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Journal

Water Resources Management: An International Journal - Published for the European Water Resources Association (EWRA), 24(11)

ISSN

1573-1650

Authors

Moreno-Mateos, David
Mander, Ülo
Pedrocchi, César

Publication Date

2010-09-01

DOI

10.1007/s11269-009-9564-5

Peer reviewed

Optimal Location of Created and Restored Wetlands in Mediterranean Agricultural Catchments

David Moreno-Mateos · Ülo Mander · César Pedrocchi

Received: 21 April 2009 / Accepted: 16 December 2009 /

Published online: 6 January 2010

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Abstract Simple tools and accessible information are needed by environmental planners to select sites for the restoration or creation of wetlands. A flexible suitability model for allocating wetlands is demonstrated in small (20–2,000 ha) agricultural catchments in the semiarid Ebro basin (NE Spain). The model used improved existing data layers (soil and geomorphology), simple geographical transformations (slope and distance to frequently flowing streams) and other created data layers (land use). Detailed scales of data layers (~1:5,000 and <30 m cell-size) are needed to work with small catchments. A deep knowledge of the study area is a requirement for reducing the subjectivity associated with experts' decision. The studied cases proved that 31% of catchment areas were suitable to create wetlands, and another 12% were very suitable. In 11 out of 12 studied catchments 100% of their existing wetlands fell into the area selected by the model as suitable. Most of the suitable area was situated in the lower parts of the catchments examined in the study. There is enough very suitable area in all catchments to fulfil the functional requirements of the wetlands to improve water quality. The model is a simple and useful tool for environmental planning in areas degraded by irrigated agricultural use.

Keywords Irrigation · Environmental planning · Slope · Land use · Soil · Geomorphology · Hydrology

D. Moreno-Mateos (✉)
Integrative Biology Department, University of California at Berkeley,
3060 Valley Life Sciences Building, Berkeley, CA 94720, USA
e-mail: davidmoreno@berkeley.edu

D. Moreno-Mateos · C. Pedrocchi
Pyrenean Institute of Ecology, CSIC, Avda. Regimiento Galicia s/n, 22700 Jaca, Huesca, Spain

Ü. Mander
Department of Geography, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia

1 Introduction

Wetland restoration and creation are common activities with many different purposes, such as wildlife preservation, water quality improvement, flood regulation and soil amelioration (Mitsch and Gosselink 2000). Problems can emerge since there is little knowledge at long term on the evolution of restored and created wetlands after their construction (Zedler and Callaway 1999). An understanding of natural processes taking place in future wetland locations, especially in those where new wetlands will be constructed, is essential to ensure the success of mitigation activities (Zedler 2000; Eades et al. 2005). A large number of environmental parameters have been included in suitability and prioritization analyses. Among them, the land-cover layer has been widely used since the first studies on site selecting for wetland restoration (Harris and Olson 1997; Russell et al. 1997; Richardson and Gatti 1999; Palmeri and Trepel 2002; Van Lonkhuyzen et al. 2004; Newbold 2005; White and Fennessy 2005; Lesta et al. 2007). In these studies, other commonly used layers were soil, slope, elevation, historical wetlands and/or hydrology.

GIS-based suitability analysis resulted in a useful tool for landscape and environmental planning at regional (Baban and Wan-Yusof 2003) and catchment scales (Wang et al. 2004; Saroinsong et al. 2007; Jasrotia et al. 2009). More specifically, suitability and prioritization studies for wetland restoration and planning have had two main perspectives: Wildlife preservation (Harris and Olson 1997; Van Lonkhuyzen et al. 2004; McCauley and Jenkins 2005) and water quality improvement. In the area of the latter perspective, studies have focused on the retention of nutrients from agricultural non-point pollution at the catchment scale (Trepel and Palmeri 2002; Newbold 2005; Lesta et al. 2007), on the retention of sediments from upstream agricultural areas (Richardson and Gatti 1999) and on retention of nutrients and sediments at the site scale (Almendinger 1998).

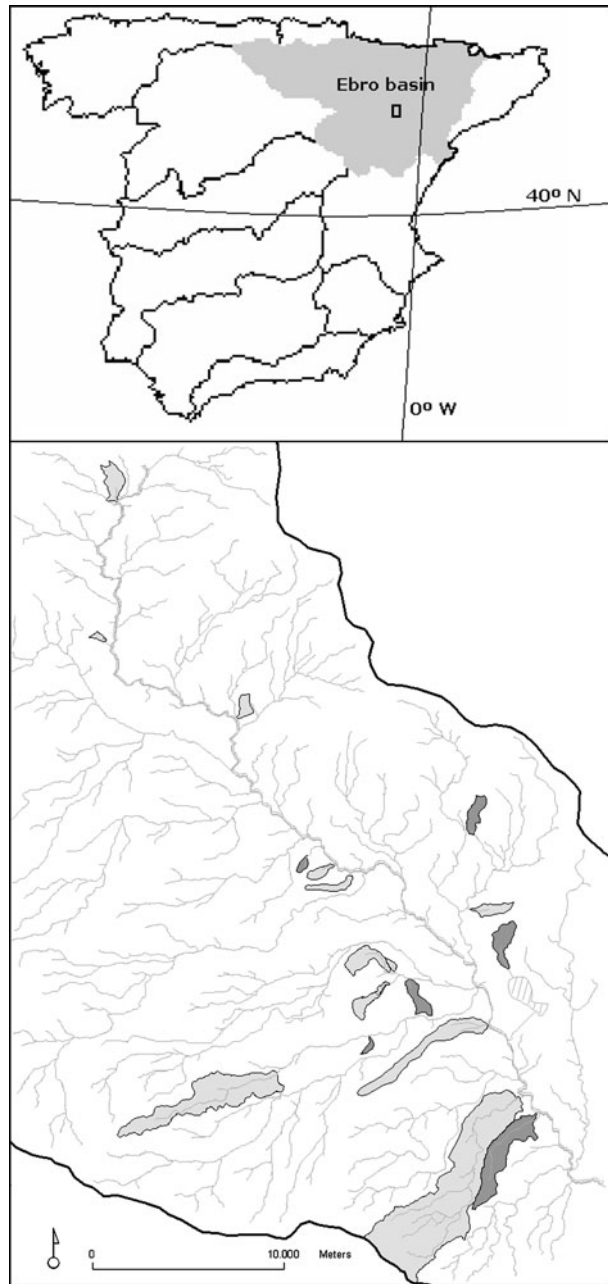
Most of these studies have been performed in large agricultural catchments (>5,000 ha), and therefore little is known about the application of the suitability models on small catchments (20–2,000 ha). Catchment scale is a convenient scale for restoration planning because it is easily identified on maps and on the ground, and allows suitable descriptions of some ecosystem processes and capabilities (Bohn and Kershner 2002). It is also important considering a multipurpose perspective on wetland restoration planning (Knight 1992; Comín et al. 2001), particularly in areas degraded by intensive agricultural use, where a few natural ecosystems remain as scattered and small patches in a very homogeneous landscape (Moreno et al. 2007).

The aim of this study is to demonstrate a method of landscape analysis that can be used to estimate the suitability of catchments for wetland restoration or creation, and to present the results of this analysis as applied to a portion of the Ebro River basin (NE Spain) which is intensively used for irrigated agriculture.

1.1 Study Area

Monegros is an inland semi-arid Mediterranean region located in the centre of the Ebro River basin, NE Spain (Fig. 1). A detailed description of the study area is provided in Moreno et al. (2007). The landscape is composed of small plateaus with valleys in between and some gentle hills. Most of this land was transformed into irrigated agricultural fields from the 1950s to 1990s. Maize, alfalfa and wheat are the

Fig. 1 Location of the study area in Spain indicating the hydrographical limits of the major river basins (*top*). The study area drained by River Flumen (*bottom*). *Light grey* indicates catchments used in the case study, and *dark grey* indicates catchments used in the calibration process



most common crops. Soil salinization and the abandonment of agriculture are now widespread in many parts of this region. As a consequence of irrigation return flow, wetlands with permanent or intermittent water aboveground were naturally formed and colonized mostly by common reed (*Phragmites australis*) which is spreading and

increasingly dominating the plant community because of its tolerance to changing water levels and salinity (Lissner et al. 1999).

Eighteen catchments within an 80,000 ha zone of the Monegros region were selected for this study (Fig. 1). All catchments with wetlands larger than one hectare ($n = 8$) were included (maximum size was $\sim 2,500$ ha). Other catchments ($n = 10$) with smaller wetlands (0.1–1.0 ha) were included if they were topographically similar to the catchments with larger wetlands, similar catchment area, and were accessible. All catchments were dominated by arable land ($77.4 \pm 13.6\%$ of the catchment area), especially irrigated farmland (73%). Rain-fed farmlands were only important ($>25\%$ of the catchment area) in two catchments (Moncalver and Paules). Few patches of natural vegetation ($17.0 \pm 10.4\%$ of the catchment area) remained, and these included 3% of naturally grown wetlands. The wetlands located in the catchments received agricultural wastewater coming almost exclusively ($>95\%$) from irrigation surpluses through drainage channels or via groundwater and their outflows drained into the fluvial system. The hydrological network was entirely dependent on the system for the irrigation of fields in the surrounding area. Wetland vegetation grew spontaneously after land transformation into irrigated farmlands, except for one wetland (Sangarrén), which is mostly fed by groundwater. Wetland topographic location varied from hillsides receiving run-off from irrigated fields to flat valley areas where the agricultural run-off flows slowly and accumulates.

1.2 Expert Decision in Model Approach

A GIS-based suitability analysis was performed to identify potential locations for wetlands. The model is designed to help to take decisions on the establishment of new wetlands following a simple, economic, realistic and ecologically based method. In devising this model, four categories were considered for decision-making: Economy, hydrology, geology and ecology, and five data layers were synthesized and used as

Table 1 Used and initial cartographic data layers

Theme	Category	Initial data layers	Initial resolution	Improved resolution
Slope	Economics, hydrology	Digital elevation model	20 m	Same (interpolated to 3 m)
Land use	Ecology, economics	Aerial photographs	0.5 m	1:5,000
Geomorphology	Geology, hydrology	Regional geomorphological map	1:50,000	1:5,000
Soil	Geology	Regional soils map	1:50,000	1:5,000
Distance to frequently flowing streams	Economics, hydrology	100 m multiple buffer from frequently flowing streams observed in the field	–	1:5,000

selection criteria to identify suitable locations: Slope, land-use, geomorphology, soil and distance from permanent streams (Table 1).

Slope is a restrictive factor in wetland construction and restoration. The main design considerations and construction budgets rely on it. The lower the slope, the cheaper the construction project, as a consequence of the smaller amount of earthwork needed. Extensive earthwork also involves higher energy expenses. Irrigated agricultural farmlands need flat areas as they are watered by flooding and gentle slopes (<10%) if sprinkling is used. There is a greater need for wetlands in areas with more farmland, which are usually larger in flatter terrain.

Existing land-use is important in determining the suitability of an area for the establishment of wetlands. The most suitable areas in this semi-arid territory would be those affected by irrigation, where frequent watering favours wetland flooding. Areas with low human activity (abandoned, fallow or rain-fed farmlands) are also suitable for wetland projects, because it is expected that there will be less development in the areas. It should also be noted that in semiarid territories intermittent and ephemeral wetlands are part of the landscape. Areas highly affected by human activities (channels, animal farms or urban areas) might be unsuitable to establish wetlands as mitigation sites and may require on purpose systems to be integrated in their land use planning. These areas are usually affected by frequent impacts of human activities, and consequently the permanence of existing land-use is less likely.

In the semiarid area where this study was carried out some geomorphological processes indicate areas where wetland establishment is strongly unwise. There are large areas covered by colluvial or mixed (alluvial/colluvial) deposits whose permeability makes it impossible to build a wetland on them without expensive interventions (e.g. long channelizations or installation of impervious layers) which make wetlands less natural. High terraces and monoclines are usually associated with ancient erosional processes that divert frequently flowing streams away from them. Low terraces and alluvial deposits near rivers are excellent locations for wetland projects because little work is needed for their construction and the proximity to frequently flowing streams provides a ready source of water.

Soil properties such as texture, depth, composition or development affect future potential mitigation sites because they facilitate or hinder the establishment of natural vegetation and water storage. This is of particular interest in the study area for two main reasons. First, there are large areas affected by salinization/sodification processes. And second, original soil has been commonly removed, especially in hill slopes, leaving large areas of parent rock uncovered. Little developed soils, like lithosols or xerosols are often mechanically problematic due to their thin layer of real soil. Regosols are weakly developed soils and, in our study area, have accumulations of gravels, which make them very unsuitable for water storage. Cambisols are more developed soils and have a cambic horizon, which makes them permeable and unsuitable for water accumulation. Solonetz and solonchaks are dominated by salinization and sodification processes respectively. Our study area is mostly composed of different proportions of clay and silt. The mixture of salts, clays and silt produces an effect of loss of structure (very unsuitable for agricultural use) and a high capacity for water storage. Finally, fluvisols are suitable soils for wetlands because of their proximity to streams and their high water table, although they may have problems of permeability if accumulated sediments are very gravelly.

Water availability is a critical factor in selecting wetland location. The distance from frequently flowing streams has a strong influence on the total cost of the wetland restoration or creation project. Very suitable areas were considered those within ~500 m from a frequently flowing stream. Long distances imply high energy requirements and financial expenditures. Buffers of one hundred and fifty meters radius were considered as the spatial units that noticeably increase energy and economical costs. We considered unsuitable for wetland mitigation all catchment areas located above the highest point where water flowed frequently. In these areas, only water pumping could keep water on the wetlands, and this energy requirement and financial expenditure was considered to render wetland creation unfeasible. Moreover, pumping involves high maintenance costs. Due to that the impervious layer of tertiary materials (mudstone) dominated almost all of the study area, the existence of outcrops or springs was extremely rare. Furthermore, a groundwater effect has not been considered in the suitability analysis.

Other criteria to select location for wetland restoration could be used in a suitability model. We suggest using these five criteria in a first approach and, after, fit the results to all potential local limitations which could present problems in the area to be restored. For example, land ownership could represent serious problems in some countries but more easily affordable in others. Also, land-use regulations could present a barrier to changes in land-use, particularly in areas governed by conservation regulations, but this kind of intervention (habitat and ecosystem restoration and creation) is not usual in protected areas. Anyway, we consider that layers might be created for these potential local limitations in a second phase of the approach to find suitable locations for wetlands.

1.3 Cartographic Analysis

Five themes were synthesized to build the suitability map (Table 1). The slope was calculated using a 20 m pixel-size digital elevation model (DEM) and interpolated to 3 m pixel-size. Although the resolution of the DEM was not improved, a slope map was interpolated to facilitate raster operation with the rest of the created themes (Fig. 2a). We calculated slope as the maximum rate of change in height between each cell and its neighbours (ArcMap 8.3, ESRI Inc).

Land-use was estimated using aerial photographs with a resolution of 0.5 m taken in 2003 (Fig. 2b). Ten land use types (irrigated farmland, rain-fed farmland, abandoned land, livestock farms, woodland, dry shrubland-grasslands, erosion deserts, wetlands, irrigation channels and urban areas) were digitalized in all catchments using ArcGIS 8.3 (ESRI, Inc.) The land cover types in the photographs were checked in situ by direct observation. Abandoned lands were considered as those with observed in situ young woody species. Most livestock farms were for the raising of pigs and, to a lesser extent, sheep and cattle but they were not distinguished in this analysis.

The geomorphological theme was synthesized from existing regional maps created by the Aragon Government at 1:50,000 scale (Fig. 2c). By using these maps and aerial photographs, the scale was improved to a scale of 1:5000. These geomorphological units were checked in situ by direct observation and corrected in a final theme.

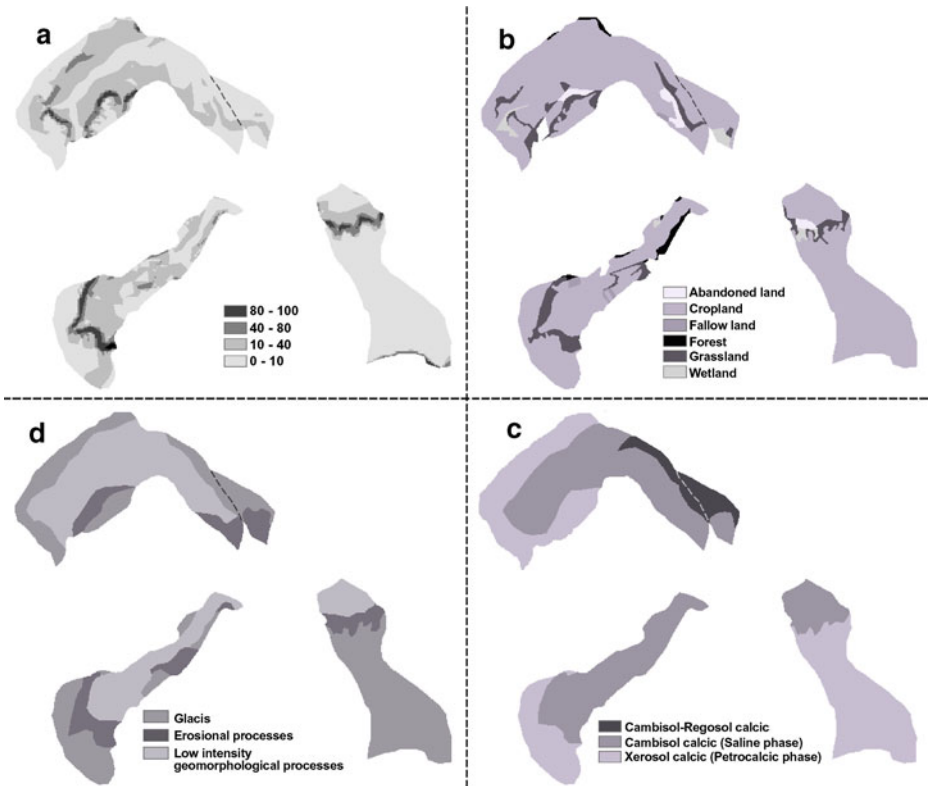


Fig. 2 Thematic layers used in the suitability model of some of the studied catchments. **a** Slope map obtained from DEM, units are expressed in percent. **b** Land uses map created using aerial ortophotos. **c, d** Geomorphological and soil maps created from existing reference layers

The soil theme was also synthesized from an existing map created by the Aragon Government at 1:50,000 scale (Fig. 2d). This map was then refined by a detailed field observation of every soil type. Field visual parameters were then used to differentiate soil types, topographic location, presence of gravels or sands, texture essentially clayey or silty, presence of salt crusts, colour and presence of organic matter. With these parameters all soils could be classified to the types previously described (cambisols, regosols, lithosols, xerosols, solonetz, solonchaks and fluvisols).

The distance from frequently flowing streams was calculated from digitized streams and the buffer function (rings of 150 m radius) of ArcMap 8.3 (ESRI Inc.). Every stream was recognized in the field by direct observation and pointed out on an aerial photograph at 0.5 m pixel-size. Streams were considered to be frequently flowing when water flow was higher than $0.1 \text{ l}\cdot\text{s}^{-1}$ on at least three of the four visits (two visits in summer and two visits in winter) carried out annually during the years 2004 to 2006. The contour line passing through the highest point of the frequently flowing stream was considered to be the maximum height for wetlands construction

suitability in the catchments. Vector-based data layers were then converted to raster-based layers using the Spatial Analyst function of the ArcMap 8.3 program (ESRI Inc.) with a 3 m pixel-size resolution.

The types of each data layer were divided into classes, and one suitability value was assigned to each class. The suitability values varied from -3 to $+3$, which represented the lowest and highest suitability respectively (Table 2). Values were based on professional judgement (soil, land-use and geomorphology) or derived arithmetically (distance to frequently flowing streams and slope). Negative values indicated unsuitability and positives ones. A raster map was then developed by reclassifying with new values.

1.4 Model Calibration and Validation

Although all data layers were considered essential to select suitable locations for wetlands, some layers represented factors that posed significant limitations to the placement of wetlands projects (e.g., a lack of water or obstacles to channelizing water to the site). Then, weights were associated to data layers to emphasize the importance of some of them. Assigned weights could be flexible depending on constrains of the area where the model was used. Model weights ranked between 1 to 1.5 in order to avoid the underestimation of other significant data layers. Model weights were after calibrated using six out of the 18 selected catchments included in the study area with areas ranging from 23 to 434 ha.

Water availability was the most determinant condition for a site to be selected by the model under semi-arid conditions and the highest weight (1.5) was assigned to the distance to frequently flowing streams layer. Only the maximum value (1.5) provided enough enhancement of the parameter in selecting places where water was available at distances with low implementation cost (established at 450 m). The geomorphological layer also presented high sensitivity to the calibration process. The presence of highly permeable substrates (glacis and colluvial or mixed deposits) made it impossible to create wetlands on them without waterproofing the bottom

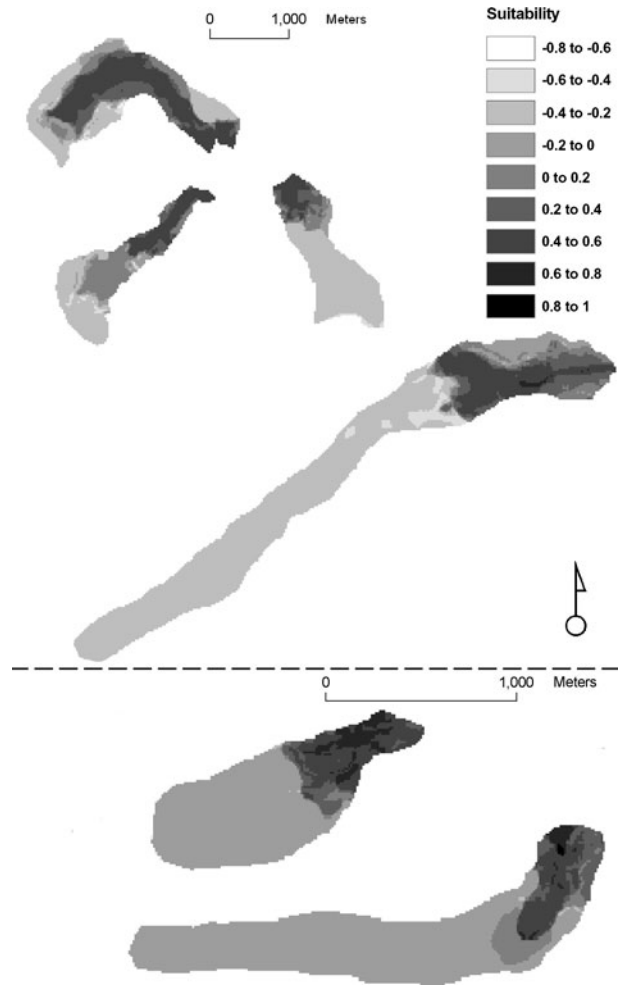
Table 2 Suitability classes of the land-use, geomorphological and soil types of the study area

Land-use	Geomorphology	Soil	Suitability
Irrigation channel Livestock farms Urban areas Woodland	Monoclinical relieves	Xerosol calcic	-3
	Glacis	Regosol-Cambisol calcaric	-2
	Alluvial-colluvial deposits	Cambisol-Litosol calcic	
Erosion deserts	High terraces		-1
Dry shrubland/ grasslands	Erosion surfaces	Cambisol calcic	0
Abandoned lands Rain-fed farmlands Irrigated farmlands Wetlands	Low intense geomorphological process		$+1$
		Solonchak orthic	$+2$
		Solonetz orthic	$+3$
	Alluvial deposits and low terraces	Fluvisol calcaric	$+3$

Table 3 Distribution of suitability areas for wetland creation and restoration selected by the suitability model and existing overlap between currently existing wetlands and areas selected by the model in different categories

Catchment	Area (ha)	Suitable (%)	Very suitable (%)	Suitable + very suitable (%)	Wetland area (ha)	Overlap with unsuitable (%)	Overlap with suitable (%)	Overlap with very suitable (%)
Torres	21.9	13.3	8.7	22.0	0	0	0	0
Poleñino	28.5	6.6	8.4	15.0	1.5	0	4.7	95.3
Grañén	59.1	6.7	92.0	98.6	3.7	0	100	0
Barranquetes	80.6	10.6	12.1	22.7	0.9	0	100	0
Af. Filadas	89.9	36.9	17.9	54.8	1.2	0	24.3	75.7
Río Ancho	102.2	26.8	40.2	66.9	2.3	67.0	24.3	9.6
Sangarrén	147.3	45.9	7.2	53.1	3.3	0	38.9	61.1
Sariñena	433.8	16.0	8.4	24.4	3.1	0	0	100
Matal	436.7	16.9	14.6	31.5	3.2	0	53.8	46.3
Albalatillo	521.7	25.0	11.6	36.6	7.3	0	0	100
Paúles	965.3	7.8	3.7	11.5	2.0	0	19.3	80.7
Moncalver	2535.5	26.1	5.0	31.1	18.9	0	24.2	75.8

Fig. 3 Results of the suitability analysis of some small (<60 ha; *top*) and medium (60–150 ha; *below*) size catchments



with synthetic materials or high amounts or foreign soil materials at high costs. A high score (1.3) must have been assigned to this layer to allow the model selecting sites out of highly permeable substrates. The slope layer was also lightly sensitive to changes in the calibration process, very little increases in slope made wetland creation exponentially more expensive, especially as consequence of the earth works. Thus, a weight of 1.1 was assigned to this parameter. Landuse and soil layers were more robust to variations in their weights and a weight of 1 was assigned to them. In order 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. The resulting data were discretized in intervals of 0.2. The final model was thus:

Suitability

$$= \frac{1.5 \times \text{Distance} + 1.3 \times \text{Geomorpho log } y + 1.1 \times \text{Slope} + \text{Landuse} + \text{Soil}}{\text{Max}(1.5 \times \text{Dis tan ce} + 1.3 \times \text{Geomorpho log } y + 1.1 \times \text{Slope} + \text{Landuse} + \text{Soil})}$$

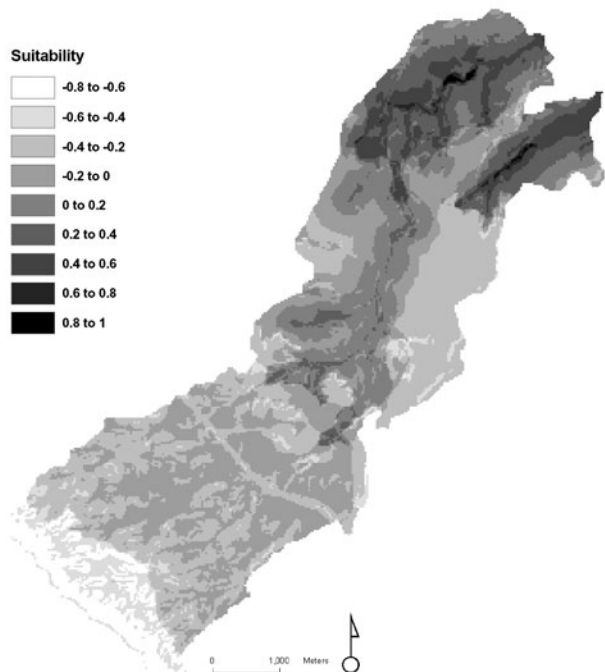
where distance, geomorphology, slope, land-use and soil were the values of the data layers described in Table 1 and assigned according to Table 2.

Finally, the model was validated by estimating the coincidence between area covered by existing wetlands and area detected by the model as very suitable for wetland creation or restoration in the catchments selected for the study (Table 3). All selected catchments not used in the calibration process (12) were used to validate the model. It must be remarked that these catchments have not been involved in any kind of creation restoration project; therefore, coincidence between existing wetlands and suitable areas is due only to natural processes.

2 Results: Case Studies

Suitability maps obtained applying the model to the 12 remaining studied catchments not used in the calibration process, excepting one outlier (Grañen), indicated that $31.1 \pm 16.3\%$ (mean \pm SD) of the area of every catchment is suitable for the establishment of wetlands (Fig. 3 and 3; Table 3). $11.8 \pm 9.9\%$ were considered to be very suitable places (>0.4), and $19.2 \pm 11.3\%$ were found to be suitable places (0–0.4) based on the model. Suitable area ranged from 7% of Poleñino catchment to 98% of Grañen catchment. The range was from 3.7% to 92% for very suitable areas (Table 3). The calibration process showed that in all cases but one (Grañen) all the area covered by wetland fell into the suitable or very suitable areas (Table 3). Figure 2 illustrates how widely the suitable area (dark zones Fig. 3) varies from one

Fig. 4 Results of the suitability analysis of some large studied catchments (500 ha catchment on the right, and 2,500 ha catchment on the left side of the figure)



catchment to another in medium and small size catchments, and Fig. 4 shows how the suitable area is mostly located in the lower third part of large catchments.

3 Discussion and Caveats

The GIS modelling approach used here is a useful and simple tool to make decisions about the allocation of wetland sites at catchment scale, and it is an interesting tool for agricultural and landscape planning in semiarid territories with intensive agricultural irrigation. The use of easily accessible data layers and the simple transformations they require (slope and distance from frequently flowing streams) make the model widely useful. The importance of using easily accessible information with standard knowledge of GIS-software in landscape planning was also considered in previous models as essential to extend its use (Palmeri and Trepel 2002; Lesta et al. 2007; Jasrotia et al. 2009). It is expected that the accessibility of improved and more complete geographical information will increase in the future (Van Lonkhuyzen et al. 2004).

More precise layers ($\sim 1:5,000$ or $3\text{--}5\text{ m}^2$ cell size) will be needed for small catchments ($<2,000$ ha) if high resolution is desired. Available information usually has rougher scales ($<1:50,000$ or $30 \times 30\text{ m}$ cell size; e.g. Russell et al. 1997; Richardson and Gatti 1999; Palmeri and Trepel 2002; Lesta et al. 2007) and produces useless maps in small catchments. We observed that current DEM resolution (cell size = 20 m) was not enough to represent the spatial variation of small catchments and reduced the accuracy of the model. It is proposed to incorporate 3 m pixel-size resolution, and lower for small catchments, in the cartography to integrate the changes observed in slope. Valuable detail for specific restoration measures was provided by Van Lonkhuyzen et al. (2004) using a DEM resolution of 0.6 m elevation contours.

Most of models previously proposed were designed using large catchments varying between $4,000\text{--}10,000$ (Palmeri and Trepel 2002; Newbold 2005) to $40,000$ or $50,000$ ha (Richardson and Gatti 1999; Palmeri and Trepel 2002) or even $200,000$ ha (White and Fennessy 2005). Only, Van Lonkhuyzen et al. (2004) proposed a model for a small area of 600 ha but was not a catchment. We consider that the model to select optimal locations for wetland restoration might be applied in large catchments only at the planning scale, but not for specific restoration measures (e.g., exact places for restoration, potential areas of important earthmoving or verifying land ownership data layers) because the level of detail will not allow it. At the catchments size of this study ($<2,000$ ha) real topography is easily recognizable and restoration works can be specified at a practical, realistic and manageable scale, provided accuracy of DEM was improved.

Although they are detailed and valuable, some proposed models use time-consuming cartography or models that require experience (Richardson and Gatti 1999; Newbold 2005; White and Fennessy 2005). This study proposes a simple model to locate suitable places for wetland restoration with “basic” knowledge of GIS and cartography which probably was accessible for a large amount of land planners and technicians. Other studies have proposed simple ways to locate suitable places for wetland restoration (Palmeri and Trepel 2002; Lesta et al. 2007) but they did not consider at the same level the limiting factors of our study area (soil salinity and

composition, semiarid conditions, varied geomorphology and irrigation). Thus, this study is especially useful in areas affected by any these conditions.

The assignment of suitability values and weights needs support from experts' decisions. The inherent subjectivity associated with this phase of the analysis was noted by other researchers. Baban and Wan-Yusof (2003) reported that GIS methodology makes decision-making processes more objective and systematic. We propose that a deep knowledge of the region under analysis is essential to reduce associated subjectivity and, subsequently, to improve the usefulness of the model in site selection (Van Lonkhuyzen et al. 2004). This knowledge must be especially attempted by understanding processes occurring at the catchment scale (Bohn and Kershner 2002). Also, the iterative calibration of the model would allow users to better find the optimal layers to be included in the model and their weights.

The model must be seen as a flexible tool that is adaptable to different conditions of study areas that are thoroughly known (Zedler 2003; Van Lonkhuyzen et al. 2004). We consider the model to be a complementary tool that can be integrated into decision-support systems used in environmental and agricultural planning (Wang et al. 2004). In further research this kind of models could be integrated in or be complementary of eco-hydrological river basin models where wetlands are integrated as elements that improve the water quality (Hattermann et al. 2006).

The application of the model to the studied catchments provided high rates of areas suitable for wetland creation or restoration (31%), including 12% of very suitable areas. These results are similar to those reported by Lesta et al. (2007) for several Estonian counties, where 42% of the area was suitable for wetland construction, including 16% very suitable areas. More restrictive models recommended between 8% and 15% of a large (2,197 km²) agricultural catchment in Ohio (White and Fennessy 2005) or 11% of a 40 km² catchment in Italy (Palmeri and Trepel 2002) as the most suitable areas for wetland restoration. These restrictive percentages are not far from those proposed by Lesta et al. (2007) and this study as very suitable areas, and consequently were the first to be selected for wetland construction. A restoration model for riparian wetlands proposed 2.3% as a high priority for wetland restoration (Russell et al. 1997), which was partly due to the fact that only the floodplain area was considered in the model. The amount of very suitable area for wetland establishment observed from the application of our model to the study area closely matches the area of wetlands needed at catchment scale to remove most of the nitrate from agricultural runoff (3.2–5.6%) proposed for the same zone in previous studies (Moreno et al. 2007).

The validation process showed that all catchments but one had their wetlands included in the suitable area selected by the model. This entails a high accuracy of the model to select optimal locations for siting restored or created wetlands under Mediterranean conditions in agricultural catchments. Using this model in decision-making processes or eco-hydrological modelling in landscape and agricultural planning will make it possible to easily determine the most suitable areas for wetland allocation in new agricultural developments and in the modernization of old irrigated zones. The model shows that there is enough "very suitable" area to establish all needed wetlands for water quality improvement, and they must be concentrated in the lower parts of the small catchments (20–2,000 ha). This will result in a mosaic of constructed wetlands at regional or catchment scale and an integrated landscape in areas that have been degraded by intensive agricultural

use. Agricultural developments could then be more sustainable by combining the objectives of improving water quality and strengthening biodiversity and landscape diversity.

Acknowledgements This work was supported by CICYT (REN2003-03040), Aragon Government–D.G. Investigación, Innovación y Tecnología–Research Group on Ecological Restoration (E61), DGA (CONAID)–CAI (CA1/07), and Diputación de Huesca “Félix de Azara” Grants 2007, Estonian Science Foundation grant No. 6083, and Target Funding Project No. 0182534s03 of the Ministry of Education and Science of Estonia. Special thanks are given to Merje Lesta from University of Tartu for her useful comments and two anonymous reviewers.

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