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.

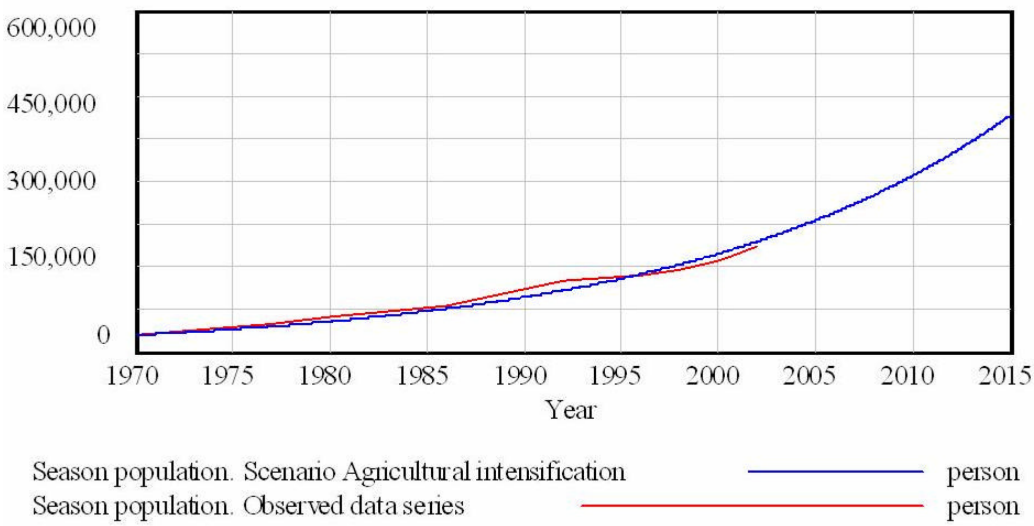

Figure 7. Seasonal population around Mar Menor under the agricultural intensification scenario. Observed and simulated data series in the period 1970-2003 are also shown.

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.

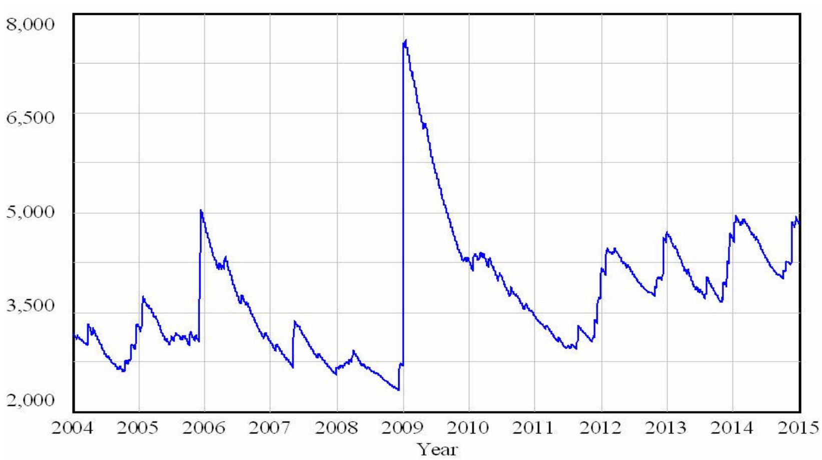

Figure 8. Pattern of daily DIN load (kg day^{-1}) using a 365 days moving average period from surface water to the complex Mar Menor lagoon-associated wetlands, under the scenario Agricultural intensification.

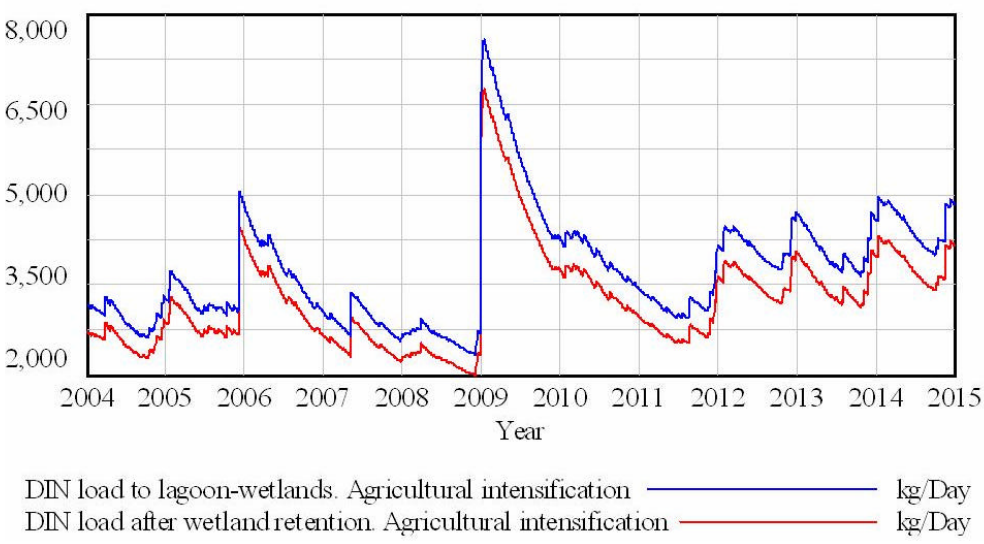

Figure 9. Pattern of daily DIN load to the lagoon coming from surface water using a 365 moving average period. Loads with and without the retention effect of wetlands are showed.

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.

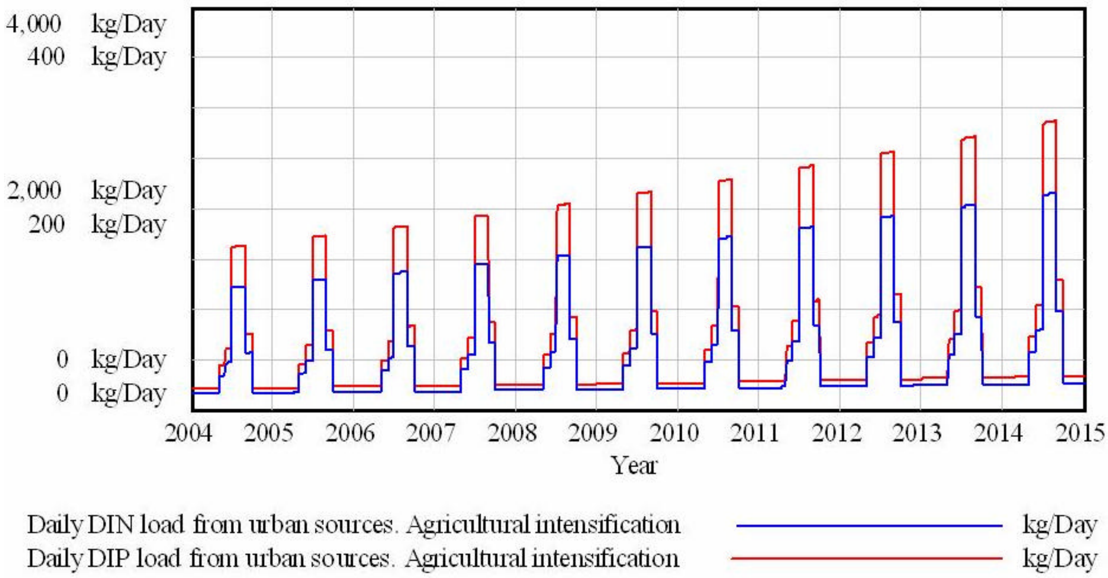

Figure 10. Daily load of nutrients into the Mar Menor lagoon from urban sources under the scenario Agricultural intensification. DIN load appears in the scale 0-4,000 kg day^{-1} while DIP appears in the scale 0-400 kg day^{-1}.

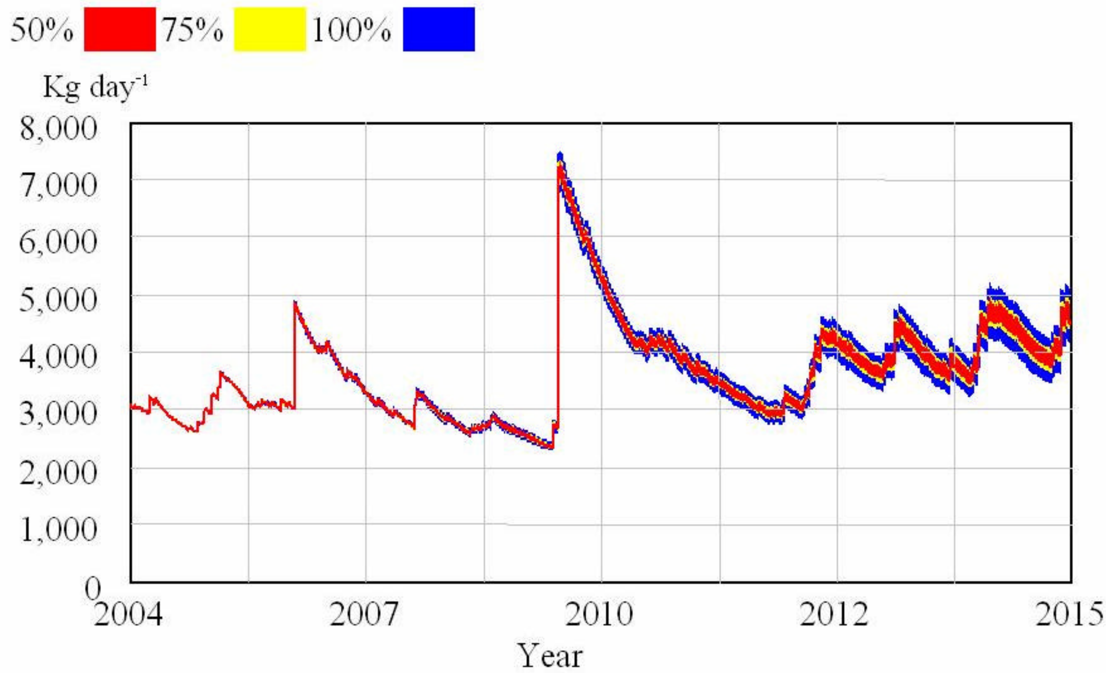

Figure 11. Results of the Montecarlo simulation for daily DIN load under a 100% variation of the rates of increase in irrigated lands. The figure shows the confidence bounds of 50%, 75% and 100% of results obtained with 200 simulation runs.

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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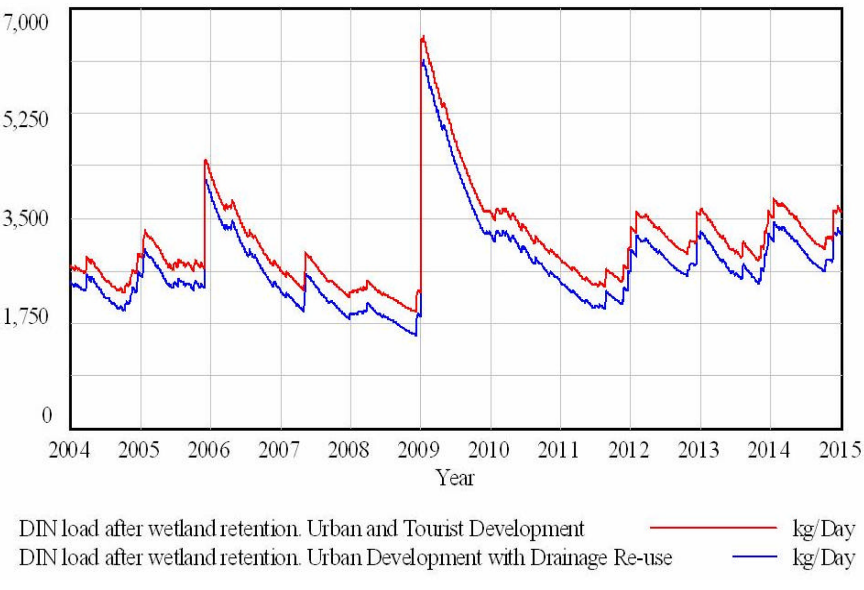

Figure 12. Pattern of daily load of DIN from surface water using a 365 days moving average period. Simulation runs under the BAU scenario (Urban and Tourist Development) and under the policy-target scenario (Urban Development with Drainage Re-use) are shown.

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.

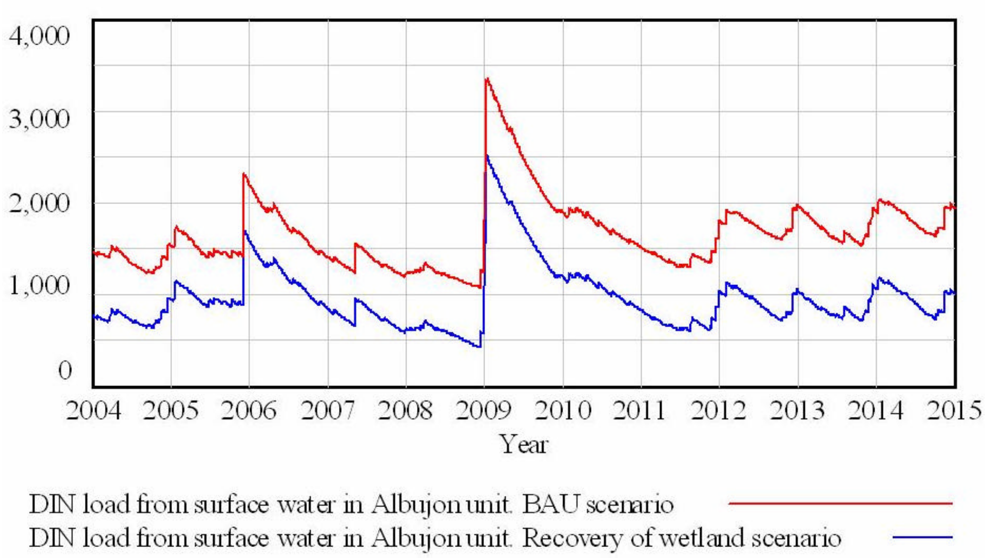

Figure 13. Pattern of daily DIN load from surface water in the Albujon sub-basin using a 365 days moving average period. Results under the BAU scenario and under the recovery of wetland scenario are shown.

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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The collaboration of CHS providing the technical documentation of management measures is also gratefully acknowledged.

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