge flows, due to its unpredictability and short durability of the Odelouca flash discharges. Despite that fact, the Portuguese team recorded in Odelouca three water surface elevations (no flow, 0,3m^3/s and bank full level, the latter from observations on trashline and local inhabitant's interviews), which were considered at the model results examination stage. Those recordings were performed in the cross sections located at the beginning and at the end of the study site, with a sub meter precision Trimble® GeoXT™ handheld GPS, signalizing the interface water/land points on those cross sections.

The HEC-RAS 4.0 modeling used cross sections (collected from the DEM in ESRI® ArcGis™ 9.2 software) spaced approximately 16 meters each in Odelouca.

The water surface elevations were modeled for a certain return period discharges and these obtained values were used to create the flow curve of the study site in the outflow cross sections (
Figure 6.49).

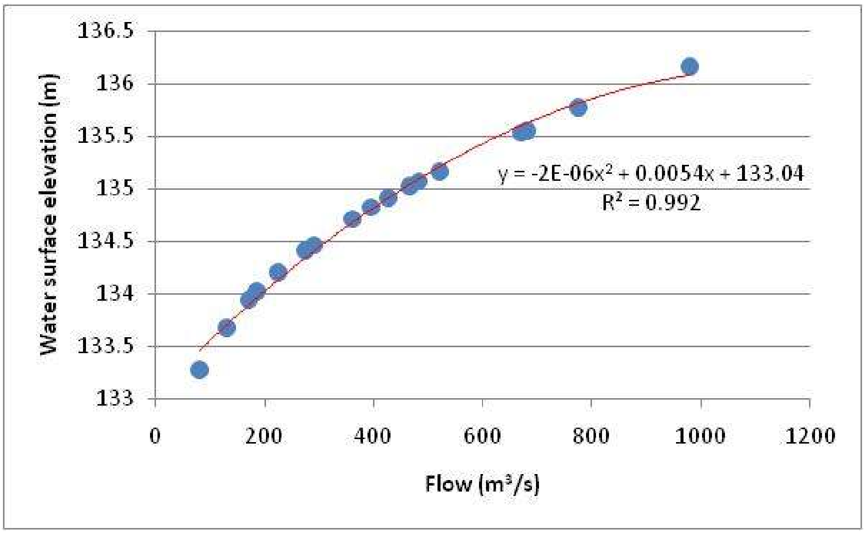


Figure 6.49. Flow curve of the outflow Odelouca study site cross section.

6.4.5.2 Hydrometry

The Odelouca flow reading was done on February 2010. The river cross section selection was made considering the best available conditions for this assessment, namely, a transition zone between pool and riffle habitats, in a straight stretch and without any flow disturbance influences like the existence of vegetation or river course obstructions. A graduated guidance cable was placed in the chosen section was placed ensure the readings were performed in a 20 cm spacing segments of the cross section. In these segments, depth and mean water velocity were measured, using a graduated rod and an ultrasonic moulinet FP101 Global Flow Probe (
Figure 6.50).

Flow calculation was made according the equation 10. (From Spain hydrometry in hydraulic survey).

Figure 6.50. Flow estimation in a river section (from left to right and top to bottom, cross section signaling, water depth and velocity measurements).

6.4.6 Hydraulic modeling

Hydraulic modeling was performed using the River2D model software (Steffler *et al.*, 2002). The model needs the following *inputs:* topography, channel roughness, discharge flow and respective water surface elevation at the outflow boundary. The channel roughness was defined by vegetation patch and according to the existent literature (adapted fromFisher and Dawson, 2003; Boavida, 2007; Wu and Mao, 2007). River 2D modeled the considered discharges in Odelouca study site. These results are presented in the next chapters.

The first three sub models in which the vegetation model lays on need several data inputs in order to model the riparian vegetation from the river flow dynamics. Those inputs are topography; fluvial zones maps; shear stress and water table elevation of the maximum year floods; and hydrologic regime database file to guide the model in the inputs use choice process through the considered modeling period

6.4.6.1 Definition of aquatic, bank and floodplain zones

The definition of the aquatic, bank and floodplain zones is done considering the submerged river areas of certain flood flows. The aquatic zone is defined as the area submerged by the base flow, in other words, is the river bed area which is permanently inundated. This area is removed from the modeling computation due to its disability for riparian vegetation establishment. Since Odelouca river dries in the Summer, the aquatic zone of this study site was considered as the remaining pools when the flow is null. Bank and floodplain zones were defined as the areas submerged by the regular and 100 years return period discharges, respectively.

River2D modeled the water depth of each flood and then the data was imported to ESRI® ArcGis™ 9.2 software were the *input* grids were created (
Figure 6.51).

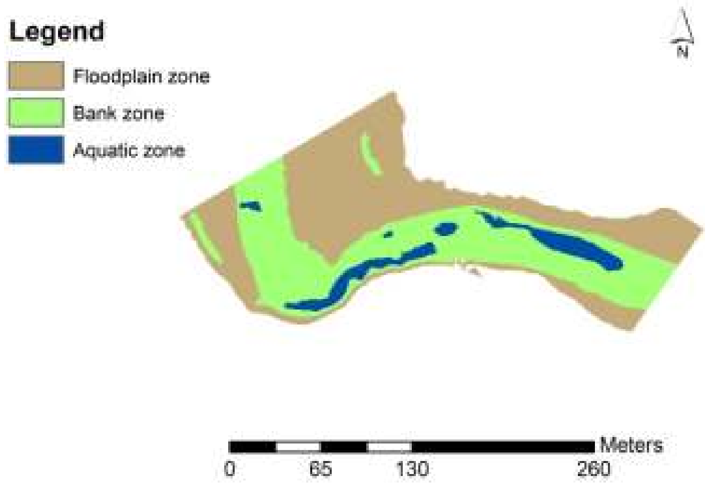


Figure 6.51. River zones definition in Odelouca.

6.4.6.2 Water table elevations (WTE)

The water table elevation is used in the vegetation model for flood analysis. The information required was obtained from River2D 0.93 modeling. Data refers to the altitude (masl) of water table in each half square meter cell of the study site modeling zone. Two examples of the WTE information can be seen in
Figure 6.52.

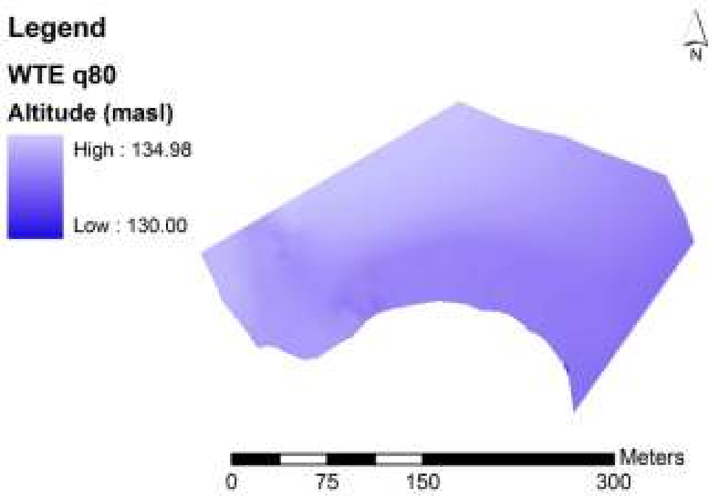


Figure 6.52. Water table elevation maps of Odelouca.

6.4.6.3 Shear stress (SS)

The shear velocity is also an output information provided by River2D 0.93. This parameter is a measure of shear stress in velocity units and is related to shear stress by the equation below:

$$V_* = \sqrt{\frac{\tau}{\rho}} \qquad (15.)$$

Where V* is the shear velocity (m/s), τ is shear stress (N/m^2) and ρ the fluid density (kg/m^3).

Shear stress was calculated in ESRI® ArcGis™ 9.2 software and the input grids were created (Figure 6.53).

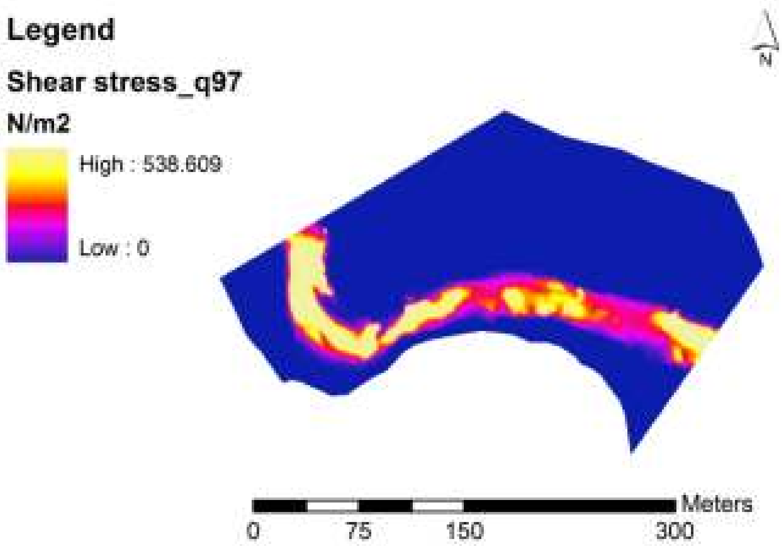


Figure 6.53. Shear stress maps of Odelouca (left) and Monte da Rocha (right).

6.4.6.4 Flood duration

In the Portuguese study case the river floods are closely related to extreme precipitation phenomenons, thus, these flash floods last in general few hours. Therefore, in the Portuguese modeling the flood duration was considered nonexistent.

6.4.7 Vegetation survey

At the initial stage of this project some field trips were realized in order to survey the natural and regulated sites selection. Once the river courses were selected, the team went again to the field in the search for the best available study site. The selection of the natural reference study site was limited by one restriction: to have the complete succession series, in order to enable the vegetation model calibration for all its phases.

The vegetation survey was carried out in Odelouca at Summer 2009. The field sampling followed the same method for both study sites and the mapping of vegetation and habitat features assessment. Vegetation and habitat assessment was performed by Instituto Superior de Agronomia team, simultaneously to the topographic survey. For the patch recording, homogeneous vegetation units were considered, each corresponding to one succession phase. The succession phase's definition was adapted from the literature (Kovalchik and Clausnitzer, 2004; Naiman *et al*., 2005; Egger *et al*., 2009).

Five succession phases were identified in the study sites: Initial phase (IP), Pioneer phase (PP), Young Successional Woodland phase (YSWP), Established Forest phase (EFP), and Mature Forest phase (MFP). Initial phase was attributed to all patches dominated by open sand or gravel bar (less than 50% of vegetation cover), with an absence of woody potential arboreal species (
Figure 6.54a). Patches dominated by woody arboreal species recruitment were considered Pioneer phase (
Figure 6.54b). The Young Successional Woodland phase category was attributed to patches with a moderate standing biomass and well established individuals, dominated by microphanerophyte pioneer species like willows and tamarisks (
Figure 6.54c). Older patches presenting high canopy cover and dominated by macrophanerophytes like ash-trees were considered Established Forest phase (
Figure 6.54d). These patches were also characterized by the appearance of soil with an A-horizon, which was absent from the earlier succession phases. The Mature Forest phase was considered at patches that were also dominated by competitive woody and long-lived riparian species (in our case, ash), but with the occurrence of terrestrial arboreal cork oak or holm oak species, that are typical of these Mediterranean landscapes.

Figure 6.54. Succession phases considered in the study sites: a – Initial phase, b – Pioneer phase, c – Young Successional Woodland phase and d – Established forest phase.

Vegetation assessment included patch georeferencing, species identification, stem diameter measurement and tree coring (
Figure 6.55).

Each patch was recorded along with its shape and georeferentiation, by walking along the limit of a patch, using a submeter precision Trimble® GeoXT™ handheld GPS. Patches were assessed in terms of vegetation cover and open soil. Vegetation cover was valued as the percentage of the patch covered by any kind of vegetation and open soil was valued as the percentage of soil in the patch without aerial cover from vegetation.

All species were identified in each patch and corresponding percentage abundance recorded for each one. Patch mean stem diameter was obtained from 3 or 4 of the oldest individuals on each patch. Stem diameter was recorded using a diameter caliper, with calculation of the mean of two crossed diameters for each individual. Stem diameters were recorded at Breast Height (DBH at ca. 1.3m) in specimens higher than 2m, and near ground for smaller ones. Diameters of multi-stemmed individuals were measured on the largest stem.

Patch aging was performed using dendrochronological methods. We cored 3 or 4 of the largest individuals on each patch with a standard 5mm increment borer, taking two (three when needed) perpendicular cores at 1.3m in adult trees (Mäkinen and Vanninen, 1999). For individuals smaller than 5cm DBH, disks were obtained for age calculation purposes. For multi-stemmed trees, the cores/disks were taken from the largest stem. Diameter and height were also measured in all sampled stems. Additional trees were selected near the study site to complete the oldest girth classes for each species and make it possible to fit growth curves together with diameter data. In the field cores were stored in polyvinyl tubes sealed with cotton caps.

Figure 6.55. Vegetation assessment performed. a – Patch georeferencing, b – species identification and c – tree coring.

6.4.8 Vegetation data processing

The vegetation data processing allowed the model expert rules definition, regarding the succession phase parameters, like age and height over water table. The procedure detailed in the next chapters contributed for the model calibration by the different project partners and allowed the creation of the vegetation maps creation and model calibration.

6.4.8.1 Growth functions

Tree cores/disks brought from the study sites were dried, mounted and polished. Age was attributed directly to all samples showing pith. For samples that didn't reach pith, an estimation considered the sample diameter, average bark width, and the average ring width for the first 10 years of life in each species (obtained from ring increment measurement in samples showing pith) (Rodríguez-González *et al.*, 2010). The aging process was performed using a stereo macroscope and a linear table RINNTECH® LintabTM with the program TSAP-WinTM table.

With the age of the cored trees it was possible to build the growth curves for each species present in Odelouca study site, which were used to determine the age of the other individuals from where only existed the diameter information (Table 6.18).

Table 6.18. Growth functions of the indicator species in Odelouca.

Species	Growth function	R^2	Sampling size
Fraxinus angustifolia	$AGE = 2.6509*DBH^{0.693}$	0.9467	32
Salix salviifolia	$AGE = 2.518e^{0.0896*DBH}$	0.8759	37
Tamarix africana	$AGE = 2.3984e^{0.1381*DBH}$	0.7698	39

6.4.8.2 Definition of succession series and phases

The woodland series was the only one found at Odelouca study site. The following succession phases were considered: Initial phase, Pioneer phase, Young Successional phase, Established forest phase and Mature forest phase (for a succession phase description see chapter 6.4.7).

For a better understanding, according to a four vegetative sucessional stages classification (Olivier and Larson 1996), the Initial phase is included in the Establishment Stage, where the disturbed patches with newly formed sandbars are colonized by vegetation. The Pioneer and Young Successional woodland phases represent the Stem Exclusion Stage, where all the available growing space is occupied by pioneer species with a competitive advantage in size or growth. The Understory Initiation Stage is characterized by the invasion of shade tolerant herbs, shrubs and trees, with a slower growth rate and multiple canopy layers. This stage corresponds to the Established Forest phase. The mature stage is characterized by three-dimensional structural characteristics like living old trees, large dead trees relative open canopies and diverse understory and is considered to be represented by the Mature Forest phase.

6.4.8.3 Vegetation maps

The patch georeferencing performed in the vegetation surveys allowed the creation of the vegetation maps presented below (

Figure 6.56). These maps characterize the patch arrangement in a determined momentum and are related with the river dynamics felt until then in each patch. The usefulness of these maps is related with the calibration and validation processes of the model.

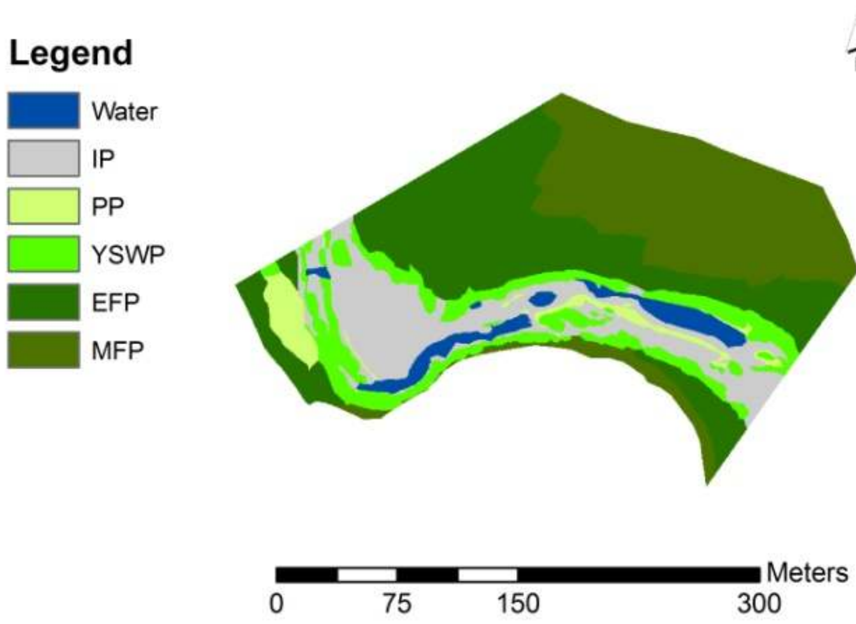


Figure 6.56. Odelouca 2009 vegetation map.

6.4.8.4 Expert rules

The relevant patch characteristics (altitude, patch area, height above water table, patch age, mean stem diameter, open soil and soil dominant substrate) observed at Odelouca were summarized using Principal Components Analysis (PCA) (Table 6.19).

Altitude, height above water table, age and mean stem diameter were the most important factors that distinguished succession phases (loadings >|0.75|, correlations and computed variances as SS/(N-1)), with 69.63% of total variance explained by the first two axes.

This result confirms the model purpose to use patch height above water table and age as parameters to define the succession phases. In fact, patch height above water table and age were tested using a Variance Analysis (ANOVA) to confirm significant differences between succession phases, which were found.

As it can be observed in
Figure 6.57, the succession phases were significantly different (95% confident interval) for height above water table (ANOVA $F_{4,105800}$=35231, p<0.0001), and EFP displayed a significant difference in age compared to the PP and YSWP phases (ANOVA $F_{3,55}$=12.731, p<0.00001).

On this analysis, Initial phase presented height above water table level between PP and YSWP. This question was assigned to the great disturbance that PP and YSWP are subject, with a constant alternation between succession and retrogression processess. Also, regarding the patch age, PP and YSWP were not significantly different. However, 75% of PP patches presented were younger than 4 years and 75% of the YSWP patches were older than 5 years old (Table 6.20).

Table 6.19. Principal Component Analysis on patch characteristics (loadings >|0.75| highlighted in red).

	Factor 1	Factor 2
Patch area	-0.626120	0.371466
Altitude	-0.827290	0.494160
Height above water table	-0.820818	0.477644
Polygon age	-0.792186	-0.526698
Stem diameter	-0.751959	-0.595258
Open soil	0.462700	0.030822
Soil dominant substrate	0.645200	0.239215
Expl.Var	3.573552	1.300242
Prp.Totl	0.510507	0.185749

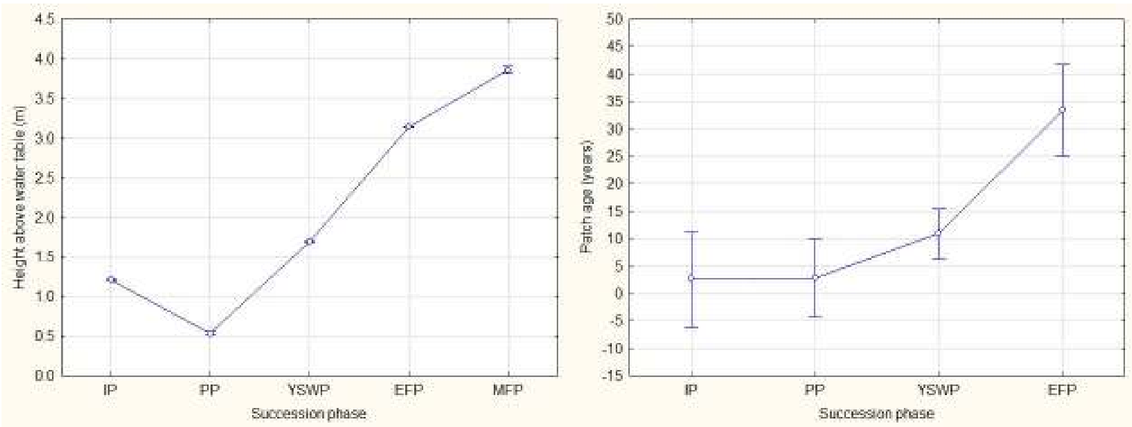


Figure 6.57. Variance analysis of height above water table (left) and patch age (right)

Table 6.20. Descriptive statistics on vegetation age by succession phase.

	Mean	Minimum	Maximum	Lower Quartile	Upper Quartile
IP	1.071	0	5	0	2
PP	2.929	0	5	2	4
YSWP	11.103	2	33	5	16
EFP	32.556	0	89	7	49

6.4.8.4.1 Ages distribution and location of vegetation in relation to base flow

In this chapter, the expert rules are presented and defined for the Portuguese model calibration regarding the mentioned parameters. The settled values were defined based on the knowledge obtained in the current chapter (Table 6.21).

Table 6.21. Patch height over base flow (HBSF) and age (years) definition for the considered succession phases of the woodland series.

Succession phase	Age (years)	HBSF (m)
Initial	0 – 2	< 0.363
Pioneer	2 – 5	0.363 – 0.683
Young Successional Woodland	5 – 16	0.683 – 2.778
Established forest	16 – 49	2.778 – 3.405
Mature forest	> 49	> 3.405

7 Model implementation

7.1 Introduction

The steps to prepare the application of the model each study case followed a defined lineage (model set up) which begun with the gathering of the input data for the model (i.e. shear stress grids). The input data have been gathered with slightly different methodologies by each project partner according to the in-house resources, budget and technical possibilities. However, the final results, for each project partner was a complete dataset encompassing all the input data required to run the model for each specific study case. The input maps required for the calibration process in each study site were:

- Vegetation succession map (observed vegetation at the end of the calibration process).
- Riverine zones map (aquatic, bank and floodplain zone). The mean annual flow was considered as the reference low flow in the Alpine site, while the base flow was the low flow reference in the Mediterranean sites (Spain and Portugal), where the difference between mean and base flow is very relevant.
- Digital elevation model (topography). The same map is used across all the simulations.
- Hydrological classes of years (period used for calibration) into year types depending on the annual average flow. The types were very dry, dry, medium, wet and very wet. A characteristic discharge was associated to each year type. For each year, the mean discharge value was replaced with the mean discharge class arithmetically more close to the real value.
- Water table elevation raster for each year type.
- Flood duration raster for each year type.
- Raster maps of shear stress (the maximum daily flow observed for each year during the calibration period was considered, and the corresponding shear stress reference flow was assigned).

Regarding the maps format, all the maps were generated with the same grid extension and pixel size (in each study site, one mask for maps creation in ArcGIS was selected). The selected size accomplished a balance between accuracy in the vegetation mapping and time consumption during the calibration process.

Once the inputs were available, and before applying the model to the case studies, the model was calibrated for each study site with the aid of statistical means. The evaluation of the calibration results was done with the confusion matrix and the coefficient of agreement, *kappa* (Cohen, 1960). For the Austrian study site, it has been considered also the outcome of the relative area balance performed with focus on the bank zone of the study site.

7.2 Spain

The model application included a first step of inputs definition. This is a general description of the different inputs necessary to run the model. The methodology used to obtain these inputs has been described in the previous chapter. Once the inputs were available to run the simulations, the calibration of the model was tackled. The calibration of the model required iteratively “simulation-results analysis" steps. The results analysis was done by comparison of last year simulated vegetation and observed field vegetation with two useful tools, the confusion matrix and the coefficient of agreement, *kappa* (Cohen, 1960).

7.2.1 Inputs definition

The RIPFLOW model is capable to simulate riparian vegetation considering one open gravel bar category as an initial phase of any succession line with naked soil (IP-SD) and different phases of several succession lines, in this case woodland and reed. These phases included a first common pioneer phase of riparian herbs (PP-RH) for both succession lines. After this phase, the succession can evolve to the reed succession line second phase of herbs (RE-HP-RH) or can evolve to the woodland succession line, which second phase corresponds to woodland dense herbs or willow shrubs phase (WD-HP-RH). In the first case the succession will evolve to the next reed phase of willow shrubs considered as riparian herbs plant functional type for the ETidx calculations (RE-SP-RH). This succession line ends in this point so the evolution will reach the third woodland succession phase. In the second case this third woodland succession phase is reached in the next step, corresponding to a complete presence of willow shrubs with different characteristics from the reed shrubs so they are simulated as riparian juveniles plant functional type for the ETidx calculations (WD-SP-RJ). In this succession point the next phase corresponds to the young willow and poplar forest (WD-ES-RA) followed by the old willow and poplar forest phase (WD-EF-RA) and after it the deciduous and coniferous trees of the mature stage (WD-MS-RA). These last three phases were considered as riparian adults and big shrubs, RA, plant functional type for the ETidx calculations. The succession line ends in a final stage of oak forest as a climax phase, considered as terrestrial vegetation for the ETidx calculations. In riparian areas, affected by the changing hydrology effects, the final stage is difficult to reach and the continuous affections allow a high vegetal biodiversity within the riparian ecosystems. Though the RIPFLOW model was defined to simulate the different succession phases, a raster file containing those phases observed in field was needed (
Figure 7.1).

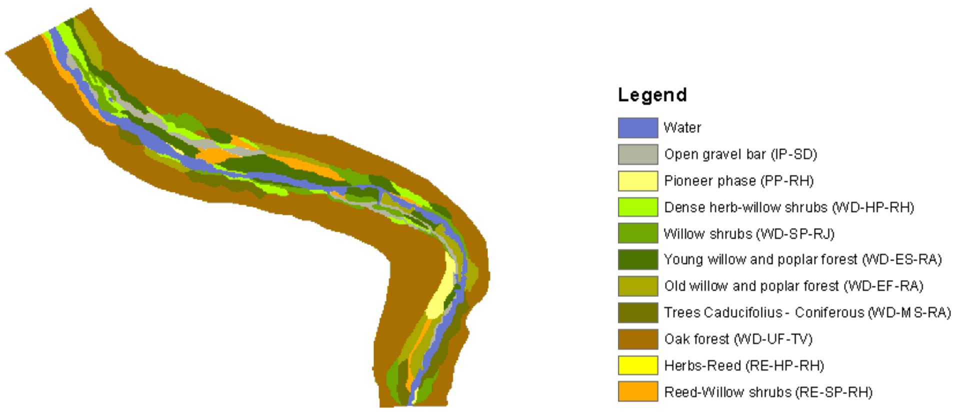


Figure 7.1. Vegetation types map in Terde stretch (Mijares River, Spain). The legend also indicates (in brackets) the succession series, phase and plant functional type.

In addition the topography information was required. A digital elevation model, as well as different hydrologic zones (aquatic zone, bank zone and floodplain zone), were the topography raster files used for the simulations (Figure 7.2).

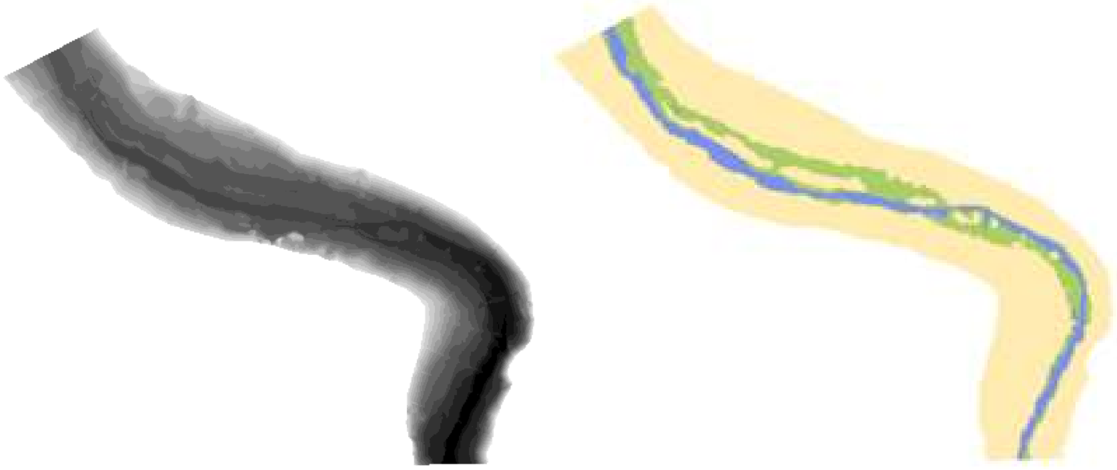


Figure 7.2. Digital elevation model (left) and hydrologic zones (right) including aquatic zone (blue), bank zone (green) and floodplain zone (yellow).

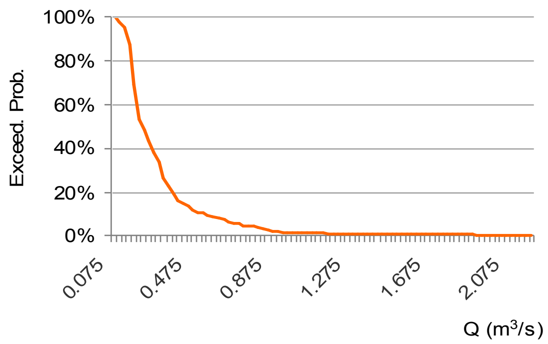
The height over base flow (HBF) and flood duration raster inputs were defined for each simulated year (Table 7.1).

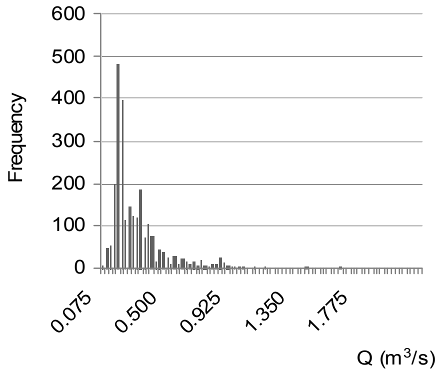
Table 7.1. Average flow and variation coefficient for each simulated year, corresponding year types, height over base flow and flood duration raster inputs.

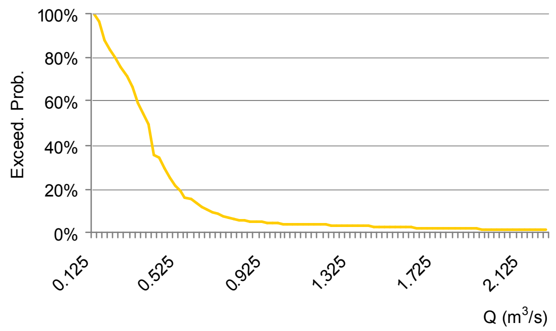
Year	Average Flow (m^3/s)	Variation coefficient	Year type	HBF	Flood duration
1988	2.071	1.62	Very wet	HBF_vw	FD_vw
1989	1.135	1.08	Wet	HBF_w	FD_w
1990	1.097	0.74	Wet	HBF_w	FD_w
1991	1.058	0.83	Wet	HBF_w	FD_w
1992	0.504	0.48	Medium	HBF_m	FD_m
1993	0.354	0.42	Very dry	HBF_vd	FD_vd
1994	0.241	0.92	Very dry	HBF_vd	FD_vd
1995	0.238	0.74	Very dry	HBF_vd	FD_vd
1996	0.474	1.00	Dry	HBF_d	FD_d
1997	0.841	0.97	Medium	HBF_m	FD_m
1998	0.420	0.72	Dry	HBF_d	FD_d
1999	0.388	2.50	Very dry	HBF_vd	FD_vd
2000	0.445	2.59	Dry	HBF_d	FD_d
2001	0.370	0.66	Very dry	HBF_vd	FD_vd
2002	0.431	1.02	Dry	HBF_d	FD_d
2003	0.848	0.92	Medium	HBF_m	FD_m
2004	0.665	0.68	Medium	HBF_m	FD_m
2005	0.247	0.39	Very dry	HBF_vd	FD_vd
2006	0.328	2.68	Very dry	HBF_vd	FD_vd
2007	0.440	1.34	Dry	HBF_d	FD_d

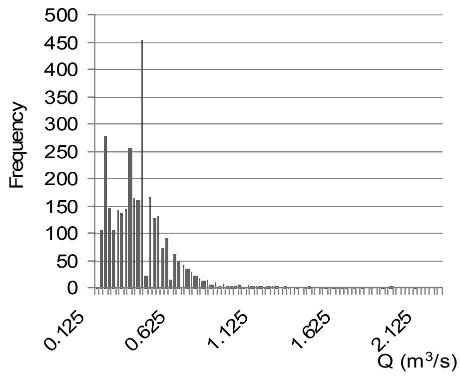
2008	0.505	0.91	Medium	HBF_m	FD_m
2009	0.597	2.21	Medium	HBF_m	FD_m

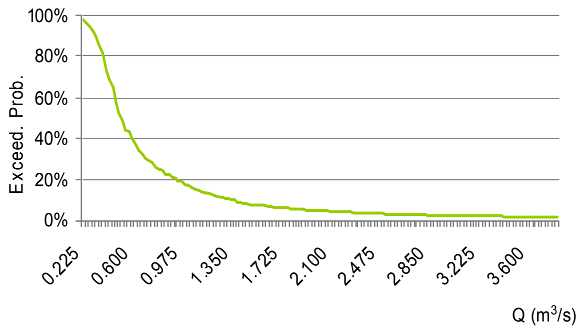
Every year was classified in five categories depending on the annual average flow (m^3/s) observed through the reach: very wet, wet, medium, dry and very dry. The global average flow of the available data series (0.864 m^3/s) was considered as reference to select the corresponding category for each year, being very dry years those which had an annual average flow (m^3/s) lower than the 10 percentile, dry years those between the percentile 10 and the first quartile, medium years between the first and the second quartile, wet years over the second quartile and under the percentile 90, and finally very dry years those with an annual average flow (m^3/s) higher than the 90 percentile. After classifying each year an analysis was done in order to identify if there was a need to introduce additional year types (Figure 7.4, Figure 7.4). The results shown that the selected classification was enough accurate for RIPFLOW simulation purposes.











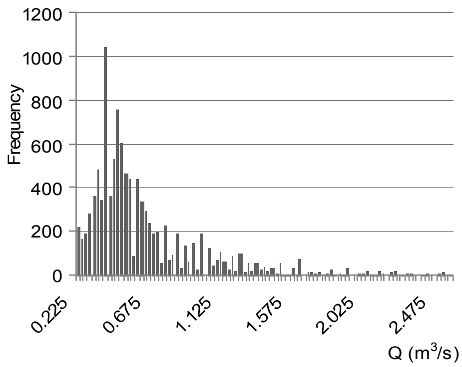
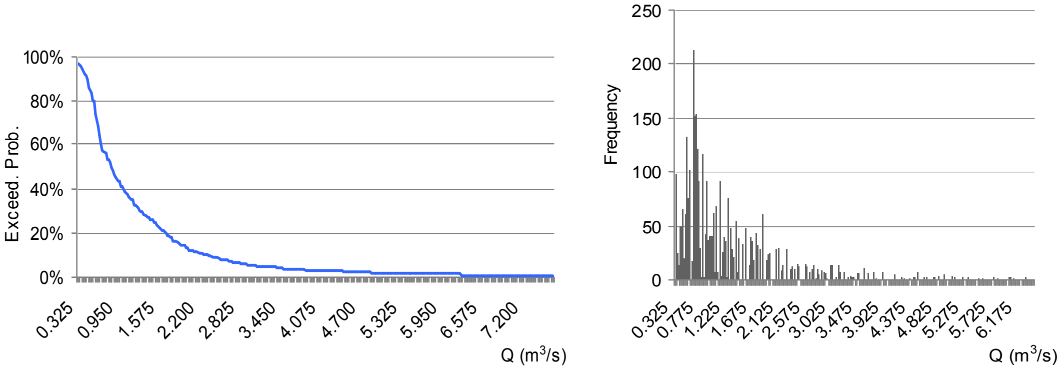


Figure 7.3. Flow analysis results for each year type in Terde reach (Mijares River, Spain). On the left side the exceedance curves, on the right the frequencies for very dry years (orange), dry years (yellow), medium years (green).



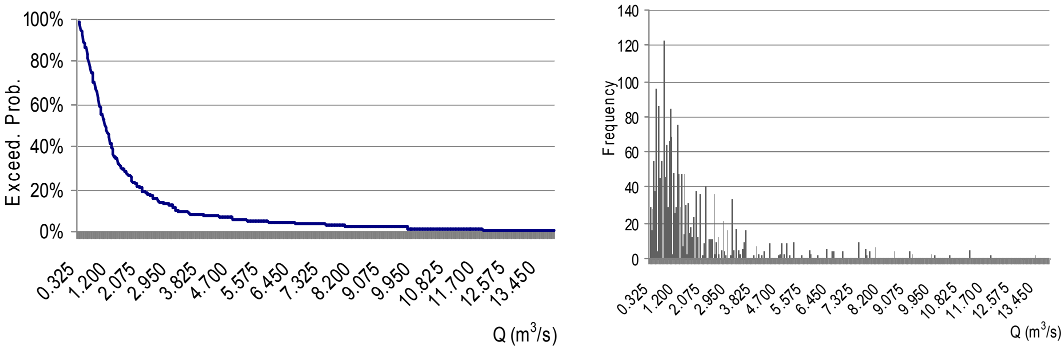


Figure 7.4. Flow analysis results for each year type in Terde reach (Mijares River, Spain). On the left side the exceedance curves, on the right the frequencies for wet years (light blue) and very wet years (dark blue).

The HBF inputs (Figure 7.5) were finally defined as the HBF associated to a 1 m^3/s base flow for very wet years (HBF_vw), the HBF associated to a 0.5 m^3/s base flow for wet and medium years (HBF_w and HBF_m), and the HBF associated to a 0.2 m^3/s base flow for dry and very dry years (HBF_d and HBF_vd).

Figure 7.5. From left to right HBF associated to a 0.2 m^3/s base flow, HBF associated to a 0.5 m^3/s base flow and HBF associated to a 1 m^3/s base flow.

The flood duration inputs (Figure 7.6), defined as the number of days that each cell is flooded during a year, were calculated for typical years of each year type. After a flow analysis the selected typical years were 1988 for very wet years (FD_vw), 1977 for dry years (FD_d), 1967 for medium years (FD_m), 1985 for wet years (FD_w) and 1996 for very dry years (FD_vd).

Figure 7.6. A selection of representative flood duration raster files corresponding from left to right, to medium, wet and very wet years (FD_m, FD_w and FD_vw)

As well, the shear stress raster inputs (Figure 7.7) were defined for each simulated year, but this time considering the maximum daily flow (Table 7.2).

Table 7.2. Maximum daily flow observed for each year during the calibration period and the corresponding shear stress reference flow considered for each year simulations.

Year	Maximum Flow (m^3/s)	Shear stress ref. flow (m^3/s)	Shear stress raster file
1988	36.4	40	Shear_40
1989	9.5	10	Shear_10
1990	6.8	10	Shear_10
1991	5.7	5	Shear_5
1992	3.5	5	Shear_5
1993	1.0	1	Shear_1
1994	2.3	2.5	Shear_2_5
1995	1.1	1	Shear_1
1996	4.1	5	Shear_5
1997	7.1	10	Shear_10
1998	2.0	2.5	Shear_2_5
1999	16.7	20	Shear_20
2000	19.7	20	Shear_20
2001	1.6	1	Shear_1
2002	4.7	5	Shear_5
2003	7.8	10	Shear_10
2004	3.2	2.5	Shear_2_5
2005	1.6	1	Shear_1
2006	16.5	20	Shear_20
2007	3.8	5	Shear_5
2008	3.6	5	Shear_5

2009	24.6	20	Shear_20

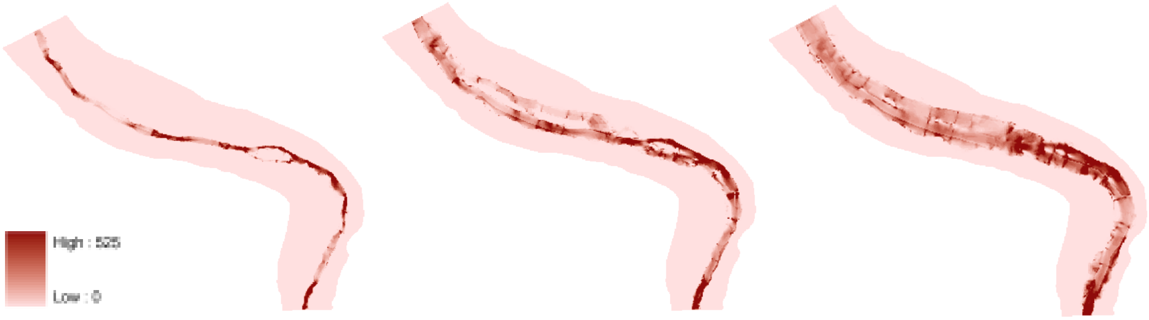


Figure 7.7. A selection of representative shear stress raster files corresponding, from left to right, to reference flows of 1, 10 and 40 m^3/s.

7.2.2 Calibration process

The model calibration required the iteratively variations of the different sub-models parameters values. In order to evaluate the quality of the calibration results we compared two raster files, last year simulated vegetation and observed field vegetation. This comparison was developed by two useful tools, the confusion matrix and the coefficient of agreement, kappa (Cohen, 1960).

7.2.2.1 Recruitment, shear stress, flood duration sub-models calibration description

The recruitment sub-model parameters involved in the model calibration process were the floodplain recruitment, woodland recruitment and scour disturbance zones height over the base flow values. Those values were established taking into account the observed distribution through the riparian areas. However some changes were necessary to reach a satisfactory result. The reed recruitment zone was indirectly defined as those zones not assigned to woodland recruitment, so there was possibilities of reed recruitment in two zones, <0.6 m and 3-7 m. Although the higher band is not typically a reed recruitment area, the observed vegetation showed a mayor presence of this succession line, and this definition of parameters (Table 7.3) improved the calibration results.

In a second group of parameters we defined the shear stress critical values for each succession phases of both succession lines analyzed. The definition of these parameters was done initially by comparison between shear_40, shear_20, shear_10 raster files and the observed vegetation. However, for each vegetation patch there were wide ranges of shear stress values independently of the shear stress raster file considered. That is why the calibration of shear stress parameters required a huge quantity of iterative simulations in order to find the best solution. The following rules had been considered in the establishment of each succession phase critical shear stress value:

- Earlier phases must have lower critical shear stress values than older phases.
- IP-SD and PP-RH are common phases in Woodland and Reed succession lines so the values must be equal for both succession lines.

- Herbs (HP) and shrubs (SP) reed phases must have lower critical shear stress values than Herbs (HP) and shrubs (SP) woodland phases respectively.

The calibration of the critical shear stress values ended when an increase of those values produced more evolved vegetation than observed and a decrease of the critical values produced huge bands of naked soil. All these critical values were set between the 20-30 N/m^2 range, except the initial phase which obtained a 12 N/m^2 critical value as optimum (Table 7.3).

The third parameters group (Table 7.3) corresponded to the flood duration sub-model. Although the sub-model required the definition of how the succession age changed accordingly to the succession type and impact severity, this definition was based in expert rules and had not been considered in the calibration process. Finally, the parameters calibrated in this sub-model were the ranges of days assigned to strong, moderate and low impacts. In a first try cells with values between 150 and 366 flooded days were considered as strongly impacted, considering a moderate impact when the flood duration was over 120 days. However, this impact definition produced a high death rate so the ranges were smoothed to 240-366 days for strong impacts, 150-239 days for moderate impacts and 90-149 for low impacts, considering than values lower than 90 days had no impact over any vegetation phase.

The succession progression from reed succession line to woodland was set in 10 years. Although this is a calibration parameter, it was considered unnecessary to modify the expert rule recommended value.

7.2.2.2 ETidx sub-model calibration description

The fifth parameters group was calibrated in order to establish the upper and lower ETidx limits. Those limits were set for each phase of both succession lines. The sub-model definition assumes that when the upper limit is overcome the succession line evolve and the vegetation obtains one more year, so if the original is in the last year of a succession phase it evolves to the next phase. If this value is not reached there are two possibilities. The first one maintains the original vegetation age if the ETidx value is higher than the lower limit. If the ETidx value is under the lower limit the vegetation dies and there is retrogression to the initial succession phase. Only one restriction was considered in these limits calibration, the upper limit had to be strictly higher than the lower limit in order to allow the consideration of the three possibilities (over the upper limit, under the lower limit and between limits). The upper limits were very similar for reed and woodland series being between 0.80 and 0.95 for every succession phase (Table 7.3). On the contrary, the optimal lower limits were very different being set from 0.20 for the last phase of woodland series to 0.70 for reed shrubs phase.

The ETidx sub-model required an additional previous calibration for the plant functional types (PFTs) parameters (Table 7.4).

The PFTs considered for this work were riparian herbs (RH), riparian juveniles and small shrubs (RJ), riparian adult trees and big shrubs (RA) and terrestrial vegetation (TV). The parameters calibrated were the different root depths, maximum (*Zr*), effective (*Ze*) and saturation extinction (*Zsat*), and the transpiration factors from unsaturated (*Ri*) and saturated (*Rj*) zones. In addition, critical (*Pcrit*) and wilting point (*Pwp*) pressures were adjusted in order to find the best solution, as well as the coverage fraction for each PFT (*Cov*) and the maximum conductivity water-root-soil (*CRT*).

7.2.2.3 Parameters values

Table 7.3. Calibration parameters values for Terde reach in Mijares River (Spain) corresponding to the recruitment sub-model (1), shear stress sub-model (2), flood duration sub-model (3), succession to woodland sub-model (4) and ETidx sub-model (5).

	Parameter	Value	Units
1	HBFL for Floodplain Recruitment Dry	> 7	meters
	HBFL for Woodland Recruitment Zone	0.6 – 3	meters
	HBFL for Scour Disturbance Zone	< -5 and > 7	meters
	Pioneer zone	≤ 3	years
2	Critical Shear Stress of Woodland	12 (IP-SD) 22 (PP-RH) 24 (WD-HP-RH) 26 (WD-SP-RJ) 26 (WD-ES-RA) 27 (WD-EF-RA) 30 (WD-MS-RA) 30 (WD-UF-TV)	$N.m^{-2}$
	Critical Shear Stress of Reed	12 (IP-SD) 22 (PP-RH) 23 (RE-HP-RH) 24 (RE-SP-RH)	$N.m^{-2}$
3	Flood Strong Impacts	240 – 366	days
	Flood Moderate Impacts	150 – 239	days
	Flood Low Impacts	90 – 149	days
	No flood impacts	0 – 89	days
4	Succession Reed to Woodland	< 10	years
5	Woodland upper ETidx limit	0.85 (IP-SD, PP-RH, WD-HP-RH) 0.90 (WD-SP-RJ, WD-ES-RA) 0.95 (WD-EF-RA, WD-MS-RA, WD-UF-TV)	-
	Woodland lower ETidx limit	0.40 (IP-SD, PP-RH, WD-HP-RH, WD-SP-RJ, WD-ES-RA) 0.30 (WD-EF-RA, WD-MS-RA) 0.20 (WD-UF-TV)	-
	Reed upper ETidx limit	0.80 (IP-SD, PP-RH, RE-HP-RH) 0.95 (RE-SP-RH)	-
	Reed lower ETidx limit	0.50 (IP-SD, PP-RH, RE-HP-RH) 0.70 (RE-SP-RH)	-

Table 7.4. Plant functional types parameters calibrated values for the ETidx sub-model.

Plant functional types	Vegetation parameters								
	Zr (m)	**Ze** (m)	**Zsat** (m)	**Ri** ( )	**Rj** ( )	**CRT** (mm.Mpa^{-1}.h^{-1})	**Pwp** (KPa)	**Pcrit** (KPa)	**Cov** ( )
RH	1.25	0.7	-0.9	0.7	0.9	0.97	1500	500	0.7
RJ	1.3	0.8	-0.3	0.7	0.3	0.97	1500	350	0.7
RA	3.2	0.8	-0.3	0.7	0.3	0.97	1500	125	0.8
TV	1.9	1.6	1.6	1	0	0.97	1500	95	0.8

In the calibration of these plant functional types parameters, the riparian adult trees and big shrubs obtained the higher root depth. This is a typical characteristic of the plants included in this functional type because they are continuously searching the water table. All the riparian functional types are capable to transpire from the water table, being the riparian herbs those which prefer that situation. That is why the transpiration factor was set very high for riparian herbs and lower but existent for riparian trees and shrubs. In the same way, the terrestrial vegetation is not able to transpire from the saturated zone so the *Rj* factor is null for this plant functional type and the unsaturated transpiration factor is maximum, equal to 1. However, the most important physiological characteristic of all the riparian vegetation functional types is their resistance to flood levels over the soil surface. While terrestrial vegetation is not capable to transpire when the water table is over 1.6 meters depth from the soil surface, riparian herbs in example can endure almost a meter of water over the soil surface and under this situation they still transpire.

In addition, critical pressures have been set higher for riparian herbs because they can continue increasing the transpiration rate when the soil moisture is higher. This critical pressure is lower and lower for older riparian trees and shrubs, getting the less value the terrestrial vegetation which transpiration rate increase is limited by lower soil moisture levels. On the contrary, the wilting point pressures have been maintained in 1500 KPa, and the maximum conductivity water-root-soil remained constant with a 0.97 mm.Mpa^{-1}.h^{-1} value for each plant functional type.

The coverage fraction was defined as 0.7 for riparian herbs and small riparian shrubs as well as riparian juvenile trees and 0.8 for adult riparian trees, big shrubs and terrestrial vegetation because of the higher biomass density for these two last plant functional types.

7.2.3 Calibration results

The results obtained in the calibration process were analyzed by a confusion matrix and the coefficient of agreement, *kappa* (Cohen, 1960). Then the simulated vegetation map was compared with the observed vegetation map considering the proportions of each vegetation succession phase.

7.2.3.1 Confusion matrix

The confusion matrix is a visualization tool where the columns represent the number of units simulated for each category while the rows represent the real or observed values. In this case the units are the cells from the vegetation raster file and the categories are the different phases of the two succession lines, woodland and reed. For each simulation point an observed and a simulated succession phase must exist. The confusion matrix is created by adding a unit value in the corresponding row and column when each simulated point is compared to the observed phase. Once all the raster cells are compared, except those with NoData value, we obtain the resultant confusion matrix (Table 7.5) which main diagonal has been highlighted to facilitate the visualization of the cells where the simulated phases match up with the observed phases.

The calibration of the model objective is to make those values as higher as possible; reducing to minimum the other values specially those further from the main diagonal. In the reed cases the minimum values must be those located far from the main diagonal and from the first succession phases observed instead they are situated at the end of the confusion matrix.

Table 7.5. Confusion matrix obtained by comparison of simulated (columns) and observed (rows) vegetation successional phases for year 2009, once the RIPFLOW model was calibrated in Terde (Mijares River, Spain)

	Confusion matrix									
	IP-SD	PP-RH	WD-HP-RH	WD-SP-RJ	WD-ES-RA	WD-EF-RA	WD-MS-RA	WD-UF-TV	RE-HP-RH	RE-SP-RH
IP-SD	441	175	143	50	41	68	18	0	50	239
PP-RH	427	23	1	0	2	1	0	17	37	19
WD-HP-RH	429	10	413	35	54	68	44	27	34	163
WD-SP-RJ	1072	23	23	278	64	42	71	45	41	233
WD-ES-RA	665	30	23	16	615	468	608	59	49	189
WD-EF-RA	410	15	5	1	1	1083	247	62	87	83
WD-MS-RA	336	3	10	6	2	12	1010	4	15	16
WD-UF-TV	918	61	23	44	5	46	136	17721	71	82
RE-HP-RH	0	0	0	0	0	0	0	0	0	0
RE-SP-RH	481	34	74	28	46	235	36	7	30	303

The resultant confusion matrix showed a very satisfactory calibration result. As can be seen most of the values from the main diagonal are maximum compared to other cells. Some confusion have been observed in IP-SD phase simulation which appears simulated in some points of every observed phases and which is simulated as other phases sometimes when it has been observed.

There seem to be a minor displacement to RE-SP-RH when first woodland succession phases were observed and vice versa, nevertheless several tries to improve the results focusing in this matter were unsatisfactory. The case of RE-HP-RH is similar but considering that it has not been observed in field. The other confusions were considered not relevant because of they were closer to the correct succession phase and because of their low influence to the total number of simulation points.

7.2.3.2 Coefficient of agreement, kappa

To complement the confusion matrix results, the coefficient of agreement, *kappa*, was calculated. This coefficient is calculated by the difference between the observed and expected frequencies relative to the maximum possible number of agreements not attributable to chance. This number is the difference between the total number of simulated points and the expected frequency. This way, kappa (16.) is defined as the measure of agreement corrected the effect of chance.

$$k = \frac{\sum f_0 - \sum f_e}{n - \sum f_e} \qquad (16.)$$

Where:

- Σf_o is the sum of the frequencies observed in the main diagonal
- Σf_e is the sum of the expected frequencies on the main diagonal. Each f_e is calculated as the product of total number of simulated points and total number of observed points for each succession phase, divided by the total number simulation points.
- n is the total number of simulation points

The maximum value of *kappa* is 1, perfect agreement when all cases fall on the main diagonal of the confusion matrix and the other cells are empty. When k is very high, greater than 0.8, it is considered that the disagreements are the result of marginal discrepancies. By convention kappa results are classified as following.

- 0.4 < *kappa* > 0.6 → acceptable
- 0.6 < *kappa* > 0.8 → good
- 0.8 < *kappa* > 1.0 → excellent

The kappa value obtained with the calibration proposed for Terde reach in the Mijares River (Spain) is 0.7127 ± 0.0067 (95% confidence limit) or 0.7127 ± 0.0089 (99% confidence limit). This result was considered a very good result taking into account that the number of points for each succession phase were not always similar and that some of those phases were barely observed in field.

7.2.3.3 Simulated vegetation

The simulated vegetation map showed the observed riparian bands zonation in a very satisfactory way (Figure 7.8). Although some confusion have been observed in several bank patches located close to the aquatic zone, where initial phase is simulated instead of other phases, the distribution of most of the patches is correct.

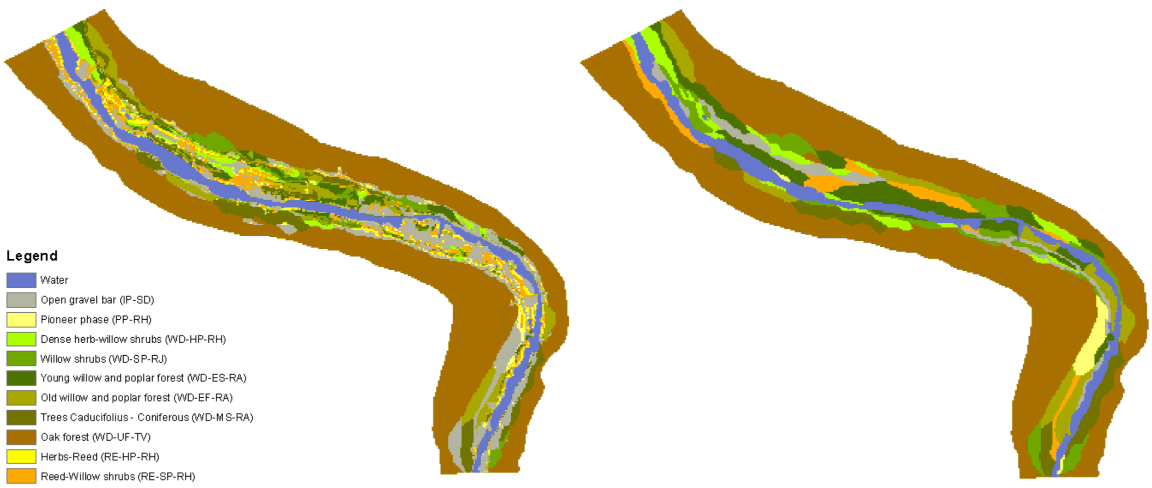


Figure 7.8. Vegetation succession phases maps in Terde (Mijares River, Spain). On the left hand the simulated vegetation for year 2009 (end of the 22 years simulation period). On the right hand the observed vegetation in year 2009.

If an extraction of some areas from the reach is done, the matching zonation is more evident. Here, seven subareas had been analyzed separately (Figure 7.9).

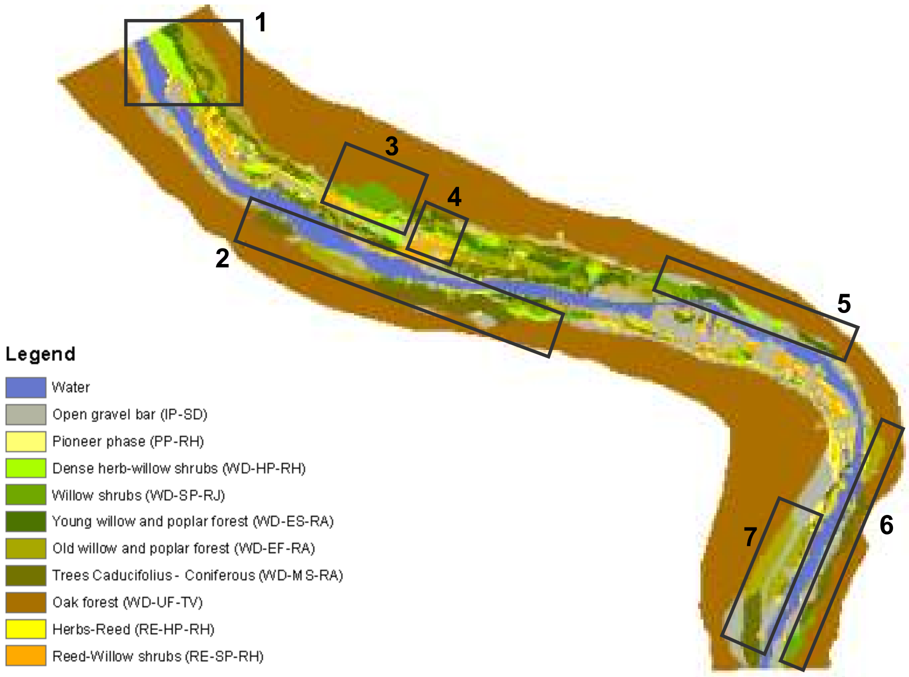


Figure 7.9. Different subareas selected from the simulated vegetation succession phases within the calibration process in Terde (Mijares River, Spain).

In the first subarea reed willow shrubs succession phase has been simulated correctly in the right bank. In addition in the left riparian area, three woodland bands parallel to the stream are correctly simulated too locating a first dense herb and willow shrubs patch close to the river, a second band of young willow and poplar forest and a third patch of old willow and poplar forest adjacent to the oak forest. This is exactly the same vegetation phase distribution observed in field for year 2009 in Terde reach.

The subarea number 2 is located in the right bank of the reach. It was simulated in a very satisfactory way, showing a deciduous and coniferous trees patch followed downstream by an old willow and poplar forest and next another big patch of deciduous and coniferous trees, ended by a group of dense herbs and willow shrubs.

In the third subarea the willow shrubs patch simulation was very accurate and the observed dense herbs mixed with willow shrubs patch was simulated in combination with reed herbs and shrubs phases, which is not a serious confusion.

The forth subarea shown presence of reed willow shrubs near the aquatic zone, a small patch of woodland dense herb and willow shrubs in a parallel band and predominance of young willow and poplar forest between that band and the oak forest sited distant from the channel. This is a very similar distribution from which was observed on field for that year.

In 5, 6 and 7 subareas occurs the same situation, the vegetation is correctly simulated. However, in those subareas some open gravel bars with naked soil are simulated when they had not been observed. Fortunately, these open gravel bars had been simulated in first succession phases expected locations, so the confusion was considered assumable.

Complementary, the balance of succession phases was compared for simulated and observed vegetation (
Figure 7.10). As can be seen in the figure there is an excess of willow shrubs from the reed succession line instead of some early phases of woodland succession line as dense herbs, willow shrubs phases and principally young willow and poplar forest phases. In addition, a slightly observed presence (0.07%) of herbs from reed succession line is simulated in a higher proportion (2.04%). Apart from these confusions, the figure shows an excellent result of the model calibration.

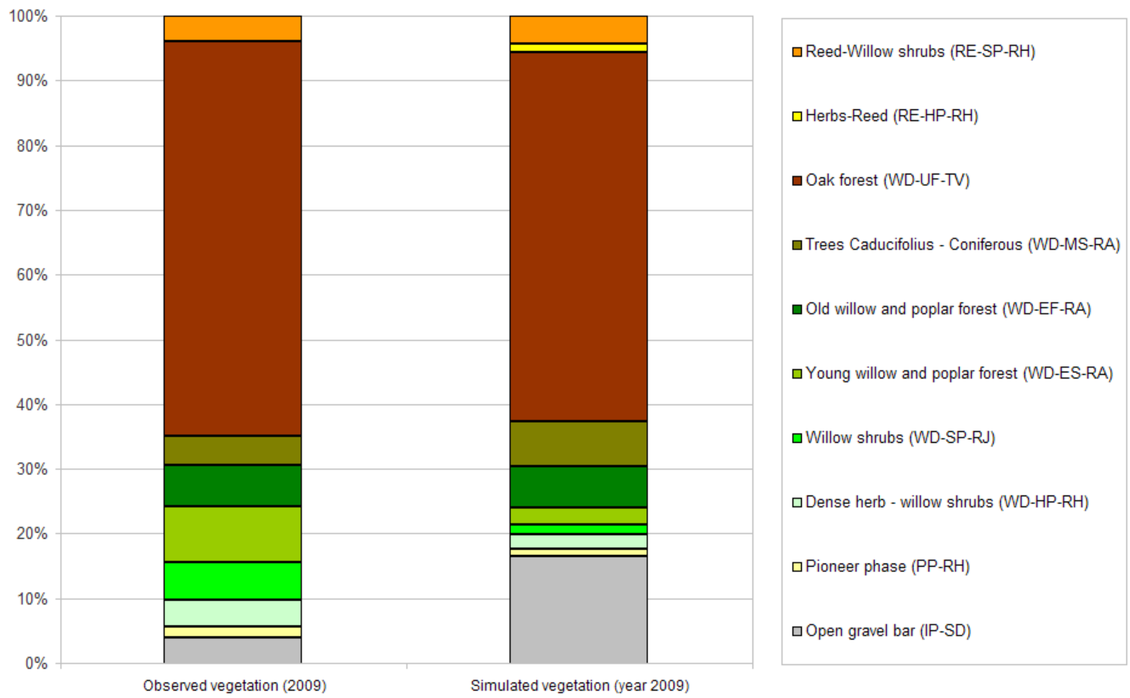


Figure 7.10. Comparison between observed and simulated succession phases balances in Terde (Mijares River, Spain) for year 2009.

Considering the resultant confusion matrix, the kappa coefficient result and the visual map comparison with the balance analysis, the calibration of the RIPFLOW model was considered a great success for Terde reach in the Mijares River (Spain).

7.3 Austria

The dynamic vegetation model applied to the Austrian study case has been applied using the recruitment and shear stress sub models. This section describes how the input data for these sub models have been yield and how their parameters have been adjusted to fit the considered ecosystem behaviour.

7.3.1 Inputs definition

The dataset required for running the dynamic vegetation model in the Austrian study case (Upper Drau) where the digital elevation model of the site, the boundaries of aquatic, bank and floodplain zone, the groundwater elevation during the recruitment period and the maximum shear stress of the simulated years. The lineage to yield these inputs have been previously described in the **sections**. In this section is explained how these inputs have been classified and lined up to mimic the Upper Drau riparian ecosystem behaviour in the natural reference study site. Particularly, the inputs which need to be classified where the groundwater and the maximum shear stress, in fact, topography (DEM) and riverine zones have been kept constant across all the simulations. Inputs classification have been performed for the calibration and for each simulated scenario, namely: natural reference, optimistic climate change scenario and pessimistic climate change scenario.

The base data for the simulations on the floodplain vegetation of the Upper Drau where represented by the time series discharge data measured at the Sachsenburg gauging station. The measures refer to daily values which have been processed to yield the maximum yearly value and the mean discharge value during the floodplain vegetation recruitment period (April-July).

7.3.1.1 Spring Mean Discharge

Recruitment period discharges have been classified according to the values in Table 7.7. Each of the classes in Table 7.7 corresponds to a ground water input grid that would be then used in the recruitment sub model. As example, in
Table 7.6 are listed the mean spring discharges between the year 1960 and 1990 (natural reference period).

Table 7.6 Mean spring discharge of the reference period

Year	***Mean Discharge (m^3/s)***
1960	144
1961	120
1962	152
1963	113
1964	89
1965	142
1966	106
1967	138
1968	123
1969	102
1970	121
1971	95
1972	141
1973	91
1974	96
1975	168
Year	***Mean Discharge (m^3/s)***
1976	78
1977	145
1978	114
1979	143
1980	107
1981	114

1982	93
1983	109
1984	96
1985	116
1986	126
1987	115
1988	103
1989	107
1990	89

In Table 7.7 are listed the groundwater elevation classes that have been used to classify the mean spring discharges for all the simulations. Each discharge class corresponds to a groundwater table raster grid (dynamic model input) and marks also the type of the year in respect of the recruitment conditions: very dry, dry, medium, wet or very wet.

Table 7.7. Mean spring discharge representative values

Mean Discharge (m^3/s) Class	***Year Type Classification***
80	Very Dry
100	Dry
140	Medium
160	Wet
125	Very Wet

The result of the mean spring discharges listed in Table 7.8 are the result of the application of the discharge classes in Table 7.7 applied to
Table 7.6. The classification have been performed replacing the real spring mean discharge value with the mean discharge class arithmetically more close to the real value.

Table 7.8 Mean spring discharge classification for the reference period

Year	***Mean Discharge (m^3/s) Class***	***Year Type Classification***
1960	140	Wet
1961	125	Medium
1962	160	Very wet
1963	125	Medium
1964	80	Very dry
1965	140	Wet
1966	100	Dry
1967	140	Wet
1968	125	Medium
1969	100	Dry
1970	125	Medium
1971	100	Dry
1972	140	Wet
1973	100	Dry
1974	100	Dry
1975	160	Very wet

	(m^3/s) Class	***Classification***
1976	80	Very dry
1977	140	Wet
1978	125	Medium
1979	140	Wet
1980	100	Dry
1981	125	Medium
1982	100	Dry
1983	100	Dry
1984	100	Dry
1985	125	Medium
1986	125	Medium
1987	125	Medium
1988	100	Dry
1989	100	Dry
1990	80	Very dry

Year	***Mean Discharge***	***Year Type***

7.3.1.2 Maximum Shear Stress

Maximum discharges have been classified in respect of the available recurrence (HQ) intervals (Table 7.9). Each of the classes in Table 7.9 correspond to a shear stress input grid (Figure 6.32) that would be then used in the shear stress sub model.

Table 7.9 Flood recurrence discharge interval classes

Discharge (m^3/s)	*HQ Class*
270	HQ0.5
320	HQ1
380	HQ2
490	HQ5
590	HQ10
790	HQ30
1050	HQ100
1140	HQ150
1310	HQ300

As example of the base data, in Table 7.10 are listed the maximum year discharges measured between 1960 and 1990 at the Upper Drau. These base data have been classified by replacing the maximum year discharge value with the maximum discharge class arithmetically more close to the real value.

Table 7.10 Maximum year discharges measured at the Upper Drau

Year	*Max Discharge (m^3/s)*	*Year*	*Max Discharge (m^3/s)*
1960	355	1976	251
1961	334	1977	312
1962	410	1978	292
1963	355	1979	352
1964	220	1980	364
1965	994	1981	471
1966	1010	1982	228
1967	306	1983	249
1968	249	1984	224
1969	236	1985	277
1970	314	1986	336
1971	179	1987	368
1972	521	1988	228
1973	214	1989	316
1974	267	1990	216
1975	330		

The result of the maximum discharge classes listed in

Table 7.11 is the result of the application of the maximum discharge classes in Table 7.9 applied to Table 7.10 .

Table 7.11 Maximum discharge classification of the reference period

Year	Max HQ Class
1960	2
1961	1
1962	2
1963	2
1964	0.5
1965	100
1966	100
1967	1
1968	0.5
1969	0.5
1970	1
1971	0.5
1972	5
1973	0.5
1974	5
1975	1
1976	0.5
1977	1
1978	0.5
1979	2
1980	2
1981	5
1982	0.5
1983	0.5
1984	0.5
1985	0.5
1986	1
1987	2
1988	0.5
1989	1
1990	0.5

7.3.1.3 Parameters values

In

Table 7.12 are listed the parameters values for the recruitment sub model and the shear stress sub model which have been used to run the model at the Upper Drau. The values refer to the recruitment zones and the mechanical (shear stress) resistance of each succession phase. The recruitment zones are defined by relative elevation above groundwater level and by the riverine zone (either bank or floodplain). Each recruitment zone has a different recruitment effect on the different succession series. Mechanical resistance is instead the measure of the maximum shear stress a succession phase can withstand without being recycled to initial phase.

Table 7.12 Calibration parameters values for Kleblach study site at the Upper Drau (Austria) corresponding to the recruitment sub model (1) and shear stress sub model (2).

	Parameter	Value	Units
1	HBFL for Woodland Recruitment Zone (bank zone)	-0.6 – 0.5	meters
	HBFL for Reed Recruitment Zone I (bank zone)	0.5-10	meters
	HBFL for Reed Recruitment Zone II (floodplain zone)	0.8-10	meters
	HBFL for Wetland Recruitment Zone (floodplain zone)	-2-0.8	meters
	HBFL for Scour Disturbance Zone (bank zone)	< -5 and > -0.6	meters
2	Critical Shear Stress of Woodland succession series	1 Initial phase 3 Pioneer phase 25 Pioneer shrub phase 60 Shrub phase 400 Early successional woodland phase 400 Established forest phase	$N.m^{-2}$
	Critical Shear Stress of Reed succession series	1 Initial phase 3 Pioneer phase 40 Herb phase	$N.m^{-2}$
	Critical Shear Stress of Wetland succession series	25 Deep oxbow 35 Shallow oxbow 40 Bog forest	

7.3.2 Calibration Process

7.3.2.1 Recruitment and Shear Stress calibration description

Dynamic vegetation model has been evaluated simulating the time period 2003 – 2009 based on the hydraulic data measured in this time span. Starting point of the simulations was the vegetation mapped in the study site in 2003. The model parameters to be adjusted where the height above groundwater at which occurs the recruitment and the shear stress resistance of each succession phase. The model parameters have been visually and iteratively adjusted based on several model runs focusing solely on the bank zone. For the final adjustment of the values, the model results have been analyzed by the means of overall accuracy, *k* coefficient (Chandra & Ghosh, 2006; Cohen, 1960) and relative area balance using as a reference some of the maps of the vegetation sampled during the post restoration monitoring. Visual comparison and statistical adjustment was based on based on the vegetation mapped in 2003, 2005, 2007, 2008 and 2009. During the simulations, have been used both the morphologies measured in 2003 and in 2008. The dynamic vegetation model is in fact capable of coping with different morphologies which are feed as inputs. In order to yield results more close to the observed situation, in the simulated time span 2003-2006 it has been used the 2003 morphology while in the simulated time span 2007 – 2010 it has been used the morphology measured in 2008.

7.3.3 Calibration results

The overall accuracy (Table 7.13) is sufficiently satisfactory. Most of the model results are around or above 50% of agreement with the observed vegetation. Cohen's k coefficient analysis shows fair model reliability in predicting the vegetation development in the bank zone with most of the calculated coefficients approaching the minimum reliability threshold of 0.4. The decreasing accuracy is clearly reflecting the fact that the morphology has to be adapted to real conditions more frequently and the Dynamic Vegetation Model would have to be coupled with a morphodynamic model.

Table 7.13 Overall accuracy and k coefficient results

Simulated Year	*Overall Accuracy*	*K Coeff.*
2003	97.2%	0.5
2005	35.5%	0.1
2007	49.0%	0.4
2008	48.4%	0.4
2009	38.5%	0.3
2010	9.9%	0.1

Table 7.14 Relative area balance comparison between the observed and simulated vegetation.

Year	Map	IP	PP	HP	PSP	SP	ESWP	Tot.
2003	*Obs.	98.70%	0.0%	0.0%	0.0%	0.0%	1.30%	100.0%
	**Sim.	100%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
2005	*Obs.	39.0%	24.9%	1.2%	33.6%	0.0%	1.4%	100.0%
	**Sim.	71.6%	0.0%	9.3%	19.1%	0.0%	0.0%	100.0%
2007	*Obs.	17.8%	53.0%	0.4%	10.8%	3.5%	14.6%	100.0%
	**Sim.	61.5%	11.4%	4.3%	0.0%	6.3%	16.5%	100.0%
2008	*Obs.	24.8%	23.0%	8.4%	27.7%	8.5%	7.6%	100.0%
	**Sim.	9.2%	52.3%	7.6%	8.2%	6.3%	16.5%	100.0%
2009	*Obs.	14.6%	14.4%	17.5%	1.2%	44.7%	7.7%	100.0%
	**Sim.	29.0%	0.0%	8.3%	32.0%	14.3%	16.5%	100.0%
2010	*Obs.	9.9%	0.0%	4.4%	53.7%	0.0%	32.1%	100.0%

**Sim.	12.8%	5.2%	10.3%	17.5%	16.1%	38.1%	100.0%

*Obs.: *Observer Vegetation; **Sim.: Simulated Vegetation

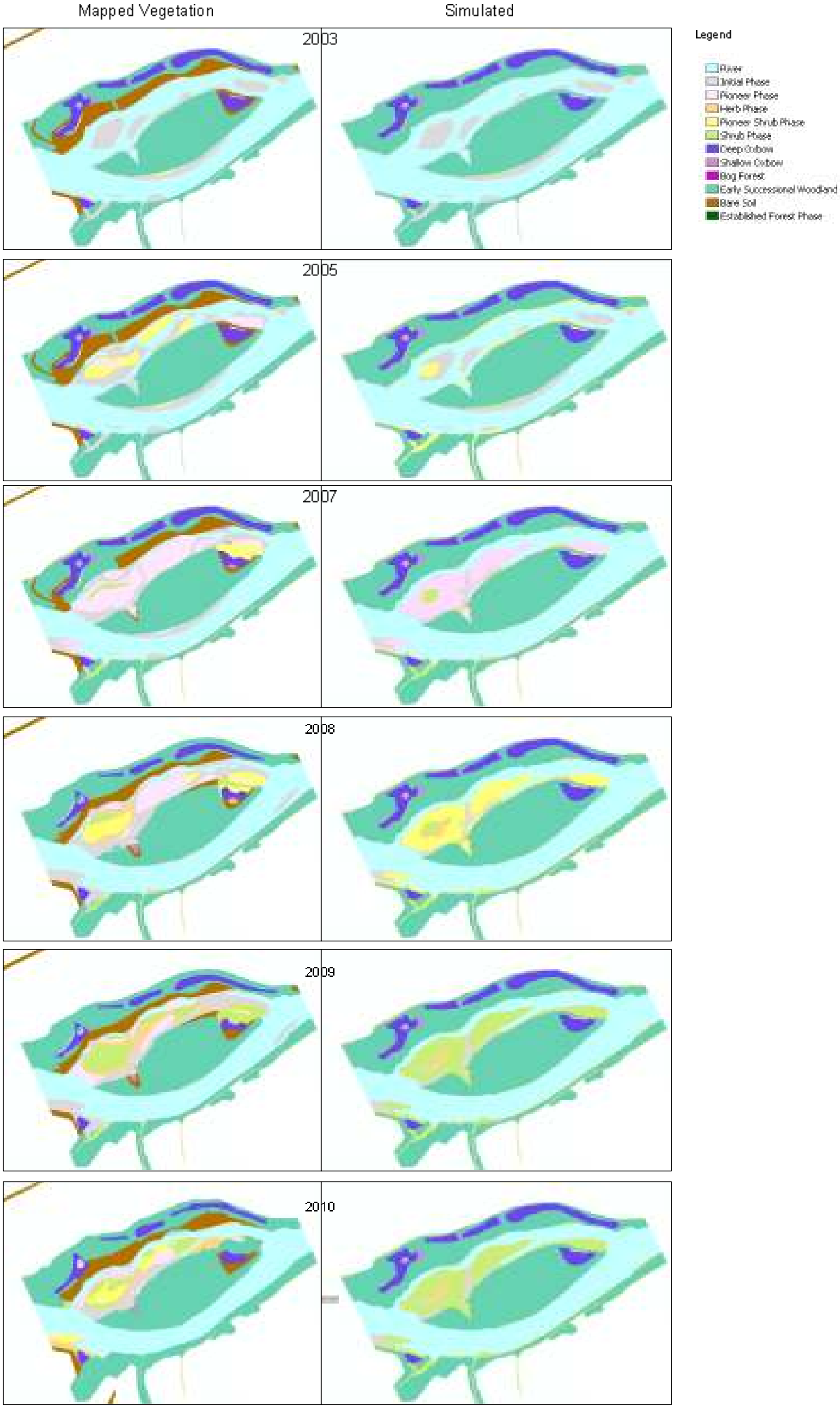


Figure 7.11 Mapped and simulated vegetation for the calibration period

Model evaluation for the *k* coefficient can be explained with the discrepancy between the cover types mapped during the restoration monitoring and the succession phases output from the model. Mapping takes into account also human managed cover types, such rip rap or groins, while the model is able to simulate only vegetation. The simulated year which extreme high accuracy and the *k* coefficient best score is 2003, but this can be explained by the choice of the starting condition model (which was the vegetation mapped in 2003).

In the model evaluation, the relative area balance have been kept in higher consideration, even if there is not a perfect match between the relative area balance observed and the relative are balance simulated.

Relative area balance comparison (Table 7.14) shows just in some cases a very close correspondence between the observed and the simulated succession phases. However the sum of contiguous observed succession phases relative cover (i.e. initial and pioneer), it is always very close to the sum of contiguous simulated succession phases relative covers.

The preference to the relative area balance index derives from the succession phases definition. In fact, youngest phases such initial, pioneer and pioneer shrub differ in their age definition just for one year, therefore, when the sum of the relative area balance cover of two observed contiguous phases was similar to the sum of the relative area balance cover of two simulated contiguous phases, the model outcome have been considered reliable.

7.4 Portugal

7.4.1 Inputs definition

The first three sub models in which the vegetation model lays on need several data inputs in order to model the riparian vegetation from the river flow dynamics. Those inputs are topography; fluvial zones maps; shear stress and water table elevation of the maximum year floods; and hydrologic regime database file to guide the model in the inputs use choice process through the considered modeling period.

The ETidx sub model needs also several data inputs which are daily information about river flow, potential evapotranspiration and precipitation; water table elevations of the maximum year floods; digital elevation model, soil type and initial vegetation maps; soil and vegetation related parameters.

Table 7.15. describes the inputs created to be used in the vegetation modeling at Odelouca study site.

Table 7.15. Inputs definition for Odelouca study site.

Input	Used files	Figure
Topography	Topography	Figure 6.48
Fluvial zones	Aquatic, bank and floodplain zones	Figure 6.51
Shear stress	Shear stress – q4 Shear stress – q16 Shear stress – q20 Shear stress – q35 Shear stress – q60 Shear stress – q80 Shear stress – q97 Shear stress – q171 Shear stress – q225 Shear stress – q290 Shear stress – q427 Shear stress – q483	Figure 6.53
Water table elevation	WTE – hbf WTE - q_{med} WTE – q4 WTE – q16 WTE – q20 WTE – q35 WTE – q60 WTE – q80 WTE – q97 WTE – q171 WTE – q225 WTE – q290 WTE – q427 WTE – q483	Figure 6.52

7.4.2 Calibration process

Calibration is an ongoing process and is being performed in the Odelouca study site. In this case, the model calibration will be achieved applying the expert rules parameters to the recruitment, flood duration, shear stress and ETidx sub model tuning. The calibration of the model is performed running a ten year period (the hydrologic regime of 1999 – 2009 was considered the calibration period) with the hydrologic regime recorded for that time schedule. The modeling result (modeled patch display for the year 2009) is then compared with the vegetation map of the existing patch display observed in the 2009 survey.

7.4.2.1 Recruitment, shear stress and flood duration sub models calibration description

The recruitment sub model calibration was achieved with the expert rules defined in previous chapters which were the result of the vegetation data treatment from the observed characteristics at the Odelouca natural study site.

The calibration of the shear stress sub model was performed by an iterative process where the calibration period was run by the model and it was paid attention at the vegetation response to the applied shear stress. The results were compared with the real vegetation patch display in 2009 at several check points of the study site. The best fitted values were used in the calibrated model.

Flood duration sub model was not calibrated as this was considered a non applicable input in the Odelouca hydrologic regime. The explanation for this decision is provided in chapter 6.4.6.4. The input information supplied to the model in the Odelouca model runs didn't interfere with the results (because flooded days where considered as zero) so it was used the model default values for this parameter.

7.4.2.2 ETidx sub model calibration description

The ETidx sub model calibration is still in performance. This process considers the vegetation parameters defined by the Spanish partners and transposing the Portuguese succession phases into the vegetation types used by ETidx sub model. On the other hand, soil parameters used in the modeling were the soil types found in the study sites.

Upper and lower ETidx limits are calibrated using an iterative process of trial-error changing those parameters to found the most suitable result.

7.4.2.3 Parameters values

The parameter values which provided the best results so far in the model calibration process are described in the table below (Table 7.16). The presented values were used in the attempt modeling for climate change scenarios at Odelouca.

Table 7.16. Calibration parameters values for Odelouca natural reference study site (Portugal) corresponding to the recruitment sub model (1), shear stress sub model (2), flood duration sub model (3), succession to woodland sub model (4) and ETidx sub model (5).

	Parameter	Value	Units
1	HBFL for Floodplain Recruitment Dry	> 3.405	meters
	HBFL for Woodland Recruitment Zone	0.363 – 2.778	meters
	HBFL for Scour Disturbance Zone	< - 0.353 and > 2.778	meters
	Pioneer zone	≤ 5	years
2	Critical Shear Stress of Woodland	20 (IP) 60 (PP) 90 (YSWP and EFP) 450 (MFP)	$N.m^{-2}$
3	Flood Strong Impacts	150 – 366	days
	Flood Moderate Impacts	119 – 150	days
	Flood Low Impacts	90 – 119	days
	No flood impacts	0 - 90	days
4	Succession Reed to Woodland	< 0	years
5	Woodland upper ETidx limit	0.70 IP 0.50 PP 0.68 YSWP 0.70 EFP 0.90 MFP	-
	Woodland lower ETidx limit	0.30 IP 0.45 PP 0.50 YSWP 0.60 EFP 0.70 MFP	-

7.4.3 Calibration results

The calibration results were evaluated by confusion matrix and Cohen *Kappa* coefficient of agreement methodology (Cohen, 1960). This comparison was made by pixel, recording the concordant/discordant classifications, attributed by the model and vegetation survey to the same pixel. The model accuracy was evaluated with and without the Evapotranspiration sub model at Odelouca study site.

7.4.3.1 Confusion matrix

The comparison between modeled and observed results can be displayed in a matrix form, known as confusion matrix, where rows stand for the observed successions and columns the modeled ones. In this matrix the diagonal line is where both events meet and indicates the extent of agree level, whereas in the other cells point out the mismatching between events (Table 7.17).

The outcome of the modeled vs. observed maps comparison for the Odelouca study site is presented in the Table 7.17 and Table 7.18, respectively, without the evapotranspiration sub model and with it.

Table 7.17. Model accuracy without evapotranspiration sub model. Confusion matrix obtained by comparison of modeled (columns) and observed (rows) vegetation successional phases for year 2009, in Odelouca natural reference study site (Portugal).

		Modeled				
		IP	PP	YSWP	EFP	MFP
Observed	IP	**14731**	**5625**	**10786**	**2134**	**0**
	PP	**2441**	**3750**	**498**	**574**	**0**
	YSWP	**6788**	**4619**	**8372**	**4233**	**0**
	EFP	**376**	**5683**	**1569**	**33030**	**0**
	MFP	**0**	**29**	**1**	**562**	**0**

Table 7.18. Model accuracy with evapotranspiration sub model. Confusion matrix obtained by comparison of modeled (columns) and observed (rows) vegetation successional phases for year 2009, in Odelouca natural reference study site (Portugal).

		Modeled				
		IP	PP	YSWP	EFP	MFP
Observed	IP	**23364**	**1180**	**7184**	**898**	**0**
	PP	**6015**	**198**	**658**	**247**	**0**
	YSWP	**18319**	**1255**	**2628**	**1313**	**0**
	EFP	**15092**	**1067**	**643**	**23261**	**0**
	MFP	**507**	**2**	**0**	**79**	**0**

7.4.3.2 Coefficient of agreement, kappa

Calibration results without Evapotranspiration sub model achieved an acceptable/good accuracy with Unweighted Kappa=0.48 and Quadratic Weighted Kappa=0.61. On the other hand, Kappa decreased considerably when considered the Evapotranspiration sub model, with Unweighted Kappa=0.24 and Quadratic Weighted Kappa=0.32.

7.4.3.3 Simulated vegetation

The bellow figures exhibit vegetation maps obtained in the calibration process, namely, Odelouca 2009 without Evapotranspiration sub model and Odelouca 2009 with Evapotranspiration sub model (
Figure 7.12).

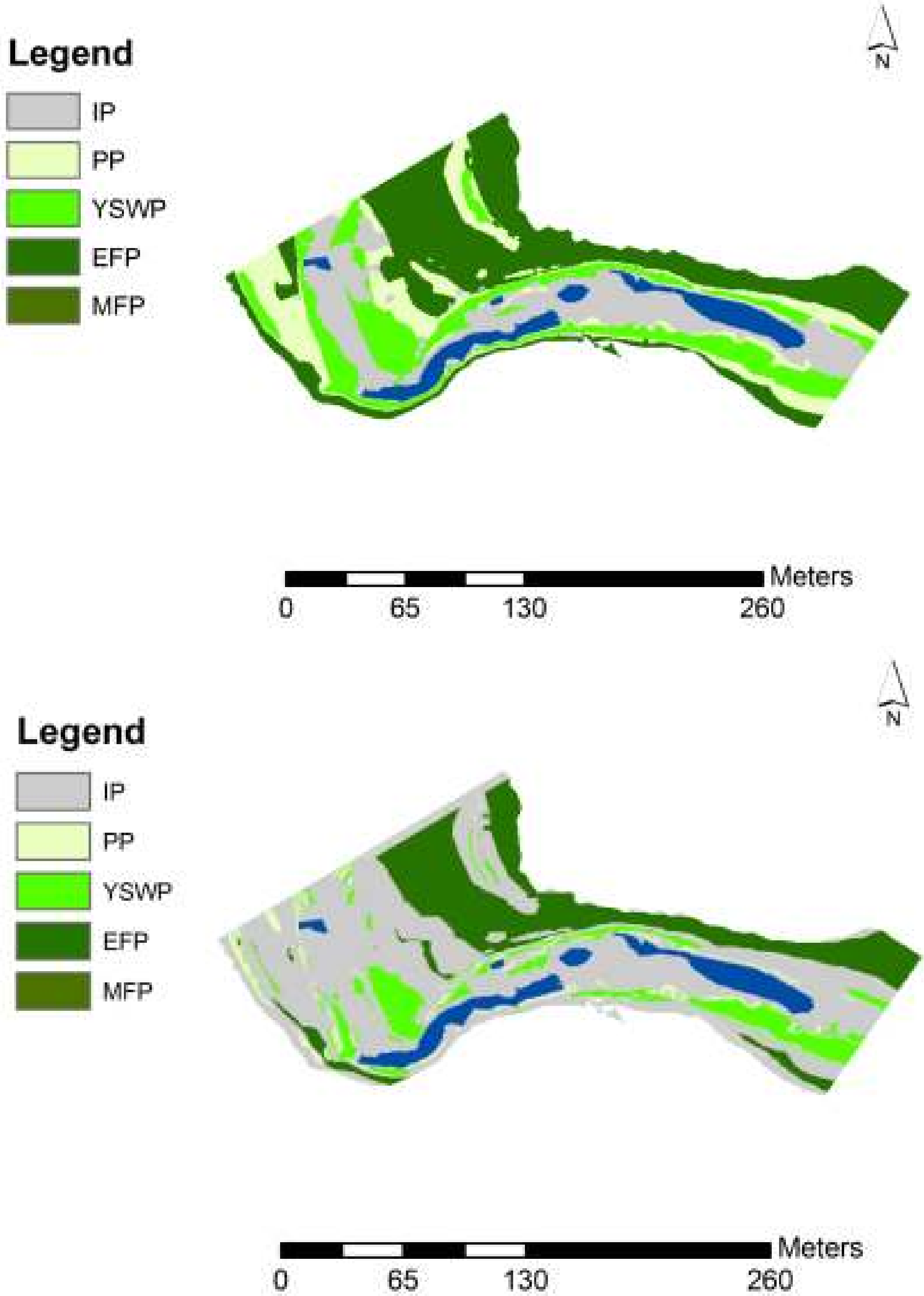


Figure 7.12. Calibration results. Modeled vegetation without (above) and with (below) the evapotranspiration sub model.

8 Discussion of Results

8.1 Introduction

RIPFLOW model has been applied in different case studies encompassing the different European hydrologic regimes, from intermittent Mediterranean rivers in southern Iberia Peninsula, to temperate ones in Eastern Europe. This wide application was possible due to the succession response level approach, eliminating differences like species composition (Merritt *et al*., 2010).

RIPFLOW model uses as inputs the critical components of the flow regime which regulate ecological processes in river ecosystems (Poff *et al*., 1997) to determine riparian patches arrangement according to these shaping forces.

Calibration accuracy of the model reached different Kappa values for each partner at the sub model's calibration process, with divergent results suggesting research is still needed on succession phase's definition and model parameters characterization (Table 8.1).

However, the good results achieved in some cases demonstrate that with a high-quality calibration developmental process the RIPFLOW model can reproduce correctly the fluvial dynamics exerted on riparian patches and its resilience response with at adequate quality.

Table 8.1. RIPFLOW model calibration accuracy results

	Model accuracy (k)	
	RIPFLOW model (without ETidx sub model)	RIPFLOW model (with ETidx sub model)
Spain	-	0.72
Austria	0.4	-
Portugal	0.48	0.24

RIPFLOW model was applied for different climate change and regulated flow scenarios. The flow regulation scenarios modeled by RIPFLOW model show an Initial phase (IP) decrease, with a consequent increase in the overall succession phases. This result is clearly related to the reduced shear stress of restrained discharges of regulated flow regimes. Due to this fact, the maximum year discharges are not enough to wash away the recruitment in channel vegetation, disrupting the retrogression process caused by river discharges and inducing stream channel narrowing.

Both in Portugal and Spain, despite the magnitude difference between modeled results, it is expected and IP and older succession phases increase in both climate change scenarios, alongside with the younger succession phase's decrease. This trend is much more pronounced in the pessimistic scenario and reflects the harder life conditions imposed by climate change scenarios to riparian vegetation. Stronger winter discharges with higher shear stress cause a wider retrogression of the younger phases and the harder hydric stress bans the recruitment attempts to colonize the IP. At the same time, the older succession phases can succeed due to its best suited features to resist to shear and hydric stress.

In a temperate river, like the Austrian study site, the expected changes lead in a different way, with the succession phase's progression towards climax. In this case the shear stress of the increased winter discharges is not enough to wash away the younger phases.

The overall view of the modeled results suggests that the hydrologic changes caused by flow regime disturbance can disrupt the riparian patches succession/retrogression dynamics. This shift triggers the establishment failure of riparian species with the consequent succession process foiling and aging of the remaining ones toward mature stages.

8.2 Spain

Once the model was calibrated satisfactory, we used it in order to analyze several selected scenarios which were described before. A flow regulation scenario considered the regulation pattern from the Arenós dam located downstream from Terde reach, in the Mijares River (Jucar River Basin District, Spain).

A second minimum environmental flow scenario was defined considering the ecological requirements with monthly variability and a complete consumption of surplus flows before the reach. Finally two climate change scenarios, one optimistic (SRES B2) and one pessimistic (SRES A2), were analyzed by comparison with the reference period (1960-1990) results.

8.2.1 Flow regulation scenario results

8.2.1.1 Changes in vegetation dynamics

As has been described in the scenarios chapter, the flow regulation scenario by a theoretical dam reduces considerably the yearly peak flow. This affects directly the shear stress suffered by the riparian vegetation of the reach, so the analysis of both natural flow and regulated flow scenarios took into account different shear stress inputs, associated to the maximum flow for each year.

Because the differences between scenarios were important, the results obtained from their analysis were different enough. The resultant balance comparison for the last year simulation (Figure 8.1) showed a reduction of the first succession phase (IP-SD) in the regulated flow scenario.

The presence of gravel bars is an evidence of high flows which have enough shear capacity to remove the existent vegetation. This presence has been reduced from 14.89% in the natural flow scenario to 9.88% in the regulated flow scenario.

The other succession phases presences were between 0.50% and 1.56% higher in the regulated flow scenario except the pioneer phase (PP-RH) which was very similar (a 0.09% higher in the regulated flow scenario) and the oak forest phase (WD-UF-TV) presence which was a 0.39% lower.

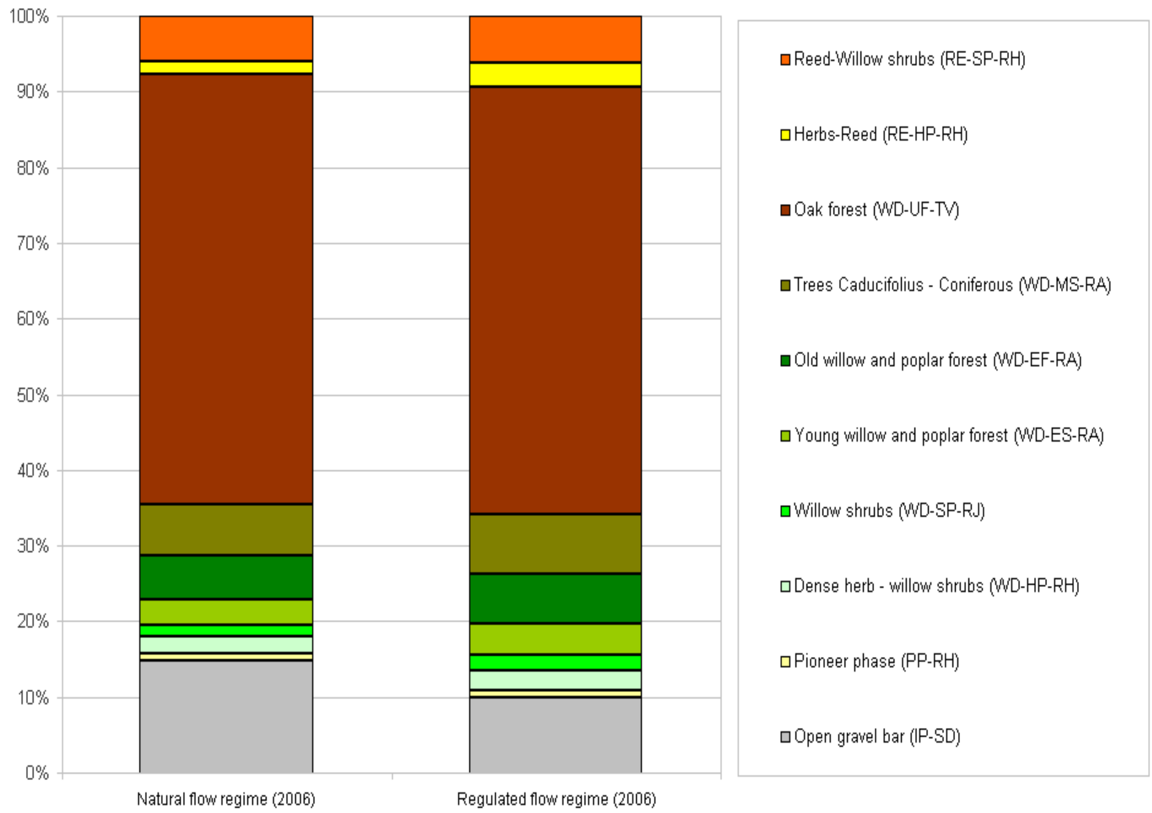


Figure 8.1. Comparison between natural flow regime and regulated flow regime scenarios simulated succession phases in Terde (Mijares River, Spain) for year 2006.

Considering the dynamic evolution of the succession phases, the same pattern was observed in most of the phases but smoothed in the regulated flow scenario (Figure 8.2).

During the first four years it did not seem to be big changes in different proportions of the phases except for the evolution from the initial phase to the pioneer phase in 1990. As can be seen, during this first period the initial phase was less present in the regulated flow scenario.

The fourth year (1991) an evolution from pioneer phase, dense herbs and willow shrubs, willow shrubs and young willow and poplar forest phases to the next one produced an increase of old willow and poplar forest phase presence in the regulated flow scenario, not observed in the natural flow one.

A similar evolution of reed succession phases was observed until year 2001 in both scenarios. The old willow and poplar forest phase presence continued growing in both scenarios until that year by reducing pioneer phase proportions.

Although the presence of deciduous and coniferous forest increased in the natural regime flow scenario along the years, this increase was more evident in the regulated flow scenario reaching a 7.72% the last simulation year while in natural regime scenario the maximum is 6.65%.

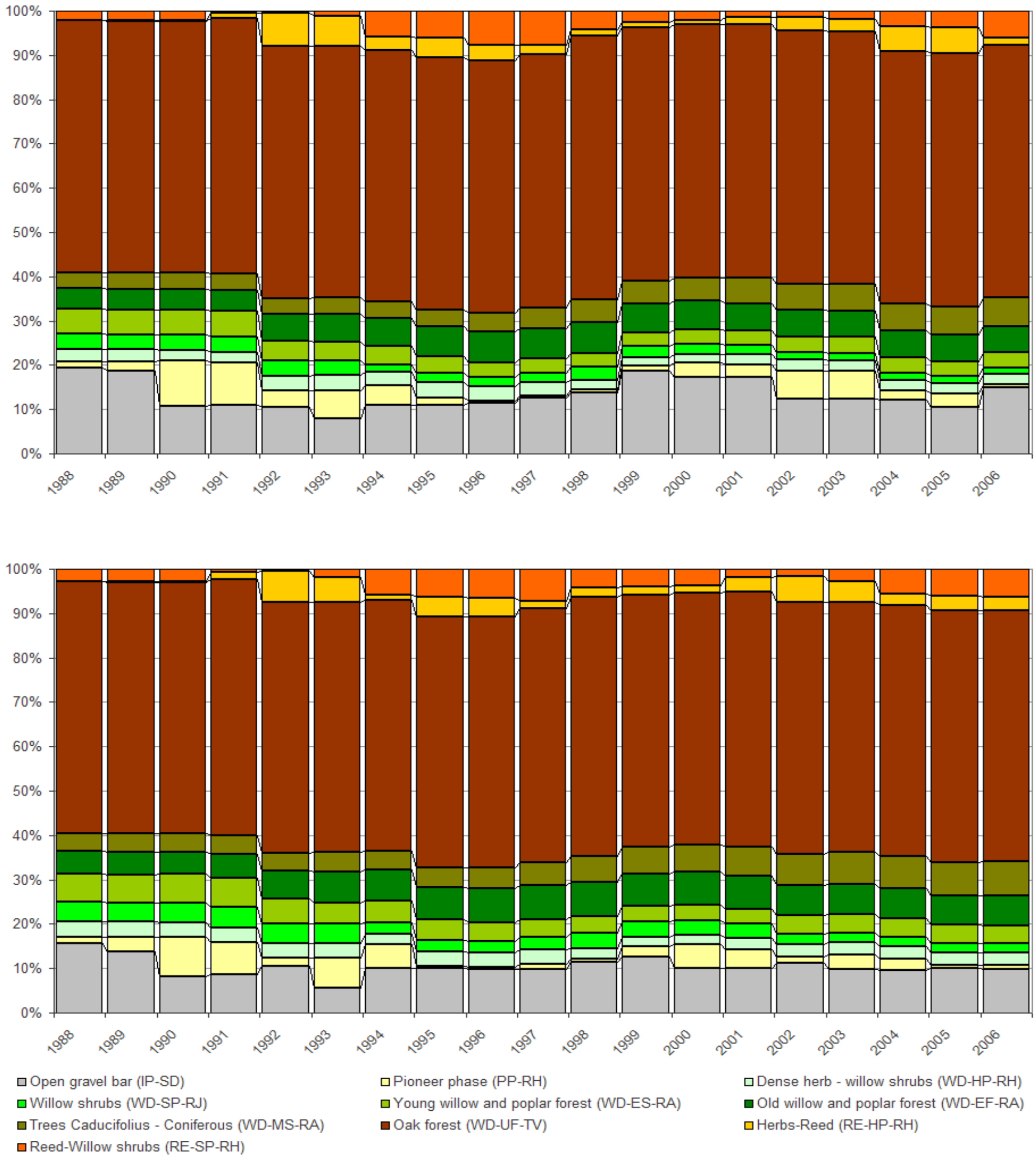


Figure 8.2. Vegetation dynamics in Terde reach (Mijares River, Spain) during the 1988 – 2006 period in two analyzed scenarios: natural flow scenario (above) and regulation flow scenario (below).

The higher differences were observed in 1999 – 2006 vegetation dynamics. In the natural flow scenario a gradual increase of the pioneer phase was observed until 2003. Then, this phase presence was reduced considerably from 6.21% in 2003 to 0.87% in 2006.

The increase was higher during 1999 – 2001 years in the regulated flow scenario but after this period a reduction was observed in 2002 and a new increase occurred in 2003 reduced again in 2004 more prominent in following years.

The reed herbs phase presence was scarce in both scenarios during the 1997 – 2000 period. While in the natural flow scenario this presence increased slightly in 2001, in regulated flow scenario this increase was more evident. This same situation but emphasized was observed in 2002 (Figure 8.3).

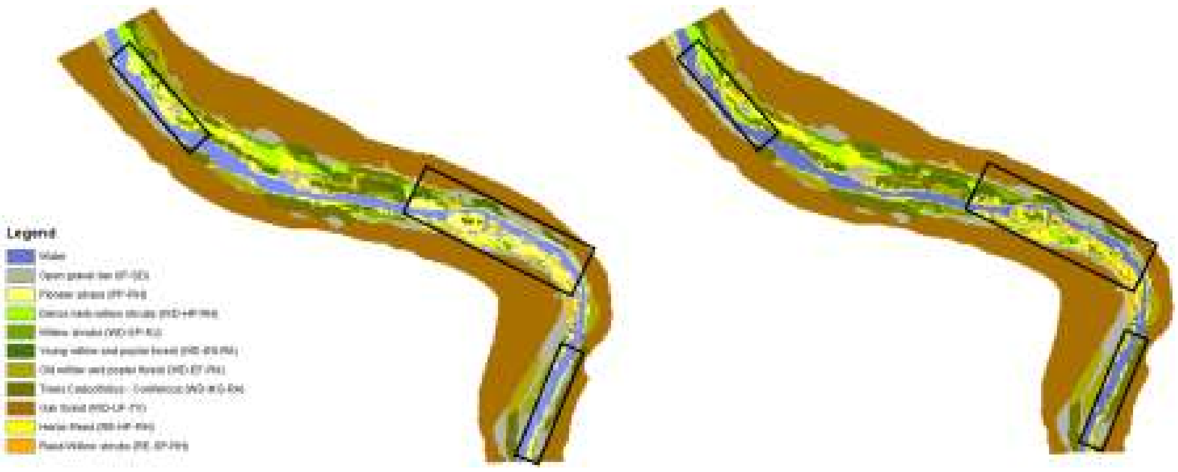


Figure 8.3. Vegetation succession phases simulated for year 2002 in natural flow scenario (left) and regulated flow scenario (right) in Terde reach (Mijares River, Spain).

In 2003 a small reduction was observed in both scenarios, being more representative in the regulated flow scenario. In both cases this reduction was associated to an evolution to the reed willow shrubs phase, next in this succession line. While during 2004 and 2005, an important reduction of reed herbs and a consequent increase of reed shrubs were observed in the regulated flow scenario, in the natural flow scenario both phases suffered an increase being higher for the herbs phase (Figure 8.4).

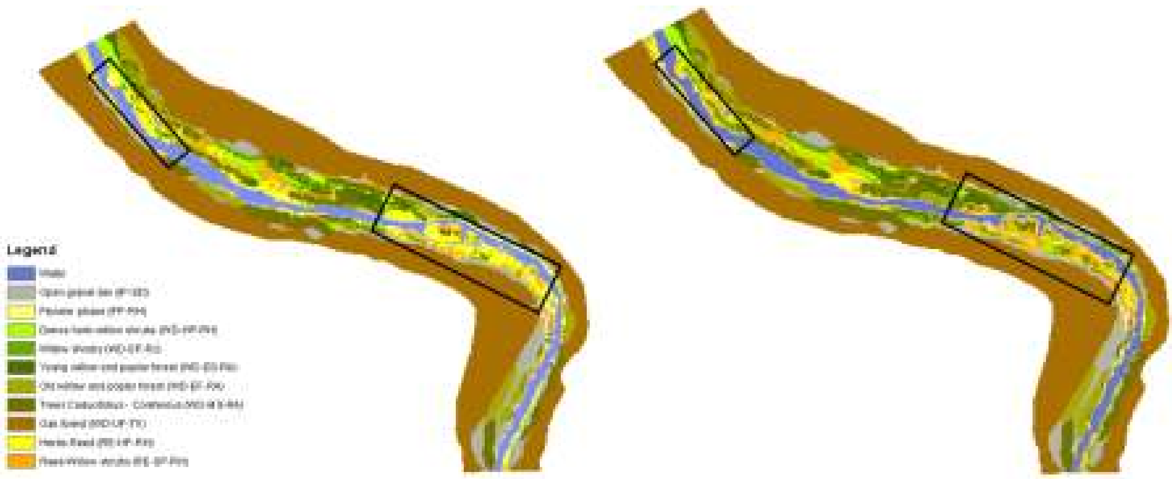


Figure 8.4. Vegetation succession phases simulated for year 2005 in natural flow scenario (left) and regulated flow scenario (right) in Terde reach (Mijares River, Spain).

Finally in 2006, the last simulation year, similar proportions of both reed phases were observed for both scenarios, being barely higher the presence of herbs in the regulated flow scenario (3.19%) than in the natural flow scenario (1.64%).

The oak forest last succession phase, associated to the terrestrial vegetation functional type, was the most stable phase in both scenarios all over the simulated years (Figure 8.5).

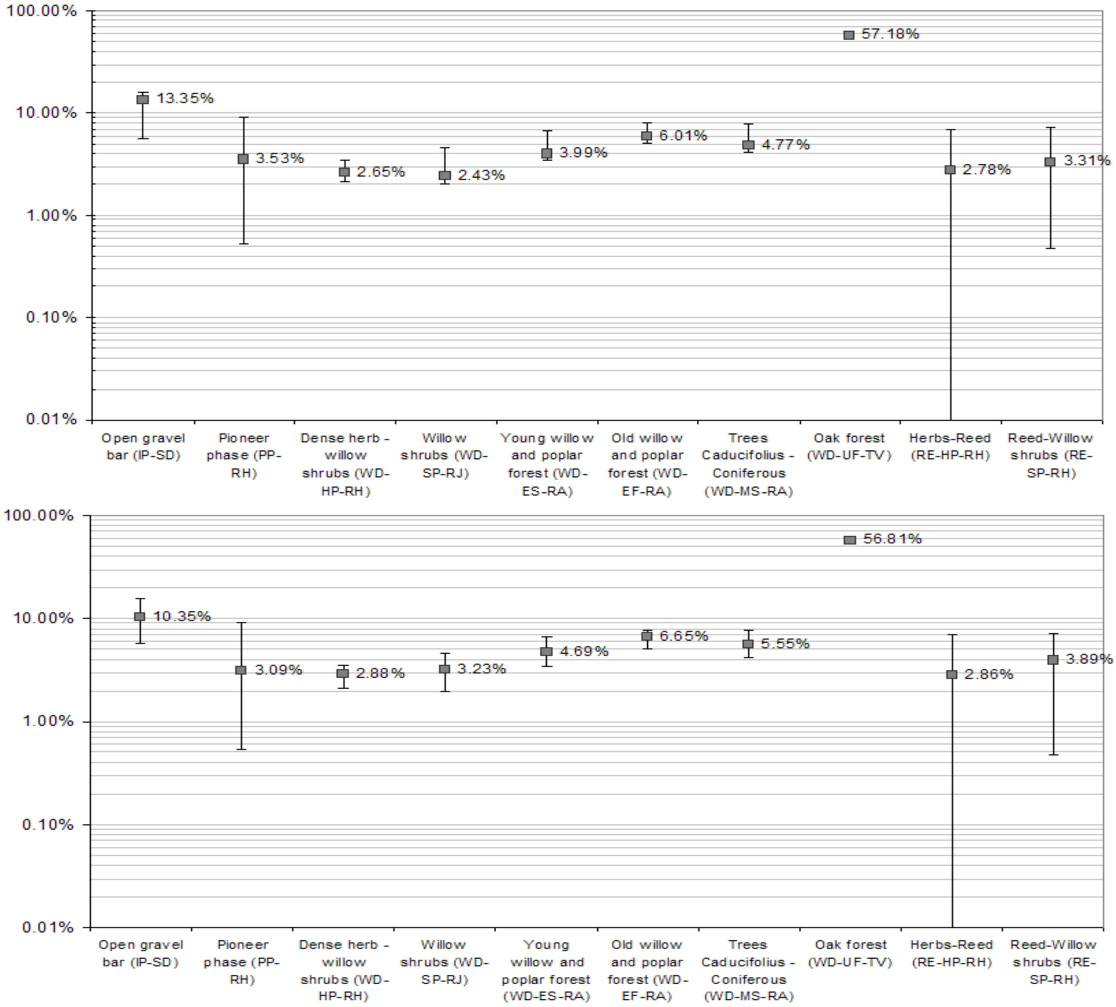


Figure 8.5. Average percentages of vegetation succession phases, with upper and lower limits, in Terde reach (Mijares River, Spain) during the 1988 – 2006 period in two analyzed scenarios: natural flow scenario (above) and regulation flow scenario (below).

The average values for this phase were very similar in both scenarios, 57.18% natural flow scenario and 56.81% regulated flow scenario. The higher variability was observed in pioneer and reed willow shrubs phases as they are usually located very near to the stream. The willow and poplar forest phases average values, as well as the willow shrubs phase, were near to the minimum limit in the natural flow scenario while they were near to the maximum limit in the regulated flow scenario. In addition, the closer average value of reed herbs phase proportion to the minimum value was distinguished in both scenarios. Obviously, there were some differences between scenarios results. However, those differences were lower as expected in spite of the great differences between hydrological inputs of each scenario definition all over the simulation period. As the Arenós dam regulation was taken into account in order to establish the regulated flow scenario in the study case, this regulation was not very hard in terms of riparian vegetation stress. Quite the contrary, the riparian vegetation seem to be favored with some kind of flow regulation for short time periods as approximately 20 years long.

8.2.1.2 Changes in Etidx evolution

Although the differences between both scenarios ETidx results (Figure 8.6) were not very huge, there were some important distinctions. In 1988 and 1989 the lower quartiles and the smallest observations, outliers not considered, were higher in the natural flow regime scenario than in the regulated one. It had to be considered that 1988 was a specially wet year and while flood resistant plants obtained a high rate of evapotranspiration some others were disfavored because of an unusual high water table elevation. That implied a huge number of extreme minor outliers for this year and the following.

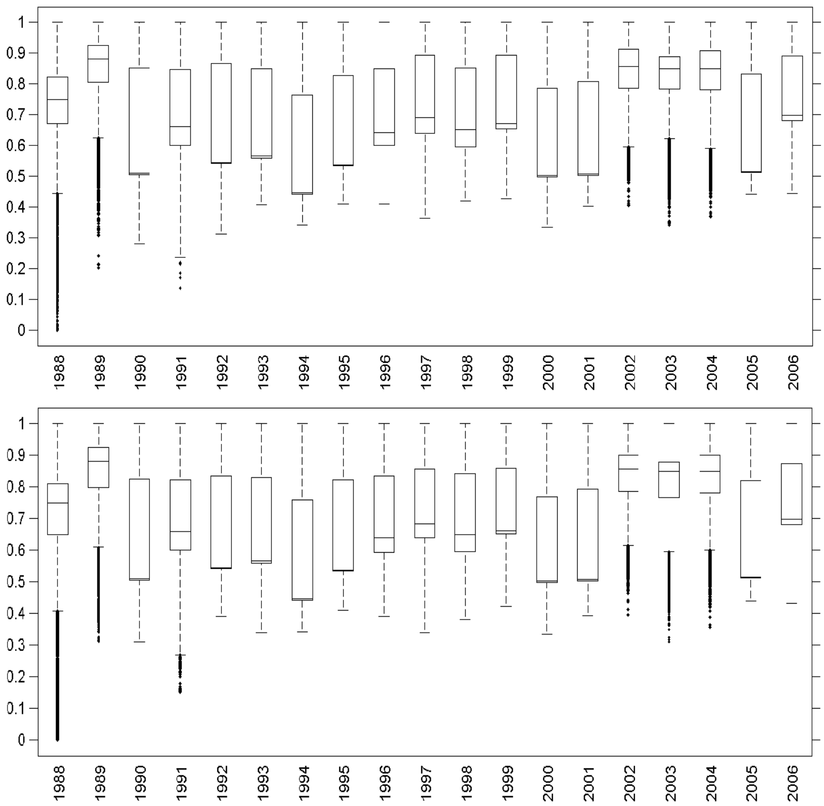


Figure 8.6. ETidx box plots for natural flow scenario (above) and regulated flow scenario (below) yearly ETidx results in Terde reach (Mijares River, Spain) for the 1988 – 2006 period.

Although in the regulated scenario the flood effect was reduced, it had not been removed completely (Figure 8.7). That is why there are a great number of outliers as well. In 1988 the water availability is high in both scenarios but there are not flood effects as observed in previous year. Nevertheless, the removal of the vegetation in some areas need some time to evolve to further succession phases and there are still a great number of very low ETidx values.

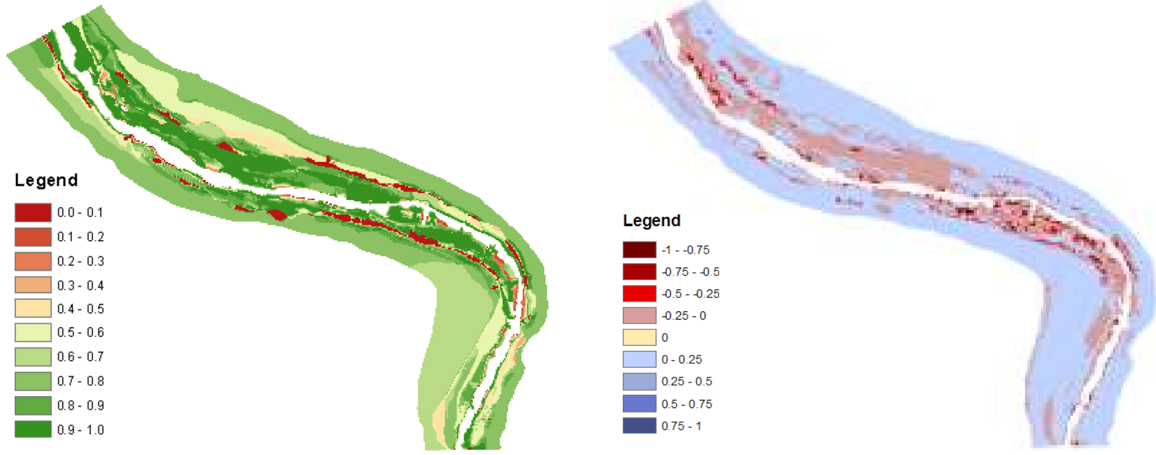


Figure 8.7. ETidx map simulated for year 1988 in natural regime flow (left) and differences observed for the same year in the regulated flow scenario (right) in Terde reach (Mijares River, Spain). Areas in red represent lower ETidx and areas in blue show higher ETindex values observed in the regulated flow scenario.

As can be observed (Figure 8.7) during such a very wet year as 1988 the riparian areas sited close to the stream were slightly unflavored in ETidx terms when the regulated flow scenario was compared to the natural flow scenario results. On the contrary, more evolved vegetation succession phases, mostly located remote from the stream, seemed to be favored in the regulated flow scenario.

In 1990 the pioneer phase started to colonize the open gravel bars and the minimum ETidx values raised in both scenarios. The third quartile remained near to 0.87 in the natural flow scenario and near to 0.83 in the regulated flow scenario during the following 11 years except in year 1994, and in the last two simulated years. The median in this period was very close to the first quartile being barely higher during the 1996 – 1999 time period. The amplitude of the boxes is high between 1990 and 2001 showing a great variability of ETidx values along the study site (Figure 8.8).

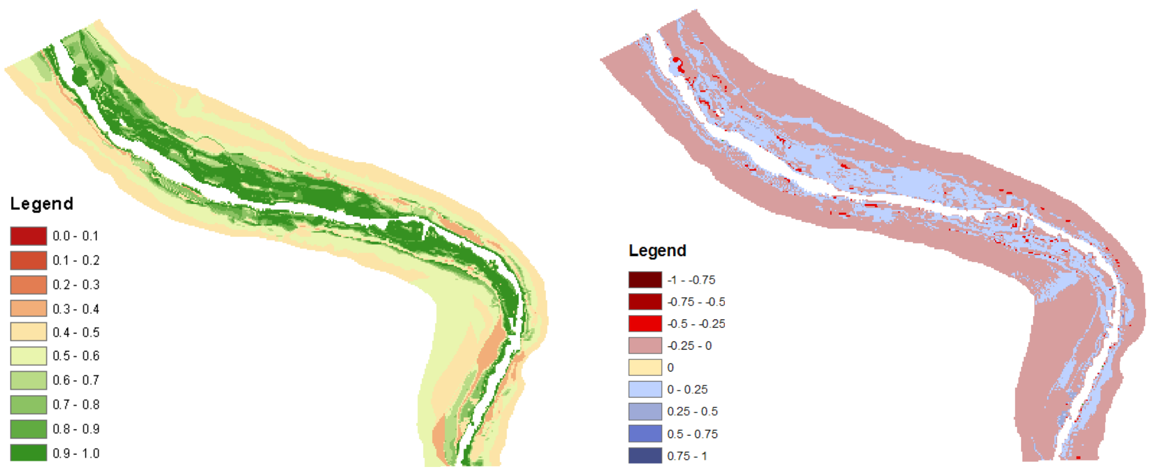


Figure 8.8. ETidx map simulated for year 2000 in natural regime flow (left) and differences observed for the same year in the regulated flow scenario (right) in Terde reach (Mijares River, Spain). Areas in red represent lower ETidx and areas in blue show higher ETidx values observed in the regulated flow scenario.

In this case (Figure 8.8), during year 2000, the riparian areas sited close to the stream were favored comparing the regulated flow scenario to the natural flow scenario ETidx results. On the contrary, the evolved vegetation succession phases located remote from the stream were favored in the regulated flow scenario. Again this situation is observed in 2005 and 2006.

In 2002, 2003 and 2004, after a very wet period in the natural flow scenario and a dry period in the regulated flow scenario (2001 – 2001) the water availability without damaging effects took place and the ETidx values between the first and the third quartile rise to values between 0.75 and 0.9 (Figure 8.6). The median is near to 0.85 in both scenarios, and the lower values are whiskers sited over 0.28 for the regulated flow scenario and over 0.35 for the natural flow scenario.

8.2.2 Minimum ecological flow scenario results

8.2.2.1 Changes in vegetation dynamics

As described in the scenarios chapter, the minimum ecological flow scenario constrains the flow passing through the stream to minimum required values. In this case the shear stress suffered by the riparian vegetation is directly reduced almost removing it completely. This scenario results were compared to the natural flow regime between 1988 and 2009. The differences between scenarios were important. Taking this into account the differences observed between both scenarios results were not surprising at all.

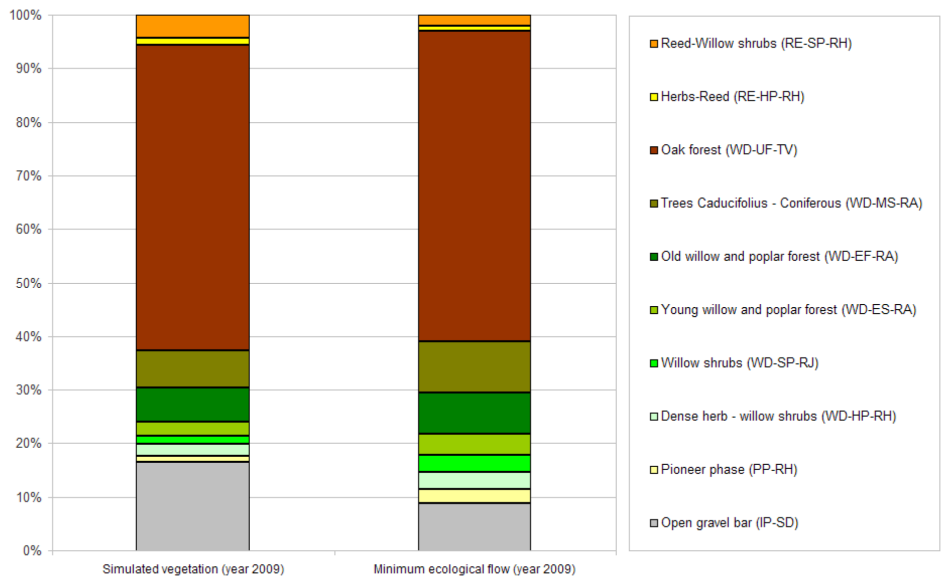


Figure 8.9. Balance comparison between natural flow scenario (simulated vegetation with historical hydrometeorological data) and minimum ecological scenario during year 2009, in Terde reach (Mijares River, Spain)

The resultant balance comparison for the last year simulation (Figure 8.9) showed a reduction of the gravel bars presence (IP-SD) in the minimum ecological flow scenario. As previously pointed out, the presence of gravel bars is an evidence of high flows which have enough shear capacity to remove the existent vegetation. This IP-SD succession phase was reduced from 16.48% in the natural flow scenario to 8.86% in the minimum ecological flow scenario. The other succession phases presences were much higher (between 0.91% and 2.51% higher) in the minimum ecological flow scenario except the reed shrubs phase (RE-SP-RH) which was considerably lower (4.22% in natural flow scenario and 2.00% in minimum ecological flow scenario).

Considering the dynamic evolution of the succession phases, the same tendencies were observed but considerably smoothed in the minimum ecological flow scenario (Figure 8.10).

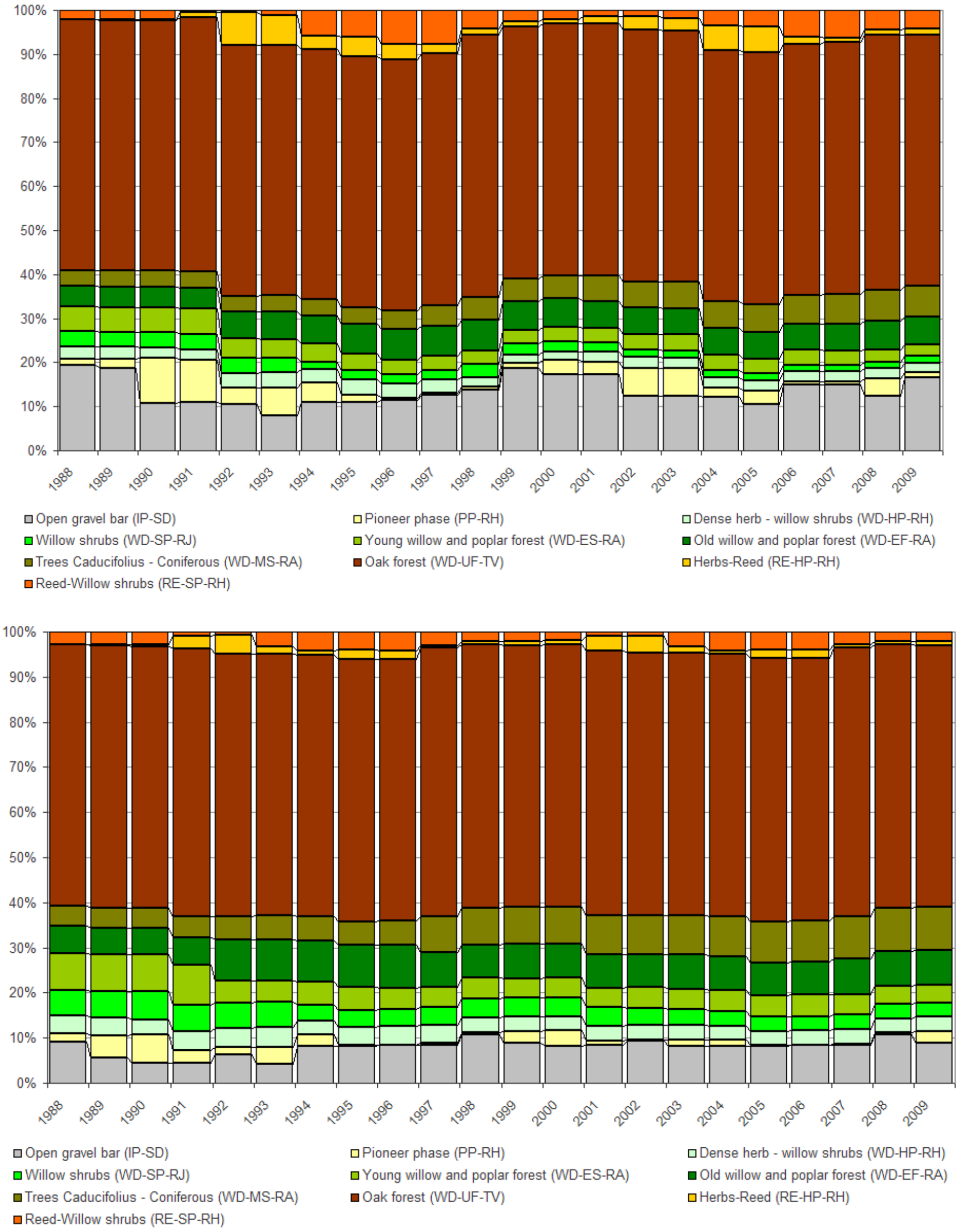


Figure 8.10. Vegetation dynamics in Terde reach (Mijares River, Spain) during the 1988 – 2009 period in two analyzed scenarios: natural flow scenario (above) and minimum ecological flow scenario (below).

During the first three years there were not big changes in the evolution of the different phases excepting the increase of the pioneer phase, reducing the gravel presence. Nevertheless, differences between scenarios were huge from the beginning, being considerably higher the presence of riparian phases from early herbs to the mature stage in the minimum ecological flow scenario. In addition the evolution from the first succession phase (IP-SD) to the pioneer phase, and then to the following phases, occurred earlier in the minimum ecological flow scenario.

The reed succession series presence, which included herbs and shrubs adapted to the fluctuating flows, is less important in the minimum ecological flows scenario. Instead of it, the woodland series evolved without suffering uprooting stress during all period, consequence of the extremely reduced shear stress established in this scenario. While the old willow and poplar forest proportions seemed to remain approximately constant during the 1992 – 2009 period in the natural flow scenario, this succession phase gave way to the deciduous and coniferous forest in some areas during the same period in the minimum ecological flow. This was highlighted with black boxes in the following figure (Figure 8.11).

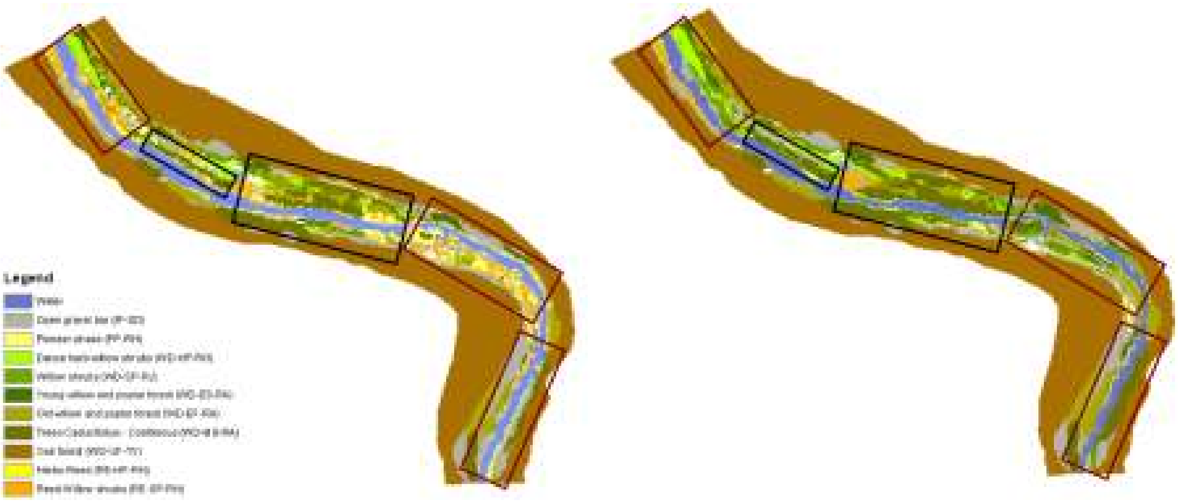


Figure 8.11. Vegetation succession phases simulated in natural flow regime scenario (left) and minimum ecological flows scenario (right) for year 2008, in Terde reach (Mijares River, Spain).

However the most evident difference observed between scenarios was, as described above, the importance of reed succession phases typical of natural flow streams, not observed in the minimum ecological scenario, as can be observed highlighted with red boxes in the figure above (Figure 8.11). Although the minimum ecological flows scenario showed an evolved riparian areas in both sides of the stream, it does not necessary mean that the riparian ecosystems would be favored with a minimum ecological flow regime.

Considering average percentages for each succession phase during the 1988 – 2009 period, the differences were evident (Figure 8.12). Early succession phases were reduced in the minimum ecological flow scenario, as well as the reed succession phases. Not only the average values were reduced. The variability observed during the period for those phases was reduced more than 1% in every case, in terms of standard deviation. In addition, the maximum and minimum values were reduced too, compared to the natural flow scenario. On the contrary, more advanced woodland succession series increased their presence during the whole period as explained above. It was traduced into an increased average presence percentage value as can be observed in the following figure. In all those phases the variability increased between 0.27% and 0.73% in terms of standard deviation, except in the dense herb – willow shrubs and in the oak forest phases which remained constant and increased 0.08% respectively. Although in some cases the variability was not hardly modified the limits were increased considerably, in example the dense herb – willow shrubs phase, which obtained a minimum percentage of 1.92% in 1999 and a maximum value equal to 3.42% in 1992 of the natural flow scenario, changed those values into 3.06% as minimum in 1994 and 4.31% as maximum in 1991.

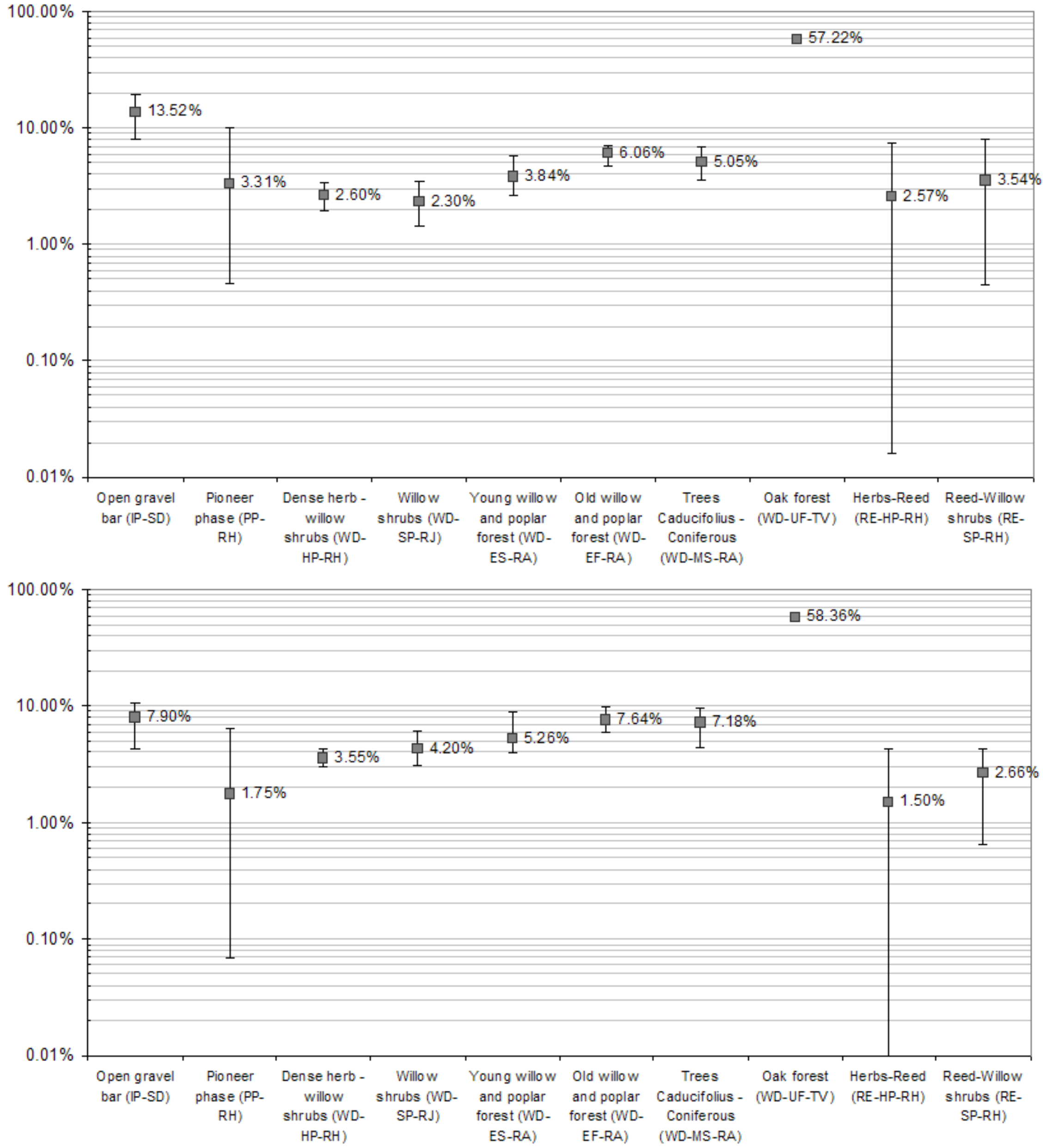


Figure 8.12. Average percentages of vegetation succession phases, with upper and lower limits, in Terde reach (Mijares River, Spain) during the 1988 – 2009 period in two analyzed scenarios: natural flow scenario (above) and minimum ecological flow scenario (below).

All these results showed that the necessity of taking into account the potential variations in the riparian ecosystems caused by the establishment of ecological flows is unavoidable.

8.2.2.2 Changes in Etidx evolution

The evapotranspiration importance over the riparian vegetation evolution was confirmed once more in these scenarios analysis. It has to be consider that the flows were extremely modified in the minimum ecological flow scenario. Nevertheless, other meteorological variables as the precipitation and the temperature were taking into account in the ETidx calculations. That is why the pattern observed in the dynamic evolution during the years is not extremely different. However, as was observed in the dynamic ETidx statistical results (Figure 8.13), the variability was lower in the minimum ecological flow scenario during all the studied period. Although it is true that the higher ETidx values were raised in the natural flow scenario, this fact was offset with higher minimum ETidx values in the minimum ecological flow scenario. The median values were over the lower limit defined for each succession phase in both scenarios. The lower variability of water availability in favorable conditions made possible the succession evolution to more advanced phases.

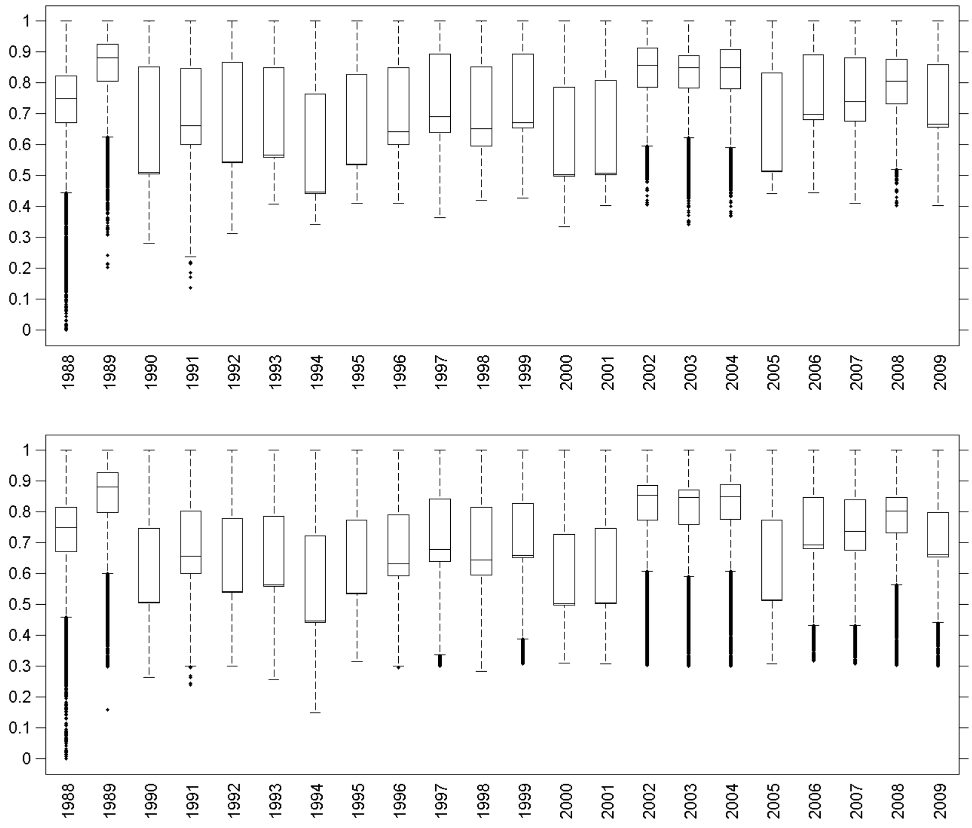


Figure 8.13. ETidx box plots for natural flow scenario (above) and minimum ecological flow scenario (below) in Terde reach (Mijares River, Spain) for the 1988 – 2009 period.

To compare the ETidx results obtained in both scenarios simulation during a very dry year, year 1994 was selected (Figure 8.14).The establishment of a limited flow regime produced in the minimum ecological flow scenario reductions in the ETidx in most of the reach analyzed areas. Although these reductions were not higher than 0.25 in most of the vegetation patches, there are some located near from the stream that suffered considerably reduction near to 0.63. In addition there are some patches that increased their ETidx values, having observed a maximum increase of

0.64 in the right side of the stream (from upstream to downstream) colored with dark blue in the figure below.

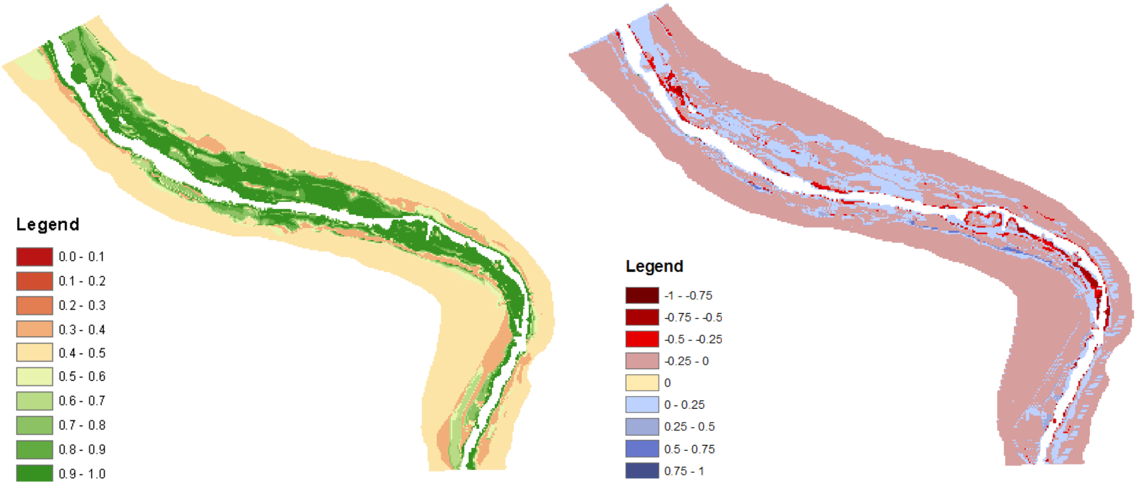


Figure 8.14. ETidx map simulated for year 1994 in natural regime flow (left) and differences observed for the same year in the minimum ecological flow scenario (right) in Terde reach (Mijares River, Spain). Areas in red represent lower ETidx and areas in blue show higher ETidx values observed in the minimum ecological flow scenario.

Some differences were observed in the comparison of a medium year results, such as 2008 (Figure 8.15). Although a large proportion of the area suffered a decrease of ETidx in the minimum ecological scenario, there are a greater number of patches that showed an increase compared to the dry year. In addition, the extreme difference values were lower than in that case, obtaining -0.60 and 0.55 as the major differences for decrease and increase respectively.

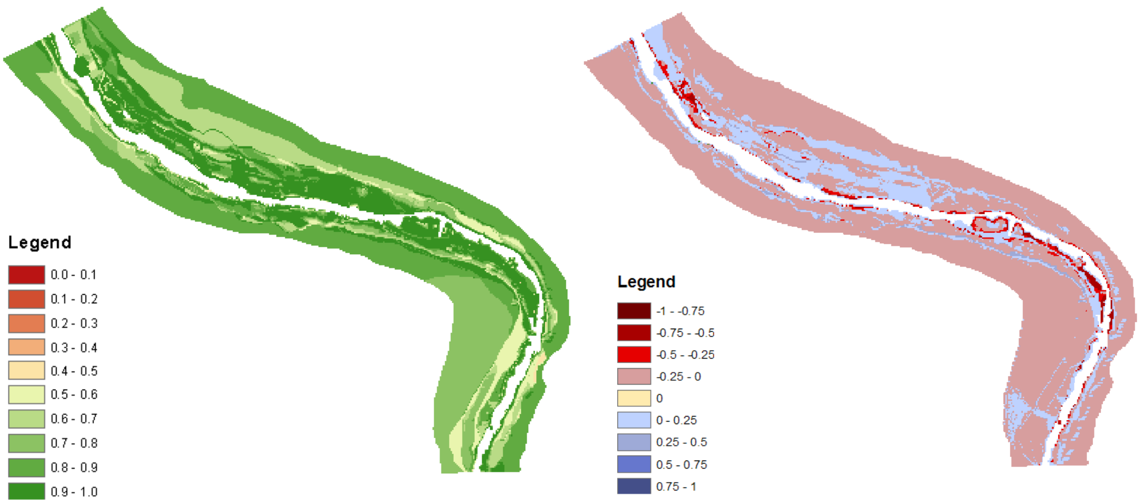


Figure 8.15. ETidx map simulated for year 2008 in natural regime flow (left) and differences observed for the same year in the minimum ecological flow scenario (right) in Terde reach (Mijares River, Spain). Areas in red represent lower ETidx and areas in blue show higher ETidx values observed in the minimum ecological flow scenario.

Finally, a very wet year as selected to analyze the differences between both scenarios. The selected year was 1988 (Figure 8.16).

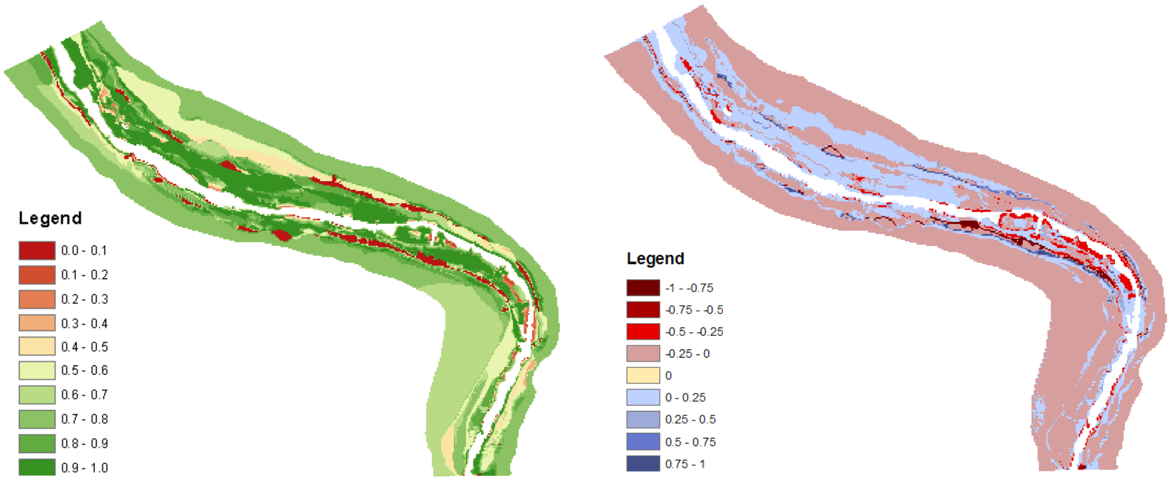


Figure 8.16. ETidx map simulated for year 1988 in natural regime flow (left) and differences observed for the same year in the minimum ecological flow scenario (right) in Terde reach (Mijares River, Spain). Areas in red represent lower ETidx and areas in blue show higher ETidx values observed in the minimum ecological flow scenario.

In this case were observed considerably increases of ETidx in the minimum ecological flow scenario, in some patches very damaged by the flood effect. The maximum increase was very close to 1 which implied that some points with an approximately ETidx value equal to 0 in the natural flow scenario were simulated with the maximum possible value of ETidx in the minimum ecological flow scenario. The same situation occurs on the contrary, when some maximum ETidx values were observed in the first scenario and values close to 0 occurred in the second one, with a maximum decrease of 0.9997.

These results suggested higher variability in ETidx spatial values during very wet years. This variability seemed to be located in specific areas with some special topographic characteristics and early successional phases.

8.2.3 Climate change scenario results

8.2.3.1 Vegetation dynamics and ETidx during the reference period

The reference period for climate change scenarios analysis was set as the 1960 – 1990 period, following the IPCC recommendations. This analyzed scenario showed a similar pattern of vegetation dynamics to other later natural regime flow periods analyzed, but with less variability along the years than in that case and with a mayor presence of middle woodland succession phases. A willow phases and poplar presence reduction tendency was simulated during the reference period but very smoothed (Figure 8.17). Nevertheless, this same tendency was showed for the 1988-2009 period but very emphasized (Figure 8.10a). This fact suggests the possibility of some early climate change effects already suffered during recent years.

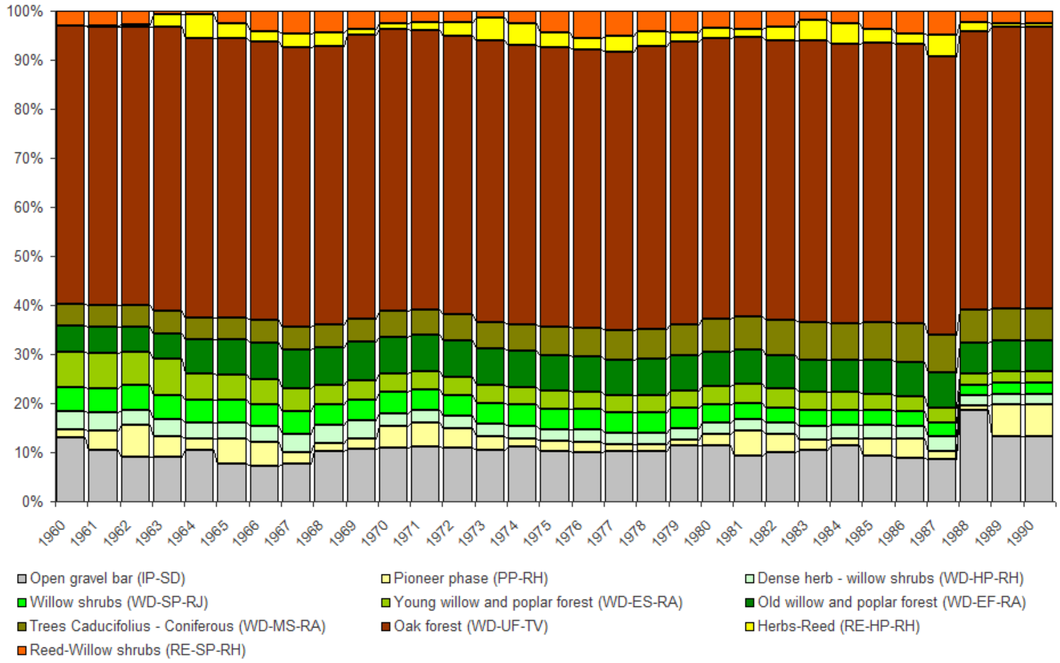


Figure 8.17. Vegetation dynamics in Terde reach (Mijares River, Spain) during the 1960 – 1990 reference period of climate change scenarios

The ETidx results analysis (Figure 8.18) showed a high variability along the years. Although most of the values remained between 0.5 and 0.9 there were a big number of lower simulated values, especially during wet and very wet years (i.e. 1969, 1962, 1972 and 1988). On the contrary there were less extreme values during dry and very dry years but the first quartile and the median values were reduced in these cases (i.e. 1983 and 1985).

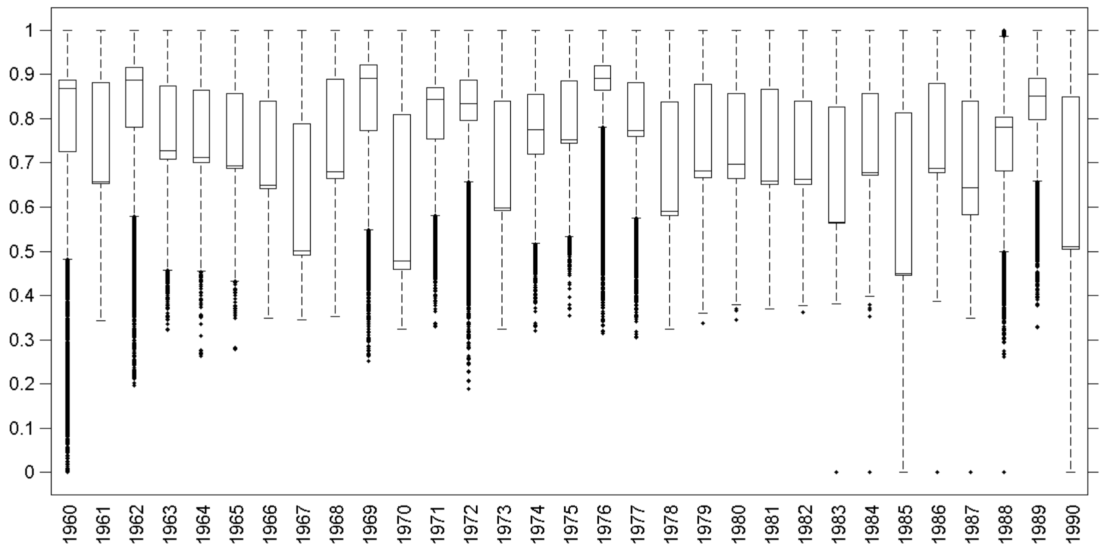


Figure 8.18. ETidx box plots for reference period (1960 – 1990) scenario in Terde reach (Mijares River, Spain).

These results were used in order to establish differences in the proposed climate change scenarios.

8.2.3.2 Optimistic climate change scenario results (SRES B2)

8.2.3.2.1 Changes in vegetation dynamics

The pattern observed in the vegetation dynamics for the proposed optimistic scenario was very similar to the reference period pattern. Nevertheless, there were some different results in the early succession phases, especially in the initial phase of open gravel bars and the pioneer phase (Figure 8.19).

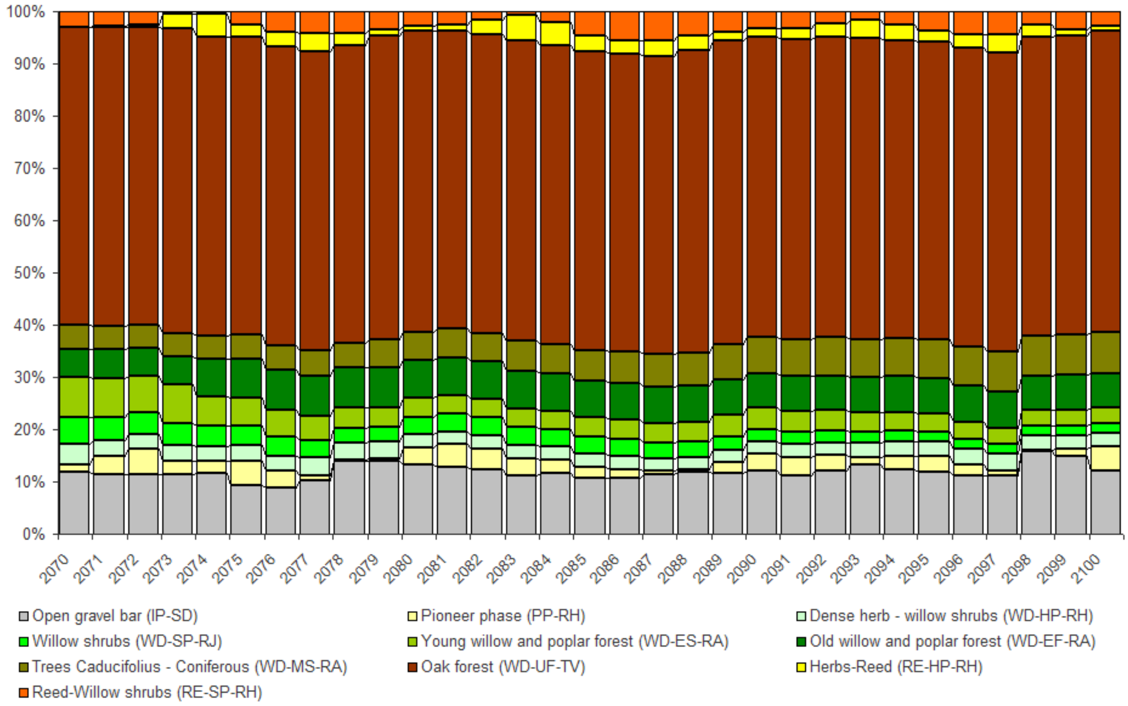


Figure 8.19. Vegetation dynamics in Terde reach (Mijares River, Spain) during the 2070 – 2100 period of HacCM3-PROMES (SRES B2) optimistic climate change scenario.

The initial phase was simulated with a higher presence in most of the simulated years than during the reference period with an average increase value of 1.38%. The maximum increase occurred for year 2078 with a 3.63% higher than the equivalent year form the reference period (Figure 8.20). Some years obtained a lower presence of this succession phase, like 2070, 2098 and 2100, produced by the change of year type. While in the reference period the related years,1960, 1988 and 1990, were very wet, very wet and wet respectively, in this optimistic scenario they were wet, very wet and medium years respectively. Although in one of those years there were no year type change, the average flows were different (2.071 m^3/s in 1988 of the reference period, 1.524 m^3/s in 2098 of the SRES B2 scenario) so the ETidx sub-model offered different results (Figure 8.21). In addition, the maximum flows were different too (36.4 m^3/s in 1988 of the reference period, 25.4 m^3/s in 2098 of the SRES B2 scenario) and as explained in previous chapters, that conditioned the shear stress sub-model simulations. The pioneer phase was typically reduced for most of the years reaching a maximum decrease of 5.24% in 2099, compared to 1989 from the reference period.

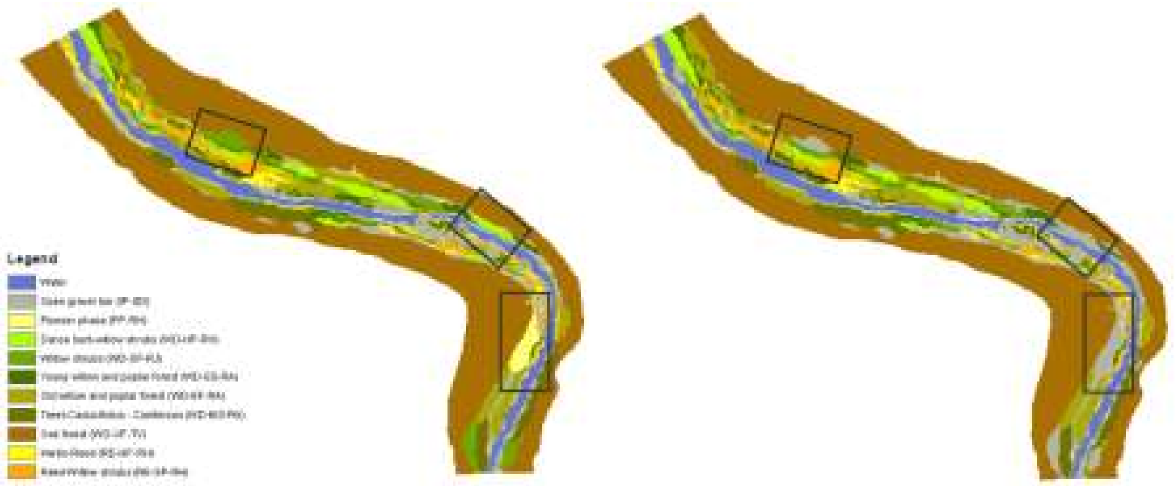


Figure 8.20. Vegetation succession phases simulated for the 1968 year from the reference period (left) and for the 2078 equivalent year from the optimistic climate change scenario HacCM3-PROMES (SRES B2).

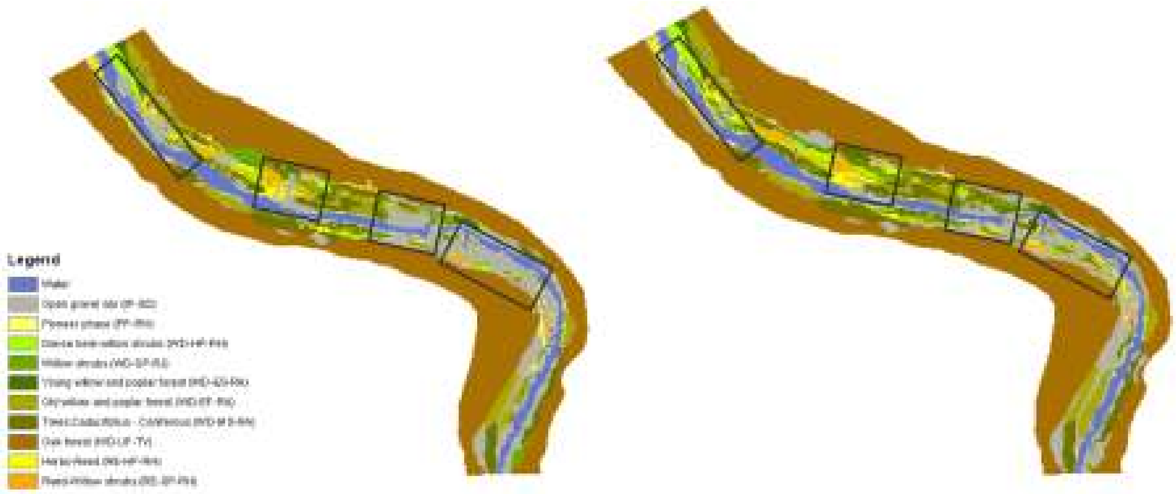


Figure 8.21. Vegetation succession phases simulated for the 1988 year from the reference period (left) and for the 2098 equivalent year from the optimistic climate change scenario HacCM3-PROMES (SRES B2).

The other succession phases showed minor variations (Table 8.2). The higher differences were observed in the Willow shrubs (WD-SP-RJ) phase with a presence decreased of approximately a 1.5% in 2078 and 2079. Similar values were observed in 2077, 2088 and 2089 corresponding to very dry, dry or medium years. The higher increase was observed for the Trees Deciduous - Coniferous (WD-MS-RA) phase with 1.21% for the last year simulated (2100), being very similar in 2099.

Table 8.2. Differences observed in the comparison between the optimistic climate change scenario HacCM3-PROMES (SRES B2) and the reference period.

Differences between SRES B2 scenario and the reference period of climate change	AVERAGE	MAX	MIN
Open gravel bar (IP-SD)	1.38%	**3.63%**	**-2.98%**
Pioneer phase (PP-RH)	-0.78%	1.04%	**-5.24%**
Dense herb - willow shrubs (WD-HP-RH)	-0.01%	0.52%	-0.46%
Willow shrubs (WD-SP-RJ)	-0.88%	0.37%	**-1.49%**
Young willow and poplar forest (WD-ES-RA)	0.15%	0.71%	-0.17%
Old willow and poplar forest (WD-EF-RA)	-0.07%	0.40%	-0.44%
Trees Deciduous - Coniferous (WD-MS-RA)	0.18%	**1.21%**	-0.31%
Oak forest (WD-UF-TV)	0.26%	0.49%	**0.06%**
Herbs-Reed (RE-HP-RH)	-0.10%	0.91%	**-1.10%**
Reed-Willow shrubs (RE-SP-RH)	-0.14%	**1.03%**	-0.89%

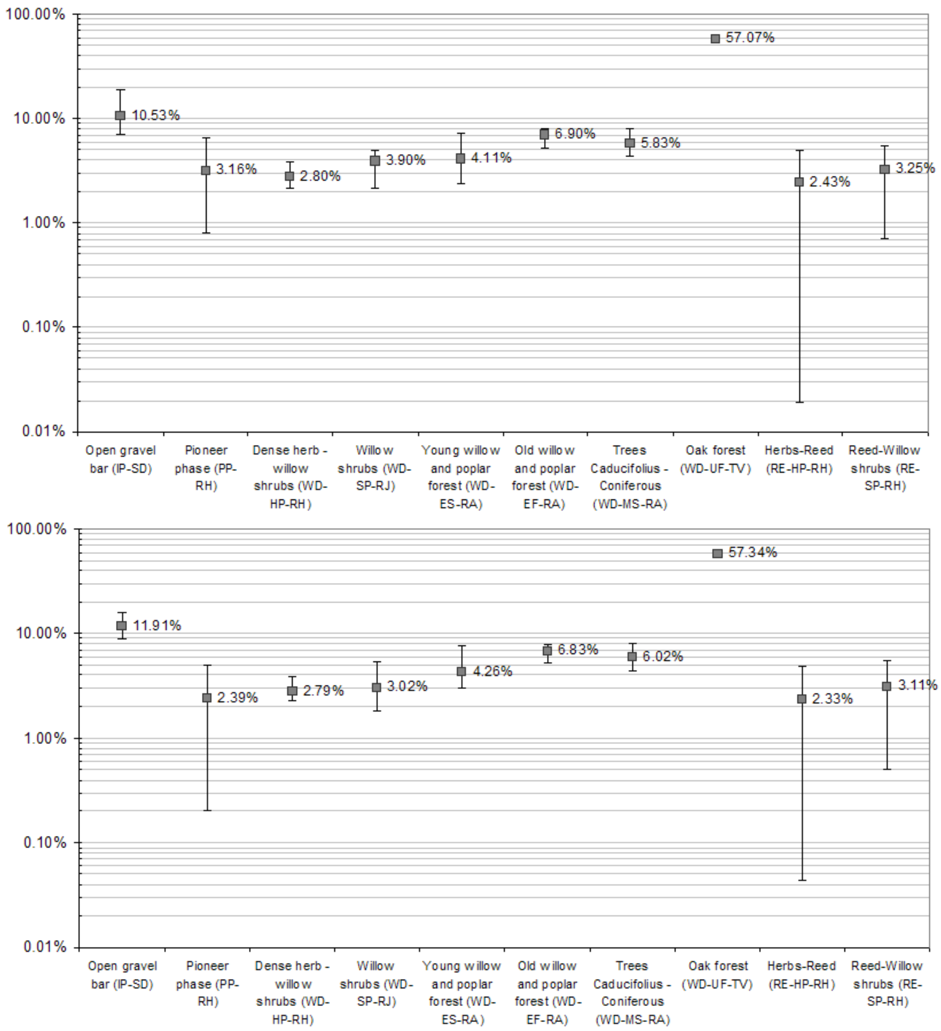


Figure 8.22. Average percentages of vegetation succession phases, with upper and lower limits, in Terde reach (Mijares River, Spain) during the 1960 – 1990 reference period (above) and during 2070 – 2100 period of the HacCM3-PROMES (SRES B2) scenario (below).

It was remarkable the Oak forest (WD-UF-TV) phase presence increased for all the simulated years. This phase, studied as terrestrial vegetation, was favored in the SRES B2 scenario while traditional riparian phases were reduced (Table 8.2).

The reed succession line seemed to be disfavored during the period for this scenario. However, the reed phases presence dynamics are very variable, having obtained maximum and minimum difference values near to ± 1% (Table 8.2). In other hand, the variability between different years of the SRES B2 scenario period was reduced considerably for the reed herbs phase compared to its reference period variability (Figure 8.22). On the contrary, the reed willow shrubs phase showed an increase of variability with lower minimum values.

8.2.3.2.2 Changes in ETidx evolution

Differences between ETidx results were huge in the comparison between the SRES B2 scenario and the reference period (Figure 8.23). The most evident variations were the reduction of minimum outliers in most of the simulated years, the reduction of the third quartile values and the increase of the variability represented as longer boxes in the following figure.

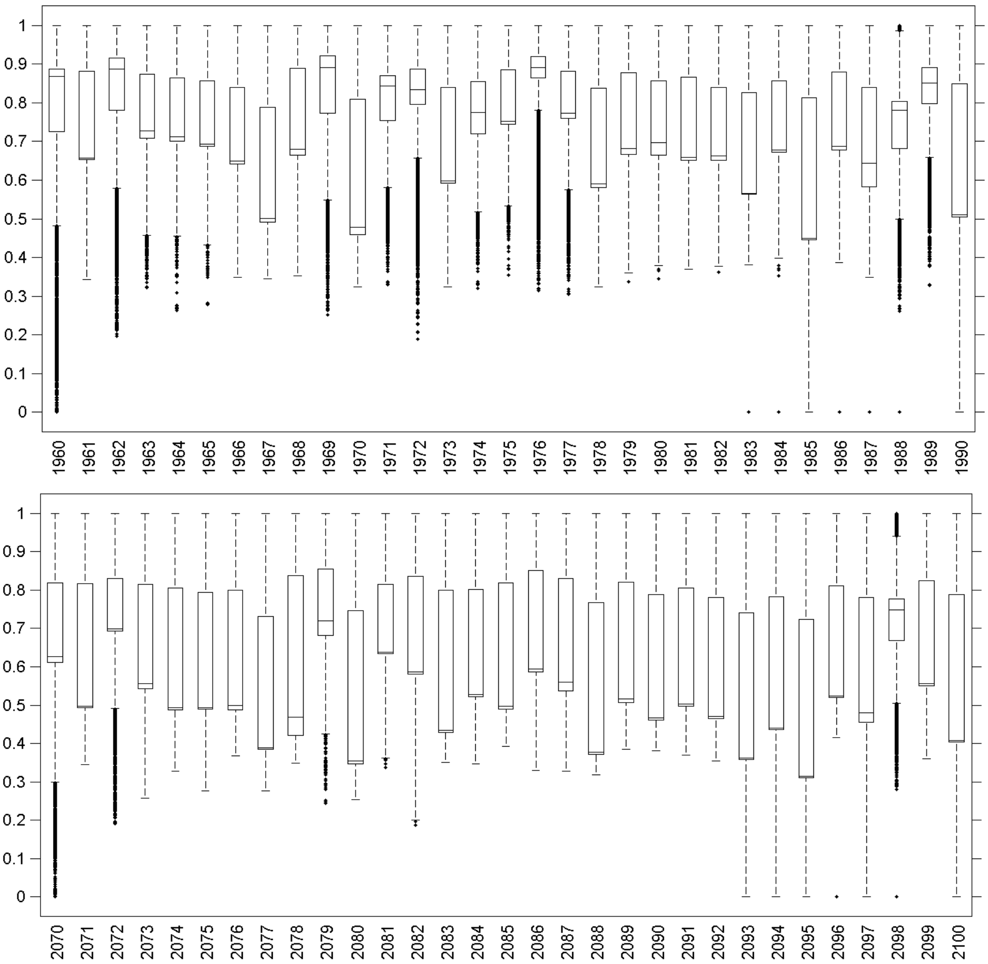


Figure 8.23. ETidx box plots for reference period scenario (above) and HacCM3-PROMES (SRES B2) scenario (below) in Terde reach (Mijares River, Spain).

The reductions of the third quartile observed were between 0.05 and 0.1 (ETidx units) especially during very dry years as 2077, 2091, 2093, 2095 and 2096. The higher variability of precipitations, a considerably temperature increase and a generalized decrease of runoff produced in this scenario analysis lower values of evapotranspiration for all the succession phases.

A medium year was selected in order to compare the ETidx resultant maps. This selected year corresponded to 1976 in the reference period and 2086 in the SRES B2 scenario (Figure 8.24). Differences are very clear without necessity of representing a difference map. Nevertheless, to make easier the effects over the ETidx yearly averaged values that difference map was represented (Figure 8.25).

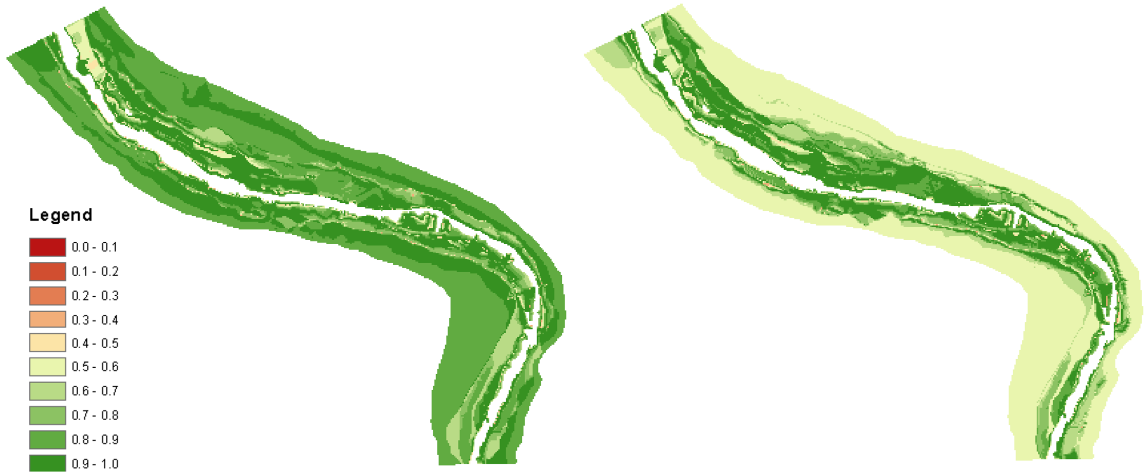


Figure 8.24. ETidx map simulated for year 1976 in reference period scenario (left) and for the equivalent year, 2086, in the HacCM3-PROMES (SRES B2) scenario (right) in Terde reach (Mijares River, Spain).

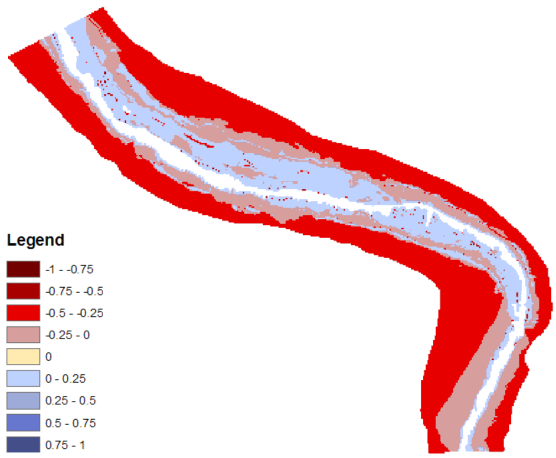


Figure 8.25. Differences observed between ETidx maps simulated and for the equivalent year, 2086, in the HacCM3-PROMES (SRES B2) scenario. Areas in red represent lower ETidx and areas in blue show higher ETidx values observed in the climate change scenario.

As observed in the results, the area more affected with decreasing ETidx values was located remote from the stream. Nevertheless, in this area the lower limits defined as parameters of the model are not exceeded so no death of those locations vegetation was observed and the effects were reduced to a detention of the succession evolution. On the contrary, most of the areas located close to the stream obtained increased ETidx values. However, these increases were slight, between 0.0 and 0.25.

It has been explained that the simulation results showed a reduction of most riparian vegetation succession phases. In addition, the ETidx analysis suggests that there will occur harder effects over areas located less close to the river if the climate change effects are increased.

8.2.3.3 Pessimistic climate change scenario results (SRES A2)

8.2.3.3.1 Changes in vegetation dynamics

One more time, this scenario analysis results showed a similar pattern in the vegetation dynamics but with higher presence of the initial phase of open gravel bars and a lower presence of the pioneer phase than observed in the reference period (Figure 8.26).

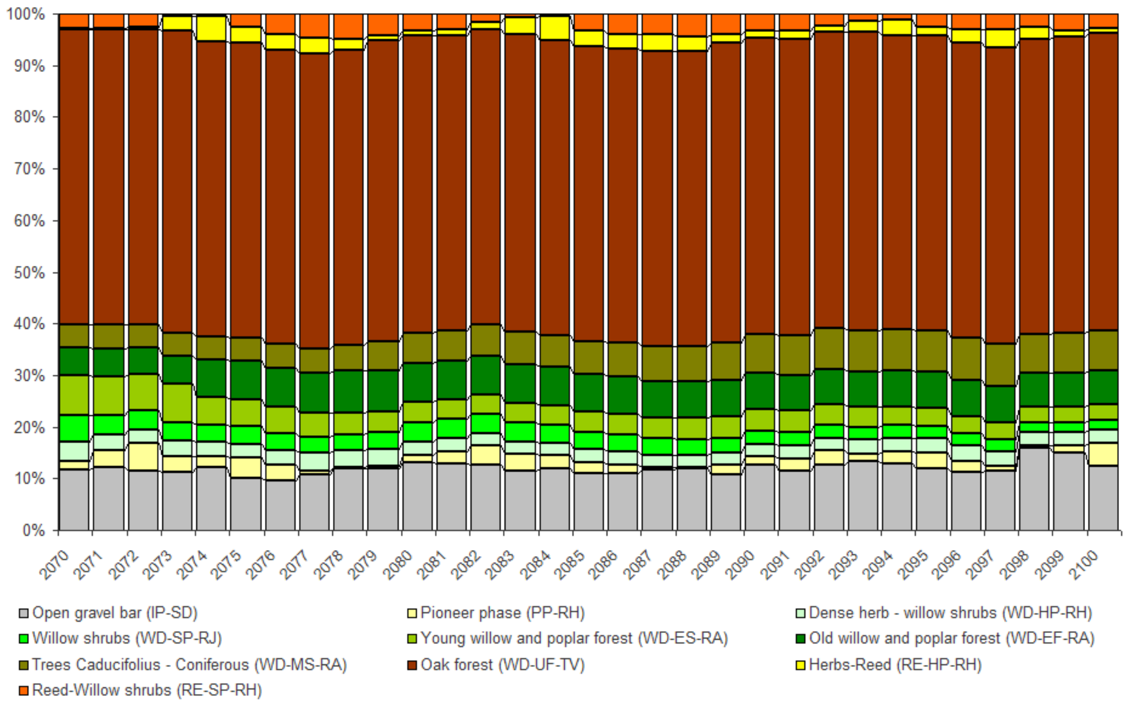


Figure 8.26. Vegetation dynamics in Terde reach (Mijares River, Spain) during the 2070 – 2100 period of HacCM3-PROMES (SRES A2) optimistic climate change scenario.

The initial phase was simulated with a higher presence in most of the simulated years than during the reference period with an average increase value of 1.49%. The maximum increase occurred for year 2077 with a 3.13% higher than the equivalent year form the reference period (Table 8.3). The increase was higher than 2% in about the half of the years, and there was observed decrease only in four years 2070, 2089, 2098 and 2100. The pioneer phase was typically reduced for most of the years reaching a maximum decrease of 5.22% in 2099, compared to 1989 from the reference period (Table 8.3).

Table 8.3. Differences observed in the comparison between the pessimistic climate change scenario HacCM3-PROMES (SRES A2) and the reference period.

Differences between SRES B2 scenario and the reference period of climate change	AVERAGE	MAX	MIN
Open gravel bar (IP-SD)	1.49%	**3.13%**	**-2.85%**
Pioneer phase (PP-RH)	-1.03%	1.00%	**-5.22%**
Dense herb - willow shrubs (WD-HP-RH)	-0.06%	0.50%	-0.54%
Willow shrubs (WD-SP-RJ)	-0.85%	0.39%	**-1.68%**
Young willow and poplar forest (WD-ES-RA)	0.33%	0.76%	-0.12%
Old willow and poplar forest (WD-EF-RA)	0.02%	0.42%	-0.36%
Trees Deciduous - Coniferous (WD-MS-RA)	0.52%	**1.18%**	-0.13%
Oak forest (WD-UF-TV)	0.29%	0.59%	**-0.52%**
Herbs-Reed (RE-HP-RH)	-0.28%	0.99%	**-1.77%**
Reed-Willow shrubs (RE-SP-RH)	-0.42%	0.91%	**-2.10%**

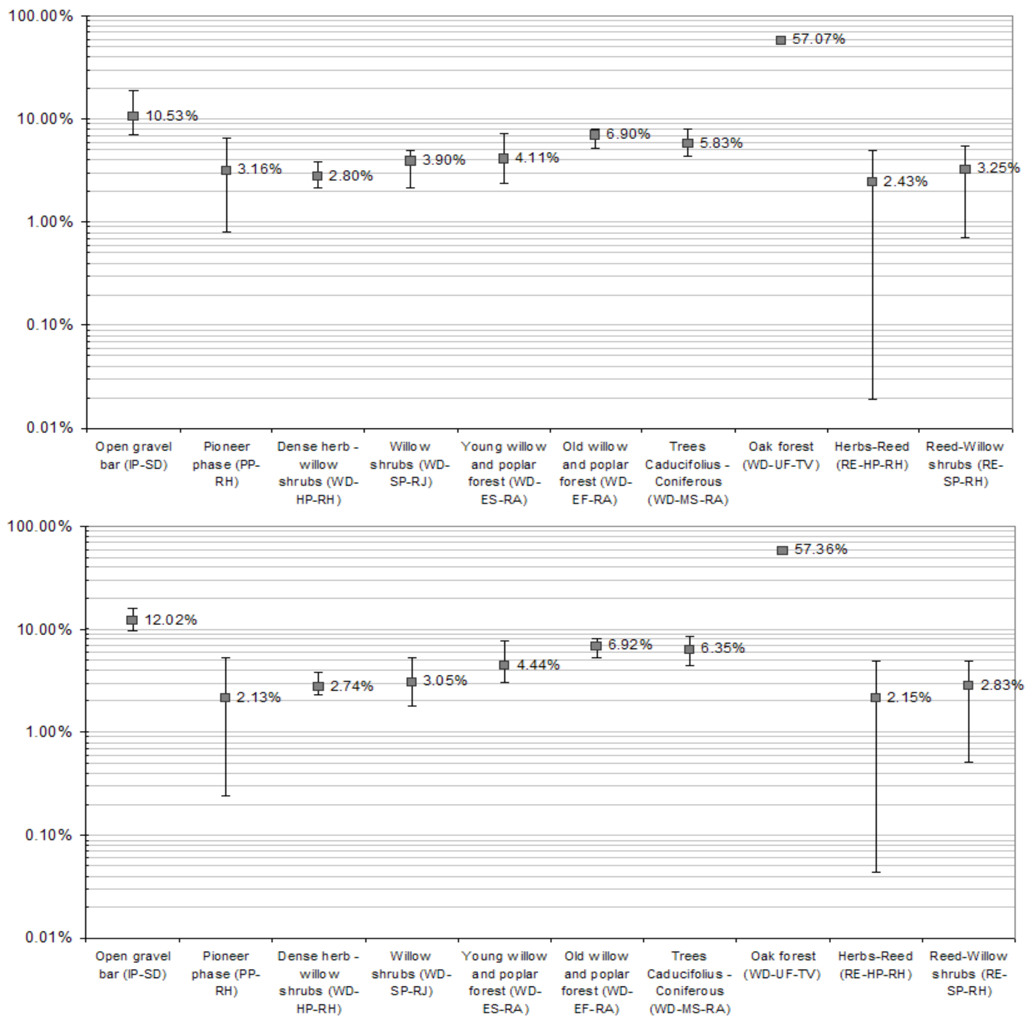


Figure 8.27. Average percentages of vegetation succession phases, with upper and lower limits, in Terde reach (Mijares River, Spain) during the 1960 – 1990 reference period (above) and during 2070 – 2100 period of the HacCM3-PROMES (SRES A2) scenario (below).

Contrary to what happened in the previous scenario, in this pessimistic scenario evolved succession phases were favored for the climate change effects (Figure 8.27). The higher increase was observed for the deciduous and coniferous trees phase which was additionally one of the phases with less negative minimum difference respect the reference period.

In addition, it must be pointed out a surprising result of this scenario analysis, the oak forest phase negative minimum difference. As expected, the average and maximum increase of this phase in this pessimistic scenario (Table 8.3) were higher than the respectively values obtained in the optimistic one, 0.26% and 0.49%. Nevertheless, the minimum difference was negative for the current scenario and it obtained an absolute value very close to the maximum difference, instead of being over cero like happened in the optimistic scenario (0.06%). These variations were very low compared to the global amount of oak forest simulation points (Figure 4.1). However, this result was justified with the ETidx reduction as an effect of the climate change over remote areas from the stream hypothesis, explained in previous chapter.

The reed succession phases showed considerably reductions during dry and medium years but some increases in wet years, probably as consequence of decreasing flows with less shear stress associated. In any case, those were exceptional years and the typical tendency was of reduction of both reed phases (Figure 8.27).

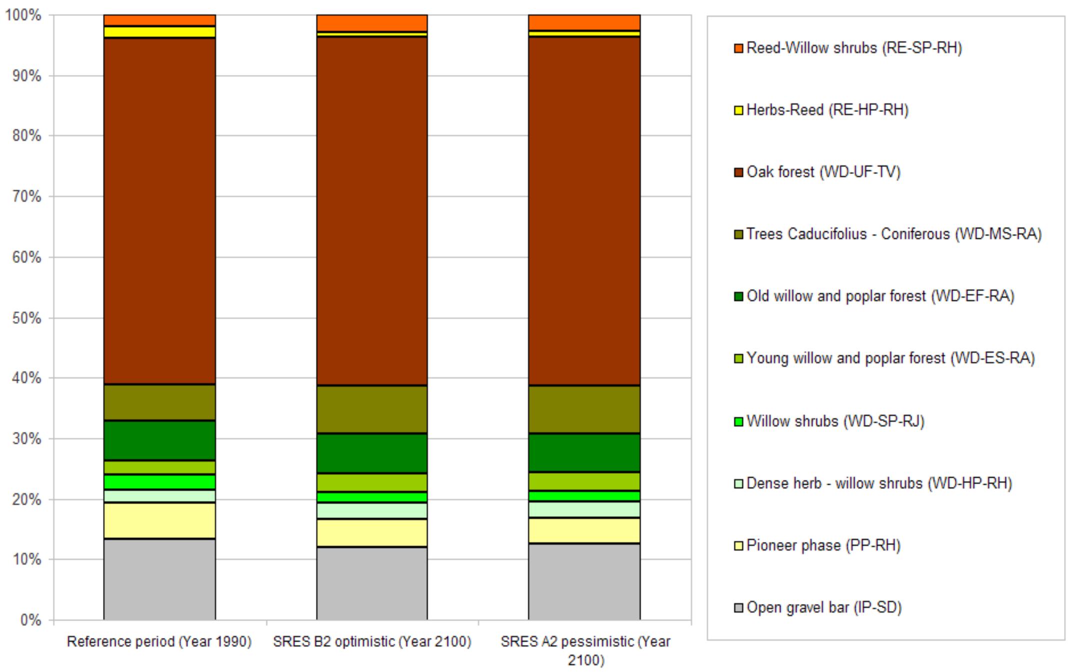


Figure 8.28. Balance comparison between optimistic and pessimistic climate change scenarios, for average percentages for 2070 – 2100 period, and the reference period (1960 - 1990), in Terde reach (Mijares River, Spain)

All the changes were very similar between the climate change scenarios analyzed but slightly emphasized in the pessimistic one. The main conclusion obtained with vegetation dynamic analysis of both climate change scenarios was that although there were some changes between the scenarios and between them and the reference period, the differences are lower than expected (Figure 8.28).

8.2.3.3.2 *Changes in Etidx evolution*

Changes in ETidx results were important in the comparison between the SRES A2 scenario and the reference period (Figure 8.29). The most evident variations were, as occurred for the optimistic scenario analysis, the inexistence of minimum outliers in most of the simulated years, the reduction of the third quartile values and the increase of the boxes size.

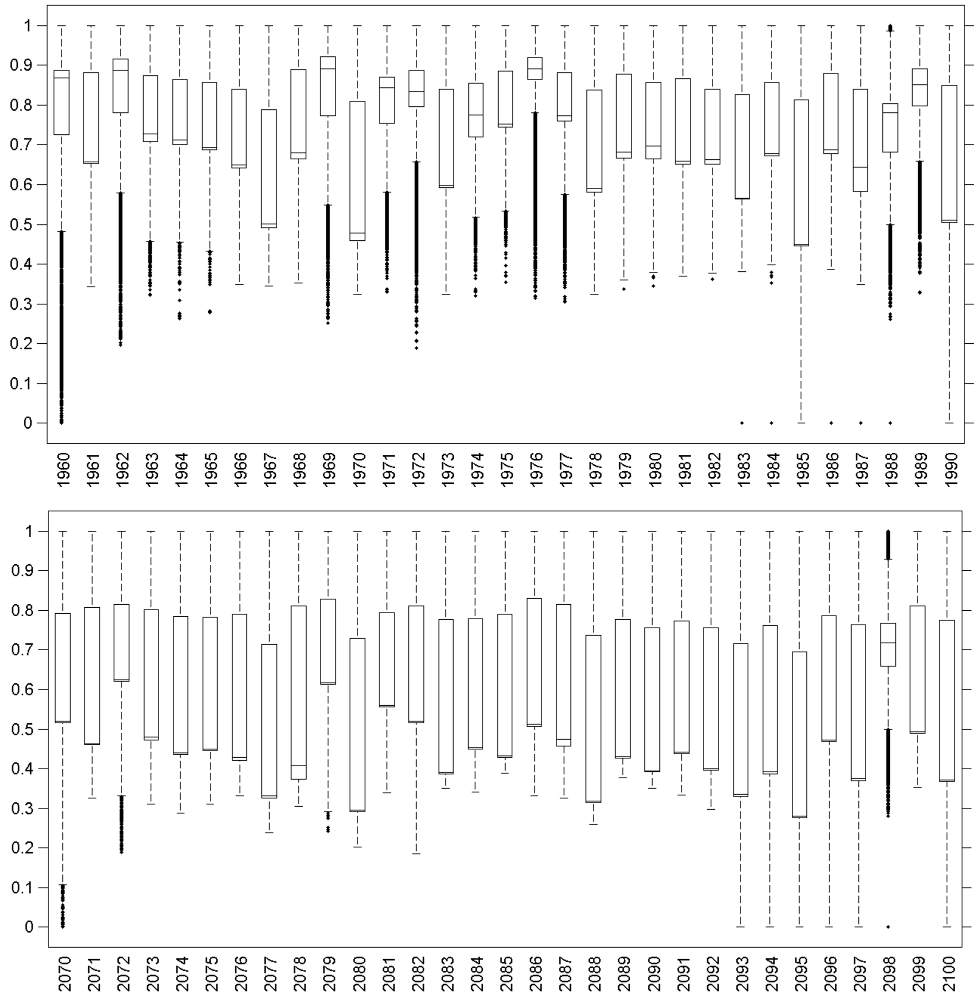


Figure 8.29. ETidx box plots for reference period scenario (above) and HacCM3-PROMES (SRES A2) scenario (below) in Terde reach (Mijares River, Spain).

The reductions of the third quartile observed were between 0.07 and 0.15 (ETidx units) especially during very dry years. These same variations were observed before in the optimistic scenario but the differences here were higher. The differences observed for the first quartile values were greater, which achieved values almost 0.3 ETidx units lower than observed for the reference period, for example during years 2088 or 2097. The median values were very close to the first quartile during all the studied period. In addition, during the reference period the minimum values rarely were under 0.3. On the contrary, during the 2070 – 2100 analyzed scenario this limit was achieved and crossed down. During the 2093 – 2097 period this situation was extremely emphasized, being in 2095 the hardest situation (Figure 8.30).

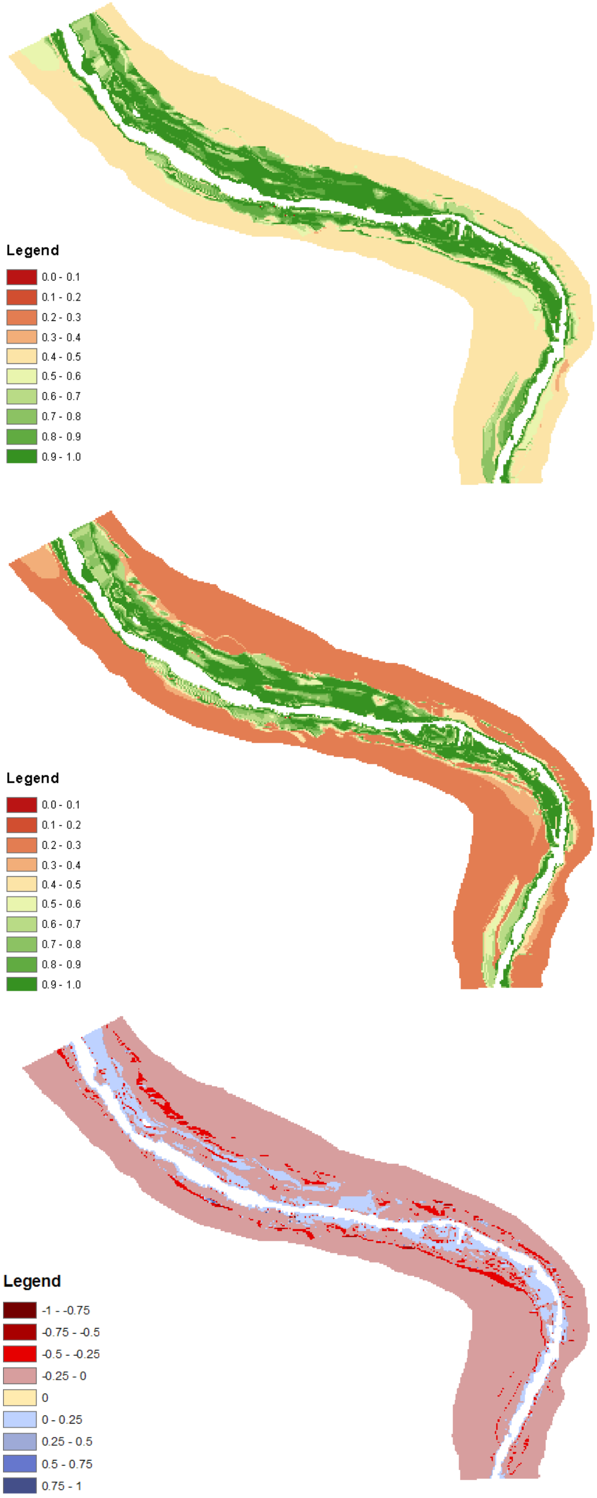


Figure 8.30. ETidx maps simulated for year 1985 in reference period scenario (above), for the equivalent year, 2095, in the HacCM3-PROMES (SRES A2) scenario (middle) and differences between them (below). Areas in red represent lower ETidx and areas in blue show higher ETidx values observed in the climate change scenario, in Terde reach (Spain)

Nevertheless, the equivalent year from the reference period obtained as well low values of ETidx, so in terms of differences between scenarios the worst year was 2090 (Figure 8.31).

Figure 8.31. ETidx maps simulated for year 1980 in reference period scenario (above), for the equivalent year, 2090, in the HacCM3-PROMES (SRES A2) scenario (middle) and differences between them (below). Areas in red represent lower ETidx and areas in blue show higher ETidx values observed in the climate change scenario, in Terde reach (Spain)

As observed in the optimistic scenario, the area more affected with decreasing ETidx values was located remote from the stream, but since in these area the lower limits defined as parameters of the model are not exceeded, the vegetation was not killed and the effects were reduced to a detention of the succession evolution. On the contrary, most of the areas located close to the stream obtained again increased ETidx values. Nevertheless, these results were much stronger than in the optimistic scenario so it was not difficult to realize that there will occur harder effects over areas located less close to the river if the climate change effects are increased.

Despite the ETidx reductions and the water availability constraints, the results for these climate change scenarios were far from being as alarming as expected. This should not be understood as reasoning for not considering the problem of climate change with the extreme care it deserves. The riparian ecosystems are closely related to the river hydrology and instead the climate change effects are shown slowly, water management must consider them carefully in order to prevent damage that can be avoided.

8.3 Austria

The simulations performed after the calibration where aimed in replicating the Upper Drau riparian ecosystem reference period (1960-1990) and to simulate the effects of climate change on the floodplain vegetation given by two possible scenarios. First scenario, postulates an optimistic climate change evolution while the second is based on pessimistic forecast on how the climate will change in the next decades. Both climate change scenarios where based on the results of a regional climate model (Stanzel and Nachtnebel 2010) and the simulated periods applied the climate model results for the period 2070-2100. All the simulations then, spanned a 31 simulated time period. The starting condition (
Figure 8.32) upon which the dynamic vegetation model performed the simulation was the situation mapped in 2003 but corrected with the morphology of 2008.

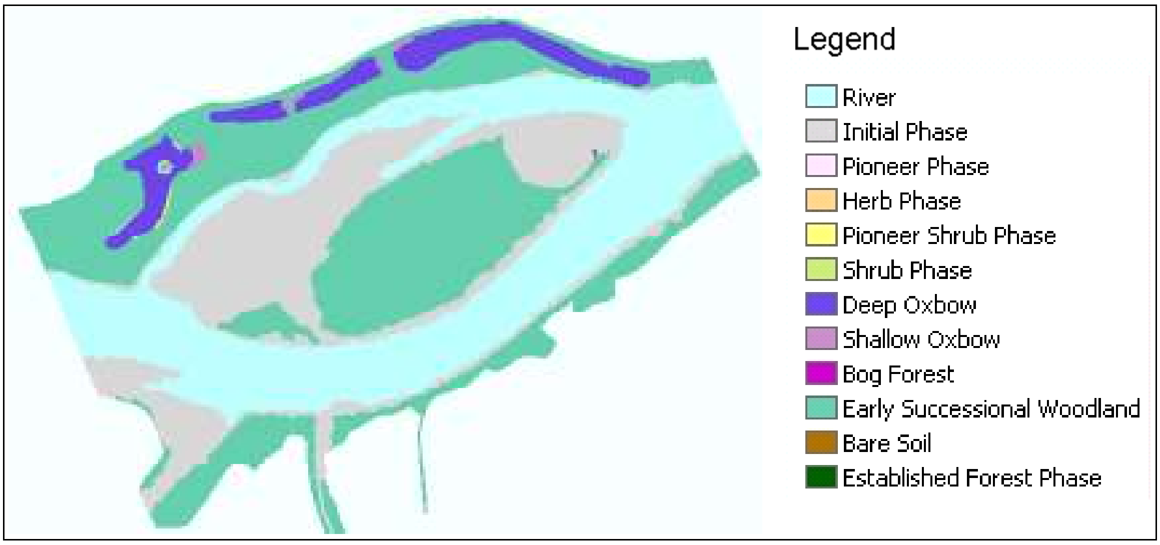


Figure 8.32. Starting condition (initial landscape) feed to the model to begin the simulations both for the reference period (1960-1990) and the climate change scenarios

The analysis of the model results for the Austrian study case have been performed focusing on the bank zone since that this section of the study site is the more relevant to evaluate the vegetation dynamics in the study site. The values which have been kept into consideration to appreciate the riparian ecosystem changes over the time simulated by the model are the relative area balance of the succession phases found in the bank zone. The analysis will focus at first on the reference period, then on the regulated scenario and finally on the two climate change scenarios. The relative area balance descriptions will focus on the main trends and percentages changes figures.

For the ease of comparison, the simulated years in the reference period and the scenarios have been re-named following an ordinal scale. In

Table 8.4 are reported the correspondences among the reference period, the scenarios and the ordinal classification.

Table 8.4 Correspondence among the simulated years of the reference period (1960-1990) and the climate change scenarios simulated years (2070-2100)

Simulated Year	Reference Period Year	Climate Change Year	Simulated Year	Reference Period Year	Climate Change Year
1	1960	2070	17	1976	2086
2	1961	2071	18	1977	2087
3	1962	2072	19	1978	2088
4	1963	2073	20	1979	2089
5	1964	2074	21	1980	2090
6	1965	2075	22	1981	2091
7	1966	2076	23	1982	2092
8	1967	2077	24	1983	2093
9	1968	2078	25	1984	2094
10	1969	2079	26	1985	2095
11	1970	2080	27	1986	2096
12	1971	2081	28	1987	2097
13	1972	2082	29	1988	2098
14	1973	2083	30	1989	2099
15	1974	2084	31	1990	2100
16	1975	2085			

8.3.1 Reference period

The reference period bank zone relative area balance (
Figure 8.33 and Table 8.5) shows in that in the first simulated year more than 30% of the total bank zone surface is colonized by the pioneer phase which after the third simulated year turns in to pioneer shrub (8.5% of the bank zone) or herb phase (approximately 23% of the bank zone). Conversely, around 65% of the bank zone is maintained by the initial phase. In the 6th simulated year, there is a small increase, up to almost 72% of the initial phase, which is driven by the two large floods (100 years recurrence interval, figure) that recycle part of the herb and shrub phase to the initial phase.

For the same reason, the recycling effect of the large floods, in this two simulated years, there is no significant development of initial phase. The 7th simulated year marks also the moment in which most of the herb phase survived to the 6th simulated year flood, step into the shrub phase. In the years following these peaks events, namely the 9th and 10th, the initial phase percentage drops again, this time until the value of 13% of total bank zone cover because replaced by the pioneer phase (51%).This behaviour is explained by the synergetic effect of the low maximum discharges (recurrence interval 0.5) of the simulated years 9th and 10th which leaves the young seedlings (pioneer phase) undisturbed and free to grow.

It is worth to underline that the recruitment conditions in the 10th simulated year are characterized by a fairly low groundwater level. The remark is underlines the ease of recruitment which typically occurs in this riparian ecosystem (check calibration period groundwater level and relative are balance to support hypothesis) in spite of low groundwater levels. In the 11th simulated year the simulated riparian ecosystem assumes a quantitative configuration which is almost constant until the 19th simulated year and upon a certain extent, further on until the 23rd simulated year. More in detail, in the 11th simulated year there is the rose of the early successional woodland phase from the shrub phase, the conversion of the pioneer phase and to herb phase and pioneer shrub. This latter, in the following year, turns into shrub phase. As a result, between the 12th and 19th year, the whole bank zone is occupied with, approximately, 25% of initial phase, 30-45% of shrub phase, 27-28% of early successional woodland phase and less than 15% of herb phase (which turns completely into shrub phase in the 16th simulated year). Such composition is constant upon a certain extent until the 23rd simulated year, because the only significant change in the percentage composition is the sudden increase (occurring at the 19th simulated year) of the early successional woodland phase. Such percentage variation in the bank zone quantitative composition is driven by the time progression rather than dynamic factors and its final result is to bring the overall percentage of the early successional woodland phase to the, dominant, value of 75%.

Another key moment is the reference period simulated scenario at years 23, 24 and 25. In the maximum discharge classification these years are classified with flood recurrence interval 0.5. This prolonged period of low disturbance drives a further decrease of initial phase which turns into pioneer phase and latter in pioneer shrub phase, herb phase and finally in shrub phase.

Observing the whole period, the tendency of the simulated system is to constantly reduce the young most succession phases (initial, pioneer and pioneer shrub phases) in favor of the mature most ones. The tendency founds its confirmation also in the field data observed in the last seven year (Figure 6.34).

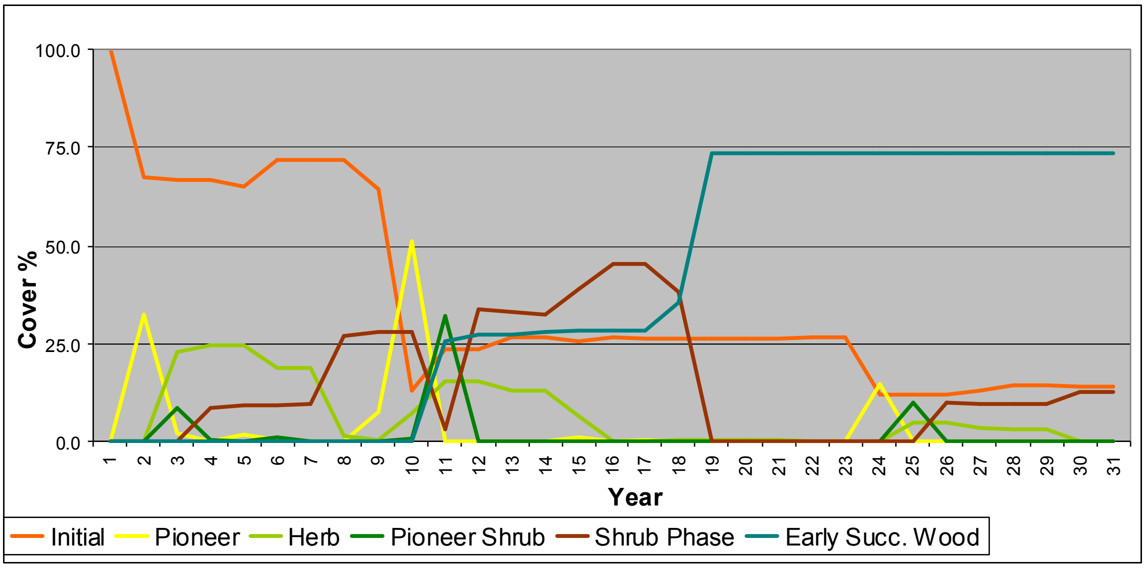


Figure 8.33 10 Bank zone relative area balance reference period

Table 8.5 Relative area balance of the bank zone for the simulated reference period

Year	Initial	Pioneer	Herb	Pioneer Shrub	Shrub Phase	Early Succ. Wood	Tot
1	100.0	0.0	0.0	0.0	0.0	0.0	100.0
2	67.6	32.4	0.0	0.0	0.0	0.0	100.0
3	66.4	2.1	22.8	8.6	0.0	0.0	100.0
4	66.4	0.0	24.5	0.4	8.6	0.0	100.0
5	64.8	1.6	24.5	0.0	9.1	0.0	100.0
6	71.8	0.3	18.5	0.8	9.1	0.0	100.0
7	71.8	0.0	18.7	0.1	9.4	0.0	100.0
8	71.8	0.0	1.3	0.0	26.9	0.0	100.0
9	64.3	7.5	0.2	0.0	28.0	0.0	100.0
10	13.2	51.1	7.1	0.6	28.0	0.0	100.0
11	23.7	0.0	15.5	32.2	3.0	25.6	100.0
12	23.7	0.0	15.3	0.0	33.9	27.1	100.0
13	26.6	0.0	13.1	0.0	33.2	27.1	100.0
14	26.6	0.0	13.1	0.0	32.4	27.9	100.0
15	25.5	1.1	6.6	0.0	38.6	28.2	100.0
16	26.6	0.0	0.0	0.0	45.2	28.2	100.0
17	26.2	0.4	0.0	0.0	45.2	28.2	100.0
18	26.1	0.1	0.3	0.1	38.1	35.3	100.0
19	26.1	0.0	0.4	0.0	0.1	73.4	100.0
20	26.3	0.0	0.3	0.0	0.0	73.4	100.0
21	26.3	0.0	0.3	0.0	0.0	73.4	100.0
22	26.6	0.0	0.0	0.0	0.0	73.4	100.0
23	26.6	0.0	0.0	0.0	0.0	73.4	100.0
24	11.8	14.8	0.0	0.0	0.0	73.4	100.0
25	11.8	0.0	4.9	9.9	0.0	73.4	100.0
26	11.8	0.0	4.9	0.0	9.9	73.4	100.0
27	13.3	0.0	3.7	0.0	9.6	73.4	100.0
28	14.3	0.0	2.9	0.0	9.4	73.4	100.0
29	14.3	0.0	2.9	0.0	9.4	73.4	100.0
30	14.1	0.1	0.0	0.0	12.3	73.4	100.0
31	14.1	0.0	0.1	0.0	12.3	73.4	100.0

8.3.1 Climate change scenarios results

8.3.1.1 Optimistic climate change scenario results

In the optimistic scenario (Table 8.6 and
Figure 8.34), after the first simulated year, there is massive increase of pioneer phase, up to approximately 35%, which in the following simulated year, the 3rd, converts mostly (26%) in herb phase and pioneer shrub (approximately 10%). The 10% pioneer shrub turns then, at the 4th simulated year, into shrub phase. This quantitative configuration remains more or less constant until

the 8th simulated year, when the all the herb phase drops to almost 0% for the effects of the time progression which drives the herb phase to the shrub phase.

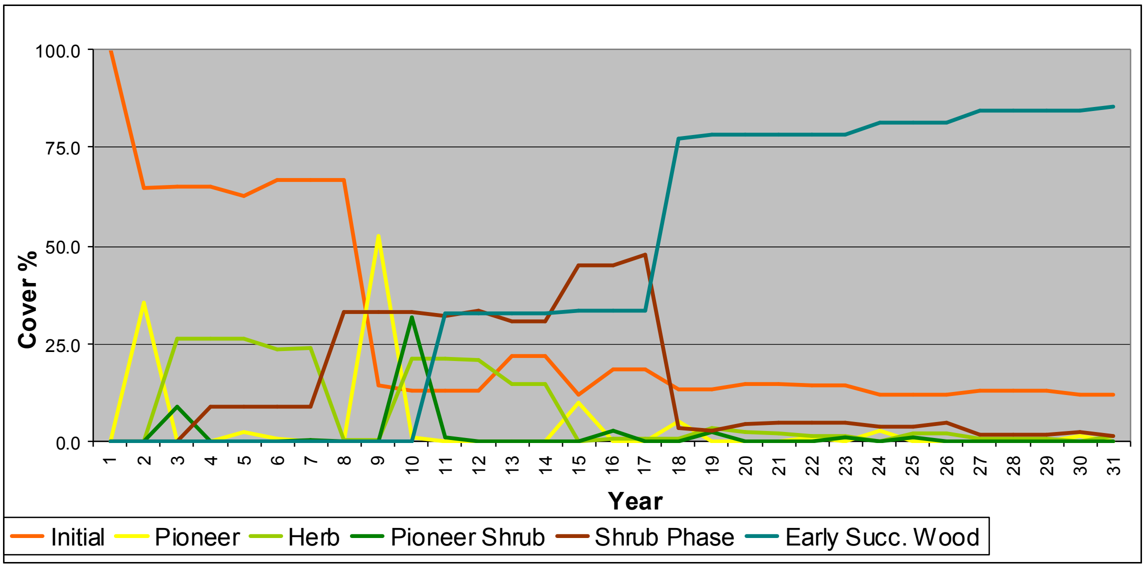


Figure 8.34 Bank zone relative area balance optimistic scenario

Remarkably, 30 years recurrence interval floods which occur at the 6th and 7th simulated years yields a negligible recycling effect on the riparian ecosystem. In the 9th simulated year there is a consistent increase, up to 52%, of the pioneer phase which in the following year turns into herb phase (approximately 21% of the total bank zone surface) and pioneer shrub phase (approximately 31% of the total bank zone surface).

In the following simulated year (11th), the shrub phase progresses totally toward the early successional woodland phase while the herb phase retains constant. On the other hand, the pioneer shrub phase progresses toward the shrub phase. As a result, in the 11th simulated year, the overall percentage of shrub phase remains constant, so does the herb phase, while the early successional woodland appears in the simulated riparian ecosystem.

A further simulated instant which has to be considered is the 13th year, when a 5 years recurrence interval flood recycles part of the herb phase to the initial phase. After this event, in the 15th simulated year, the pioneer phase re-appears in the simulated ecosystem with a roughly 10% of total bank zone cover. Such percentage in the following year (16th simulated) is partially converted to pioneer shrub (approximately 2.5%) while mostly of it is again recycled to initial phase. Yet in the 15th simulated year, the residual herb phase progresses toward the shrub phase which therefore reaches the 45% of the total bank zone cover.

Table 8.6 Relative area balance of the bank zone for the simulated climate change optimistic scenario

Year	Initial	Pioneer	Herb	Pioneer Shrub	Shrub Phase	Early Succ. Wood	Tot
1	100.0	0.0	0.0	0.0	0.0	0.0	100.0
2	64.6	35.4	0.0	0.0	0.0	0.0	100.0
3	64.8	0.0	26.2	9.0	0.0	0.0	100.0
4	64.8	0.0	26.2	0.0	9.0	0.0	100.0
5	62.6	2.2	26.2	0.0	9.0	0.0	100.0
6	66.7	0.6	23.7	0.0	8.9	0.0	100.0
7	66.7	0.0	24.0	0.4	8.9	0.0	100.0
8	66.7	0.0	0.3	0.0	33.0	0.0	100.0
9	14.4	52.4	0.3	0.0	33.0	0.0	100.0
10	13.2	1.1	20.9	31.7	33.0	0.0	100.0
11	13.2	0.0	20.9	1.1	32.1	32.7	100.0
12	13.2	0.0	20.7	0.0	33.4	32.7	100.0
13	21.7	0.0	14.9	0.0	30.8	32.7	100.0
14	21.7	0.0	14.9	0.0	30.8	32.7	100.0
15	11.8	9.8	0.0	0.0	45.1	33.3	100.0
16	18.5	0.0	0.5	2.6	45.1	33.3	100.0
17	18.5	0.0	0.5	0.0	47.7	33.3	100.0
18	13.3	5.2	0.5	0.0	3.7	77.3	100.0
19	13.3	0.0	3.6	2.2	2.6	78.3	100.0
20	14.7	0.0	2.4	0.0	4.5	78.3	100.0
21	14.7	0.0	1.9	0.0	5.1	78.3	100.0
22	14.6	1.0	1.3	0.0	4.8	78.3	100.0
23	14.6	0.0	1.3	1.0	4.8	78.3	100.0
24	11.8	2.8	0.0	0.0	4.1	81.4	100.0
25	11.8	0.0	1.9	0.9	4.1	81.4	100.0
26	11.8	0.0	1.9	0.0	4.9	81.4	100.0
27	13.3	0.0	0.7	0.0	1.7	84.4	100.0
28	13.3	0.0	0.7	0.0	1.7	84.4	100.0
29	13.3	0.0	0.7	0.0	1.7	84.4	100.0
30	11.8	1.5	0.0	0.0	2.3	84.4	100.0
31	11.8	0.0	1.3	0.1	1.3	85.4	100.0

At last, in the 18th simulated year, the riparian landscape assumes a spatial quantitative configuration more or less constant, with the initial phase occupying approximately 11-15% of the bank zone, the shrub phase mostly progressed to early successional woodland with a percentage below the 5% of the bank zone and the early successional woodland stably placed around the 80-85% of the total bank zone area.

The global tendency of this simulated scenario shows a fair dynamic system in the first ten simulated years. In this period, there is an active turnover of succession phases driven by disturbance. This situation applies, but with a consistent reduction, also in the second part of the simulation, more or less until the 15th-16th year. On the other hand, the final simulated period, from the 15th-16th years, portrays an ecosystem quite static where the vegetation dynamics are, like for the reference period, driven by time rather than riparian disturbance processes.

8.3.1.2 Pessimistic climate change scenario results

As in the situations previously examined, in the early simulated years of the pessimistic scenario (Figure 8.35 and Table 8.7), after a large decrease of initial phase in favour of the pioneer phase, there is the establishment of the herb phase at the 3rd simulated year, with a total of approximately 25-30%, together with the pioneer shrub first and then shrub phase a little above the 10%.

The herb phase turns, at the 8th simulated year to shrub phase due to the succession progression effect. A similar development pattern is observed between the 9th and 11th simulated year, when, a sudden decrease of initial phase starts up the colonization of open soil not occupied by vegetation. Once this colonization occurs, the overall turnover of the succession phases is quite limited , shrub and early successional woodland phases increase over time and the initial phase is limited to a small percentage (between 10 and 12%) of the bank zone. In the final simulated years, after the 23rd, the shrub phase drops to negligible cover percentages and at the end of the simulation only the initial phase (almost 12%) and the early successional woodland (87%) are significantly represented.

The overall indication given by this scenario is a marked lack of diversity in the final result. Only two succession phases are present and with a very stable surface percentage, therefore depicting a very static situation.

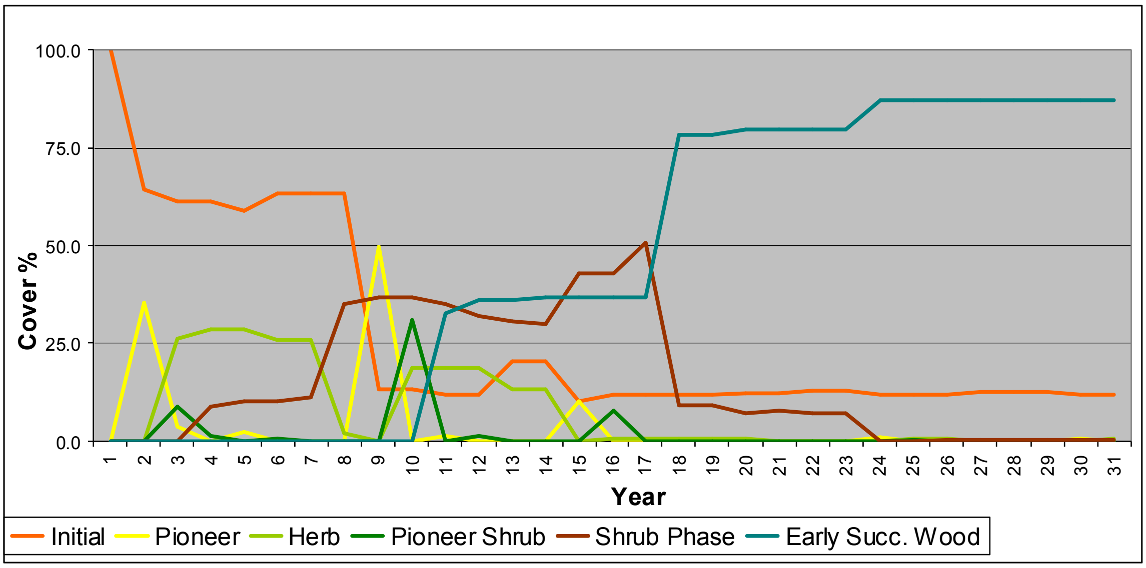


Figure 8.35 Bank zone relative area balance pessimistic scenario

Table 8.7 Relative area balance of the bank zone for the simulated climate change pessimistic scenario

Year	Initial	Pioneer	Herb	Pioneer Shrub	Shrub Phase	Early Succ. Wood	Est. Forest	Tot
1	100.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
2	64.6	35.4	0.0	0.0	0.0	0.0	0.0	100.0
3	61.1	3.7	26.2	9.0	0.0	0.0	0.0	100.0
4	61.1	0.0	28.6	1.3	9.0	0.0	0.0	100.0
5	58.9	2.2	28.6	0.0	10.3	0.0	0.0	100.0
6	63.1	0.0	25.8	0.8	10.3	0.0	0.0	100.0
7	63.1	0.0	25.8	0.0	11.1	0.0	0.0	100.0
8	63.1	0.0	2.1	0.0	34.8	0.0	0.0	100.0
9	13.2	49.8	0.0	0.0	36.9	0.0	0.0	100.0
10	13.2	0.0	18.8	31.0	36.9	0.0	0.0	100.0
11	11.8	1.4	18.8	0.0	35.3	32.7	0.0	100.0
12	11.8	0.0	18.8	1.4	31.8	36.1	0.0	100.0
13	20.2	0.0	13.0	0.0	30.6	36.1	0.0	100.0
14	20.2	0.0	13.0	0.0	29.8	36.9	0.0	100.0
15	10.2	10.1	0.0	0.0	42.8	36.9	0.0	100.0
16	12.0	0.0	0.5	7.7	42.8	36.9	0.0	100.0
17	12.0	0.0	0.5	0.0	50.6	36.9	0.0	100.0
18	11.9	0.1	0.5	0.0	9.2	78.3	0.0	100.0
19	11.9	0.0	0.5	0.1	9.2	78.3	0.0	100.0
20	12.3	0.0	0.5	0.0	7.4	79.8	0.0	100.0
21	12.3	0.0	0.0	0.0	7.9	79.8	0.0	100.0
22	12.9	0.0	0.0	0.0	7.3	79.8	0.0	100.0
23	12.9	0.0	0.0	0.0	7.3	79.8	0.0	100.0
24	11.8	1.1	0.0	0.0	0.0	87.1	0.0	100.0
25	11.8	0.0	0.8	0.3	0.0	87.1	0.0	100.0
26	11.8	0.0	0.8	0.0	0.3	87.1	0.0	100.0
27	12.6	0.0	0.1	0.0	0.2	87.1	0.0	100.0
28	12.6	0.0	0.1	0.0	0.2	87.1	0.0	100.0
29	12.6	0.0	0.1	0.0	0.2	87.1	0.0	100.0
30	11.8	0.8	0.0	0.0	0.3	87.1	0.0	100.0
31	11.8	0.0	0.7	0.1	0.3	87.1	0.0	100.0

All the climate change scenarios show a similar pattern: the initial phase is progressively replaced by more mature phases until the simulated riparian ecosystem reaches a stable situation in which the succession phases turnover is nearly or totally absent and the quantitative distribution of the succession phases is constant. In last instance then, all scenarios return a quite static picture of the simulated ecosystem. Even though, there are some significant differences among the reference period and the climate change scenarios.

In the reference period, the percentage of initial phase is larger, likely due to the larger magnitude of the peak events (Figure 5.14). On the other hand, in the climate change scenarios, in the central part of the simulation, between the years 9th and 17th, more or less all the succession phases are present, thus portraying a more diverse landscape than in the reference period. Yet, all the climate change scenarios and the reference period, show a low recruitment sensitivity to the groundwater level. Although this physical factor is crucial for the vegetation recruitment (Mahoney and Rood

1998), in the simulations, large portions of bank zone are colonized by the initial phase in years which, given the mean spring discharge, are classified as dry or wet. Such behaviour is confirmed also by the vegetation sampled in the natural reference (
Figure 7.11) site and then used to calibrate the dynamic vegetation model. In the year 2007, the vegetation sampled in the bank zone of the study site was mostly pioneer, despite the fact that 2007, according to the mean spring discharge (98m^3/s), was a “dry” year. The impacts of climate change on floodplain vegetation processes lead by hydrology do not seem to differ significantly from the reference period. Such unexpected results suggest that either in the reference period some climatic change was already acting on the floodplain vegetation or that the discharge variations forecasted by the climate models are still within the system resilience limits.

8.3.2 River management scenarios results

8.3.2.1 Small In-Stream Bars alternative

In the fictive, artificial Small In-Stream Bars alternative with static bed geometry the following development was calculated: Relative area balance analysis for this bank zone section shows very little succession phases turnover in the first 16-17 simulated years. Most of the simulated landscape is occupied by initial phase while there are small portions of pioneer and herb phase, soon replaced by the shrub phase. Yet, there is a constant growth of the relative area occupied by early successional woodland phase.

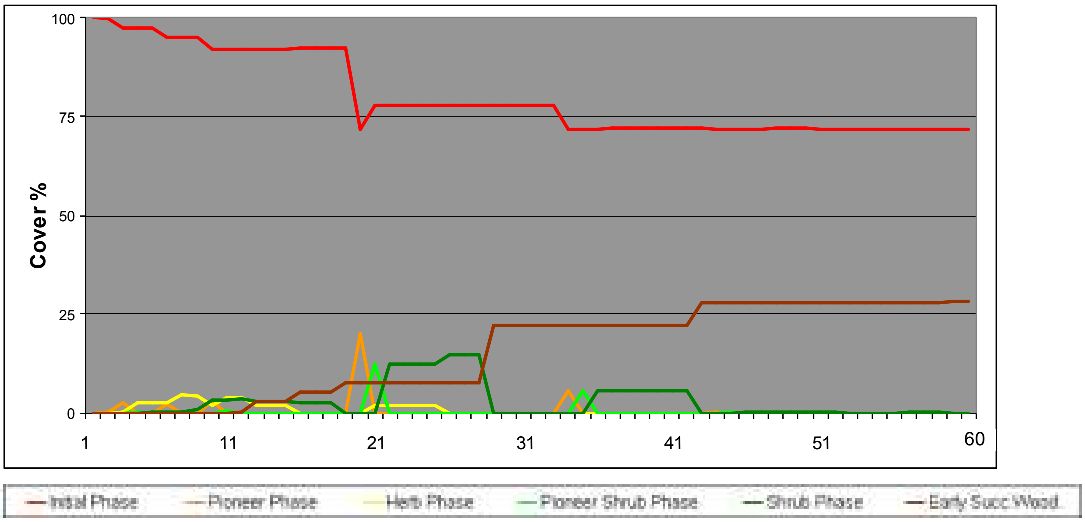


Figure 8.36 Relative area balance chart of Scenario 1, Small In-Stream Bars. On the Y axis, the relative area covered by each succession phase in each simulated year (X axis)

Between the 18th simulated year and the 28th simulated year there is a significant change in the simulated landscape. Initial phase decreases significantly turning in pioneer phase then in pioneer shrub followed by shrub and ultimately by early successional woodland phase which becomes the succession phase more represented with nearly the 30% of total cover while the remaining 70% is occupied by initial phase.

8.3.2.2 Large In-Stream Bars alternative

Until the 27th simulated year, the simulated system shows some degree of dynamics while in the last simulated years the system is in equilibrium and succession progression is the leading vegetation process.

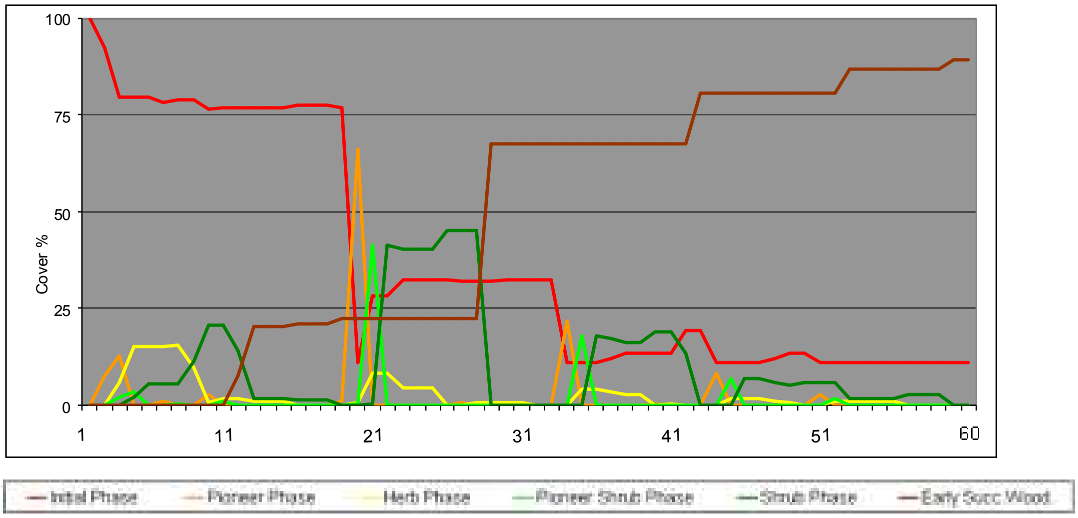


Figure 8.37 Relative area balance chart of Scenario 2, Large In-Stream bars. On the Y axis, the relative area covered by each succession phase in each simulated year (X axis)

The key moment is the time frame between the18th and 28th simulated years, where most of the phases turn in early successional woodland. After this simulated period, there is still some active turnover between the 33rd and 45th simulated years but after this short time frame, the vegetation composition is stabilized with the 90% of the bank zone section occupied by early successional woodland phase and the residual 10% occupied by initial phase.

Given the sedimentation trends observed in the restored site, it is likely that partial or total recycling can be triggered by sediment deposition and consequent plant burial or lateral erosion of bars and banks. This lack of information deserves further investigation especially for the morphology 2008 alternative, where large parts of the side channel bank zone where, at the end of the simulation, covered with vegetation.

Nonetheless simulations value resides in the possibility afforded by the model, to appreciate the long term response of the riparian system so that uncertainty about the measures' effects are reduced. In order to compare real case vegetation scenarios or development the morphodynamics should be included. In both river management alternatives, the final picture portrays a static, artificial system with no habitat shift. This doesn't reflect the real field environment, but allows to investigate processes separately. Although the final results of the two alternatives look different, under the ecological point of view the meaning is not dissimilar.

The lack of shift in the model has a negative effect on the ecological functions of the river corridor because there is a depletion of habitats which can host different species types and their different life stages. However, the two alternatives strongly differ in the path that lead to their results. While alternative "small in stream bars" reaches the static condition with very monotonic steps, in the alternative "large in stream bars", the phase transitions are more dynamic. In fact, at least in the central part of the simulated period, "large in stream bars" has an active succession phases turnover.

8.4 Portugal

8.4.1 Climate change scenario results

8.4.1.1 Vegetation dynamics during the reference period

The modeled result for the considered reference period is presented in
Figure 8.38, considering the ETidx sub model in the modeling process. This result presents a much higher area of retrogression compared with the calibration period, probably because of the existence of 100 years return period discharge (1987) occurred in this reference period.

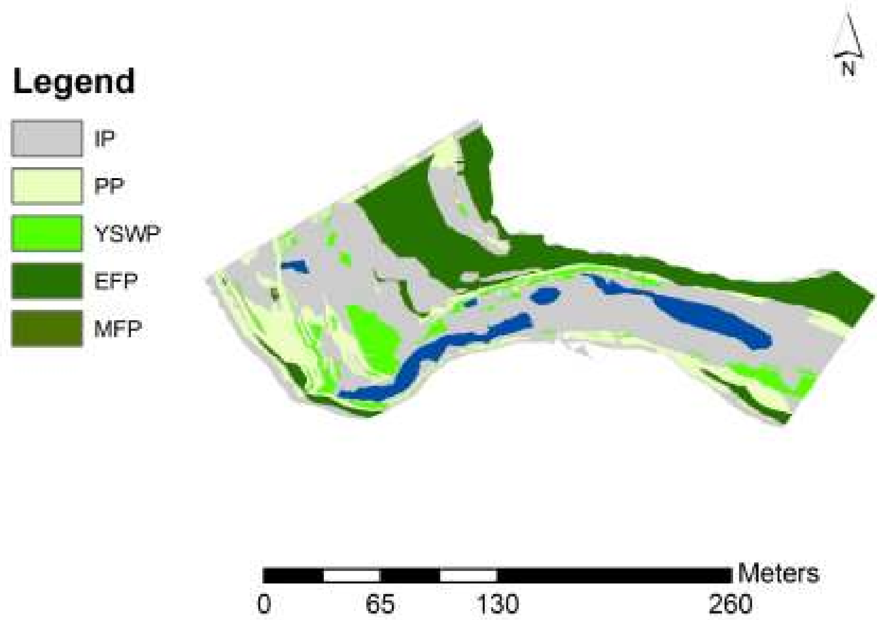


Figure 8.38. Riparian vegetation at 1990 (modeling with ETidx sub model).

8.4.1.2 Optimistic climate change scenario results (SRES B2)

8.4.1.2.1 Changes in vegetation dynamics

The expected vegetation for 2100 considering the optimistic climate change SRES B2 is presented in
Figure 8.39. Comparing the reference period scenario with the optimistic B2 climate scenario, the results show an increase of the IP and a decrease of the other succession phases. Biggest change is found in the IP, with a 21% area increase due to the retrogression of the older existing riparian patches (11, 1 and 9% decrease in PP, YSWP and EFP, respectively) (Figure 8.40). It was expected to found MFP in the outer parts of the floodplain zone, so a more accurate calibration is suggested.

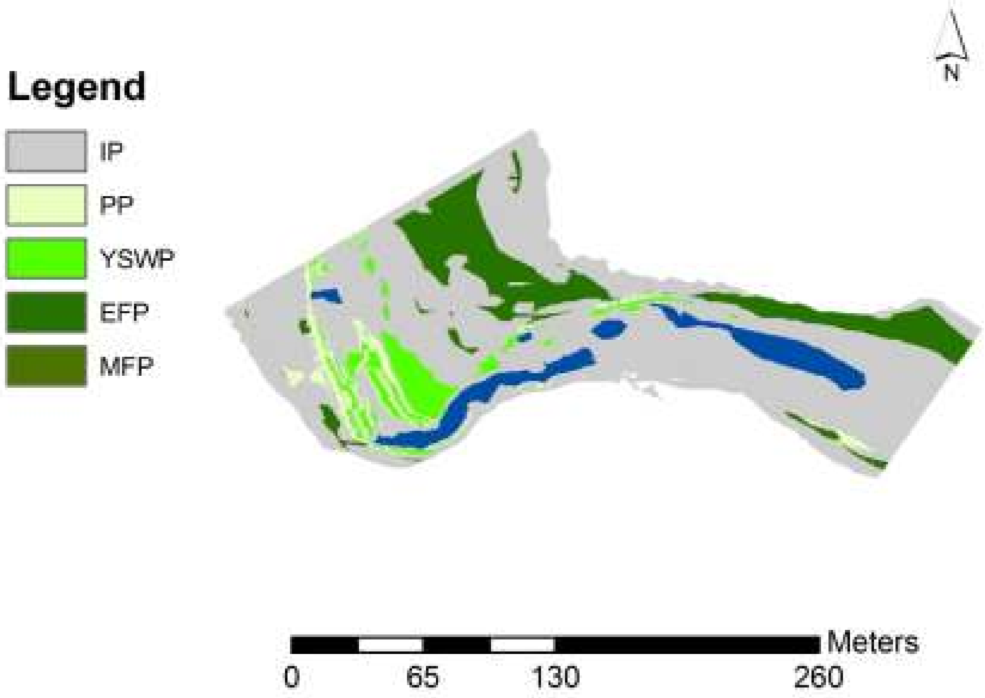


Figure 8.39. Riparian vegetation expected for 2100 considering the optimist climate change scenario SRES B2 (with ETidx sub model).

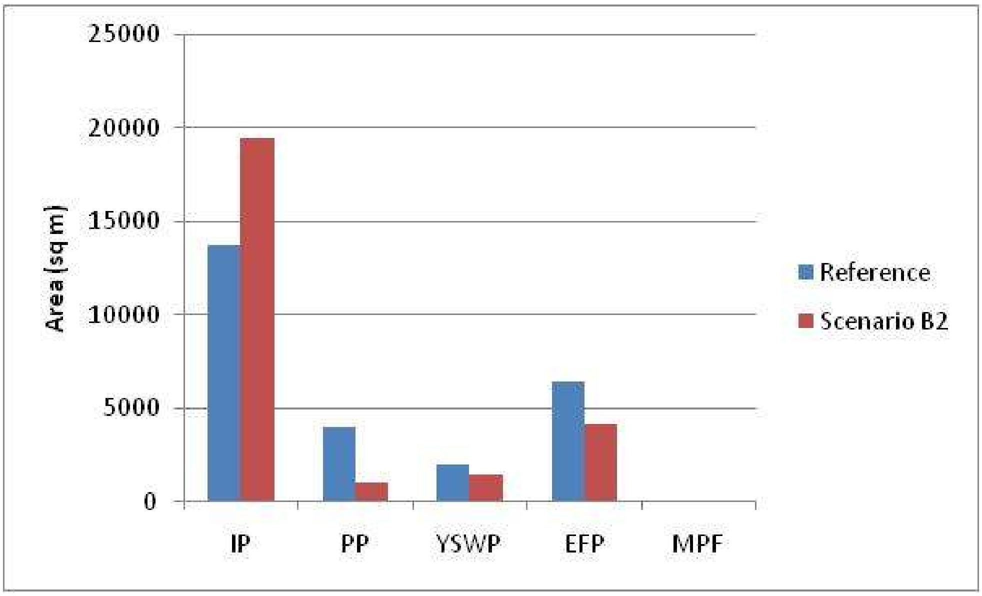


Figure 8.40. Succession phases comparison between reference period and scenario B2.

8.4.1.3 Pessimistic climate change scenario results (SRES A2)

8.4.1.3.1 Changes in vegetation dynamics

Pessimistic climate change scenario is foreseen by RIPFLOW as an even worst case of vegetation patch vanishing. In this case, the lower water table levels and more intense flood discharges drive the younger succession phases to extinction, remaining only the EFP, with a much higher resistance to shear stress and hydric stress (Figure 8.41).

These changes in the riparian pachiness mean a 30% increase of the IP by the replacement of the older phases. In this pessimistic scenario, the EFP is the only one resisting the altered flow regime, although with 8% decrease in area (
Figure 8.42).

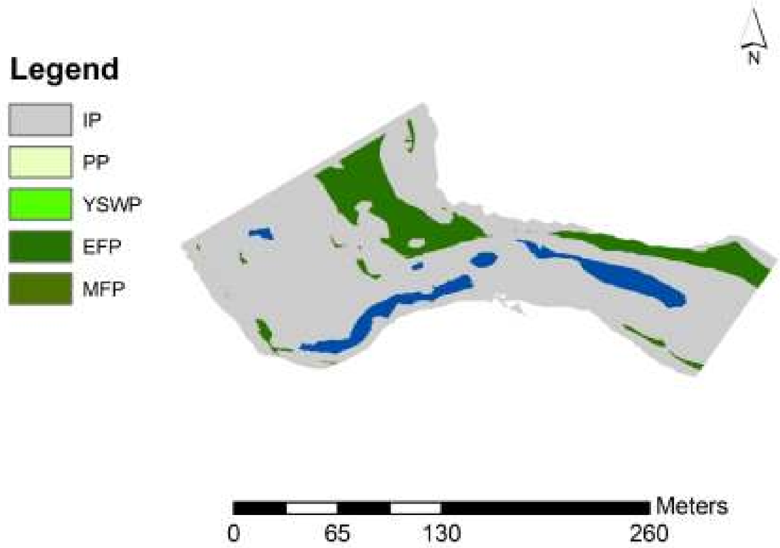


Figure 8.41. Riparian vegetation expected for 2100 with pessimistic climate change scenario SRES A2 (with ETidx sub model).

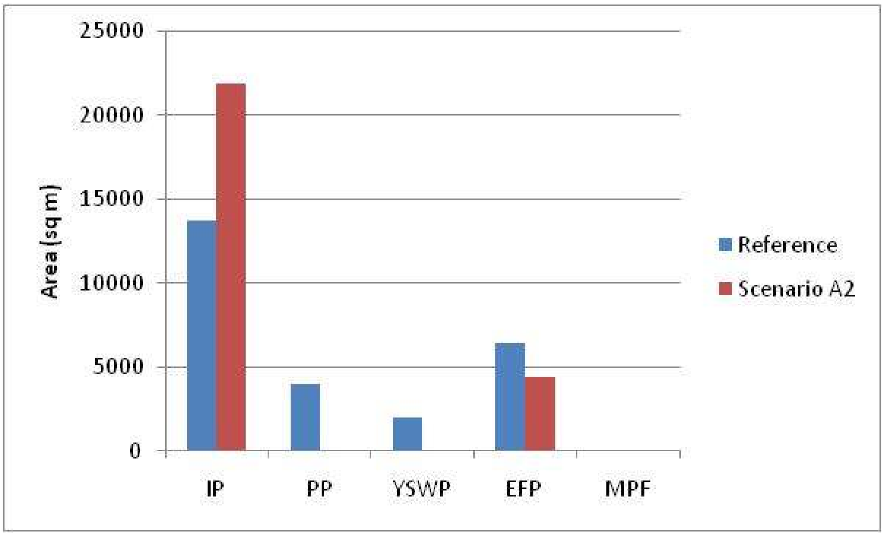


Figure 8.42. Succession phases comparison between reference period and scenario A2.

9 Main conclusions

The main conclusion in the project are:

1. The RIPFLOW model simulates riparian vegetation distribution in space and time. It takes into account the vegetation succession or retrogression in response to physical parameters, particularly flow regime. Beside its scientific value, this is a practical tool to manage the water resources of rivers with different characteristics, under different scenarios hypothesis.

2. The model application is flexible and adaptable to different regions in many ways. For example, the hydrological classes of years are flexible, because the user can define 3 classes (dry, medium, wet year), 5 classes, etc. However, it is important that all the maps and analyses are coherent with these classes, in all the information generated in a study site. Regarding the maps format, it is very important that all the maps must be generated with the same grid extension and pixel size (in each study site, one mask for maps creation in ArcGIS was selected). The selected size has to accomplish a balance between accuracy in the vegetation mapping and time consumption during the calibration process. Other example is that the mean annual flow was considered as the reference low flow in the Alpine site, and the base flow was the low flow reference in the Mediterranean sites (Spain and Portugal), where the difference between mean and base flow is very relevant.

3. Before the model can be used in any other study case different from those that are presented in this report, the users will need to implement a first phase of field data survey:

    - In the data acquisition for hydraulic simulation, it is advisable to repeat the survey at different flow stages, and it is very important to survey water levels for high flows. The quality and reliability of the rating curves and the hydraulic model depend very much on the data of water surface elevation when the water covers the floodplain, and that is the moment when shear stress and other riparian processes play an important role in the forest development.

    - The vegetation survey usually demands an important effort in the modelling. The vegetation patches were defined in the field, together with soil and vegetation characteristics. Therefore, it is important to make a careful planning of the field operations, with a stepwise work from the more general and economic assessments (working over aerial photographs, for example), to more detailed surveys to determine representative species, biometric variables (diameter, height), growth functions and stand ages. Besides, the succession and retrogression processes need to be correctly interpreted in the field, what requires field-based knowledge adapted to the study site. It is very important that the selected sites include natural or reference sites, where the rules for vegetation succession and retrogression, as well as the natural processes in the riparian habitats, can be reliably identified in the natural status. All possible vegetation patches comprising the succession should be present in the chosen study site. When the model is applied to a regulated river, this site must be comparable to the natural one (e.g., based on an ecological or hydrological river classification), so that the natural relationships occurring in the riparian ecosystem can be used as a reference to understand the effects of flow regulation.

4. During the development of the field data, the quality of the DEM is very important, because its quality determines the accuracy of the hydraulic model and the input maps. Our conclusion is that small improvements or investments in a better quality of the DEM, can potentially significantly improve the model results and can facilitate the following data processing and interpretation.

5. The comparison of results about different possible solutions of a problem, analyzed in the form of scenarios, can help in the decision making. Once the model is set up for a specific reach, it allows a large number of scenarios analyses, expanding the range of possibilities to make a better decision.

6. The hydrological inputs must be reviewed and redefined in order to be coherent with the scenario that is going to be analyzed. In some cases, morphological inputs or soil data information should be modified too.

7. Regardless of which type of scenario is being proposed, a hydrological analysis must be done in order to establish some yearly inputs.

   - The maximum flow for each year determines the shear stress input to be considered by the model in that year simulation.
   - In addition, the average flow (in wet environments) or the base flow (in semiarid environments) determines for each year the type of hydrologic year (in a user-specified number of classes).

8. The model selects the inputs for each year, the characteristic water table elevation, flood duration and bank zone. A hydrological analysis based on exceedance probability curves and histograms will be very useful in the definition of year types.

9. The analyses of climate change scenarios for each specific study case must consider the variations expected for the climate model (or group of models) with the best performance in the country of origin, being very advisable to apply regionalization techniques. To obtain the hydrological future variations at the local scale, some additional hydrologic simulations are usually necessary, considering the precipitation and temperature data series for each scenario.

10. After each model iteration, a vegetation cover map and an evapotranspiration index map (raster format) are generated. The end user can group the maps to produce an animation which displays the evolution of the system over the simulated years. In addition, it is also possible to build an animated chart of the landscape along the years of study using the discharge data for each year. Maps outputs can be also used to perform spatial analyses and give summary data for decision support.

11. The results interpretation must take into account the lack of a sediment transport sub-model (leading to bed erosion and aggradation), as well as bank erosion and bank accretion (controlling channel width), which play an important role in the shaping of the riverine vegetation community (Bendix & Hupp, 2000; Edwards *et al.*, 1999).

12. Policy makers should take into account that the vegetation evolution takes place very slowly especially in advanced stages of the succession. It is important not only to consider a time period long enough to show consistent scenario effects, but also to check if the trends of potential long term effects are maintained or stable.

13. Water managers should take into account that although not always more advanced stages of a riparian succession indicate a better environmental performance. For example, in the minimum environmental flow scenario analyzed for the Spanish study case, the

retrogressions in the succession caused by flood events are avoided. Although the riparian ecosystem succession seems to be favoured with minimum environmental flows implementation, no retrogressions in the succession favour that finally (long-term) the terrestrial vegetation replaces the riparian one.

14. RIPFLOW is a reach scale model, and for watershed scale decision support, several representative reaches of the river should be analyzed and an upscaling methodology should be developed.

10 Recommendations for future Work

Once the modelling efforts have been accomplished, a complete tool is available for its use in other study sites. For this purposes some specific field information will be needed, and depending on the availability of the required resources (time, technical equipment, trained human resources, etc.) and the site accessibility, the model application will be affordable or not. That is why we consider very interesting to focus future work on the development of some techniques in order to reduce the field data survey requirements.

In this project the riparian vegetation types, as well as the succession expert rules, have been established from field data survey and analyses. This decision was made considering the necessity to obtain the best possible species knowledge, to develop a model capable of reproducing the vegetation behaviour in riparian areas. Nevertheless, once the tool is created and tested under several environments and different hydrometeorological scenarios, its use will not require such detailed information. A high resolution aerial photography could be enough to evaluate the validation quality of the model in other study sites.

In the same way, LIDAR technology can provide the required high resolution digital elevation model. The combination of aerial photography and LIDAR digital elevation models can provide enough information to establish the succession expert rules. With this approach the field work can be reduced considerably. Besides, an effort must be made in the field to know the ages of the vegetation succession phases, specific to each region.

Riparian vegetation aging is a challenging task, considering that flow events promote fragmentation of riparian individuals and that many riparian species present vegetative growth. Future research should include dendrochronological validation of the stand age. Equally, physiological and morphological parameters needed in the evapotranspiration module should be experimentally confirmed at regional level.

Alternative sources for soil information survey will be more difficult to find. Nevertheless, in every European country several companies offer the complete service including field sampling, samples analysis and data processing. For inaccessible areas or large scale problems, can be very interesting to develop a new model that allows the simulation of soil characteristics, considering for example the channel morphology, the vegetation related sources/drains of organic matter and nutrients, and the erosion/transport/deposit of several sediments diameter ranges.

The model can be used for many scientific purposes, from hydro-meteorological scenarios analysis, vegetation affections by soil characteristics changes, variation of evapotranspiration rates between different vegetation types in a selected area, comparison of different succession lines and succession velocity in other regions, etc.

Although there are many scientific challenges to rise with the RIPFLOW model there are some tasks that can improve it too.

The role played by morphodynamic processes on the vegetation dynamics is twofold. On one hand, the erosion and deposition processes acting during the floods are responsible for vegetation burial and disruption and consequent vegetation recycling (Bendix & Hupp, 2000). On the other hand, sedimentation creates new sand or gravel bars which are suitable sites for the vegetation establishment and can therefore trigger the recruitment of new stands, favouring, in last instance, the vegetation renewal (Polzin & Rood, 2006).

Climate change effects seem to be little apparent in some cases study but the neglecting of the morphodynamic processes may have introduced uncertainty in the interpretation of the final results.

- For the Portuguese study case, climate change effects are more extreme and result almost in the disappearance of the pioneer and juvenile riparian patches because recruitment cannot proceed and result in tree establishment due to winter flows and summer dryness. A common factor in the two climate change scenarios, which have been simulated, is the reduction of the peak discharges, also for the extreme events. This reduced flood magnitude would have also a direct impact on the magnitude of the sediment/erosion processes and consequently on the recycling and recruitment of vegetation.

- For the Spanish study case, climate change scenarios showed the same trend as in Portuguese study case but but with less intensity. Although the changes on the vegetation phases were less than expected, the analyses of both scenarios (optimistic/pessimistic) in Terde (Mijares River, Spain), showed a generalized reduction on evapotranspiration rates, harder during dry years and for the pessimistic scenario.

- For the Austrian Alpine region, the flow variations of both scenarios highlight the shift of the maximum mean discharge from June to May while over the spring and summer there is a discharge decrease compensated by a late winter mean discharge increase. The simulations of the Austrian study case highlight a stationary percentage composition of the older succession phases which are not heavily affected even by large floods. On the other hand, the younger most succession phases abundance fluctuate in response of the flow variations determined by the climate change scenarios.

The morphodynamic effects in the implemented modelling procedure are partially accounted with the shear stress sub-model. In fact, the shear stress, in the model concept, is considered as an indicator of the morphodynamic process intensity. When the shear stress is strong enough (more than the succession phase shear resistance), in the model, it is responsible for the disruption of the vegetation. Now the model allows the incorporation of new digital elevation models in different time steps; however, it is necessary a morphological processes modelling to evaluate (externally) how this future changes may occur. However, for a more holistic modelling approach it would be advisable to somehow introduce also the creation of new bare habitats (initial phase) which occur with the deposition processes. This point represents an open challenge and gives room to further investigation efforts.

Other possibility would be to improve the recruitment sub-model incorporating empirical data related to the soil texture from each region. These data would make also reference to the elevations and optimum slopes for recruitment in the bank zone.

About working on different spatial scales, it must be consider that the RIPFLOW model is a reach scale model. For watershed scale analysis we propose to develop a methodology which includes the analysis of several representative reaches of the river segments (based on coherent river classification systems) with the current version of the model and a subsequent upscaling methodology.

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Appendix

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Terms and Definitions

Term	Definition
ETidx	An index based in the quotient between the current and the potential evapotranspiration. It is the general RibAV model (soil moisture sub-model) output.
FFH-Habitats	Habitats classification systen used in the EU Habitats Directive
masl	Meters above sea level
Reach	A straight, continuous, or extended part of a river, stream, or restricted waterway
Recruitment	Process in which some plant types are allowed to start a succession on bare soil with preference over other vegetation types
Riparian	Relating to or inhabiting the banks of a natural course of water
Scenario	A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships.
Shear stress	An applied force per unit area needed to produce a distortion on a body, in this case, the water force per unit area needed to produce a riparian plant remotion
SRES scenarios	SRES scenarios are emission scenarios developed by Nakičenovič and Swart (2000) and used, among others, as a basis for some of the climate projections used in the Fourth Assessment Report (AR4).
Succession	The gradual replacement of one type of ecological community by another in the same area, involving a series of orderly changes towards a stable climax community
TIN	Triangular Irregular Networks
Vegetation type	Non-phylogenetic groupings of species which perform similarly in a ecosystem and which have similar response to disturbance or changes in environmental variables
WFD	Water Framework Directive

Glossary of Acronyms and Abbreviations

ASCII	American Standard Code for Information Interchange
CIS	Common Implementation Strategy for the WFD
DLL	Dynamic-link library
EF	Establish forest successional phase
EFP	Established Forest phase
ES	Early successional phase
ET_0	Reference crop's potential evapotranspiration
ETidx	Evapotranspiration index
HBFL	Height over base flow
HBNF	Height over bankfull flow
HOMW	height over mean water level
HP	Herb successional phase
IP	Initial successional phase
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated water resource management
MFP	Mature Forest phase
MS	Mature successional phase
PFTs	Plant functional types
PNV	Potential natural vegetation
PP	Pioneer successional phase
RA	Riparian adults plant functional type
RE	Reed succession line
RH	Riparian herbs plant functional type
RJ	Riparian juveniles plant functional type
SP	Shrub successional phase
SRES	Special Report on Emission Scenarios
TV	Terrestrial vegetation
UF	Upland forest successional phase
WD	Woodland succession line
WFD	Water Framework Directive
YSWP	Young Successional Woodland phase

RIPFLOW PROJECT

Project Summary

Joint project title	**“Riparian vegetation modelling for the assessment of environmental flow regimes and climate change impacts within the WFD”**
IWRM-NET Project No.:	
Project partner #1 (Co-ordinator):	Félix Francés García
Organisation:	Universidad Politecnica de Valencia (Valencia, Spain)
Email:	ffrances@hma.upv.es
Project partner #2:	Gregory Egger
Organisation:	Umweltbüro (Klagenfurt, Austria)
Email:	gregory.egger@umweltbuero-klagenfurt.at
Project partner #3:	Teresa Ferreira
Organisation:	Technical University of Lisbon (Lisbon, Portugal)
Email:	terferreira@isa.utl.pt
Project website:	http://www.iiama.upv.es/RipFlow/index_archivos/Page2329.htm
Objectives	This project has been focused on a the implementation of a dynamic riparian vegetation model, which takes into account the major components of the floodplain ecosystem, and is a valid basis for assessing impacts and management measures on riparian ecosystems
Background	The developed techniques and the methodology applied to obtain the necessary field data survey, the model calibration and all the scenarios analysis, have been based in the experience of project consortium.
Research	▪ Development of a flexible dynamic model of riparian habitats and vegetation to be easily applied in a wide range of conditions across Europe, from humid regions of Austria to Mediterranean conditions. ▪ Creation of software to run such model in a user-friendly interface to give decision support in the implementation of the WFD by the water managers. ▪ Identification and application of cost-effective methods for the acquisition of biological information needed to calibrate the model in most regions of the European Union. ▪ Calibration of the model in the case studies ▪ Identification of scientific based guidelines for assessing the impacts of altered hydrology on riparian vegetation, due to climate change or dam operation rules, considering extreme hydrological events like droughts and floods ▪ Analysis of several representative disturbed flow and climate change scenarios in the study sites in order to show the capabilities of the model. ▪ Illustration of how the results should be exposed and interpreted
Key Findings	The great potential of the model is its capability of visualizing and quantify the changes occurring both at spatial and temporal scale on the riparian ecosystems, in response to hydraulic driven variables. The time series output maps are easily interpretable also for non expert users such as policy makers or generic stakeholders, who can be involved in water allocation conflicts or administration of river restoration funding. The model demonstrates its potential to evaluate the possible outcome of different management strategies (establishment of in-stream islands, flow regulation, environmental flows regimes design) and different climate change scenarios.
Implications and Recommendations	The RIPFLOW model is a reach scale model, flexible, adaptable to different regions and simulates riparian vegetation distribution in space and time. Field data survey for each case of study is necessary. The model allows a wide range of scenarios analyses, expanding the range of possibilities to make the better decision. The hydrological inputs must be reviewed and redefined in order to be coherent with the analyzed scenario. The results interpretation must take into account that not always more advanced stages of a riparian succession indicate a better environmental performance and the lack of a sediment transport sub-model.

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