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Definition of Environmental Objectives in Relation with Nitrate Pollution in the Aquifers of Spain. Simulation Model and Scenarios used.

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Abstract: Nitrate pollution in groundwater (GW) is a major problem in European Union that also affects a large number of GW bodies in Spain. The Spanish Ministry of Environment, and Rural and Marine Affairs has defined environmental objectives for each GW bodies of Spain in relation to pollution by nitrates, for water planning horizons, 2015, 2021, 2027. These objectives have been made available to the Spanish River Basin Authorities (RBAs) to support the elaboration of River Basin Management Plans established by the European Water Framework Directive (EC, 2000). The definition of nitrate concentration objectives in the groundwater bodies has been performed by means of the construction of a distributed hydrological model with water quality for all Spanish territory, using the Patrical model. The effect of three fertilizer application scenarios on nitrate concentrations has been assessed with this simulation model: 1) baseline scenario that corresponds to maintain the current fertilization; 2) optimal scenario, which is the application of the nitrogen optimal dose that requires a strong economic investment through the application of techniques such as fertigation; 3) trend reversal and improvement scenario that is an intermediate stage between the two previous ones, which includes the development of the action plans defined in current vulnerable areas and it is the more plausible scenario in the short to medium term. The results obtained and provided to RBAs are: the GW bodies that will reach the objective in the year 2015, when nitrate concentration is lower than 50 $mgNO_3/l$ in that year and also do not have a growing trend; the GW bodies that require extended deadline until 2021 or 2027; and the GW bodies that need to establish less stringent objectives, due to that is not possible to obtain a nitrate concentration lower than 50 $mgNO_3/l$ in 2027, even with the implementation of fertilizer optimal doses.

Keywords: Nitrate pollution on groundwater bodies, WFD objectives, water balance model, large river basins.

1 INTRODUCTION

Water pollution by nitrates degrades the natural environment and prevents water use for urban purposes, or requires installation of expensive water treatment systems. The European Water Framework Directive (WFD) (EC, 2000) aims to achieve the good status for all water bodies by 2015, which implies the implementation of all water quality directives, such as the Nitrates Directive (EC 1991). The Nitrates Directive forms integral part of the WFD and is one of the key instruments in the protection of waters against agricultural pressures.

In this paper are defined the environmental objectives in relation to nitrate pollution for each one of the groundwater (GW) bodies in Spain. It is established if it reaches the objective in 2015, if it is required extend deadline until 2021 or 2027, or if the compliance is not possible and requires the establishment of less stringent objectives, and also, the needed measures to obtain these purposes. This task was performed using the simulation of three future fertilizers application scenarios with a simulation model of the hydrologic cycle and water quality, the Patrical model (Pérez-Martín, 2005), which is fitted to historical data.

This work uses a common methodology to the entire territory of Spain that it is based on the application of a hydrologic simulation model with water quality: firstly, it is analyzed the current nitrate concentration trends in the groundwater bodies and secondly, it is assessed the nitrate concentration forecasting for three scenarios with different degrees of mitigation measures implementation.

The obtained results have been made available to the River Basin Authorities (RBAs) to support the current elaboration of River Basin Management Plans (RBMPs) established by the WFD (MARM, 2009).

2 METHODOLOGY

The developed methodology (figure 1) is based on the use of the distributed model that simulates the nitrate transport through the hydrologic cycle, the Patrical model, applying it with different pollution scenarios. Patrical model provides monthly nitrate levels in surface waters and GWs of the river basin. The model uses the annual data of nitrogen surplus, which has been obtained in previous studies by means of the nitrogen balance in soil at municipal level (MARM, 2008). The surplus is the result of the nitrogen balance on soil. The nitrogen inputs on soil mainly come from the agriculture and livestock, and also from atmospheric deposition, biological fixation, nitrogen in water and seeds. The nitrogen outputs on soil are: the plant uptake, the volatilization and the denitrification. The nitrogen surplus obtained at municipal level is distributed within the municipality by means of the land use map, the Corine Land Cover (CLC, 2000).

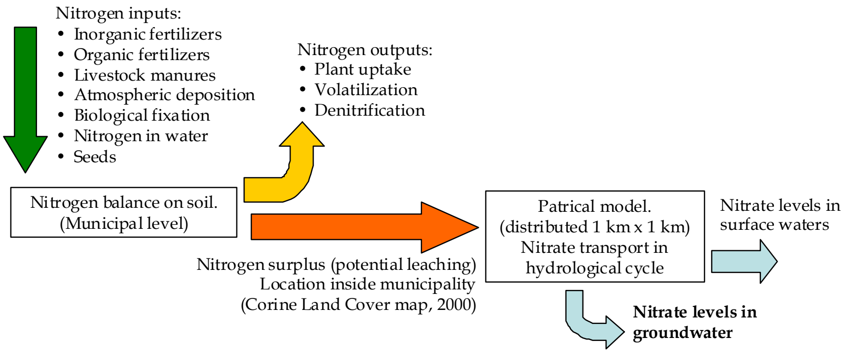

Figure 1. Methodology to obtain nitrate levels in rivers and aquifers.

To set the environmental objectives is analyzed the forecasting of nitrate levels in the GW bodies or in the parts of the GW where it has been divided, the sectors, for three fertilizer application scenarios until the year 2027. The scenarios are:

1) Baseline scenario, which corresponds to maintain the current fertilization.
2) Optimal scenario, which is the application of the nitrogen optimal dose that requires a strong economic investment through the application of techniques such as fertigation.
3) Trend reversal and improvement (TR&I) scenario, which is an intermediate stage between the two previous ones, which includes the development of the action plans defined in current vulnerable areas and it is the more plausible scenario in the short to medium term.

The first two scenarios provide an interval of future nitrate concentrations for each water body, in the case of maintaining current practices or in the case of implementing advanced and expensive systems, taking into account the inertia of aquifers. Within this range the third scenario provides a preliminary forecast of the future nitrate concentration with the application of the action plans in vulnerable areas defined by the Nitrates Directive (figure 2).

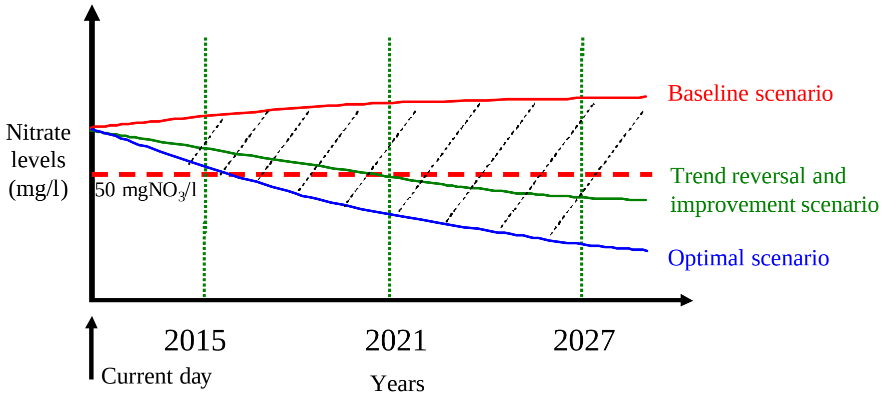

Figure 2. Methodology to establish the compliance of the objectives.

3 RESULTS AND DISCUSSION

3.1 Pollution Pressure

The data of non-point source (NPS) pollution come from the annual nitrogen balance on soil at municipal level for the period between years 1996 to 2006 (MARM, 2008), which is the expansion of the annual balance elaborated for the year 2004 at municipal scale in Spain (MAPYA, 2005). The result of this balance is the nitrogen surplus in each municipality.

Nitrogen surplus in 2004 is estimated at 823,000 tN (tN tones of nitrogen) (figure 3). The main NPS pollution (table 1) is the use of inorganic fertilizers in the agriculture (48%), which is followed in importance by: atmospheric deposition (15%), organic fertilizers in the agriculture (14%) and livestock manures (14%), and biological fixation (10%). The plant uptake efficiency is around 51%, 1.2 10^6 tN respect to the total input of nitrogen 2.38 10^6 tN, and the nitrogen surplus represent the 35% of total nitrogen inputs, which corresponds with an average pressure of 21.7 kgN/ha of crops and pastures. Finally, this pressure represents a mean of 16.1 kgN/ha respect to the total land area.

Table 1. Nitrogen balance on soil in Spain for the year 2004 (MAPYA, 2005).

Nitrogen inputs	tN	%	kg/ha	Nitrogen outputs	tN	%	kg/ha
Inorganic fertilizers	1.105.400	48%	29,2	Plant uptake	1.200.000	83%	31,7
Atmospheric deposition	361.900	15%	9,5				
Organic fertilizers	347.100	14%	9,2	Volatilization	265.300	16%	7,0
Livestock manures	330.100	14%	8,7				
Biological fixation	166.400	7%	4,4	Denitrification	17.800	1%	0,5
Nitrogen in water	43.000	2%	1,1				
Seeds	26.700	1%	0,7				
TOTAL	2.380.000		62,8	TOTAL	1.557.400		41,1
Nitrogen surplus					823.200		21,7

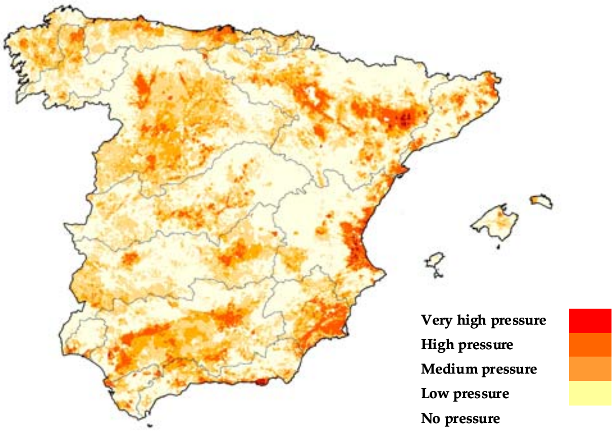

Figure 3. Nitrate surplus pressure in Spain for the year 2004.

The expansion of 2004 balance to the period between years 1996 to 2006 shows that, the mean inputs ranges from 55.5 to 62.8 kgN/ha of crop and pastures, the mean outputs are between 44.1 and 33.1 kgN/ha depending on crop production each year, and the mean nitrogen surplus varies between 24.6 and 17.6 kgN/ha of crop and pastures (figure 4). As example, in years 2005 and 2006 there were the same input value but the nitrogen total output was the result of the amount of annual crop production, and then, the nitrogen surplus was different on each year.

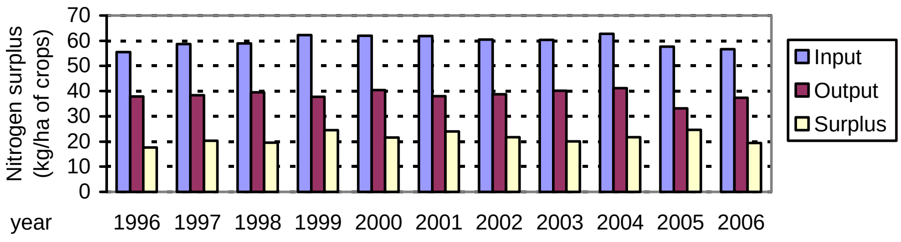

Figure 4. Mean input, output and nitrogen surplus in Spain in the period 1996-2006 (kgN/ha of crops and pastures).

Spain is one of the countries with lower nitrogen pressure of Europe, the average EU-15 gross nitrogen balance in 2000 was estimated at 55 kgN/ha (EEA, 2005), varying from 226 kgN/ha in Netherlands or 224 kgN/ha in Belgium and 37 kgN/ha in Italy or France, 25 kgN/ha. However, due to the rainfall in Spain is lower than other countries and then the water flows are lower, this pressure produces high nitrate concentrations and especially in the GW bodies. To analyze this effect is required the use of a water balance model with water quality

3.2 Simulation Model

Patrical model simulates the hydrological cycle in altered regime by human activities. The results of river flows and water storages have been calibrated with the observed data of circulating flows in rivers and groundwater levels in the GW bodies (figure 5) during the period from October 1971 to September 2006.

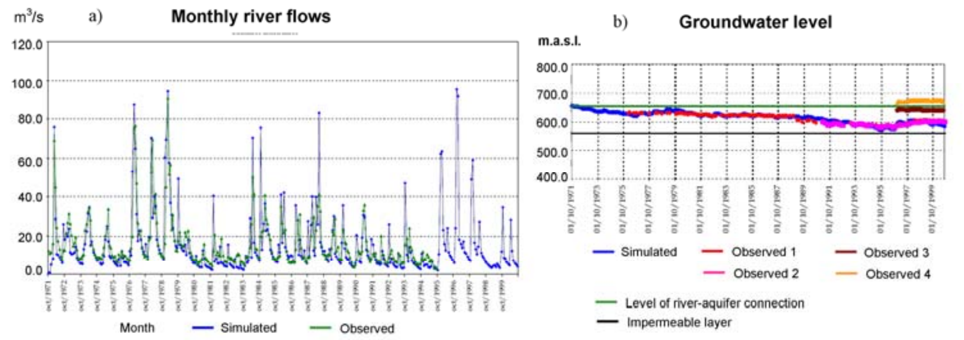

Figure 5. Observed and simulated river flows (m^3/s) in "*Entrepeñas*" reservoir in the Tajo River Basin District (RBD) (a) and GW levels (m.a.s.l) in the Western "*Mancha*" in the Guadiana RBD (b).

The nitrate transport simulation has been calibrated at the same period of time, fitting the results of nitrate concentration in rivers and aquifers to observed data (figure 6), also it is included the level 50 (nitrate concentration) that indicates no good status and 37.5 level that indicates risk of no good status according to nitrates directive.

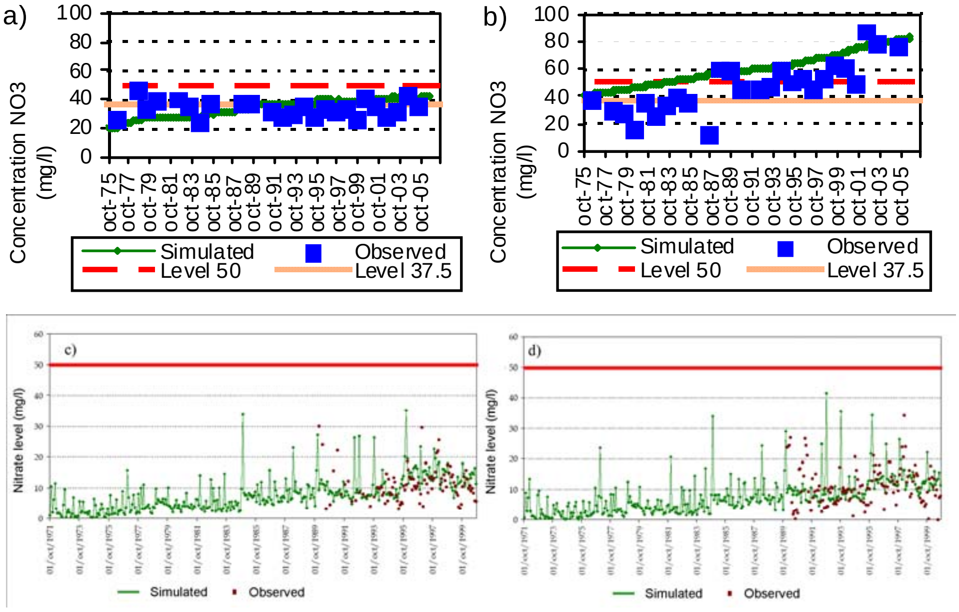

Figure 6. Nitrate concentration ($mgNO_3/l$) observed and simulated in the GW bodies of "*Villafáfila*" (a) in the Duero RBD and "*Campo de Cartagena*" (b) in the Segura RBD. Nitrate concentration in the rivers of "*Pisuerga*" (c) and "*Duero*" (d) in the Duero RBD.

3.3 Nitrate Forecasting

The nitrate levels forecasting in groundwater bodies has been developed by means of the simulation of three scenarios with different doses of fertilization that are characterized by: 1) Baseline scenario, the nitrogen surplus is the average of 2000-2005. 2) Optimal scenario, where the application of optimal doses in all municipalities is considered. 3) TR&I scenario, where is considered the implementation of the action plans in current vulnerable areas.

Mean pressure (table 2) varies between 22.3 kgN/ha of crops in the baseline scenario to 14.9 kgN/ha of crops in the optimal scenario, placing the investment scenario in a intermediate case with 18.8 kgN/ha of crop. The optimal scenario corresponds with a 19% reduction in the inputs, which produces a 33% of reduction in the nitrogen surplus, while the TR&I scenario represents a inputs reduction of 7% that produces a 16% reduction in nitrogen surplus.

Table 2. Summary characteristics of the scenarios considered.

Scenario	Baseline	Optimal	TR&I
Nitrogen inputs (tN) (a)	2.305.500	1.873.200	2.142.000
Nitrogen outputs (tN)	1.461.800	1.310.200	1.431.300
Nitrogen surplus (tN) (b)	843.600	563.000	710.700
Relative surplus (b/a)	37%	30%	33%
Local Nitrogen pressure (kgN/ha of crops and pastures)	22,3	14,9	18,8
General Nitrogen pressure (kgN/ha)	16,5	11,0	13,9

Historical and forecasting nitrate levels are obtained for each groundwater body (figure 7). The combination of these results allows to determine if is possible or not achieve the environmental objectives on schedule.

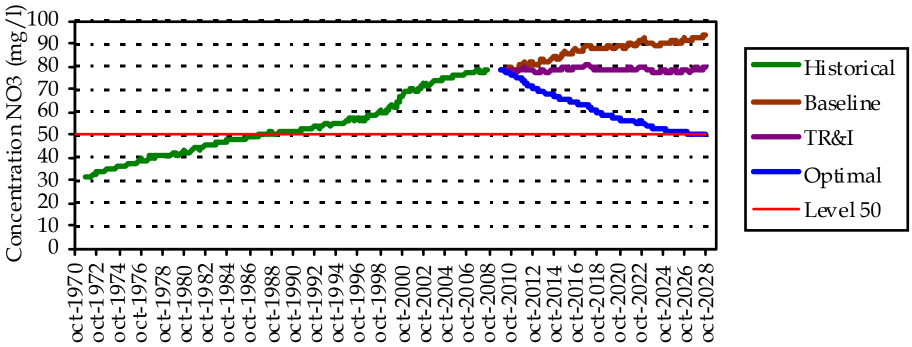

Figure 7. Nitrate levels simulated for each scenario in the GW body "*Raña del Órbigo*" in the Duero RBD.

Combining the results of the three scenarios is obtained that 558 GW bodies, or sectors of GW body, reach the objective in 2015 with current agricultural practices. The rest of GW bodies, 196, require the setting up of action plans to reduce nitrate levels (table 3).

Table 3. Final state of GW bodies and measures needed to achieve it.

Scenario	Baseline	TR&I	Optimal	**Final status**
Reach the objective in 2015	558	60	82	**618-640**
Extend deadline until 2021	0	7	22	**7-22**
Extend deadline until 2027	0	57	45	**57-45**
Stringent objectives	0	72	47	**72-47**
Total GW bodies modelled	558	196	196	**754**

In the case of TR&I scenario application (figure 8a) 72 GW bodies will require the establishment of less stringent objectives, due to the high inertia of aquifers not allow to reach nitrate levels below 50 mg/l in the year 2027. In the case of applying significant investments to implement measures such as fertigation, to more significantly reduce nitrogen surplus, the number of GW bodies that require the establishment of less stringent objectives would be 47 (figure 8b).

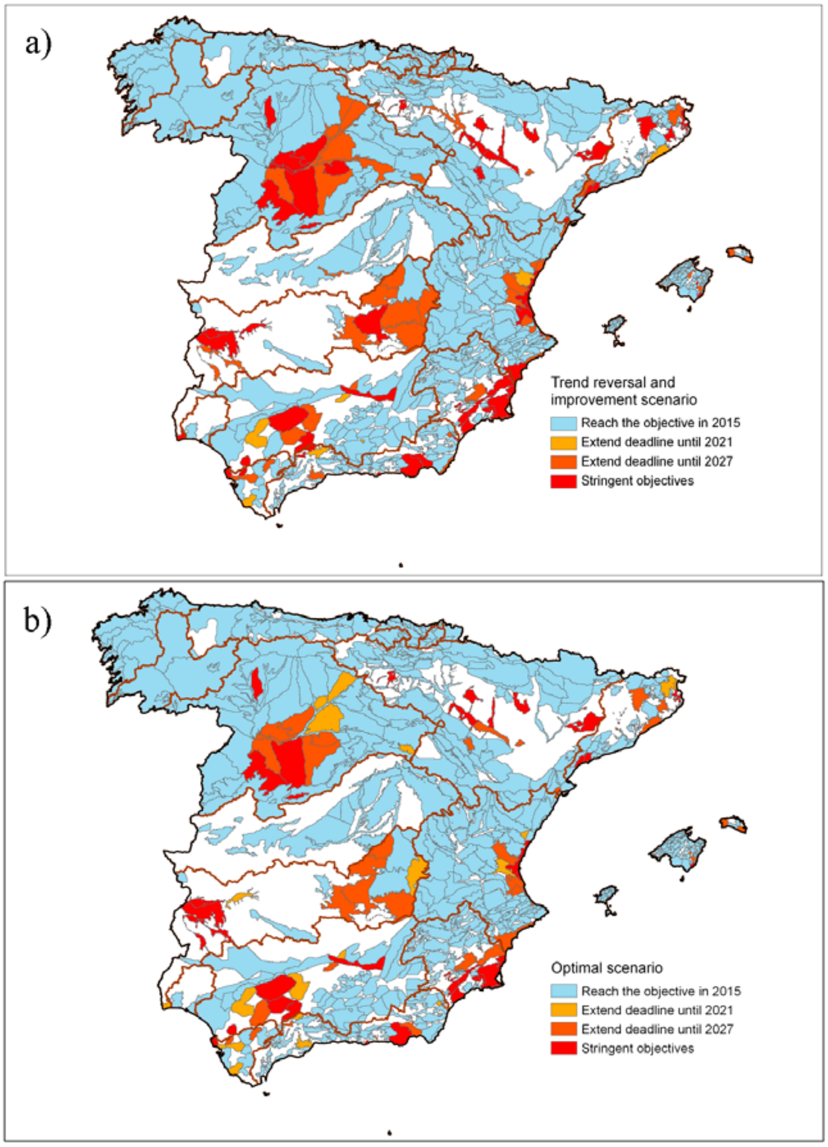

Figure 8. Final state of GW bodies in the TR&I scenario (a) and optimal scenario (b).

4 CONCLUSIONS

The time to achieve environmental objectives in each GW body depends on many factors, including: the aquifer characteristics, the water renewal time in the aquifer and the type of mitigation measures applied. To evaluate the effectiveness of the measures to be applied and the time necessary to achieve the objective is necessary to use simulation models that consider all these factors.

This analysis is based on the use of a distributed simulation model of the hydrologic cycle with water quality, the Patrical model, to assess nitrate levels in each groundwater body in three scenarios of fertilizer application. The results have established the water bodies that will reach the objectives in 2015, with current agricultural practices, and the groundwater bodies that require the implementation of action plans, which will allow to some of them to achieve the objective in 2015 or in subsequent extensions to 2021 or 2027, while the rest would require the definition of less stringent objectives. The results obtained have identified those GW bodies that may not reach the objective in 2027 and therefore require more detailed analysis.

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