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A protocol to prioritize wetland restoration and creation for water quality improvement in agricultural watersheds

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ABSTRACT

With adequate planning, wetland restoration and creation can be useful tools for improving the water quality of natural ecosystems in agricultural territories. Here, a protocol for selecting wetland-restoration sites at the watershed scale is proposed as part of a demonstration project (EU Life CREAMAgua) for improving wastewater from irrigated agricultural land discharging into the Flumen River (Ebro River Valley, NE Spain). This watershed is semiarid, and 70% of its 1430-km^2 area is used for irrigated agriculture. A preliminary study of the physical and chemical characteristics of the Flumen River and its watershed identified nitrates as the key water-quality characteristic in terms of data variability. The protocol consisted of five steps that encompassed scientific–technical, social and economic criteria. The first step was to select all of the sites in the watershed that had the hydrogeomorphic characteristics of a wetland. The second step was to estimate the levels of nitrate discharge through all of the tributaries discharging to the river and to select the sub-watersheds that contributed the most nitrates. The program SWAT (Soil and Water Assessment Tool), which considers the biophysical characteristics and land uses of the watershed, including farming practices, was utilized in these first two steps. In the third step, a first-order area-removal model was used to rank wetlands for nitrate removal. The wetland sites that were estimated to be most efficient for nitrate removal were selected. These wetland sites were located in the agricultural zone within the watershed, where fertilizers and irrigation are intensively used. In the next step, the previously selected sites were considered based on a social-availability criterion (the potential to obtain at no cost the land required to restore or create wetlands at those sites). Finally, the concordance between site availability and funding was used to sequentially select 15 sites (135 ha) that would be cost-effective for the Flumen River watershed project, which provided a case study. This protocol is compared to previously published protocols with the same purpose, and the applications of this procedure are discussed in terms of up-scaling and integrating experience in land-use and agricultural policies.

1. Introduction

Interest in developing methodology for wetland restoration at the watershed scale has increased during recent years. Wetland-restoration researchers have increasingly recognized that first, they must plan the recovery of a huge amount of wetlands degraded or lost during the last century; and second, wetland restoration is more efficient if considered at the landscape scale (Verhoeven et al., 2006; Moreno-Mateos and Comin, 2010). For example, wetland restoration has been proposed to restore the nutrient-removal function of wetlands in the Mississippi–Missouri watershed (Mitsch and Day, 2006). Wetland restoration has been practiced at different scales, from small (Richardson et al., 2011) to large watersheds (Chimney and Goforth, 2006). Indeed, wetland restoration at the landscape scale has been proposed as the most effective approach to improve the water quality within watersheds (Bedford, 1999; Zedler, 2003; Crumpton, 2001).

One of the major environmental challenges for agricultural development is to increase production while decreasing the impacts of pollutants on the water quality of aquatic ecosystems (Tilman et al., 2002). Restoring and creating wetlands at the watershed scale has been suggested as a general strategy to accompany

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sustainable agricultural development by buffering the impacts of non-point-source pollutants on aquatic ecosystems (Mitsch et al., 2001; Zedler, 2003). Changes in agricultural practices as adequating the fertilizer rates to the plant requirements both in time and doses are necessary to reduce nutrient losses from farming uses to the state that there are no further avoidable nutrient losses. Then, integrating wetland restoration and creation into sustainable land uses and land cover planning would recover the ecosystem services and economic benefits that wetlands provide at the watershed scale (Jenkins et al., 2010). Therefore, protocols for planning wetland restoration and creation at the watershed scale are needed for land-use management and ecosystem conservation and restoration. Also there are general statements in the European legislation to improve the water quality of natural surface waters through both limiting the emission of contaminants as a consequence of water uses in the watersheds and establishing controls to avoid contaminant discharges into natural ecosystems, as well as specific suggestions to restore and create wetlands as a measure to improve the water quality and the ecological status of natural aquatic ecosystems (EU Parliament and Council, 2000).

However, a simple and unique protocol for planning wetland restoration and creation at the watershed scale is difficult to obtain because watersheds and land and water uses differ greatly among regions and societies. A landscape approach analyzing the relationships among landscape, wetland and watershed characteristics was suggested as a general approach to establish restoration priorities at the watershed scale (Bohn and Kershner, 2002). This approach was used to select appropriate sites for restoring and creating wetlands in watersheds (Lesta et al., 2007; Martín-Queller et al., 2010). Another landscape approach, relating the land-use and morphological characteristics of river networks to water-quality data, was used to analyze the relationships between wetland characteristics and particular water-quality characteristics, such as phosphorus removal (Weller et al., 1996). A general protocol to restore and create wetlands for water-quality improvement at the watershed scale was proposed based on optimizing a proxy variable for water-quality improvement, the water-residence time in the wetlands (Almendinger, 1999). The same approach was used to predict nitrogen retention in several potential restored wetlands under three different nitrogen-removal models (Trepel and Palmieri, 2002). Newbold (2005) used an 8-step algorithm combining hydro-ecological modeling and experience-based restoration costs to prioritize sites for wetland restoration by optimizing the benefit–cost criteria.

This paper presents a protocol that integrates previous approaches to restore and create wetlands for the improvement of water quality at the watershed scale. This protocol consists of a greedy algorithm incorporating the three aspects (scientific–technical, economic, social) of ecological restoration (Comín et al., 2005).

2. Materials and methods

The Flumen River watershed (1431 km^2), located in the Ebro Basin (NE Spain), is a semiarid region with high inter-annual rainfall variability (150–400 mm/yr) and high potential evapotranspiration (900–1200 mm/yr) (Fig. 1). The average water discharge of the Flumen River (5 Hm^3/yr) is not sufficient to meet the water demand for agricultural irrigation in this watershed (800 Hm^3/yr). The intense agriculture that occupies most of the middle and lower parts of the Flumen River watershed is irrigated with water transported by a dense network of canals from two other rivers, Cinca and Gallego, located to the east and west of the Flumen River basin, respectively. Another dense network of drainage canals collects excess water from irrigated fields (March–October) into larger canals and finally drains into the Flumen River through natural gullies in the lower parts of every sub-watershed.

A preliminary survey of the water quality of the Flumen River was performed to determine differences between water characteristics in different parts of the river. Water samples were collected bimonthly during 2009–2010 at several points along the Flumen River and its tributary. Some variables (temperature, specific conductivity at 25 °C, pH, dissolved oxygen) were recorded in situ with calibrated electronic equipment. Samples of running surface water were collected directly from the river in polyethylene bottles and stored (24 h) in cold conditions (4 °C). Analysis of alkalinity (no filtrated water), major dissolved ions, and different forms of nitrogen and phosphorus were performed following standard methods (APHA, 2012).

The program SWAT (Soil and Water Assessment Tool) was used to model water flow and nitrate discharges in each sub-watershed draining into the Flumen River during 2006–2009. Data on water and nitrogen used as fertilizer for various agricultural uses were obtained from interviews with selected farmers. Maps of land use, soil type, elevation (from a digital elevation model), terrain slope, and climatic characteristics required for SWAT modeling were obtained from official mapping agencies (CHE-Confederación Hidrográfica del Ebro) SWAT modeling begins by defining Hydrologic Research Units (homogeneous hydrologic areas within the region), which were aggregated to form sub-watersheds here.

Based on the climatic and other data sets listed above, monthly water flows were estimated using SWAT for the whole Flumen River watershed and calibrated using a two-year dataset recorded continuously with an automatic sampler placed at the lowest reach of the Flumen River. This model was then employed to estimate monthly and annual water and nitrate discharges for each of the 163 sub-watersheds discharging to the Flumen River.

The greedy algorithm presented here to prioritize sites for wetland restoration and creation in agricultural watersheds consists of several successive steps integrating scientific–technical (hydrogeomorphic, biogeochemical, morphological), social and economic criteria (Fig. 2).

(1) The first step is to delineate potential areas of the watershed for wetland restoration and creation. SWAT modeling can delineate all of the sub-watersheds through which water flows to the river. There is at least one potential site for wetland restoration or creation in the lowest part of each sub-watershed, where water draining into the Flumen River forms sediment deposits covered with emergent vegetation. The lowest reach of each stream collects water from the entire sub-watershed and discharges the water, with the pollutants that it carries, into the river. Thus, these are the sites within each sub-watershed where a wetland is most likely to improve the quality of the water discharged into the river. In-stream wetlands are already present at these sites, making them suitable areas for wetland restoration (Martín-Queller et al., 2010). Additionally, old maps showing the former wetland distribution in the region can be overlapped with the digital elevation map to identify low-elevation areas not directly connected to the drainage network where off-stream wetlands could be restored or created (Moreno-Mateos and Comin, 2010).
(2) The second step is to select among the previously delineated potential sites based on their nitrogen loads. SWAT modeling estimates the water flows and nitrate concentrations in each sub-watershed. Sub-watersheds that drain agricultural areas will discharge larger amounts of nitrate than those that do not. For a simple sub-watershed discharging directly to the river, nitrate removal can be effected by a single wetland located

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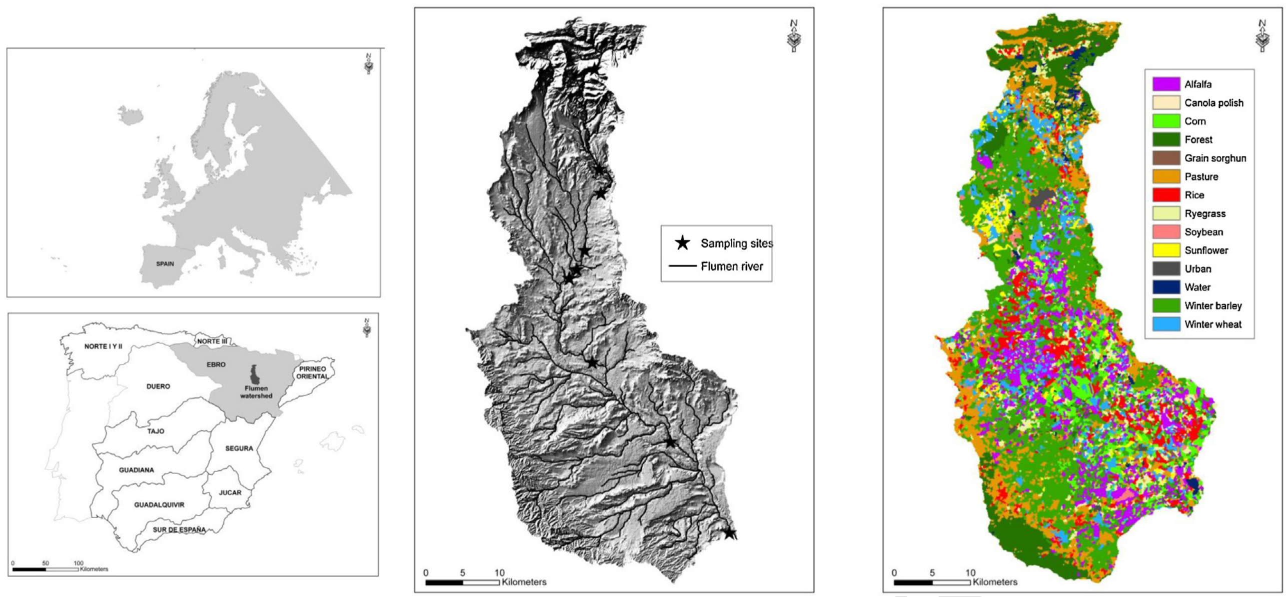

Fig. 1. Location of the Flumen River watershed in the Ebro River Basin (NE Spain); map of the Flumen River watershed showing the sampling points in the Flumen River (F) and its permanent tributary, the Isuela River (I), the remaining streams are ephemeral; map of the Flumen watershed with the distribution of major land uses.

in the lowest part of the sub-watershed, near the river intercepting the water flow (in-stream wetland), where most of the pollutant is discharged. For complex sub-watersheds encompassing several other sub-watersheds that ultimately drain to the river through a single stream, a wetland site can be restored or created in the lowest part of the complex sub-watershed; however, sites located in the sub-watersheds that drain into the last one draining into the river are also considered. The selected site may be a former wetland or a floodable area (e.g., an abandoned rice paddy) adjacent to a drainage channel (off-stream wetland), and part of the water discharge may be derived naturally (restored wetland) or artificially (created wetland). The water does not return to the stream but remains in the site, where it is dispersed above ground and infiltrates or evaporates. These circumstances are considered in the subsequent steps of the protocol.

(3) The third step is to estimate the area of surface-flow wetlands required to remove nitrate. The first-order model used to estimate the area of surface-flow wetland required to achieve a target nitrate-discharge level in each

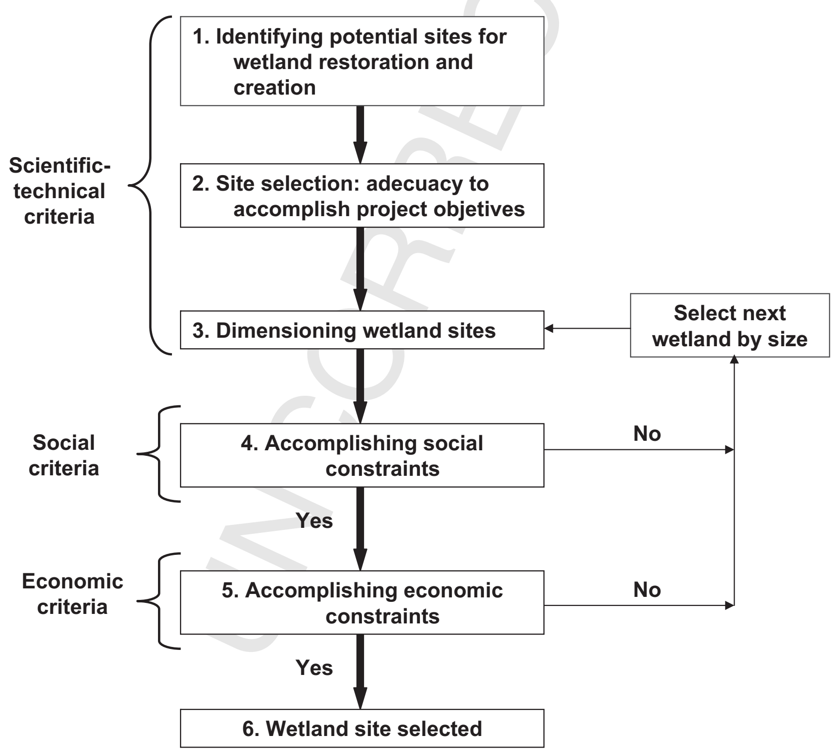

Fig. 2. Protocol to prioritize sites for wetland restoration and creation based on scientific, social and economic criteria.

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Q2 sub-watershed is as follows (Kadlec and Wallace, 2008): $A = (0.0365\,Q/k) \times (\ln(C_i - C^*/C_o - C^*)$, where A is the wetland area; C_i is the inlet concentration (mg/L), here defined as the minimum concentration of the third quartile modeled by SWAT (i.e., the maximum concentration of the 75th percentile); C_o is the target outlet concentration, here defined as 5 mg/L; C^* is the base-flow nitrate concentration in a surface-flow wetland, here set at 2 mg/L; Q is the water flow rate (m^3/d), here considered to be the maximum flow observed for a given inlet nitrate concentration; and k is the experimental first-order areal rate constant (here we used 35 m/yr, which is suggested by Kadlec and Knight (1996) in Table 13.12 as a common constant for preliminary dimensioning of wetlands for nitrate removal obtained from data bases on the functioning of wetlands).Dimensioning parameters must be established according to the specific requirements for water-quality improvement. Nitrate concentration was selected for wetland dimensioning in this project because it has previously been recognized as the most relevant pollutant for water-quality degradation in the lower part of the Flumen River (Martín-Queller et al., 2010). To optimize the wetland area for nitrate removal in each sub-watershed, the dimensioning criteria were restricted to avoid extremely high water flows and nitrate concentrations, which are inversely related. Thus, the inlet concentration was defined as the minimum of the third quartile (maximum of the 75th percentile) of the nitrate concentrations obtained from the SWAT model for each sub-watershed; the outlet concentration was established as 5 mg/L of N–NO_3, which is close to 25 mg/L of nitrates established as a maximum concentration for natural waters useful to provide water to produce potable water in the European Community (EU Council, 1975) and also close to 15 mg/L of nitrates established by Spanish national authorities as the concentration of nitrates in the treated urban wastewater discharging to ecosystems labeled as sensitive to eutrophication (MOPTMA, 1996); and the water flow considered was the maximum observed water flow for the nitrate-concentration value used as the inlet concentration.The wetland sites defined in this step are listed in decreasing order of the area required to decrease nitrates to the target concentration. It is expected that the larger the wetland area required to remove nitrates, the greater will be the contribution of the wetland to the overall improvement of water quality. The remaining steps are followed sequentially for each selected wetland site in decreasing order of area.

(4) The fourth step is to consider the social aspect of restoration. Here, the social criterion used to prioritize wetland sites for restoration or creation was the availability of land at no cost. Either public or private lands were eligible for wetland restoration or creation if they were offered to the project at no cost. The ownership of the sites identified as suitable for wetland restoration or creation in each sub-watershed was determined using public land records kept by the regional and local governments and through interviews with the mayors of the municipalities. If the land required for restoring or creating a wetland was not available for the project, the site was rejected, and the next site on the list created in step 3 was considered. If the land required for restoring or creating a wetland was available for the project, consideration of the site proceeded to step 5. Finally, a memorandum of understanding for the use of the selected land areas in wetland restoration and creation was signed between the landowners and the project managers.

(5) The fifth step is to select areas for wetland restoration and creation based on economic criteria: here, the availability of funds in the wetland-restoration project. In this step, the sites selected in the previous step were sequentially checked against the project budget to identify restoration activities for which funding was available. Based on construction requirements, the standard restoration costs provided by a regional construction company that uses established official costs were applied to estimate the cost of restoration for each wetland. Here, the standard costs were $5200 U.S. per hectare, including soil and land conditioning, embankment construction, simple water-flow controls, and planting, which is planned at low density in selected sites as most of the potential sites already have abundant wetland plants and rhizomes. The costs of planning, maintenance and monitoring were disregarded in this case study, but they may be included in the restoration costs in other projects.

3. Results

3.1. Flumen River water quality

Suspended and dissolved compounds increase as water progresses along the Flumen River and its tributary, with marked differences in suspended solids and nitrate concentrations (Fig. 3). The water quality of the Flumen River is highly degraded in the central and lower portions of its watershed due to point-source pollution (urban areas and pig farms) and non-point-source pollution (wastewater from irrigated agriculture), respectively (Martín-Queller et al., 2010).

Nitrate concentration is strongly and positively related to the first component of the multivariate analysis of water characteristics (Fig. 3), while the concentration of suspended solids is opposite to that of nitrates on the same axis (which accounts for 31% of the data variability). Total dissolved phosphorus is related to the second axis (which represents only 18% of the data variability).

3.2. Selecting potential sites and modeling water and nitrate discharges

Using SWAT, 43 sub-watersheds were delineated within the Flumen River watershed. These sub-watersheds drain to the Flumen River directly through a single stream that joins the river or through other sub-watersheds (Fig. 4). Each sub-watershed may have a wetland located on the lowest part of its final drainage stream (an in-stream wetland), where the water flow discharges accumulated sediments. These wetlands can be restored to improve water quality. However, markedly higher nitrate discharge occurs in 21 sub-watersheds delineated by SWAT that accumulate water and nitrates from inner sub-watersheds in the irrigated-agricultural region of the central and lower Flumen River watershed. These 21 sub-watersheds discharge directly into the Flumen River, rather than through other sub-watersheds in the northern part of the study region, as modeled by SWAT. The annual water and nitrate discharges estimated by SWAT for these 21 sub-watersheds are shown in Fig. 5. Water from any part of a sub-watershed is collected and transported through the network of small channels that drain agricultural fields and is discharged through the network of natural streams converging in a final stream that flows into the Flumen River.

3.3. Wetland dimensioning

As estimated by the first-order area model, the wetland area required for nitrate removal in the 21 selected sub-watersheds is inversely related to the inlet nitrate concentration and directly related to the water flow (Fig. 6). This pattern indicates that according to the dimensioning model used here, water flow

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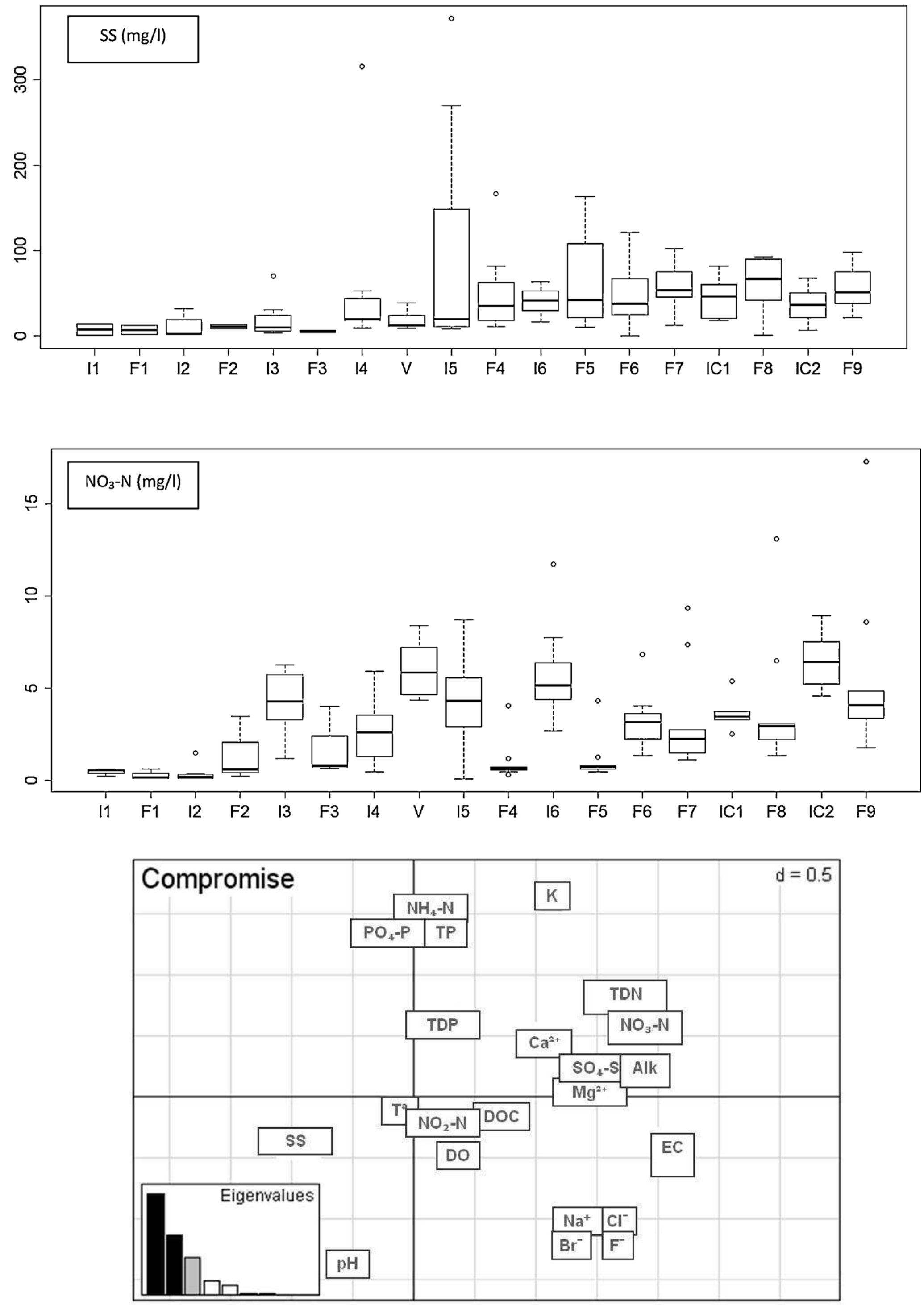

Fig. 3. Top and center: Median values and ranges of suspended solids and nitrates along the Flumen River (see Fig. 1 for sampling locations). Bottom: distribution of water-quality characteristics in the space defined by the first and second principal components of the multi-criteria analysis of the analyzed variables for the Flumen River (NO_3—N, nitrogen as nitrates; NH_4—N, nitrate as ammonium; TDN, total dissolved nitrogen; SS, suspended solids; TDP, total dissolved phosphorus; DOC, dissolved organic carbon; EC, electrical conductivity; Alk, alkalinity; DO, dissolved oxygen).

is more relevant than inlet nitrate concentration to nitrate removal. The required wetland area is not related to the area of the sub-watershed (Fig. 6). Clearly, land cover and use are relevant for determining the nitrate discharge in a sub-watershed and consequently the wetland area required to remove nitrate.

3.4. Selected wetlands

The protocol used to select wetland sites for restoration and creation in the Flumen River watershed incorporated social and economic criteria (Fig. 2). No major site-availability restrictions were found because public lands were offered for use in the project

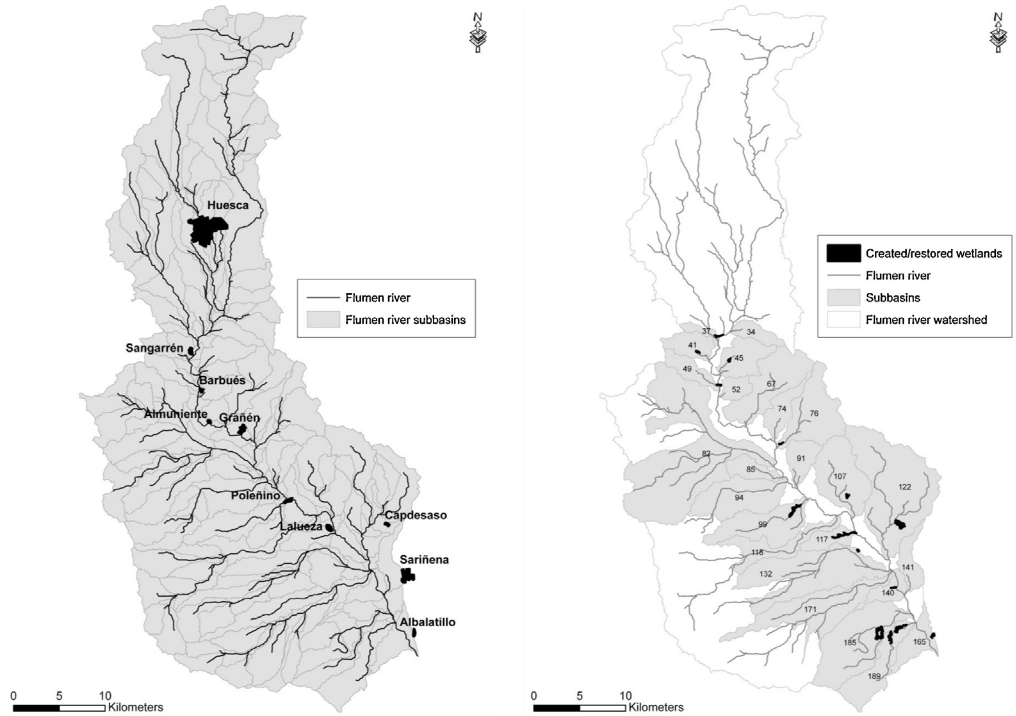

Fig. 4. Left: sub-watersheds of the Flumen River watershed modeled with SWAT using hydrogeomorphic criteria. Right: sub-watersheds within the agricultural area located in the central-lower Flumen River watershed, selected as potential sub-watersheds with wetlands because of their high nitrate-discharge levels and sites finally selected after application of the protocol for wetland restoration and creation with this project.

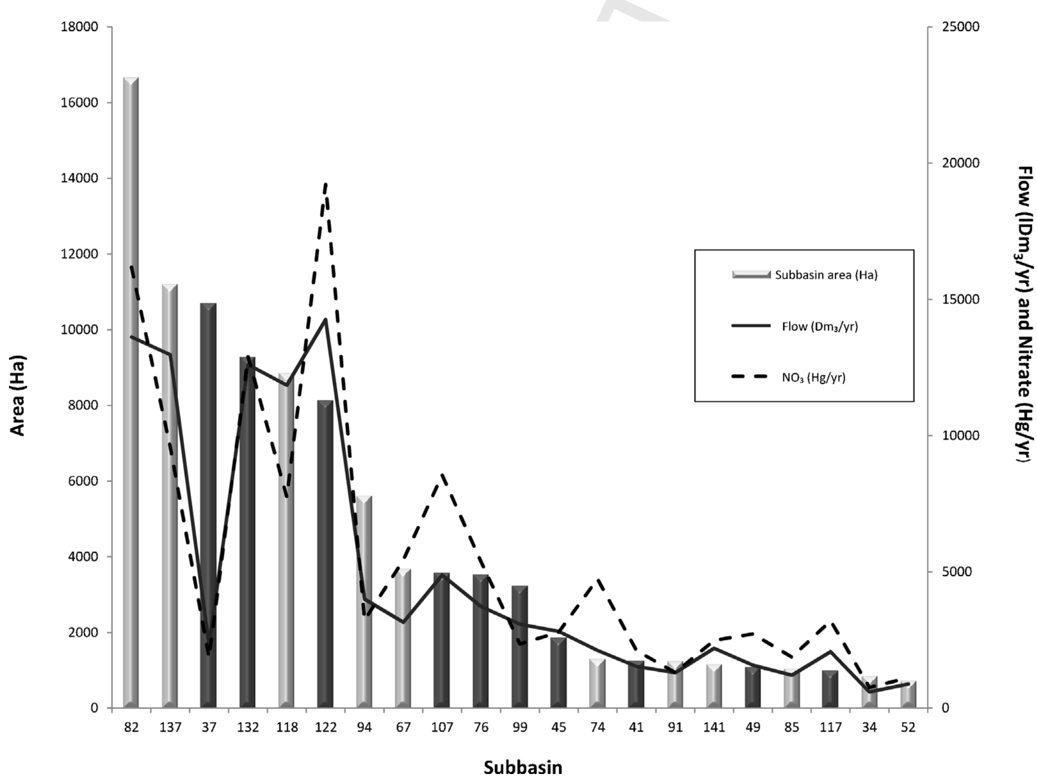

Fig. 5. Distributions of the areas, water-discharge volumes and nitrate-discharge levels of the potential sub-watersheds to allocate wetlands in the central-lower part of the Flumen watershed.

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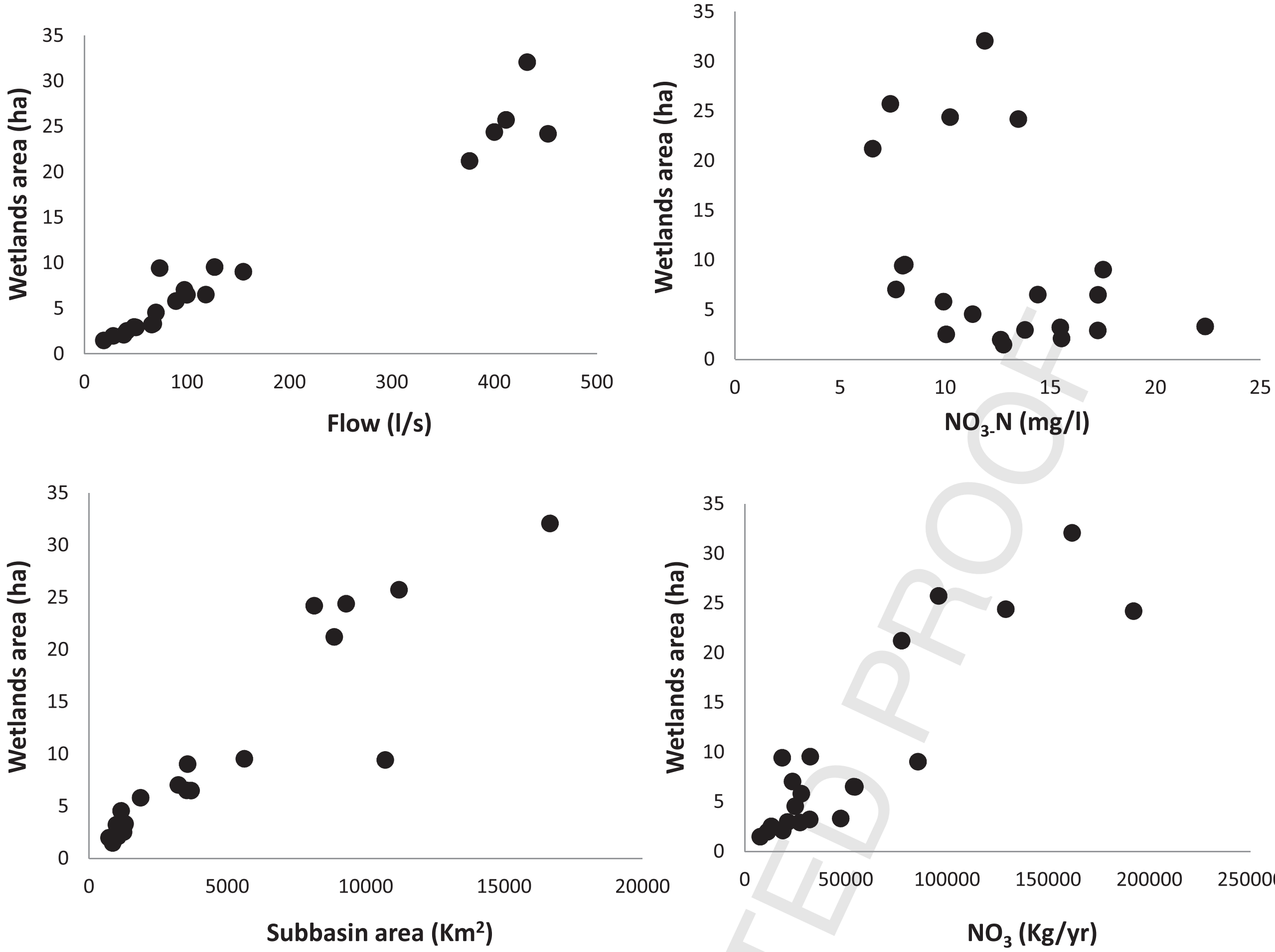

Fig. 6. Relationships between the wetland areas estimated by the first-order area model and their respective average water flows (top left), average nitrate concentrations (top right), sub-watershed areas (bottom left), and nitrate discharges (bottom right).

in most of the 21 sub-watersheds selected based on the hydrogeomorphic (step 1) and biogeochemical (steps 2 and 3) criteria. One of the selected wetland sites was located on private land offered at no cost by a group of neighboring landowners in the municipality of Albalatillo, in the southernmost part of the watershed.

However, due to severe economic restrictions related to the characteristics of the project, funding was available for wetland restoration or creation at only 15 of the 21 sites. These 15 wetlands contributed 70 flooded hectares to the areas ultimately selected for the project Life CREAMAgua by following this protocol (Fig. 4). These sites included 8 in-stream wetlands located in the lowest parts of sub-watersheds draining directly to the Flumen River and 7 off-stream wetlands located in sub-watersheds draining into another sub-watershed (Fig. 2).

Two in-stream wetlands were constructed by the end of 2011 as pilot projects. The construction of these wetlands followed the dimensioning results and general indications yielded by the protocol described here, such as leveling the soil surface, building embankments to retain water, and favoring the colonization and persistence of aquatic plants. Because of the characteristics of the available sites, both wetlands consisted of multiple basins arranged in a series, with each basin receiving water from the previous basin. The preliminary results for these two wetlands showed that the nitrate-removal process began in the first year after wetland construction. Compared to sites where wetland restoration or creation had not yet occurred, these two wetlands exhibited nitrogen removal (Fig. 7).

4. Discussion

The protocol presented here is a practical approach that can be applied to any wetland-restoration or -creation project at the watershed scale. This protocol integrates social and economic

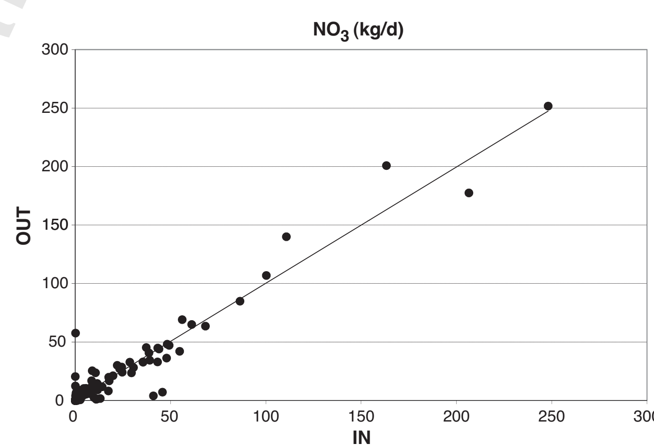

Fig. 7. Monthly average nitrate discharges into the sites selected for wetland restoration or creation in the Flumen River watershed versus out-flowing nitrate discharges from these sites. Two sites corresponding to restored wetlands, where nitrate removal is taking place, are distinguished.

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criteria, which are key factors in the efficient implementation of any ecological-restoration project (Comín et al., 2005; Petursdottir et al., 2012). Many projects do not yield efficient results because they fail to incorporate the preferences of local people. This factor was considered here by determining the availability of land, either public or private, for use in this project. The economic aspect is also crucial. A project designed to restore or construct a single wetland is based on a specific budget. However, a project intended to restore multiple wetlands within a watershed, where the sites to be restored and the actions to be taken are not defined at the outset, must base its budget on previous restoration-cost experience. Furthermore, restoration projects at the watershed scale may involve many alternative or additional actions that are not covered by a limited budget. The present project allowed a construction cost of $5000 U.S. per hectare, within the typical range for this type of wetland (Bystrom, 1998; Kadlec et al., 2000), with no allowance for land purchasing. The cost per hectare may triple easily if land purchase is required (Newbold, 2005). Under limited funding, a common condition for ecological-restoration projects, a flexible protocol to select alternative sites is a critical component of the restoration process.

This protocol can be applied to any project at the watershed scale because it considers all of the potential sites for restoration and is flexible enough to incorporate decision-making criteria at any step. Here, the protocol was applied to water-quality improvement in the EU Life CREAMAgua Flumen River Project and considered nitrates as the limiting factor because it is the major nutrient forcing eutrophication, but it can be applied to any other purpose and can consider different criteria at any step. Phosphorus, which can be released from the wetland sediments in anaerobic conditions, will likely precipitate in the calcareous natural waters of the study area (Moreno-Mateos et al., 2008a).

Using SWAT and first-order removal models to identify and select the most important sites for improving water quality in irrigation runoff ensures that the hydrogeomorphic and biogeochemical characteristics that are essential for wetland allocation and design will be taken into account (Grimson, 1993; Mitsch and Jorgensen, 2003). The efficiency of SWAT for modeling the terrain and its hydrologic characteristics depends on data availability and quality. We delineated sub-watersheds by aggregating terrain units with coherent hydrologic characteristics (hydrologic response units, or HRUs). Changing the scale of the analysis involves aggregating different numbers of HRUs, which determines the number of potential sites and the water- and pollutant-discharge values to be used in modeling the wetland dimensions required to remove nitrates or to accomplish another specific objective. We used a scale that identified important drainage canals transporting quantifiable amounts of pollutants, which is a key factor in modeling the wetland area required to remove nitrates. Delineating smaller sub-watersheds would result in the identification of many sites with no relevant water or pollutant discharges and would yield a multitude of potential wetlands without a significant impact on the project objective. On the other hand, larger sub-watersheds discharging greater amounts of nitrates would require very large areas that might not meet the hydrogeomorphic or the social-availability criteria.

Greedy algorithms, like the protocol presented here, do not offer an optimal solution for a defined problem (Underhill, 1994). Once a site is selected by this type of algorithm, it cannot be unselected. This protocol does not compare alternative combinations of wetland sites, nitrate-removal targets or areas. In this case study, we used decreasing wetland area as a criterion in applying the algorithm because the estimated wetland area required for water-quality improvement is directly related to the discharge flow, indicating that optimizing the wetland area will help to meet the water-quality criteria established in the protocol. Newbold (2005) showed that maximizing wetland area instead of nitrogen-load reduction under the same budget restrictions would increase the area of wetlands restored by 30–50% but would decrease the nitrogen-load reduction by more than 50%. Considering that the total wetland area modeled by either approach is less than 1% of the total watershed area, smaller than the more realistic figure of 2–7% cited by various authors (Mitsch and Gosselink, 2000; Verhoeven et al., 2006; Moreno-Mateos and Comin, 2010), this prediction is of interest for further research. Usually, wetland-restoration projects have more than one objective (Comín et al., 2001; Martín-Queller et al., 2010). Therefore, wetland-restoration planning should integrate multiple objectives related to the combined ecosystem services provided by the wetlands in a watershed (Zedler, 2003; Trabucchi et al., 2012).

Using a first-order areal-rate model is a well-supported approach because such a model is based on experimental estimates. In practice, however, several complications may arise (Kadlec, 2000). These challenges can be addressed by overestimating the wetland area (for example, by establishing an increased area percentage as a security factor) or by using a high first-order rate constant. We followed the latter approach, using a rate constant for nitrate removal that was higher than those for ammonium and organic nitrogen (Kadlec and Wallace, 2008). In addition, plant cover in the constructed wetlands in the study area is expected to develop quickly due to the use of *Phragmites australis* (Moreno-Mateos et al., 2008b, 2009), a commonly used and efficient plant cover. The establishment of plant cover will make it possible to apply the plug-flow-based first-order model used for dimensioning surface-flow wetlands (Kadlec et al., 2000).

The preliminary results of integrating a hydrologic model and a wetland-dimensioning model in a protocol to select sites for wetland restoration and creation at the watershed scale are promising. This procedure yields a list of potential sites with their major hydromorphologic (site, form) and biogeochemical (pollutant removal) characteristics. Subsequent steps of the protocol refine the selection of sites based on the social and economic constraints of the restoration project. In our case study, maximizing wetland area helps to enhance biodiversity and landscape diversification, which are additional objectives in the region and for the type of project performed (Moreno-Mateos et al., 2007; Moreno-Mateos and Comin, 2010).

This protocol is similar to others in that it consists of a series of successive steps to select potential wetland-restoration sites based on hydrogeomorphic and biogeochemical characteristics, but it differs in the types of hydrologic and pollutant models used. Almendinger (1999) used an indirect approach based upon a fixed water-retention time to define the dimensions and design the wetlands. Newbold (2005) proposed a similar algorithm that included economic criteria but not social criteria, which are critical in any restoration project. Further progress could be made by integrating other objectives for wetland restoration and creation. For example, this protocol does not incorporate biological criteria or more specific targets on nitrate discharge reduction, which may be important in wetland design (Bohn and Kershner, 2002; Davies et al., 2004). Such criteria could be incorporated as a sub-step in our protocol or could be added as a key step to meet the multiple objectives of a wetland-restoration or -creation project at the watershed scale.

Uncited references Q3

Ministerio de Obras Públicas (1996) and Moreno-Mateos et al. (2010).

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