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MONOGRAPH

Simulating management options and scenarios to control nutrient load to Mar Menor, Southeast Spain

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Abstract

1 - The Mar Menor, with an area of 135 km^2, is the largest coastal lagoon in the Western Mediterranean. The ecological value of the Mar Menor lagoon and associated wetlands has been recognised in a series of rules and resolutions, at regional, national and international level. However, several hydrological and land-use changes in the Mar Menor watershed are threatening the conservation of the Mar Menor as a result of urban and tourist developments and the intensification of agriculture. As a result, an initial eutrophication process is affecting the ecological functioning of the lagoon and the tourist activities. Several BAU (Business As Usual) and PT (policy-target) scenarios have been defined, characterised and simulated using hydrological and integrated watershed models developed for the Mar Menor site.

2 - The load of nutrients into the lagoon constitutes a key issue for all relevant scenarios for Mar Menor. Under the BAU scenario of urban and tourist development, it is expected a high rise in resident and seasonal population, which would lead to a 50% increase in the average annual load of nutrients and would further promote the eutrophication process in the lagoon. The management option of re-use of agricultural drainages would allow around a 10% reduction in nutrient loads into the Mar Menor lagoon. The recovery of wetlands constitutes a better option to reduce DIN load into the lagoon, as compared with the management option of re-use of agricultural drainages, since the achieved reduction in total nutrient loads doubles the one achieved by the re-use of agricultural drainages. As revealed by the cost-effectiveness analysis, the optimisation of wetlands for nutrient removal seems to be also more efficient compared to the re-use of agricultural drainages, with unitary costs around four times lower.

3 - The results obtained confirm the usefulness of the applied methodological approach for the overall understanding of coastal lagoons and the provision of practical inputs for the decision making process.

Keywords: Coastal lagoons; dynamic model, nutrients, scenario analysis, cost-effectiveness analysis, Mar Menor.

Introduction

Environmental and socio-economical context of Mar Menor

The Integrated Coastal Management and the Water Framework Directive have given rise to a new approach for coastal lagoons characterised by an integrated approach, a sustainable management and the achievement of a good ecological status of rivers, aquifers, transitional and coastal waters. Coastal lagoons cannot be understood nor managed in a sustainable way without taking into account all environmental and socio-economical forces driving their dynamics, a considerable part of which are located in the watershed. This complexity cannot be tackled using partial knowledge and, especially for decision-making processes, it makes necessary to apply approaches integrating the coastal lagoon with its watershed and the key environmental and socio-economic processes and their interactions. This has brought about an increasing interest in the integrated analysis of scenarios regarding coastal lagoons by means of suitable simulation models and tools (Turner *et al.* 1999; Cave *et al.*, 2003; Scheren *et al.*, 2004; Jessel and Jacobs, 2005; Heathwaite *et al.*, 2005). This is also the case of the Mar Menor lagoon (Southeast Spain), where environmental conservation and sustainable management clearly require to overcome the current lack of knowledge and policies integration.

The Mar Menor, with an area of 135 km^2, is the largest coastal lagoon in the Western Mediterranean. The Mar Menor is characterised by hypersaline waters, with a salinity range between 42 and 47. The Mar Menor waters are in general clear and relatively oligotrophic, with a low phytoplanktonic biomass, since primary production is dominated by macrophytes, especially *Cymodocea nodosa* and *Caulerpa prolifera* (Pérez Ruzafa *et al.*, 2002). When compared to other coastal lagoons, the fish community in Mar Menor is characterised by a higher species richness. It is relevant the presence of the sea horse (*Hippocampus guttulatus*) and the fish *Aphanius iberus*, an endemic threatened species included in Annex II of the European Habitat Directive. The Mar Menor lagoon and associated wetlands are important sites for wintering and breeding waterfowl, with the presence of flamingos, herons, waders, gulls, terns, grebes and seaducks (Martínez *et al.*, 2005). The lagoon and wetlands maintain 18 habitats of European interest, according to the Habitat Directive. The ecological value of the Mar Menor lagoon and associated wetlands has been recognised in a series of rules and resolutions, at regional, national and international level (Ramsar site, Special Protection Area for Birds, Site of Community Importance and Special Protection Area for the Mediterranean). However, during recent decades several hydrological and land-use changes, as a result of urban and tourist development and agriculture intensification in the Mar Menor watershed, are threatening the conservation of the lagoon.

The Campo de Cartagena or Mar Menor watershed (Figure 1) has approximately an area of 1,200 km^2 and it is drained by several rivers running into the Mar Menor lagoon. More than 80 % of total area of Campo de Cartagena is used for agriculture, especially for open-air horticultural crops, citrus fruits and greenhouses.

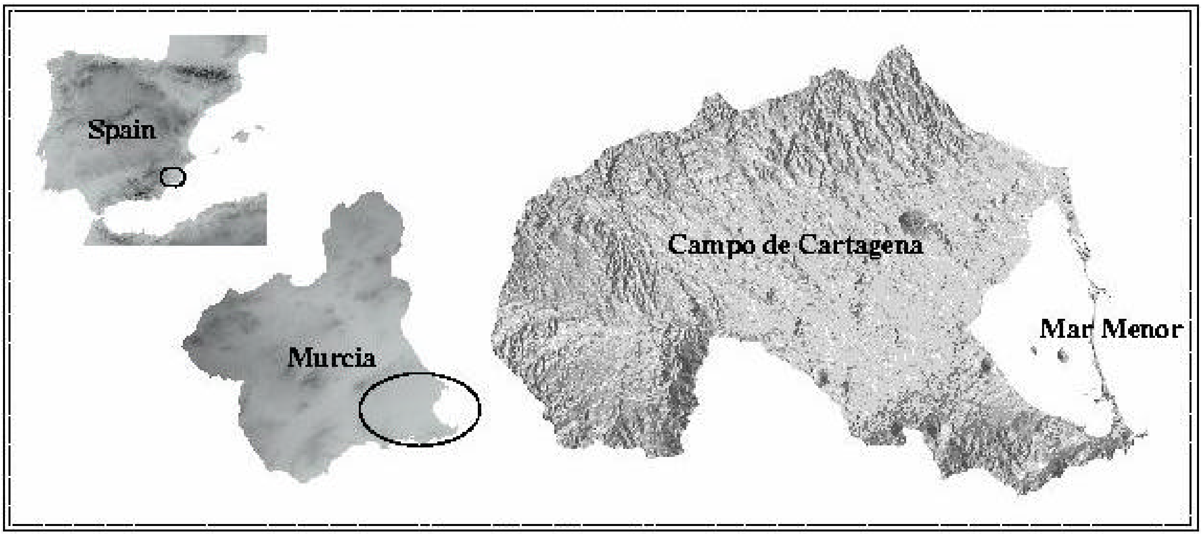

Figure 1. Location of the Mar Menor lagoon and its watershed (Campo de Cartagena)

The Tagus-Segura water transfer system, which opened in 1979, has given rise to a significant increase in the total area of irrigated lands, characterised by a very intensive use of fertilisers, at the expense of drylands. As a result, there has been a significant increase in nitrogen and phosphorus loads reaching the Mar Menor lagoon-associated wetlands complex.

Population in the area of influence of Mar Menor has shown a very high increase since the last four decades due to the expansion of tourist and residential activities. There is also a strong seasonal dynamic, leading to very high increase of total population during summer, which generates problems to manage wastes.

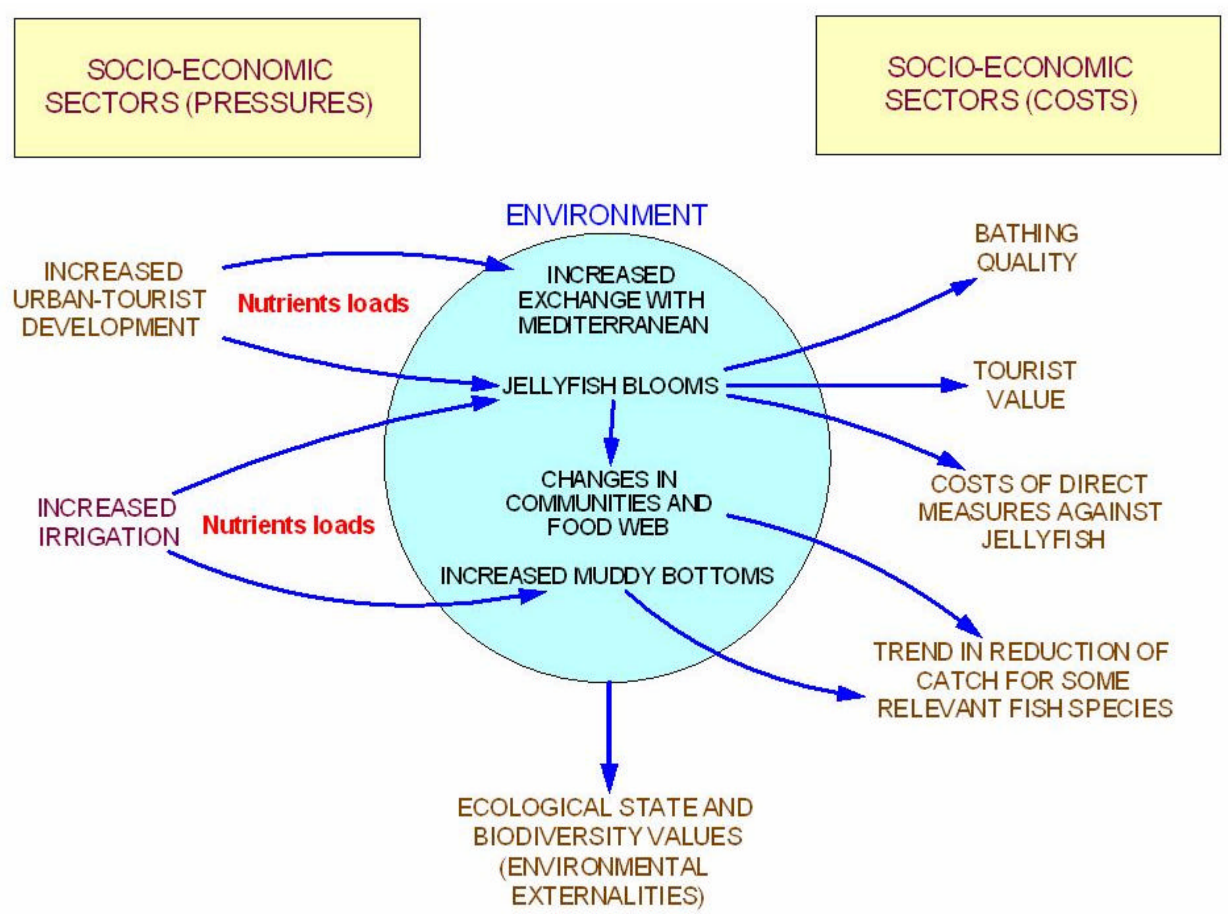

Figure 2. Crossed impacts between the relevant socio-economic activities in the Mar Menor area, connected through the ecological state of the lagoon.

Agriculture and urban-tourist activities did not generate only environmental impacts, which might be considered as environmental externalities, but also crossed effects among socio-economic activities, connected through environment. Figure 2 shows these crossed economic impacts among agriculture, urban development, tourism and fishing, connected via the ecological changes taking place in the lagoon. All these crossed effects emphasise the need for an integrated assessment of available options and policies for Mar Menor sustainability .

Methods

Identification and simulation of management options

Key processes and relevant Mar Menor scenarios

The Mar Menor is characterised by oligotrophic waters but during the last years there are clear symptoms of an initial eutrophication process affecting the ecological functioning of the lagoon, the state of several bird assemblages but also the bathing quality and the tourist activities. The latter are linked to summer jellyfish blooms, a first signal of this eutrophication process, impacting the tourism and economic costs to implement several mitigation measures.

The scenarios of highest interest in the Mar Menor site are those related with or having a potential effect on the main socio-economic activities and on the ecological state of the lagoon, whose conservation state according to the current legal status, has to be preserved. These aspects (agriculture, tourism and environmental values) are particularly linked via the load of nutrients into the lagoon, one of the key factors driving the long-term evolution of the ecological conditions of the lagoon. This is not unexpected, since nutrient fluxes appear as one of the main processes to be taken into account in the analysis of scenarios for the sustainability of coastal zones and transitional waters, as showed by an increasing number of studies (Wit and Bendoricchio, 2001; Scheren *et al*., 2004; Jessel and Jacobs, 2005). Selected scenarios belong to the PT (Policy Target) and BAU (Business As Usual) type of scenarios, as established in the EUROCAT project (Ledoux and Turner, 2002) and adopted by DITTY project. The comparison between the BAU and PT scenarios will allow a full assessment of the main management options. These scenarios have been identified and characterised taking into account opinions and points of view of stakeholders and decision makers, especially the Confederación Hidrográfica del Segura, the water management institution. These scenarios give rise to a series of effects that are frequently interconnected. Figure 3 shows such interconnected effects. The table 1 presents a synthetic description of the relevant Mar Menor scenarios.

Agricultural intensification. This BAU scenario assumes that current trends of increases of irrigated land area and of resident and tourist population will be maintained along the next 10 years. Therefore, all parameter values of models have remained unchanged.

Table 1. Synthetic description of relevant Mar Menor scenarios

Scenario	Type	Description
Agricultural intensification	BAU	Current trends of increases of irrigated land area and of resident and tourist population will be maintained along the next 10 years
Urban-tourist development	BAU	Urban development will accelerate during the next years due to the spread of golf-resorts, increasing the urban pollution
Re-use of agricultural drainages	PT	Expected effects of the hydraulic works built up to collect a part of the agricultural drainage to be re-used for irrigation.
Recovery of wetlands for nutrient removal	PT	Re-connection of the water flow of the Albujón watercourse with the Marina del Carmolí wetland, increasing the active wetland area

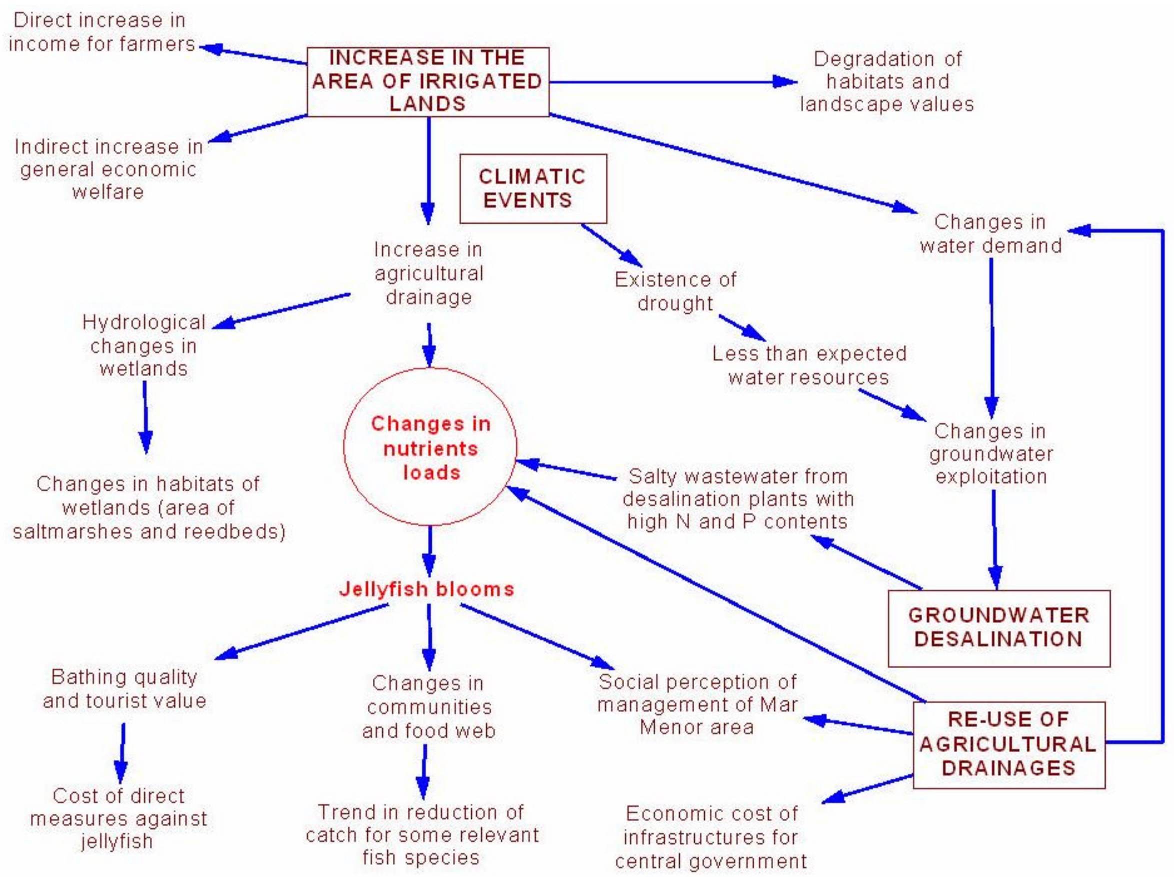

Figure 3. Interconnected effects of four scenarios for Mar Menor site: increase in the area of irrigated lands; climatic change, groundwater desalination and re-use of agricultural drainages. All these scenarios generate changes in nutrient load into the lagoon and therefore may potentially affect the jellyfish blooms.

Urban-tourist development. During the last years the urban development has been maintained at a high rate. In this BAU scenario it is assumed that this trend will accelerate during the next years respect to the previous scenario, due to the quick spread of new urban and tourist development in the form of golf-resorts. In fact, this shift is already observed since 2003. The golf-resort model for residential use is quickly spreading over the Mar Menor watershed. There are around 16 golf-resorts at different stages of construction or planning process, each one of them including between 800 and 2,000 new houses. The most likely trend of "business as usual" scenario is therefore characterised by a high rise in the rates of land-use change into urban areas and in that of resident and tourist population growth. Because of the lack of integration among policies, all these new urban-tourist developments would increase the urban pollution reaching the lagoon.

Re-use of agricultural drainages. This PT scenario concerns the expected effects of several hydraulic works built up by the Confederación Hidrográfica del Segura (CHS), the water management institution, to collect a part of the agricultural drainage coming from the irrigated lands. This drainage water, rich in nutrients, would be pumped to a desalination plant, after which it would be re-used for irrigation. The objectives of this project are the removal of a part of the agricultural pollution reaching the lagoon and the increase in the available water resources for irrigation. The implementation of management options as those considered in the policy-target scenarios, does not imply that trends characterising “business as usual” scenarios do not apply. Therefore, the management option of re-use of agricultural drainage has been implemented over the assumptions of the basic BAU scenario, this is, the Urban and Tourist Development. In this way, expected results taking into account basic trends with and without the concerned management option can be compared and conclusions obtained on a more useful and realistic basis.

Recovery of wetlands for nutrient removal. The Mar Menor coastal wetlands, located along the boundary between the lagoon and the watershed (figure 4), constitute a key element to retain and eliminate nutrients and organic matter coming from Mar Menor watershed. This natural functionality is especially important in case of big rainfall events generating floods, which represent a significant fraction of the total load of nutrients into the lagoon. Under big rainfall events and overland flow, the nutrients accumulated in the watershed are mobilised through floods which cannot be managed by means of any drainage system. Therefore, wetlands are playing a key role to increase the residence time of flows and to remove a significant fraction of the nutrients mobilised during flood events, role which might be enhanced.

The man-induced alterations in watercourses crossing these wetlands have in some occasions reduced their capacity to retain the agricultural non-point pollution. The proposed management option under this PT scenario focuses on the re-connection of the water flow of the Albujón watercourse, the main ephemeral channel, with the Marina del Carmolí wetland. This requires to increase the active wetland area of Marina del Carmolí by recovering a part of the area previously lost due to its land-use change into irrigated land.

As in the previous case, this scenario also includes the assumptions of the basic BAU scenario of Urban and Tourist Development. This PT scenario is based on the recovery of part of the Marina del Carmolí wetland area lost during the past decades due to land-use changes. This would re-establish the connection between the Albujón watercourse, the main watercourse, and the Marina del Carmolí, so the nutrient removal functionality of this wetland can be fully applied to the Albujón water volumes, both in case of base flows and in case of big storms and floods. This management option only applies to the Albujon sub-basin. Despite of this, the effect on final DIN loads might still be of interest, since the Albujon sub-basin represents almost half of total water volumes from surface water coming from the watershed.

It has also been carried out a first cost-effectiveness analysis (CEA), applied to the valuation of the two policy-target scenarios sharing the final objective of achieving a significant reduction of nutrient load into the Mar Menor lagoon. CEA studies have also been applied in other studies on the performance and efficiency of using wetlands versus conventional measures to treat pollution processes (Baker, 1991, Zanou *et al.*, 2003).

Models for scenario simulation

The scenarios have been simulated and explored using the hydrological and the integrated watershed models developed for the Mar Menor site. In the following paragraphs, a synthetic description of these models and their main variables is presented.

Hydrological model

The Mar Menor hydrological model is a physically based, spatially distributed (2D) model. It runs on hourly and daily time steps, according to the process. A 25 m grid resolution is used to perform calculations whereas final outputs are provided with a semi-distributed resolution (sub-basins). It has been specifically developed to fit several objectives. First, it was necessary to simulate the hydrological behaviour of a large watershed over long time periods (several years) and taking into account continuous processes, such as irrigation and evapo-transpiration. All this requires a daily time step. Second, it was necessary to adequately cope with the rainfall pattern of Mediterranean arid areas, as the Mar Menor site.

This requires simulating rainfall events and, hence, an hourly time step is necessary. Therefore, the developed model integrates an event-based approach (in case of rainfall episodes) within a continuous time approach which constitutes the general frame for the model. Developed in R language code, it also integrates geospatial databases and tools. The table 2 presents the main input and output variables of the hydrological model.

Figure 4. Wetlands associated to the Mar Menor lagoon (in yellow).

Table 2. Main input and output variables of the hydrological model of Mar Menor site.

Main Model Inputs	Main Model Outputs
Rainfall time series	Daily water volume inside watercourses per sub-basin
Radiation time series	Daily overland flow per sub-basin
Temperature time series	Daily deep percolation per sub-basin
Land-use maps for several years	Daily average soil moisture per sub-basin

Integrated watershed model.
The Mar Menor watershed model (Martínez *et al.*, 2005a) is a dynamic system model developed to simulate the main socio-economic and environmental factors driving the dynamic of nutrient loads into the lagoon. It focuses on a long-term time horizon, allowing a simulation time span of twenty years on a daily basis. The model has a spatially semi-distributed structure corresponding to the sub-basins of the hydrological model. Several sectors have been considered, accounting for the nitrogen and phosphorus dynamics, the land-use changes between natural areas, irrigated-tree crops, open-air horticultural crops, greenhouses and urban areas, the role of wetlands on nutrient removal and the nutrient loads from urban sources and wastewater. Dynamic system models integrating environmental and socio-economic processes have revealed especially useful in the understanding and analysis of scenarios in these type of systems (Saysel *et al*, 2002; Guneralp and Barlas, 2003).
Main model inputs are provided by the basic outputs of the hydrological model: daily series of water flow inside watercourses, overland flow in case of floods and deep percolation per sub-basin. Figure 5 presents a simplified diagram of main model sectors.

Spatial and temporal scales
The scenarios have been analysed and explored at watershed scale, the relevant scale for management and planning purposes. However, some specific issues have been analysed at a smaller scale, such as the scenario of wetland recovery , since it affects only one specific sub-basin and the specific wetland of Marina del Carmolí. The time span for all scenarios was the period 2004-2015, for which long term daily series of simulation results under each scenario have been obtained. Temporal patterns, final values for 2015 and average values for the period 2004-2015 for main model outcomes were obtained and analysed.

The DPSIR approach
The DPSIR (driving forces, pressures, state, impact, responses) approach constitutes a standard framework for an integrated approach to analyse inter-linked environmental and socio-economic processes and their associated indicators. Its wide application includes the integrated assessment of water pollution in transitional waters and the assessment of agricultural impacts on water quality under the WFD (Newton *et al.*, 2003; Scheren *et al.*, 2004; Zalidis *et al.*, 2004; Giupponi. and Vladimirova, in press).
The table 3 presents a preliminary application of the DPSIR scheme to the most relevant socio-economic and environmental issues in the Mar Menor site, whose main linkages and crossed effects were shown in figure 2. The DPSIR scheme shows that nutrient load into the lagoon constitutes the key factor linking most of driving forces, impacts and responses. The main identified driving forces are the agriculture intensification, the urban and tourist development, the groundwater desalination and the occurrence of severe meteorological events (droughts and floods).
Some responses to perceived impacts are being in course of implementation. This is the case of the designation of the watershed as Vulnerable Area to Nitrate pollution, the implementation of

an Agricultural Good Practices Code and the improvement of wastewater treatment plants. Other responses, such as the re-use of water coming from agricultural drainages and the recovery of wetlands for nutrients removal remain as not implemented.

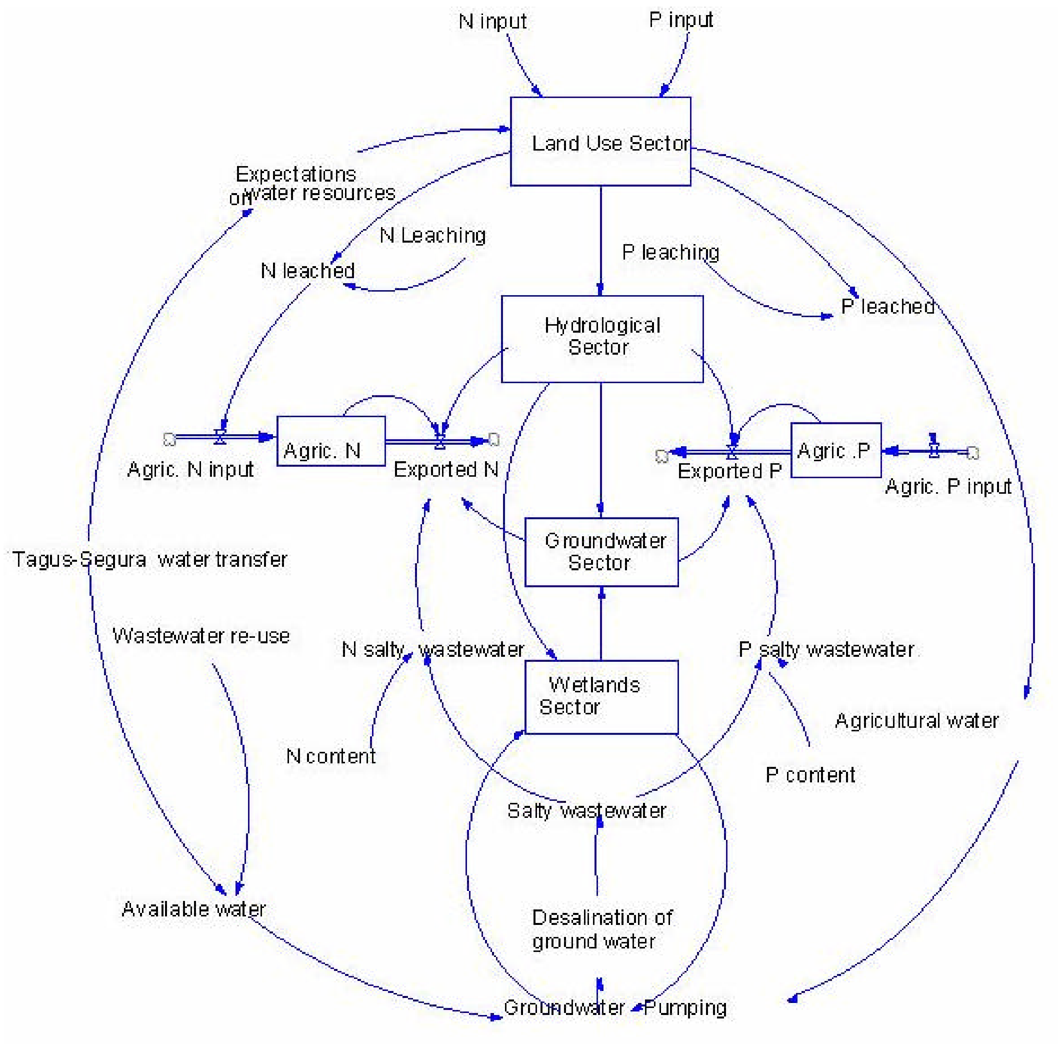

Figure 5. Simplified diagram of main sectors of the integrated watershed model of Mar Menor.

Results and discussion

Base rainfall series for the period 2004-2015 have been extrapolated following a pattern similar to the observed values during the period 1970-2003. While expected model outputs for specific days during the scenario simulation period would be of little interest, yearly averaged values, final outputs and average values for the whole simulation period (2004-2015), depending on the nature of the variable under consideration, have been taken into account.

BAU1. Agricultural intensification

Total irrigated lands and open-air horticultural crops keep increasing, although at a reduced rate, until the end of the simulation period. The area of greenhouses increases at the similar high rate observed during the period 1970-2000 (figure 6), since it is the type of irrigated land with the highest profitability.

Table 3. Relevant driving forces in the Mar Menor site following the DPSIR sheme.

Driver	Pressure	State	Impact	Response
Agriculture intensification: Increase in irrigated lands Increase in greenhouses	Water consumption Groundwater exploitation Aquifer salination Load of fertilisers	Area of irrigated lands Piezometric levels Content of DIN and DIP in water	Changes in the hydrological dynamics of the watershed Increased load of nutrients Lagoon eutrophication Summer jellyfish blooms Negative effects on tourism	Designation of watershed as Vulnerable Area to Nitrates Implementation Agricultural Good Practices Code Re-use of water coming from agricultural drainages Recovery of wetlands for nutrients removal
Groundwater desalination for irrigation	Groundwater consumption Generation of salty wastewater with high content of nutrients	Amount of salty wastewater from water desalination plants Content of DIN and DIP in salty wastewater	Increased load of nutrients into the lagoon Lagoon eutrophication Summer jellyfish blooms	Restoration of natural wetlands Management of natural saltmarshes to treat salty wastewater
Urban and tourist development: Increase in seasonal population New urban developments New tourist facilities	Freshwater consumption Soil sealing Increase in wastewater	Permanent population Seasonal population Area occupied by urban and tourist facilities Amount of wastewater	Loss of natural habitats Landscape degradation Load of nutrients Lagoon eutrophication Summer jellyfish blooms Negative effects on tourism	Improvement of wastewater treatment plants
Climatic events: Changes in rainfall Increased frequency of great rainfall events	Floods Runoff of water discharges	Content of DIN and DIP in water	Increased load of nutrients Changes in wetlands	Wetlands Restoration Increase in area occupied by natural vegetation in the watershed

Simulated resident and seasonal (peak tourist population during July and August) population around the Mar Menor lagoon during the simulation period keeps growing at observed trends. Resident population, reaches a value of 66,000 persons at the end of the simulation period while seasonal population (figure 7) reaches 415,000 persons, representing a 70% and 100% increase respect to observed values in 2003.

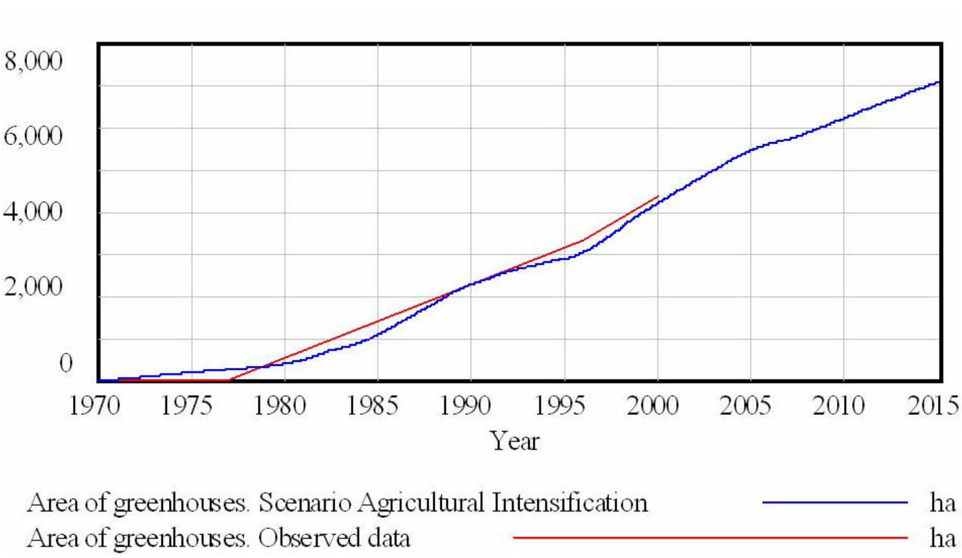

Figure 6. Area of greenhouses under the agricultural intensification scenario. Observed and simulated data series in the period 1970-2003 are also shown.

Results show high fluctuations of daily DIN loads from watercourses and overland flow to wetlands-Mar Menor lagoon complex. These fluctuations are associated to the high variability on rainfall and the occurrence or not of floods. The annual average value during the period 2004-2015 would be around 1,400 ton year^{-1}, which represents a 50% increase with respect to the average value during the period 1999-2003.

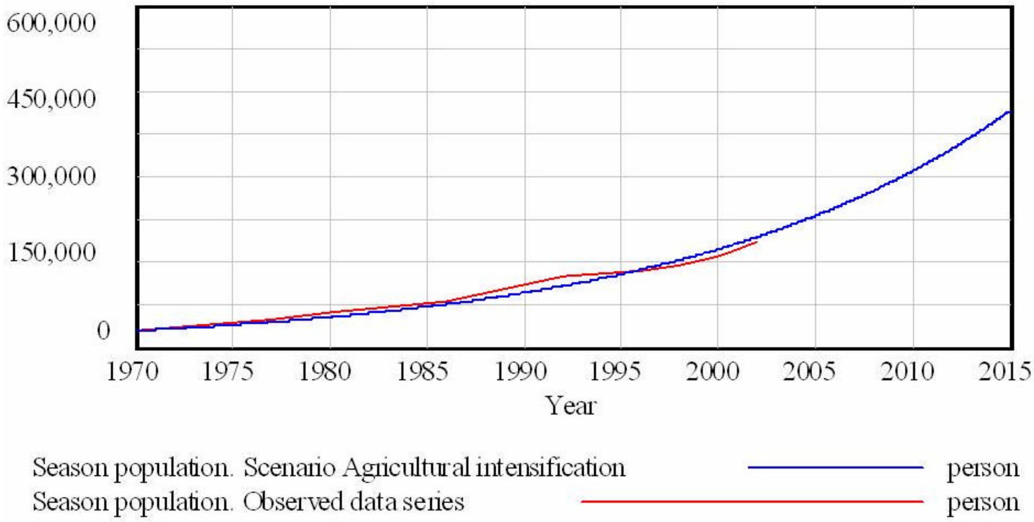

Figure 7. Seasonal population around Mar Menor under the agricultural intensification scenario. Observed and simulated data series in the period 1970-2003 are also shown.

Figure 8 shows the pattern of DIN loads using a 365 days moving average period. DIP load also shows a rising trend under the agricultural intensification scenario, from an average annual value of 268 ton year^{-1} during the period 1999-2003 to a value close to 385 ton year^{-1} during the period 2004-2015, representing a 43% increase. Figure 9 shows the overall effects of wetlands on the final load of DIN coming from surface waters. Actual wetlands retain in average around 200 ton year^{-1} of DIN during the 2004-2015 period, which represents 14% of the DIN of watercourses and overland flow.

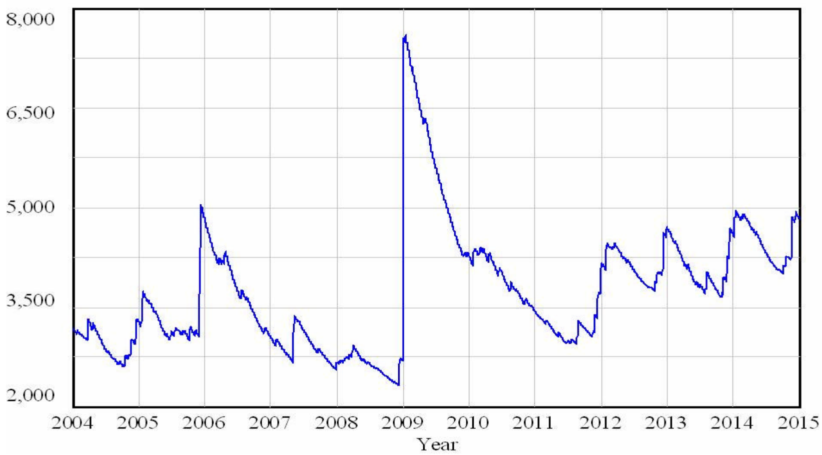

Figure 8. Pattern of daily DIN load (kg day^{-1}) using a 365 days moving average period from surface water to the complex Mar Menor lagoon-associated wetlands, under the scenario Agricultural intensification.

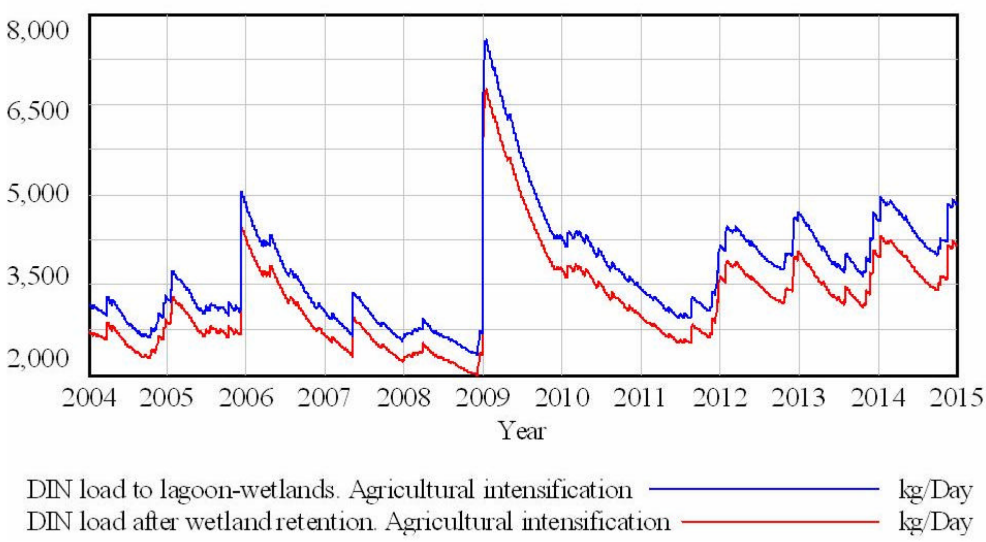

Figure 9. Pattern of daily DIN load to the lagoon coming from surface water using a 365 moving average period. Loads with and without the retention effect of wetlands are showed.

Regarding nutrient loads to the lagoon from urban sources, figure 10 presents the results obtained under the scenario of agricultural intensification, in which the growth of resident and tourist population is maintained at similar rates to those observed in the past. Figure 10 reveals a quite marked seasonal dynamics in DIN load from urban sources due to the synergistic effect of several factors, mainly the high peak of tourist population during July and August, which substantially increases the total amount of wastewater, and the induced overload of the wastewater treatment plants, which generates a steep fall in overall performance of the treatment plants and frequent breakdowns, leading to direct spillages into the lagoon. An increasing trend of DIN and DIP urban loads along the 2004-2015 period, especially during the peaks of summer months, is also shown. The simulated average annual DIN load from urban sources during the 2005-2015 period reaches 200 ton year^{-1}, which represents a 57% increase with respect to the corresponding simulated value during the 1999-2003 period. In the case of DIP, the average annual load is 26 ton year^{-1}, representing a 52% increase respect to the 1999-2003 period.

When all nutrient sources are considered (surface water flows, groundwater flows and urban sources), the average annual total DIN load into the lagoon during the period 2004-2015, under the scenario Agricultural intensification, would be around 1,560 ton year^{-1}, a value 45% higher than the simulated one corresponding to the 1999-2003.

It has been explored the sensibility of the model to some key parameters, in particular those defining the base rate of increase of the three types of irrigated lands. It has been carried out a Montecarlo simulation where these three parameters were simultaneously varied taking random values within a range 50% higher and lower than the corresponding base values. Figure 11 shows the results of the Montecarlo simulation for DIN load. Under a 100% variation of the rate of increase in irrigated lands, in 2015 the range of expected DIN load represents only a 22% variation respect to the output under the base model parameters. This shows the existence of non-linearity’s due to the role of the negative feedback loops of the model and its relative robustness to some parameter changes.

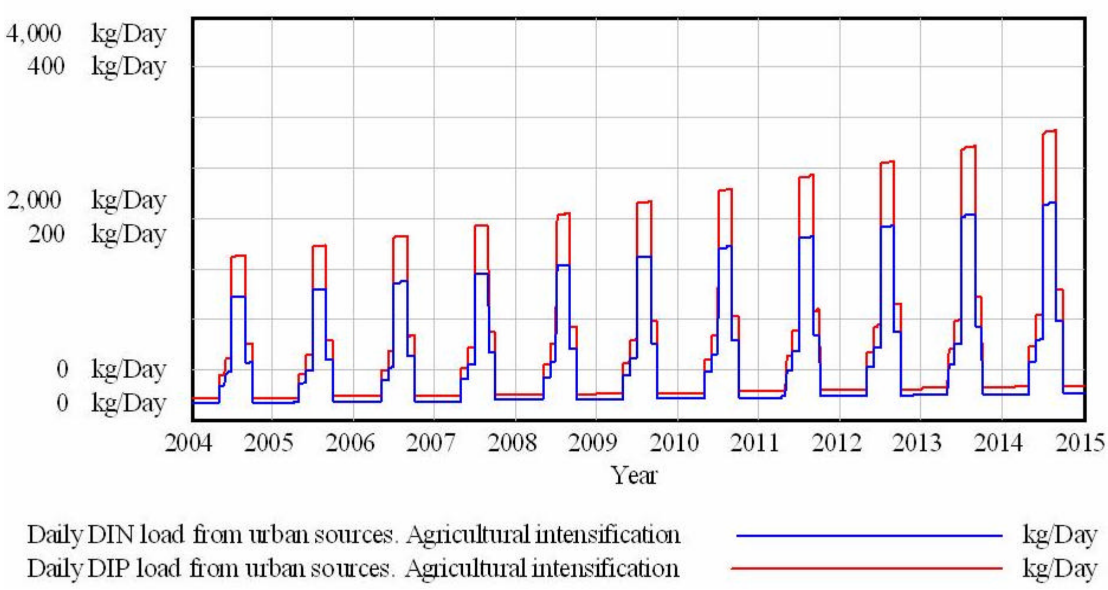

Figure 10. Daily load of nutrients into the Mar Menor lagoon from urban sources under the scenario Agricultural intensification. DIN load appears in the scale 0-4,000 kg day^{-1} while DIP appears in the scale 0-400 kg day^{-1}.

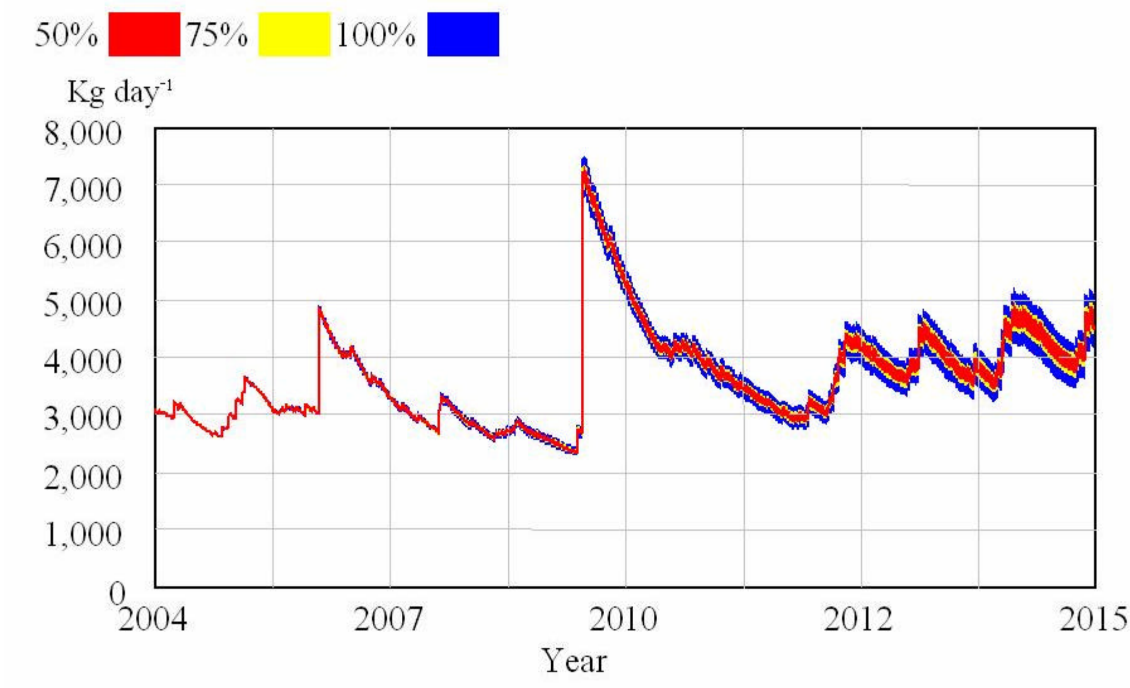

Figure 11. Results of the Montecarlo simulation for daily DIN load under a 100% variation of the rates of increase in irrigated lands. The figure shows the confidence bounds of 50%, 75% and 100% of results obtained with 200 simulation runs.

MM-BAU2. Urban and tourist development

This BAU scenario is characterised by a sudden shift in dominant trend of land-use changes, from a high rate of increase in irrigated lands to a very high rate of increase in urban areas.

Under this scenario there is a high rise in resident and seasonal population. The average annual values of urban DIN and DIP loads during the period 2004-2015 reaches 270 and 35 ton year^{-1} respectively. However, when all DIN sources are taken into account (surface water, groundwater and urban sources), both BAU scenarios generate quite similar final results.

The expected 50% increase in average annual loads of nutrient with respect to present situation would aggravate the initial eutrophication process in the lagoon and might lead to dramatic changes in its ecological state if water transparency diminish enough to cause a massive collapse of *Caulerpa prolifera* beds and a subsequent oxygen depletion phenomena (Lloret *et al*., 2005). In addition, it has been established clear relationships between the long-term trend of nutrient loads into the Mar Menor lagoon and the response of the aquatic birds assemblages, favouring opportunistic species such as grebes while other species as *Mergus serrator*, a typical piscivorous bird, showed some decline (Martínez *et al*., 2005b). The expected increase in the load of nutrients under the scenario of urban and tourist development would further promote these trends of change in the waterbirds communities.

MM-PT1. Re-use of agricultural drainage

This policy-target scenario represents the effective implementation of planned measures and infrastructures to collect, pump, desalinate and re-use agricultural drainages for irrigation. Figure 12 shows the expected results on DIN loads from surface water after the retention effect of wetlands. The figure compares results obtained under the BAU scenario of Urban and Tourist Development and under the policy-target scenario of Re-use of Agricultural Drainage. When the management option of re-use of agricultural drainage is implemented, the average annual DIN load from surface water during the period 2004-2015 is close to 1,029 ton year^{-1}, which represents a value 11% lower than the BAU scenario. Taking into account all DIN sources, final DIN load represents a 8.5% reduction respect to the BAU scenario.

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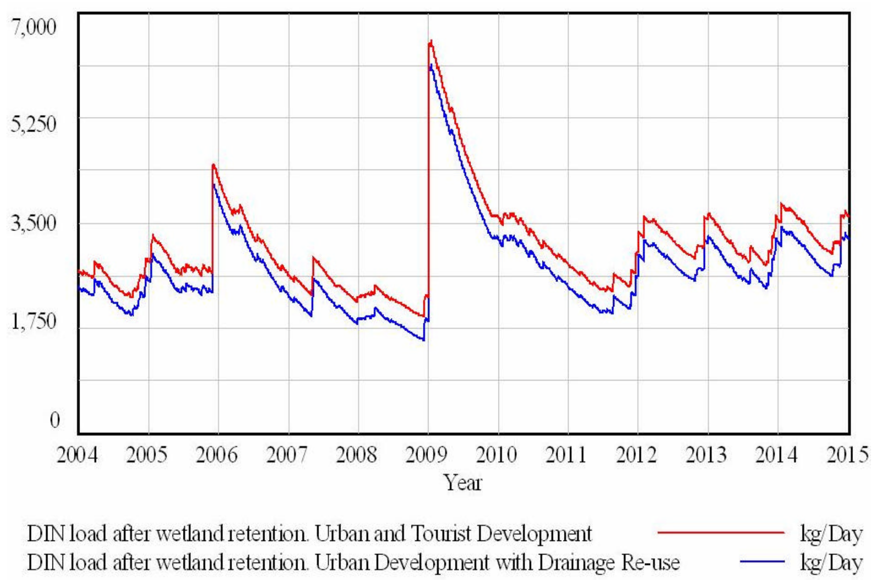

Figure 12. Pattern of daily load of DIN from surface water using a 365 days moving average period. Simulation runs under the BAU scenario (Urban and Tourist Development) and under the policy-target scenario (Urban Development with Drainage Re-use) are shown.

MM-PT2. Recovery of wetlands for nutrients removal

Figure 13 presents the results obtained for the Albujón sub-basin for the DIN loads from surface water under the BAU and the Recovery of Wetlands scenarios. In this sub-basin this management measure represents for DIN loads a reduction of 42% respect to the BAU scenario. This reduction would be very relevant for the ecological state of the Mar Menor lagoon, since the clearly defined gradients of water column transparency and nutrient concentrations in the lagoon, responsible for important changes in the macrophytes assemblages from the dominance of the phanerogam *Cymodocea nodosa* to the benefit of the macroalga *Caulerpa prolifera*, are associated to the inputs from the Albujón watercourse. The observed changes in the macrophytes assemblages have other consequences for the lagoon dynamics, such as the accumulation of organic matter under the meadows of *Caulerpa prolifera*, the subsequent appearance of anoxic conditions in some areas and the decrease in the populations of some commercial fish, mainly sparidae and mugilidae, negatively affected by the spread of the macroalga (Lloret *et al*., 2005). Hence, a significant reduction of the nutrient inputs from the Albujón watercourse might imply a substantial improvement of the ecological state of the Mar Menor lagoon.

When all sub-basins are considered, the management option of recovery of wetlands still represents a significant reduction of 23% respect to DIN load from surface water under the BAU scenario. This reduction is twice that obtained under the other policy-target scenario of re-use of agricultural drainage. This is also the case when all DIN sources are considered. Clearly, the impact of the management option of recovery of wetlands on the reduction of total DIN loads into the Mar Menor lagoon is higher when compared with the other PT scenario.

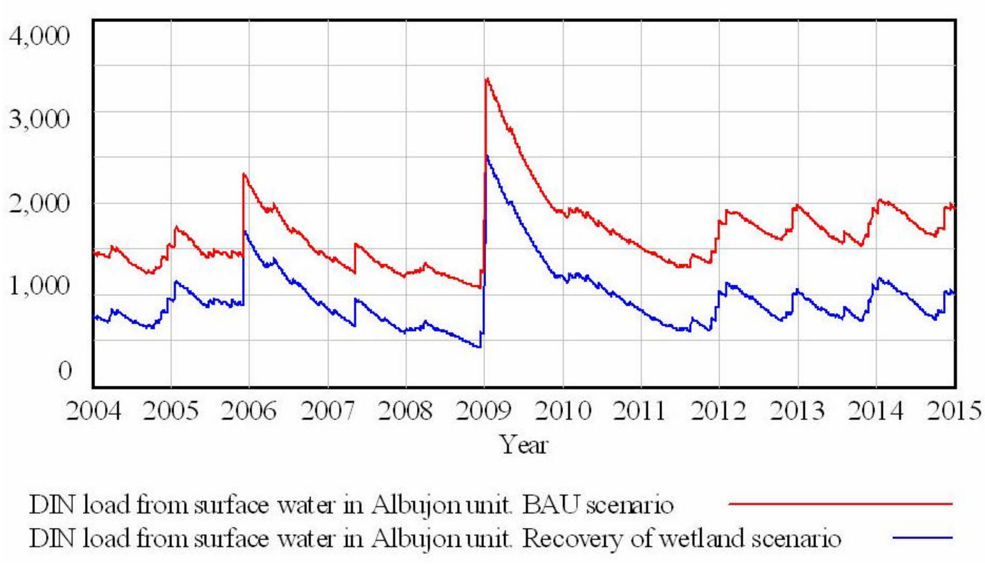

Figure 13. Pattern of daily DIN load from surface water in the Albujon sub-basin using a 365 days moving average period. Results under the BAU scenario and under the recovery of wetland scenario are shown.

Another question of interest regarding the two considered policy-target scenarios is about the relative efficiency of such management options in terms of cost-effectiveness. This question has been addressed through a cost-effectiveness analysis, focusing on the unitary costs of both management options per unit DIN and DIP load being removed. The scenarios Re-use of Agricultural Drainage and Recovery of Wetlands have been compared by means of the cost-effectiveness ratio (CER) (Zanou *et al.*, 2003). The table 4 shows the unitary costs of removing DIN and DIP under both scenarios.

Table 4. Total cost and cost-effectiveness ratio (CER) of removing DIN and DIP loads into the lagoon under both PT scenarios. In the case of the re-use of agricultural drainage, results with and without including the costs of the primary drainage channels are shown.

Scenarios ($€_{2005}$)	Total Cost (15 years)	CER DIN (€/kg)	CER DIP (€/kg)
MMPT1. Re-use of agricultural drainage	14,839,086	10.31	28.842
MMPT1. Without costs of primary drainage channels	11,192,156	7.78	21.753
MMPT2. Recovery of wetlands	3,364,554	1.94	5.525

The results obtained indicate that the unitary costs of removing DIN under the recovery of wetlands scenario is around four and five times lower than the corresponding values under the re-use of agricultural drainages scenario. This is true even if only two flood events are taken into account and the construction costs of the primary drainage channels are not included. These results agree with other studies (Gren *et al*., 1997; Turner *et al*., 1999; Gustafson *et al*., 2000), showing that the construction and specially the recovery of wetlands is a highly cost-effective option to reduce diffuse pollution in agricultural watersheds.

These results constitute a relevant input for the management institution (CHS), since they offer new and useful insights and criteria for the decision-making process. These new elements, which up to date had not been considered by CHS, arise from the assessment of the expected effects upon nutrient load into the lagoon under different management options and from the assessment of the relative efficiency of allocation of costs to achieve such environmental objective. In our case, the recovery of wetlands for nutrient removal is the management option achieving a higher reduction in the loading of nutrients into the lagoon in absolute terms and it is also the most cost-effective measure.

Conclusions

The load of nutrients is one of the main processes driving the long-term evolution of the ecological conditions of the Mar Menor lagoon and emerges as a key factor in all relevant scenarios and management options for the Mar Menor site.

Under the most likely BAU scenario of urban and tourist development around the Mar Menor lagoon, it is expected a high rise in resident and seasonal population which would lead to a 50% increase in the average annual load of nutrients. This would further promote the eutrophication process in the lagoon and might cause serious changes to the Mar Menor lagoon, affecting not only its ecological state and biodiversity values, but also current socio-economic activities, especially tourism and fishing.

The full implementation of the management option of re-use of agricultural drainages would allow around a 10% reduction in the nutrient loads into the Mar Menor lagoon. This constitutes a relevant output for the decision makers (CHS) since an assessment of the expected results of this management option, whose hydraulic works have already been built-up, was lacking. The use of the developed dynamic system model to simulate the nutrient dynamics and to explore the effects of different scenarios has allowed a first assessment of the effectiveness of this measure.

The recovery of wetlands constitute a better option in terms of the degree of achievement of the desired environmental goals, since the reduction in total nutrient loads doubles the one achieved by the re-use of agricultural drainages.

As revealed by the cost-effectiveness analysis, the optimisation of wetlands for nutrients removal seems to be also a more cost-effective management option as compared to the re-use of agricultural drainages, with unitary costs around four times lower.

The first results obtained confirm the usefulness of the applied approach, which will be extended to perform a more detailed analysis of management options for the Mar Menor and an extended cost-effectiveness analysis covering a wide range of hypothesis and options under the policy-target scenarios. Such extended analysis of scenarios will be used in combination with a Decision Support System specifically being developed for the Mar Menor site, to guide the decision makers for a more sustainable management of the Mar Menor lagoon and its watershed.

Results also show the interest of this approach for the overall understanding of coastal lagoons and for the provision of practical inputs to the decision making process. This approach is based on the integration of models under a common framework, the adoption of a long-term horizon and the integration of the relevant environmental and socio-economic processes at watershed scale in order to simulate and analyse the expected effects under a set of scenarios.

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