

# Comparing Two Multi-Criteria Methods for Prioritizing Wetland Restoration and Creation Sites Based on Ecological, Biophysical and Socio-Economic Factors

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**Abstract** Wetland restoration has been recognized as a useful tool for improving water quality. Many studies have focused on developing strategies and models to optimize wetland performance. However, some important wetland placement characteristics have not been taken into account. In this research and unlike other studies, we included the social aspect (availability of public lands) as a fundamental factor to locate wetlands. Thus, environmental, biophysical and socio-economic factors were integrated through the comparison of two multi-criteria methods (a suitability model and a greedy algorithm). With nitrate removal as the main goal, the suitability model was applied considering the “terrain slope”, “proximity to watercourses” and “soil permeability”. The greedy algorithm was executed based on the “availability of public lands” and the “wetland restoration project costs”. These factors were chosen based on the Eu Life-CREAMAGua Flumen River project, which was carried out previously in the study area. Both the suitability model and the greedy algorithm provided critical information for siting a wetland and demonstrated the effectiveness of both approaches. By means of this study, we present highly applicable results as they are based on a real project (Eu Life-CREAMAGua Flumen River project), besides proposing and using the social factor as an innovative approach for the wetlands siting. This research and its possible adaptations can be used by decision makers to improve water quality using social and economic criteria, resulting in the efficient implementation of ecological-restoration projects.

**Keywords** Wetlands · Nitrate removal · Environmental planning · Watershed management · Multi-criteria · GIS

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## 1 Introduction

High nitrogen (N) concentrations have been noted in rivers across Europe (Sutton et al. 2011). Decreasing the nitrogen concentration in freshwater bodies involves interventions during all phases of nitrogen flow through the landscape, including the improvement of the land use practices to reduce general nutrient losses in adjacent ecosystems (Schimming et al. 2001), the restoration of buffer zones in groundwater discharge areas (Haycock et al. 1993; Hoffmann et al. 2000) and the restoration of surface flow wetlands located in the river network (Leonardson et al. 1994, Kotti et al. 2016).

Wetlands are progressively more being accepted as essential elements of the environment because of the high biodiversity, goods and services that they supply to humanity (Acreman et al. 2007). A growing number of policy makers are faced with the issue of identifying suitable locations for the creation or restoration of wetland systems (Palmeri and Trepel 2002). Many wetland restoration projects fail because of poor planning and design (Mitsch and Wilson 1996). In addition to inappropriate structural design, failure may occur due to having an improper mitigation site location relative to other landscape features (Van Lonkhuyzen et al. 2004; Swinson et al. 2015). Likewise, many projects do not yield efficient results because they fail to incorporate the preferences of local citizens (Comín et al. 2005, 2014).

Many researchers have utilized GIS-tools for landscape and environmental planning at both the regional (Baban and Wan-Yusof 2003) and catchment scales (Wang et al. 2004; Saroinsong et al. 2007; Jasrotia et al. 2009; Mdee 2015). Some studies have focused on the retention of nutrients from agricultural non-point pollution at the catchment scale (Trepel and Palmeri 2002; Lesta et al. 2007), the retention of sediments from upstream agricultural areas (Richardson and Gatti 1999) and the retention of nutrients and sediments at the site scale (Almendinger 1998). Newbold (2005) used an eight-step algorithm combining hydro-ecological modelling and experience-based restoration costs to prioritize sites for wetland restoration by optimizing the benefit–cost criteria. However, watersheds and land uses significantly vary between regions and societies, hindering the development of protocols that can be adapted for different study areas.

In this study, we present two approaches (a suitability model and a greedy algorithm) that can be used to identify suitable sites for wetland placement in a watershed to remove nitrates from excess agricultural irrigation waters. One of these approaches uses a suitability model, which assigns weights to various biophysical factors. The second approach consists of a greedy algorithm that combines socioeconomic criteria with nitrate removal capacity. The variables chosen for both models are based on previous experiences from the EU Life Project CREAMAgua, which restored wetlands in the Flumen River basin (Huesca, Spain). EU Life-CREAMAgua Flumen River project was a demonstration project funded by the European Union to improve water quality, reduce nitrates and phosphates from agricultural activity, and increase biodiversity. 16 wetlands were created and restored from 2011 to 2014. The main purpose of wetland restoration was to increase the water retention, allowing biological activity in order to decrease suspended matter, and nitrogen and phosphorus from agricultural inputs.

The objective of this work was to compare the effectiveness of these two methodologies to provide a hierarchical allocation of sites suitable for wetland restoration. Through this study, we present a highly applicable research, as it is based on the results of a real project (EU Life-CREAMAgua Flumen River project). We have also considered the social aspect (availability of public lands) as fundamental in the wetlands siting. This factor has not been commonly implemented in this type of actions, which also shows the novelty of this work.

## 2 Materials and Methods

### 2.1 General Methodology and Study Area

The methodologies developed in this study are mainly composed of two steps: (1) sizing the appropriate area for nitrate removal and (2) siting surface flow wetlands. This model has been applied to the Flumen River basin, which is located in the Province of Huesca (Aragón, Spain) in the north-central part of the Ebro River catchment (80,093 km<sup>2</sup>, NE Spain) (Fig. 1). After the mountainous area, the Flumen River flows through flat plains with extensive agricultural land cover and intensive irrigation, eventually reaching its confluence with the Alcanadre River at 240 m.a.s.l. Water for irrigation is provided through canals from two neighboring watersheds (Rivers Gállego and Cinca). Irrigation occurs from March to September, but the summer months are those with the greatest irrigation activity. Water discharge in the Flumen River is higher during the irrigation season due to the contribution of the irrigation runoff. We apply this approach to only the agricultural part of the basin, as the major influence of the irrigation return flows on the river water quality has been clearly demonstrated (Darwiche-Criado et al. 2015a, b).

The SWAT program (Soil and Water Assessment Tool) (Arnold et al. 1998) was used to classify the agricultural area of the Flumen River basin into 38 sub-basins and 15 inter-river areas. This hydro-agro-environmental model established the sub-basins according to the hydrographic network calculated from the digital elevation model (DEM) with a 20 m grid resolution (offered by CHE-Confederación Hidrográfica del Ebro). Nitrate concentration was selected for wetland siting and sizing because it has been previously recognized as the most relevant pollutant for water quality degradation in the study area (Martín-Queller et al. 2010; Comín et al. 2014). Nitrate concentration and hydrological data monitoring under different agricultural periods and meteorological circumstances are widely described in Darwiche-Criado et al. (2015a, b, 2016). SWAT uses these data to estimate the monthly water flows and nitrate concentrations, and thus, the monthly nitrate load in each sub-watershed.

### 2.2 Sizing the Required Area to Remove Nitrates

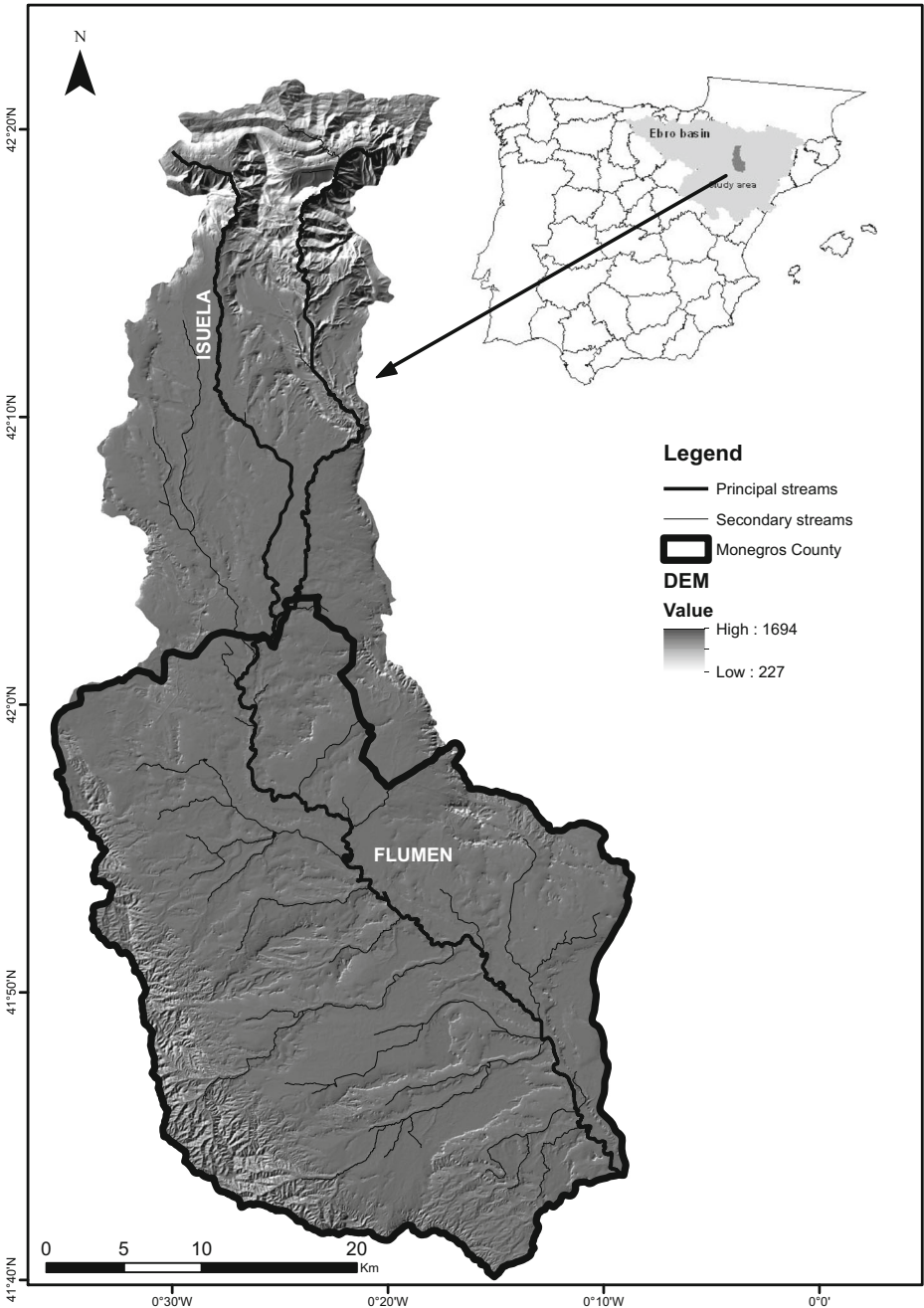
To estimate the surface-flow wetland area required to achieve a target nitrate-discharge concentration in each sub-basin, a first-order areal removal model developed by Kadlec and Knight (1996) was used:

$$A = (0.0365 * (Q/k)) \times (\ln(C_i - C^* / C_o - C^*)) \quad (1)$$

where A is the wetland area (ha),  $C_i$  is the inlet concentration (mg/L), defined as the minimum concentration of the third quartile modelled by SWAT (i.e., the maximum concentration of the 75th percentile),  $C_o$  is the target outlet concentration, defined as 5 mg/L,  $C^*$  is the base-flow nitrate concentration in a surface-flow wetland, set at 2 mg/L,  $Q$  is the water flow rate (m<sup>3</sup>/d), considered to be the maximum flow observed for a given inlet nitrate concentration and  $k$  is the experimental first-order area rate constant (35 m/yr., from Kadlec and Knight 1996). Detailed dimensioning parameters were described in Comín et al. (2014).

### 2.3 Location of Wetlands

Two methods were used to prioritize wetland restoration sites in the River Flumen watershed: a suitability model and a greedy algorithm. The suitability model was



**Fig. 1** Location of the Flumen River watershed in the Ebro River Basin (NE Spain)

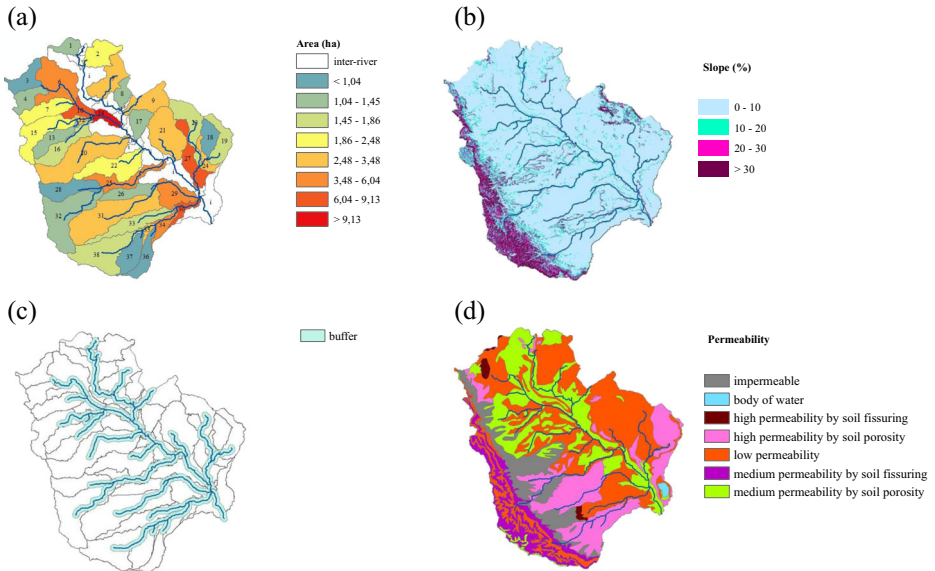
applied using ecological and biophysical criteria, while the greedy algorithm incorporated economic and social factors. The nitrate loads from each sub-basin were considered by both methods.

### 2.3.1 Applying a Weighted Suitability Model

Four data layers were used for applying the suitability model (Fig. 2). We wanted to apply the same criteria as Moreno-Mateos et al. (2010) in their research in the same study area. Similar factors were also used by Trepel and Palmeri (2002), and Palmeri and Trepel (2002). In our case, we tried to adjust this model according to our acquired experience with LIFE-CREAMAGua project. Thus, we weighted each factor depending on those which had a greater importance in designing the wetland restoration, and subsequently in its performance. A GIS based score system (ArcMap 10.2.1, ESRI Inc.) was developed to identify the best potential locations for surface wetland creation and restoration. Score values varied from  $-3$  to  $+3$ , representing the lowest and highest suitability, respectively. Values were based on professional judgement from previous wetland restoration experiences in the study zone. Negative values designated unsuitability, while positive values represented suitable sites. The items in each data layer and their specific score values are shown in Table 1. Data layers were as follows:

**Outflowing Nitrate Load** The nitrate loads were ranked so that wetlands restoration was prioritized in the most polluted sub-basins. Thus, the highest loads were scored with  $+3$  and the lowest with  $-3$ .

**Slope** The slope was calculated from a 20 m grid resolution DEM. Slope is a limiting factor in wetland creation because steep slopes are inappropriate for wetlands. Gentler terrain slopes received the highest score.



**Fig. 2** Data layers used for applying the suitability model. Outflowing nitrate load, surface-flow required wetland area to achieve a target nitrate-discharge concentration defined as 5 mg/L in each sub-basin (a). Slope calculated from a 20 m grid resolution (b). Distance to streams calculated from the digital river network (c). Soil permeability map based on existing regional maps (d)

**Table 1** Score values for data layers

Data layer	Score
<i>NO<sub>3</sub><sup>-</sup> loads</i>	
7000–12,000	3
5000–7000	2
2000–5000	1
1000–2000	-1
500–100	-2
0–500	-3
<i>Slope (%)</i>	
0–10	+3
10–20	1
20–30	-2
> 30	-3
<i>Distance to streams (m)</i>	
< 500	+3
> 500	-3
<i>Soil Permeability</i>	
Body of water	3
Medium permeability by soil porosity	3
Low permeability	3
Impermeable	3
Medium permeability by soil fissuring	-2
High permeability	-3

**Distance to Streams** The distance to streams was calculated from the digital river network. Restoring in-stream wetlands is feasible, as water flows naturally through drainage areas to streams. The cost of wetlands restoration increases if the wetland is allocated far from a stream, requiring transport channels and dikes. Very suitable areas were considered those within 500 m of a frequently flowing stream.

**Soil Permeability** Due to the semiarid conditions of the study area, soil permeability is a limiting factor in wetland construction and restoration. This data layer was created based on existing regional maps from the Aragon Government at a scale of 1:300,000. The score values were based on the infiltration capacities of the soils. High soil permeability zones, as well as medium permeability areas due to soil fissuring, received low scores because these features make it impossible to construct wetlands without expensive interventions.

As noted above, the Moreno-Mateos et al. (2010) model was adjusted for this study. The highest weight (1.5) was assigned to the “outflowing nitrate load”, a high weight (1.3) was assigned to “slope”, a weight of 1.1 was given to “distance to streams” and “soil permeability” was scored with a weight of 1. To make suitability values easier to interpret, they were centred between -1 and +1 by dividing them by the maximum value of the resulting sum of the real values of all data layers. Thus, the resulting values indicated the least (low values) and most (high values) suitable areas for wetland restoration.

The final model is given by:

$$\text{Suitability} = (1.5 * \text{outflowing nitrate load} + 1.3 * \text{slope} + 1.1 * \text{distance to streams} + \text{soil permeability}) / \text{Max}(1.5 * \text{outflowing nitrate loads} + 1.3 * \text{slope} + 1.1 * \text{distance to streams} + \text{soil permeability}) \quad (2)$$

### 2.3.2 Implementing a Greedy Algorithm

A greedy algorithm was utilized to optimize the benefit-cost criteria. In this case, social (availability of public lands) and economic factors (wetland restoration costs) were taken into account, in addition to nitrate loads.

Restored wetlands during the Life-CREAMAGUA project were situated on public lands, which were not used for agricultural activities. Some of these areas were located on soils with some salinity (Martín-Queller et al. 2010). Thus, in addition to improving water quality and achieving an increase in biodiversity, we integrated the social aspect, rarely included in this type of studies. In this way, the ownership of sites that were identified as appropriate for wetland restoration or creation in each sub-watershed was determined using public land records, which are available via regional and local governments. To reduce project costs, only free, public plots were considered. The construction costs in each sub-basin were calculated based on those of the Eu Life-CREAMAGua Flumen River project. In this case, wetlands in sub-basins whose construction costs were lower were prioritized in a descending order.

This algorithm consisted of several successive steps, which integrated the hierarchical order of data layers. Sub-basins with higher nitrate loads were prioritized based on a descending order. Then, the availability of public lands was checked. If that constraint was met, the following criterion was checked, and so on. If not, that cell was rejected and the process restarted with the next potential location. If the first two criteria were met, we proceeded to check the economic factor (Fig. 3). Because the main goal of this study was the nitrate removal, priority was established based on the inflowing nitrate load in those sub-basins that met the criteria. In this manner, sub-basins receiving higher nitrate loads had higher priority over others that met the same criteria.

## 3 Results

### 3.1 Estimation of Required Wetland Area

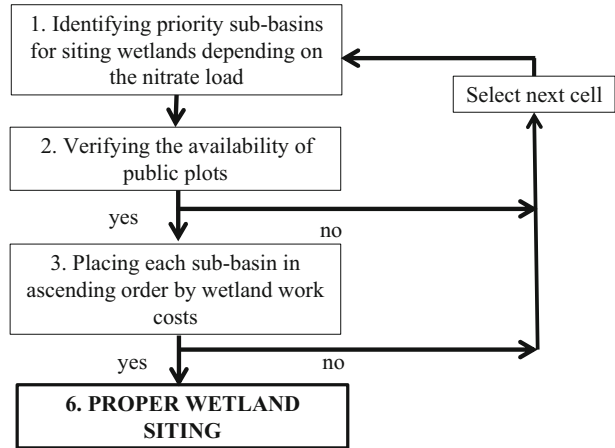
We estimated that a wetland area of less than 1.04 ha is needed to reduce the nitrate concentration to 5 mg/L in sub-basins 3, 18, 28, 36 and 37. Sub-basins 1, 4, 8, 13, 17, 26 and 32 would require a wetland area between 1.04 and 1.45 ha, sub-basins 16, 19, 23, 33 and 38 between 1.45 and 1.86 ha and sub-basins 2, 7, 15 and 22 between 1.86 and 2.48 ha. In sub-basins 5, 9, 12, 20, 21, 24 and 35, wetlands should have an area ranging from 2.48 to 3.48 ha. Sub-basins 6, 11, 25, 29 and 34 would require a wetland area between 3.48 and 6.04 ha, and sub-basins 10, 27 and 30 between 6.04 and 9.13 ha. Lastly, sub-basin 14 would require a wetland area of 15.88 ha to decrease the nitrate concentration to 5 mg/L (Fig. 4).

Figure 5 shows that the required wetland area was strongly correlated with water and nitrate discharges. Moreover, there was not a significant relationship between these two variables and sub-basin area, or between wetland and sub-basin areas.

### 3.2 Suitability Model and Greedy Algorithm Implementation

The suitability model resulted in values between  $-0.7$  and  $0.7$  (Fig. 6). Higher values indicated the highest priority wetland location sub-basins, while the lowest values showed represented lower priorities. Sub-basin 14 exhibited the highest priority, while sub-basins 10, 11, 12 and 29 occurred in the same high priority range ( $0.4$  to  $0.7$ ). Sub-basins 1, 27, 30, 34 and 35 ranged

**Fig. 3** Greedy algorithm for prioritizing wetland restoration and creation sites



between 0.2 and 0.4, while sub-basins 2, 6 and 25 exhibited a moderate priority (0 to 0.2). The remaining sub-basins were not suitable wetland restoration or construction.

The greedy algorithm indicated the criteria satisfied by each sub-basin (Fig. 6). Thereby, those sub-basins fulfilling the three criteria were considered high priority wetland location sites. Sub-basins 6, 10, 11, 12, 14, 25, 27, 29, 30 and 34 met the three criteria, thus exhibiting the highest priority. Sub-basins 2, 5, 7, 15, 9, 16, 20, 21, 22 and 35 met two conditions, and the remaining sub-basins fulfilled only the first criterion.

### 3.3 Priority Sites for Wetland Allocation at Watershed Scale

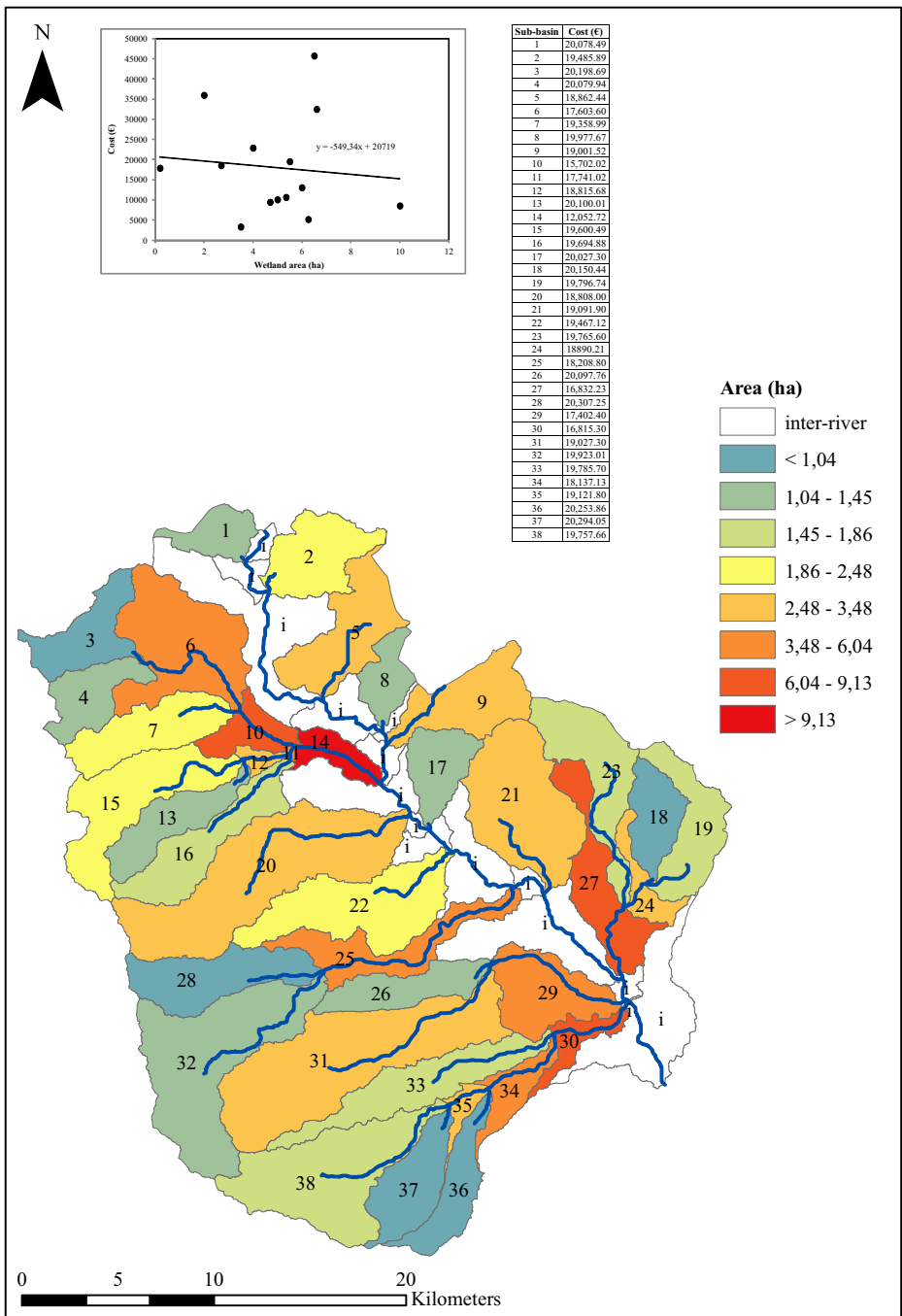
Table 3 shows the priority order for each sub-basin with each method. Both approaches reported sub-basins 14, 10, 11 and 29 to be high priority wetland sites and in the same order of precedence. The remaining sub-basins did not coincide based on position, but were in the same priority range. While the greedy algorithm indicated sub-basin 18 as the lowest priority area, the suitability model found sub-basin 28 to be the lowest priority location.

## 4 Discussion

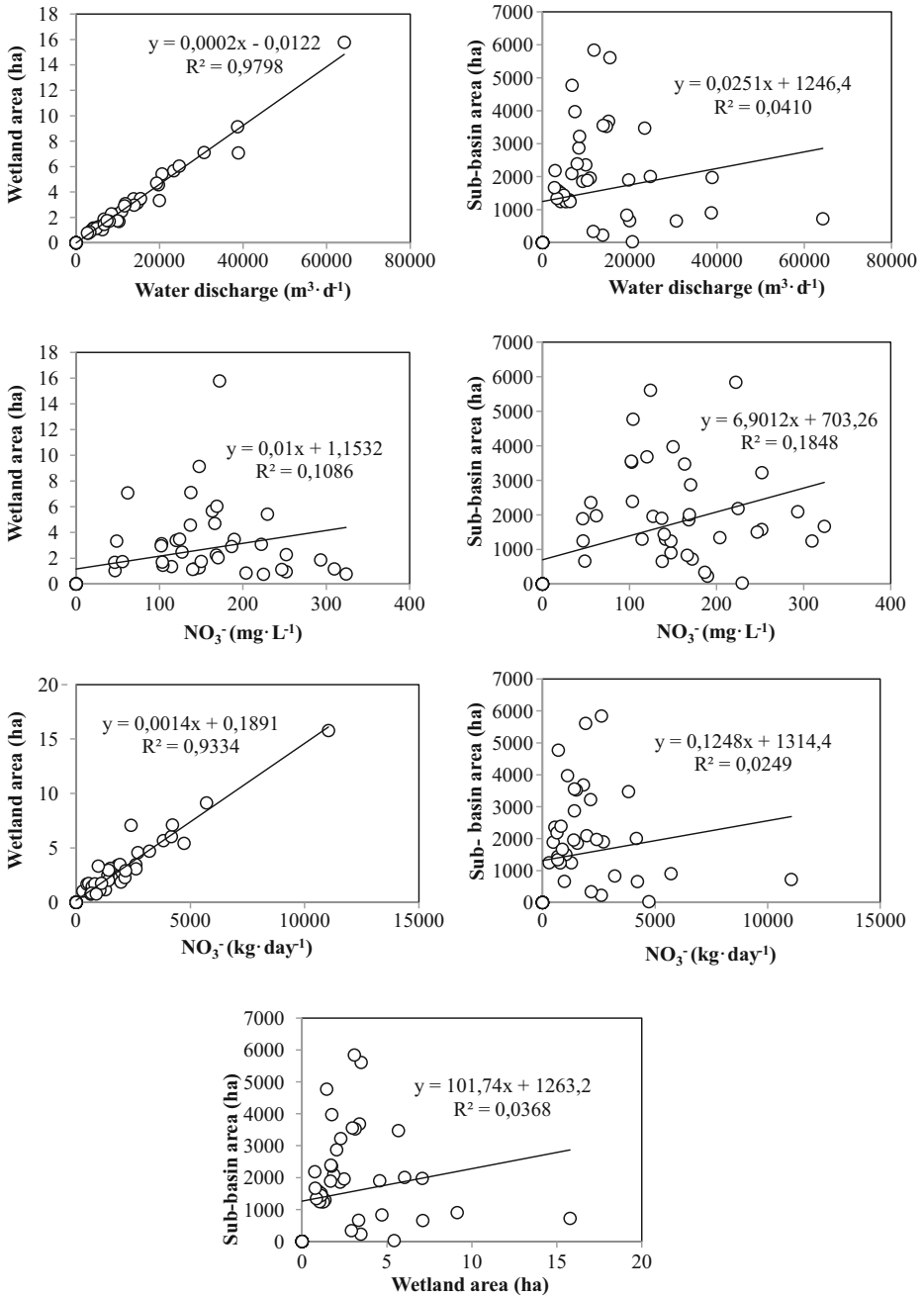
Over the past few decades, a variety of multicriteria evaluation and spatial analysis techniques have been utilized for proper site selection (Zucca et al. 2008). Some applications focused on habitat suitability modelling (Store and Kangas 2001) and other environmental management issues (Giupponi et al. 1999; Phua and Minowa 2005). In addition, several studies applied suitability models (White and Fennessy 2005; Moreno-Mateos et al. 2010) or greedy algorithms (Newbold 2005; Comin et al. 2014) to find optimal wetland locations, thereby improving water quality.

The objectives of each study considerably influence the choice of factors involved in developing each approach. In the case of suitability modelling, the use of GIS makes decision-making more objective. Yet, there is some subjectivity associated with assigning scores to data layers (Baban and Wan-Yusof 2003). However, different scoring and





**Fig. 4** Wetland areas required in each sub-basin to reduce the nitrate concentration to 5 mg/L. Top left: Relationship between the wetland areas and costs based on the EU CREAMAgua LIFE project. Top right: The cost of restoring or creating a wetland in each sub-basin based on our findings

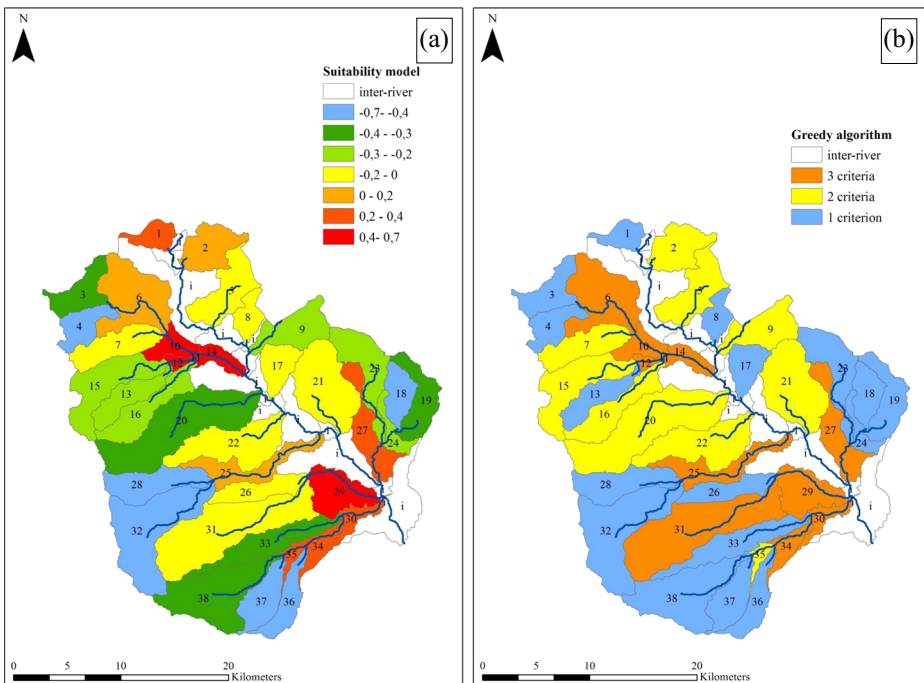


**Fig. 5** Relationships between wetland and sub-basin areas and their respective water flows (top), nitrate concentrations (centre) and nitrate loads (below). Relationship between wetland area and sub-basin area (bottom)

prioritization strategies allow for this method to be adapted to different areas and requirements. Greedy algorithms do not present a comprehensive answer for a defined trouble (Underhill 1994) because when a site is selected, it cannot be unselected. Consequently, an overall

knowledge of the study area will be essential for effectively conducting such simulations. In this case, based on previous wetland restorations in the same area (Eu Life-CREAMAGua Flumen River project), we used scientific and technical criteria to prioritize important factors, such as nitrate load and terrain slope. Thus, we sought to optimize the benefit-cost criterion.

Although both models were useful tools for planning wetland locations, the accessibility of required information can be a restrictive element. Firstly, as in Moreno-Mateos et al. (2010), the resolutions of various data layers were good enough for this study, but smaller areas would require higher resolutions. On the other hand, SWAT also depends on data availability and quality. The scale used in this study identified important drainage canals, which transport quantifiable amounts of pollutants and are essential factors in modelling the wetland area nitrate removal. Delineating smaller sub-basins would cause the representation of places with no significant water or nitrate discharges, generating a multitude of potential wetlands without relevance for the project purposes. Conversely, bigger sub-basins discharging higher nitrate loads would need greater zones, which could not fulfil the hydrogeophysical or socioeconomic criteria (Comin et al. 2014). Likewise, using a first order areal removal model was adequate for wetland dimensioning based on the hydro-chemical features of the study zone (Mitsch and Jorgensen 2003). Our results (Fig. 5) suggest that water flow and nitrate discharge were the key factors influencing wetland dimensioning. In this regard, sub-basins 11 and 14 are smaller, but would require larger wetland areas to reduce the nitrate concentrations (Fig. 4). These sub-basins are located in intensively irrigated areas. Consequently, the nitrate loads are higher and irrigation return flows increase the steam water discharge (Darwiche-Criado et al. 2015a, b). In contrast, sub-basin 32 is much larger, but would require a small wetland area for nitrate removal. This sub-basin mainly consists of dry cereal cultivation, with no irrigation. Therefore, water and nitrate discharges are low in this sub-



**Fig. 6** (a) Suitability model values in each sub-basin. (b) Results of the greedy algorithm in each sub-basin

**Table 2** Prioritized sub-basin order for the Greedy algorithm and Suitability Model

Priority order	Sub-basins in Greedy Algorithm	Sub-basins in Suitability Model
1	<i>14</i>	<i>14</i>
2	<i>10</i>	<i>10</i>
3	<i>11</i>	<i>11</i>
4	<i>29</i>	<i>29</i>
5	30	12
6	6	30
7	34	35
8	25	34
9	31	1
10	12	27
11	27	25
12	35	6
13	22	2
14	16	22
15	20	8
16	5	17
17	2	5
18	9	21
19	21	26
20	15	31
21	7	7
22	1	24
23	38	23
24	13	15
25	24	16
26	3	13
27	37	9
28	33	19
29	17	38
30	4	33
31	32	20
32	8	3
33	26	36
34	36	37
35	28	32
36	23	4
37	19	18
38	18	28

basin. Thus, independent of the sub-basin area, land use was a significant factor in determining the nitrate discharge and calculating the required wetland area.

Both approaches found sub-basins 14, 10, 11, 12 and 29 to be the highest priority wetland sites (Fig. 6). In the suitability model, they were the only sub-basins that fell within the highest priority range. However, the greedy algorithm also reported that sub-basins 6, 25, 27, 31, 30 and 34 met the three criteria. Sub-basins 6, 25, 27, 30 and 34 also achieved positive values with the suitability model. However, differences were observed in the results from both approaches. The suitability model found sub-basins 1 and 35 to be high priority wetland locations (Fig. 6). According to the algorithm results (Fig. 6), sub-basin 35 met the first two criteria, which means that project cost requirements were not adequate in those sub-basins. Sub-basin 1 fulfilled only the first criterion, so in addition to the project costs, the availability of public lands also failed. We consider the availability of public lands to be a fundamental social criterion. The integration of social criteria is fundamental in restoration projects (Comín

**Table 3** Differences and attributes of each applied method

	Suitability Model	Greedy Algorithm
Values assigned to sites	Numerical value assignment	Relative order of sites
Resolution/differentiation between sites	High resolution and each site is differentiated	Relative differentiation, where two sites may have the same order of preference.
Ease to use	Not simple, requiring scientific-technical skills	Easier to use if sub-basin nitrate export data are available
Data requirements	Requires data that may not be readily available, potentially requiring field work	Requires data that may not be readily available and may require administrative work to obtain socio-economic data
Work effort	Tedious, but can be developed by specialized team or technicians	Tedious and requires compliance from stakeholders
Practical results	Good technical results, but may be difficult to put into practice	Relatively good results, and easy to put into practice

et al. 2005; Petursdottir et al. 2013) and is not commonly implemented in such actions. For example, Newbold (2005) suggested a similar algorithm, which included economic factors, but not social variables. He also reported that in restoration projects, the cost per hectare may triple if land purchases are required. Although sub-basin 1 exhibited the required nitrate load for a wetland site, the project budget would be higher due to purchasing the land. Figure 4 shows the experience based relationship between the construction costs and the area of created wetlands from the Eu Life-CREAMAgua Flumen River project. In addition, the table displays the cost involved in wetland creation for each sub-basin according to this equation. In this sense, the initial budget restoration budget of sub-basin 1 (20,078.5 €) should increase, due to the purchase of private lands. In addition, the non-inclusion of economic criteria in the suitability model caused both sub-basins to be defined as “suitable” despite their actual restoration costs falling well above average due to land purchases (Fig. 4).

Conversely, the greedy algorithm found that sub-basins 3, 25 and 31 met the socio-economic criteria. However, the suitability model scored these sub-basins as having low values or a negative score, in the case of sub-basin 31. In this respect, omitting the biophysical factors could also affect the project budget. Trepel and Palmeri (2002) accounted for the importance of soil substrate when finding optimal wetland sites. They scored various factors based on soil infiltration capacity and distance from the nearest river. Likewise, Moreno-Mateos et al. (2010) reported restoration cost increases due to the inclusion of long canals or installation of layers in high soil permeability areas, which also make wetlands less natural. These authors also stated that the distance from water streams greatly affected the total budget of wetland creation projects. Steep slopes also imply the need for greater earthmoving, which increases construction costs. For this reason, the economic aspect becomes critical and the wetland restoration projects that do define sites and actions at the onset must base budgeting on previous restoration-cost experiences (Comin et al. 2014).

Both the suitability model and the greedy algorithm provided critical information for siting wetlands at the watershed scale to improve overall water quality (via nitrate removal). The suitability model ranked each sub-basin based on biophysical conditions, while the greedy algorithm was based on socioeconomic criteria. In this regard, our results indicate that considering both perspectives can be effective because there was a high coincidence between the methods (Table 2). Both models can be adapted to the conditions and objectives of other areas, but a detailed knowledge of the study area is necessary (Zedler 2003). The use of either ranking must be

linked to the conditions and capacities of each project. Some general differences between the two approaches may cause one to be more applicable than the other (Table 3). However, we propose the combined use of both methods. The suitability model will display the prioritized ranking of areas for wetland restoration projects, while the greedy algorithm will report practical information about priority sites that is required for wetland restoration (land availability, costs or restoration).

## 5 Conclusions

The developed methodologies are highly applicable to other study areas with different problems and circumstances, and the obtained results incorporated an innovative approach by including the social factor in the wetland restoration projects. We propose the combined use of both approaches. The suitability model will determine the prioritized sub-basins for wetland restoration, and the greedy algorithm will report the socio-economic costs, in terms of the availability of public lands or work to be performed. This information will be essential for calculating budgets and optimizing project costs. Considering that the overall knowledge of the study zone will be essential, this approach and possible adaptations can be used by decision makers to improve water quality using social and economic criteria, resulting in the efficient implementation of ecological-restoration projects at the watershed scale.

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