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Nonpoint pollution in Aragon: emission loads and control issues

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Abstract

This paper evaluates nitrogen pollution loads from irrigation return flows in the Spanish region of Aragon. Percolation and nitrogen leaching estimates are found for each municipal area based on crop surface, irrigation systems, climate, and crop management data. Aggregate nitrogen discharges at watershed and county level are then calculated and compared with results published in monographic studies and nitrate concentrations in watercourses.

This paper aims to contribute to future proposals of the Water Framework Directive for nitrate pollution abatement measures. The relevance of this issue is increased by the fact that the Ministry of the Environment and various ecological organizations are under the false impression that diffuse pollution can be solved by raising water prices. Water pricing is in fact highly inefficient and severely prejudices the interests of farmers, and is thus the least desirable of all potential instruments for the control of diffuse pollution.

Key words: *Diffuse pollution, Nitrogen leaching, Percolation, Middle Ebro Valley, Water.*

1. INTRODUCTION

Concern over the environmental costs of nitrate pollution from agricultural sources has risen in recent years. Between 50 and 90 percent of the nitrate loads in EU watercourses is caused by agricultural practices (EEA 1999), in particular the overuse of nitrogen fertilizer. Additional factors, such as deficient crop management or low irrigation efficiency, have also degraded water quality in recent decades. Irrigation return flows with high nitrate concentrations have a negative effect on both the physical and chemical properties of the waters in catchment areas. The increase in nitrogen concentration, both in surface and ground water, results in the eutrophication of rivers, reservoirs, estuaries and coastal waters.

It is hard to assess the impact of nitrogen pollution from irrigation on rivers and aquifers, but it may impair water quality to the point of rendering it unsuitable for other purposes. Excessive inputs may even pose an ecological and public health risk. Nutrient (nitrogen, phosphorous and potassium) enriched surface waters stimulate the growth of aquatic plants, which, as they grow, die and decompose, deplete the oxygen level in the water, thus causing death by asphyxiation to any life within it.

In 1991, the European Union drew up the Nitrate Directive in order to reduce and prevent ground water pollution from agricultural nitrate, and to protect public health and aquatic ecosystems. This Directive was incorporated into Spanish legislation in 1996. In Spain, as in other countries, however, the implementation of the Directive was quite flawed, since all the affected aquifers were not declared and the adopted measures were not very effective. The Directive sets forth guidelines to reduce aquifer pollution from nitrates and obliges governments to elaborate codes of good practices for the use of nitrogen fertilizers, with a view to curbing ground water pollution.

The consumption of nitrate-contaminated water poses a public health risk and can cause a disorder known as methemoglobinemia. Health authorities both in Spain and the European Union have set the tolerance threshold for nitrate concentration in drinking water at 50 mg NO_3^-/l.

The use of chemical fertilizers rose sharply in Europe during the second half of the twentieth century, though it leveled out in the final decades. The average use of nitrogen per hectare in countries such as the Netherlands or Belgium is above 150 kg/ha, while the Spanish average is 68 kg/ha, which is close to the E.U. average of 70 kg /ha. Excess nitrogen in the soil averages 40 kg/ha in Spain, which is well below the 215 kg/ha of the Netherlands and the 100 kg/ha of Belgium and Germany (EEA 2003).

Overuse of nitrogen fertilizers in Spain is a major problem in intensive irrigation areas, such as the Mediterranean coast and some of the Castilla La Mancha, Ebro and Guadalquivir watersheds, where nitrate concentrations range between 50 and 100 mg NO_3^-/l. Aragon registers its highest levels in the alluvial aquifer of the Ebro river and the upper course of the Ebro, where it flows through Zaragoza, taking in water from the Gallego and Huerva tributaries and return flows from irrigation ditches. With a view to reducing diffuse pollution, it is important to estimate the pollution load from irrigation returns to surface waters, and assess the damage to fluvial ecosystems from environmental pollution.

The need for regulation and control of water pollution from irrigation return flows in Aragon has been highlighted in Isidoro (1999) and Causape (2002). These researchers, who claim that the high level of nitrate pollution is due to inefficient irrigation and the misuse of fertilizers in irrigated areas, propose a range of alternative pollution control instruments.

2. IRRIGATION IN THE MIDDLE EBRO VALLEY

The mechanization of agriculture during the nineteen sixties brought with it an increase in the use of mineral fertilizers. The application of nitrogen fertilizer in Spain increase between 1960 and 1990 from 0.24 to 1.12 million tones, which explains the increase in nitrogen pollution in the country's watercourses.

This paper investigates diffuse nitrate pollution from irrigation return flows in Aragon, and estimates the mass transfer of nitrate for year 2002. All of the crops cultivated in the counties of Aragon were examined, taking into account the irrigation system, the area under cultivation, climate, soil type, and crop water and nitrogen fertilizer consumption.

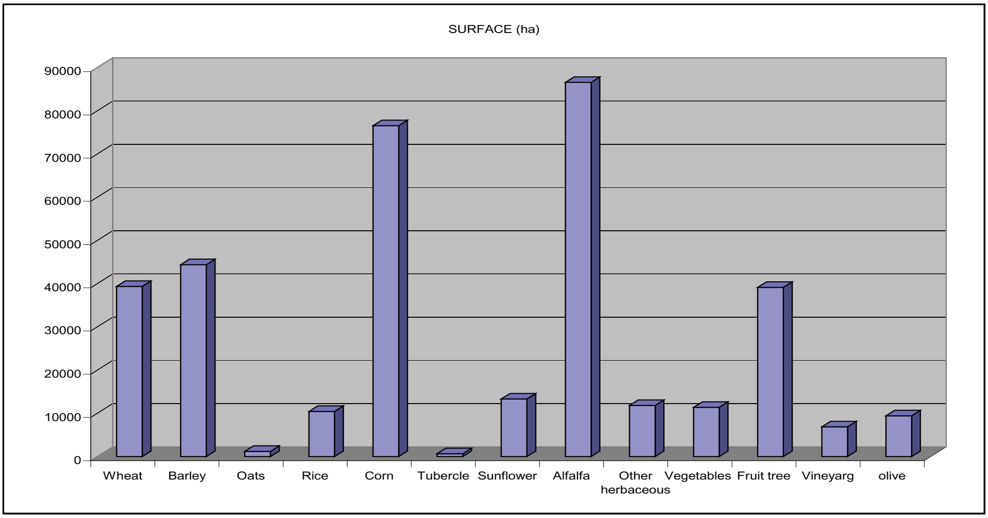
Of Aragon's thirty-three counties, the analysis covered the twenty-one that are located in the Ebro basin, where there are large expanses of irrigated crop cultivation. Some individual municipal areas have over 250 hectares under irrigation.

Aragon has several large collective irrigation networks: the Aragon and Catalonia canal, the Cinca canal, the Monegros canal, and the Bardenas canal.

The irrigation area in Aragon is up to 400.000 ha. The majority are gravity fed systems, this being the dominant form of irrigation, covering 80 percent of the total irrigation surface, while sprinkler and point source systems account for 18 and 2 percent, respectively. The newer irrigation areas use sprinkler or point source irrigation systems, which help to increase efficiency and reduce water loss and the drainage of pollutants. Irrigation efficiency is defined as the amount of water absorbed by the plants in relation to the total amount of water used to irrigate scheme.

Not all the irrigation water not absorbed by the plants is lost through surface runoff, deep percolation, and evaporation. The irrigation efficiency rates used in this paper are 0.6 for irrigation by flooding, 0.75 for sprinkling, and 0.9 for point source irrigation. The crops with the largest irrigation surface in the midcourse Ebro valley are alfalfa, corn, barley and wheat.

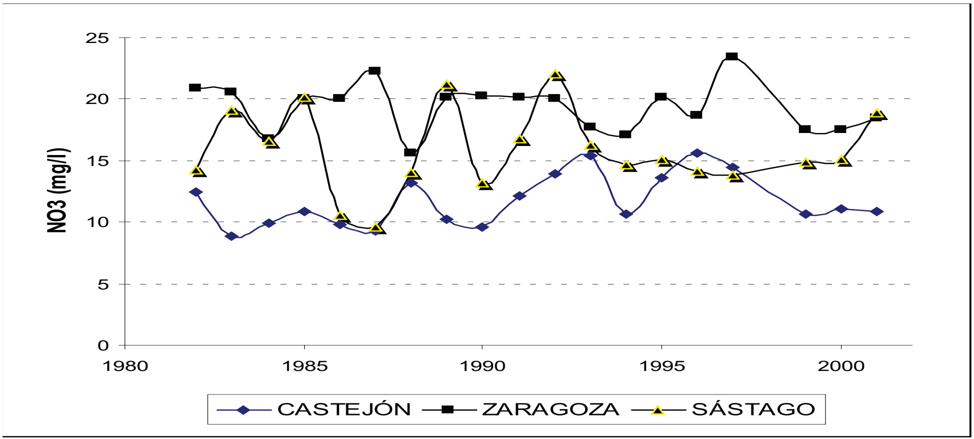
Figure 1. Distribution of total irrigation surface by crop type



Percolation and nitrogen leaching levels are determined by irrigation system and crop type. When nitrogen fertilizer is applied to crops, some is taken up by the crop, some accumulates in the soil, some is lost in volatization, and some through drainage by percolation or surface runoff. Water courses are polluted by nitrate discharges from percolation and runoff.

A model was created to assess the level of nitrate pollution in the midcourse Ebro valley by estimating nitrogen discharge loads. Figure 2 gives the evolution of nitrate concentrations in Castejon, Zaragoza and Sastago for the period 1982-2001. The lowest concentrations are found in Castejon and the highest in Sastago and Zaragoza, though average levels remain below 50 mg NO3 /l.

Figure 2. Nitrogen concentration in river Ebro (1982-2001).



3. PERCOLATION AND NITROGEN LEACHING LEVELS

The variables involved in the amount of nitrogen leached by crops include crop type, soil type, climate, fertilizers, and crop growth management. In this paper, nitrogen leaching from crops is estimated by means of the EPIC (Environmental Policy Integrated Climate, Mitchell et al. 1996) crop growth package. This enables us to simulate the relationship between crop growth in the soil, the amount of irrigation water applied, climate, crop type and crop growth management. This produces an estimate of the percolation volume and nitrogen leaching level. The EPIC package was chosen because of the major advantage offered by its being especially designed to examine environmental factors. The results yielded by the EPIC package were validated with experimental data[1].

1. Farmer surveys and field tests were used in the validation (Martinez 2002).

Table 1. Nitrogen fertilization and leaching by irrigation system and crop type.

Irrigation system	Sprinkle		Gravity		Drip	
Crop	Nitrogen fertilization	Nitrogen Leaching	Nitrogen fertiliza-tion	Nitrogen Leaching	Nitrogen fertiliza-tion	Nitrogen Leaching
	kg $N\text{-}NO_3^-$	kg $N\text{-}NO_3^-$/ha	kg N-NO3$^-$	kg $N\text{-}NO_3^-$/ha	kg N-NO3$^-$	kg $N\text{-}NO_3^-$/ha
Wheat	150	17	150	31	-	-
Barley	150	12	150	22	-	-
Corn	400	70	400	180	-	-
Sunflower	100	6	100	22	-	-
Alfalfa	75	21	75	31	-	-
Rice	-	-	200	50	-	-
Tomato	-	-	200	25	200	15
Green pea	-	-	100	25	100	15
Apple	-	-	100	25	100	15
Pear	-	-	100	25	100	15
Peach	-	-	100	25	100	15
Grape	-	-	100	25	100	15
Olive	-	-	100	25	100	15

Table 1, which presents the nitrogen fertilization and leaching data per crop and irrigation system, shows that corn not only uses the highest quantity of nitrogen fertilizer per hectare (400 kg $N\text{-}NO_3^-$/ha) but also covers the largest irrigation surface. Nitrogen leaching level from irrigation return flows in Aragon averages 41 Kg $N\text{-}NO_3^-$/ha. In the paragraphs that follow we will present the nitrogen percolation and leaching data by county and watershed.

3.1 Results by county

Table 2 shows the results for each county considered, including irrigation surface, volume of water applied, percolation volume, and nitrogen leaching level.

The Monegros county has the highest irrigation water consumption, followed by Cinco Villas, Zaragoza and Cinca Medio, which has a large irrigation surface. The Bajo Cinca county also consumes a considerable amount of water because of the large surface used for fruit crops (peach, pear and apple).

Table 2. Results by country

County	Surface (ha)	Irrigation (hm^3)	N Leaching (Tm N-NO$_3^-$)	Percolation (hm^3)	N Leaching (kg N-NO$_3^-$/ha)	Percolation (m^3/ha)
Cinco Villas	65.625	345	2.362	134	36	2.034
Hoya de Huesca	22.775	134	941	42	41	1.829
Somontano	15.711	65	541	19	34	1.236
Cinca Medio	36.287	218	1.038	75	29	2.076
La Litera	27.605	170	819	51	30	1.85
Monegros	76.042	544	3.601	186	47	2.444
Bajo Cinca	30.389	194	925	55	30	1.826
El Moncayo	3.915	18	191	7	49	1.816
Campo de Borja	10.075	64	481	25	48	2.483
Ribera Alta	14.823	107	879	42	59	2.812
Valdejalón	15.062	74	464	21	31	1.407
Zaragoza	30.882	275	1.951	106	63	3.419
Ribera Baja	11.938	85	471	29	39	2.431
Caspe	9.029	51	251	18	28	1.975
Calatayud	4.607	34	194	12	42	2.675
Cariñena	5.655	20	153	5	27	839
Belchite	2.937	9	68	3	23	925
Bajo Martín	4.881	27	113	10	23	2.106
Calamocha	5.484	23	195	9	36	1.585
Bajo Aragón	7.342	44	427	17	58	2.331
Teruel	7.975	25	210	8	26	1.061
Total Aragón	409.039	2.526	16.273	874	40	2.137

Alfalfa and rice have a high water requirement, which explains the high consumption levels exhibited by Monegros, Cinco Villas and Zaragoza. The highest per hectare water consumption levels are registered by Zaragoza, Calatayud and Monegros and the lowest by Campo de Belchite and Teruel.

Percolation is linked to water consumption, the largest percolation volumes being found in Monegros, Cinco Villas, Zaragoza and Cinca Medio. Since percolation also depends on crop type and irrigation system, there are counties with a high volume of percolation per hectare such as the Ribera Alta del Ebro or Calatayud. Zaragoza has the highest percolation per hectare and Campo de Carinena the lowest.

In terms of nitrogen leaching, meanwhile, Monegros has the highest level, followed by Cinco Villas and Zaragoza. Top of the table with respect to nitrogen leaching per hectare are Zaragoza, Ribera Alta del Ebro and Bajo Aragon, with scores of 63, 59, and 58 kg/ha, respectively.

Observation of the data shows that the counties with the largest surfaces of corn, alfalfa or rice under irrigation by flooding are those with the highest water consumption, and thus the highest levels of nitrogen discharge.

4. RESULTS BY WATERSHED

The nitrogen leaching and percolation levels per watershed are shown in Table 3. The Ebro watershed has the highest nitrogen leaching level, both in aggregate and per hectare terms. Cinca and Arba take second and third place because of their large irrigation surface. Nitrate mass transfer per surface unit is at its highest level in Regallo, with a yearly average of 71 kg N-$NO3^-$/ha, followed by the Ebro watershed with 54 kg/ha, Gallego with 50 kg/ha, and Queiles and Flumen with 49 kg/ha. The Cinca, Ebro, Arba and Flumen watersheds have the highest percolation levels because of the large amount of irrigation water used per unit of irrigation surface.

The results for the Cinca watershed stand out from the rest shown above because of a high level of water consumption coupled with a low level of nitrogen leaching per hectare. The explanation for this is to be found in the low fertilization dosage levels used in the Cinca watershed, where the main crops are alfalfa and fruits, both of which are low in fertilizer and water requirements.

Total nitrogen leaching in the whole of the midcourse Ebro valley stands at 16.300 Tm N-NO_3^-. The Ebro watershed generates a nitrogen discharge load of 3.500 Tm N-NO_3^-, due to the large surface used for flood-irrigated corn cultivation. Discharge levels are also high in the Cinca, Arba and Flumen watersheds.

The highest percolation volume (184 hm^3) is registered by the Ebro watershed. This is largely caused by the cultivation of alfalfa, which covers 60 percent of the irrigation surface and requires large quantities of irrigation water, a high volume of which is lost through percolation.

Table 3. Results by watershed

Watershed	Surface (ha)	Irrigation (hm^3)	N leaching (Tm $N\text{-}NO_3^-$)	Perco-lation (hm^3)	Leaching (kg $N\text{-}NO_3^-$/ha)	Perco-lation (m^3/ha)
Ebro	65786	516	3.52	184	54	2.797
Gállego	10998	68	555	24	50	2.177
Cinca	107532	625	3.038	196	28	1.827
Aragón y Yesa	3239	13	68	5	21	1.534
Arba	66208	368	2.62	143	40	2.156
Alcanadre	29212	192	1.378	56	47	1.911
Guatizalema	6610	43	287	12	43	1.885
Flumen	44095	321	2.153	122	49	2.77
Queiles	3493	16	170	6	49	1.821
Huecha	7948	47	341	19	43	2.363
Jalón	25165	125	831	37	33	1.489
Manubles	933	7	26	3	28	2.707
Ginel	323	3	13	1	40	3.346
Aguas Vivas	4035	14	89	5	22	1.222
Matarraña	2540	13	72	4	28	1.562
Jiloca	14279	54	442	19	31	1.35
Martín	4000	23	102	9	25	2.204
Regallo	4542	31	323	12	71	2.678
Guadalope	8101	44	246	16	30	1.983
Total Aragón	409.039	2.526	16.273	874	40	2.137

5. COMPARISON OF EMISSION LEVELS AND POLLUTANT LOADS IN WATER COURSES

Estimates of municipal emission loads of nitrate leached through irrigation drainage in Aragon are around 16.300 tons $N\text{-}NO_3^-$. These estimates are then compared with the nitrate concentration in watercourses based on readings taken at the CHE (Ebro basin authority) measuring stations. The nitrate pollution load in watercourses is estimated by multiplying river flow by nitrate concentration based on Ebro Water Board data.

The estimated emission levels are validated by readings of Ebro River nitrate concentration taken at the Pignatelli and Asco stations, i.e. the points where the river Ebro flows into and out of Aragon.

Table 4. Nitrate loads in the Ebro and nitrogen emissions from irrigation (2002)

Measuring station	Pignatelli	Ascó	Loads
	CHE Measurement	CHE Measurement	Estimate
Water flow (hm^3)	4.840	11.132	
Water percolation (hm^3)			874
Nitrogen load (Tm $N\text{-}NO^{3-}$)	10.931	26.394	
Emission from irrigation (Tm $N\text{-}NO^{3-}$)			16.273

The nitrate emission loads from nitrates leached through irrigation drainage in Aragon should be roughly equal to the difference between the nitrate pollution load readings taken at the Pignatelli and Asco measuring stations (table 4).

Other components that add to the pollutant emissions, however, include emissions from non-irrigated crops, and nitrate loads from urban or industrial sources. Meanwhile, the transport and fate processes of nitrates leached at the source (at plots) reduce the nitrate pollution load. One example is the filtering that takes place on wetlands, which reduces the amount of pollutants arriving into watercourses. It is also worth noting that the concentration of nitrates is reduced at the Mequinenza and Ribarroja reservoirs.

In the Arba and Flumen watersheds, a comparison was made between the nitrate load carried by the two rivers and the nitrate emissions via leaching from irrigation (Table 5). There is a measure of error in the water flow estimate for the Arba watershed, due to inaccuracy in the Ebro basin authority estimation of the Arba river flow. The nitrate load estimate for the Arba is roughly the same as for the emissions from irrigation in the watershed.

The estimated annual nitrate load for the River Flumen, meanwhile, is considerably lower than the estimated emissions from irrigation. The first of these estimates may be unreliable, however, because it is based entirely on readings taken on two daily readings that may not necessarily represent the situation for the whole year.

Table 5. Nitrate load in the Arba and Flumen, and emissions from irrigation (2002)

Basin	Arba		Flumen	
	CHE Measuement	Estimate	CHE Measuement	Estimate
Water flow (hm^3)	290		222	
Water percolation (hm^3)		143		138
Nitrogen load (Tm N-NO_3^-)	3.168		1.165	
Emission from irrigation (Tm N-NO_3^-)		2.720		2.235

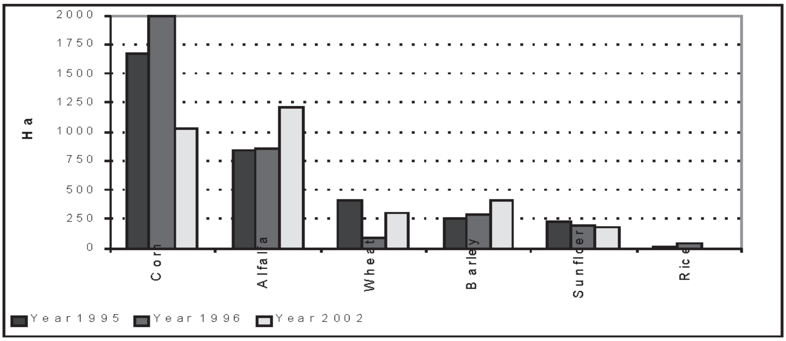
6. COMPARISON OF RESULTS WITH THE VIOLADA IRRIGATION DISTRICT

In this section we compare the data presented by Isidoro for the Violada irrigation district, with our estimates for the Almudevar municipal district. The Violada irrigation district includes the municipal district of Almudevar, and part of the Tardienta and Gurrea de Gallego municipal districts. The Violada irrigation district has an irrigation surface of some 3.600 ha, while Almudevar municipal district has about 3.200 ha. The comparison is therefore made between the results for the Violada irrigation district studied by Isidoro (1999), and the findings of this study for the Almudevar municipal irrigated area, which do not fully coincide.

Isidoro (1999) presents an estimate of the nitrogen balance in the Barranco de la Violada for 1995 and 1996, while our estimates are for 2002.

The main crops grown under irrigation are corn and alfalfa, along with some wheat, barley, sunflower and rice (Figure 3).

Figure 3. Irrigated crops in the Violada district and in Almudevar (ha)



Isidoro (1999) estimates nitrate emission levels of 249 Tm N-NO_3^- for 1995 and 266 for 1996 in the Violada irrigation district. Our estimate for the Almudevar area in 2002 is 215 N-NO_3^- (Table 6). The Violada district uses some 35 hm^3 of irrigation water, while Almudevar uses about 23 hm^3. This difference in volume reflects the difference in size between the irrigation surfaces in Violada and in Almudevar, but is also largely due to the fact that the 2002 corn surface was smaller in Almudevar than in Violada in 1995 and 1996. Since corn is associated with high nitrate emissions, the size of the corn surface has a significant impact on nitrate emission levels.

Table 6. Results for Violada and Almudevar

	Violada		**Almudevar**
	1995	1996	2002
Irrigated area (ha)	3510	3580	3220
Fertilizer (Tm N-NO_3^-)	950	1160	640
Irrigated water (hm^3)	35	36	23
Nitrogen emissions (Tm N-NO_3^-)	249	266	215
Percolation (hm^3)	18	19	8

7. CONCLUSIONS

This paper has estimated nitrate emission levels from irrigation sources in Aragon for the year 2002. The data used in the estimation include municipal crop surface, meteorological data to calculate crop water requirements, and crop tillage operations data. The EPIC crop growth package was used to estimate percolation and nitrogen leaching. Estimates at municipal level were first made, and then they were aggregated by county and watershed.

Aragon has a total irrigation surface of 410.000 ha, with alfalfa, corn, barley and wheat covering the largest areas. The amount of water used for irrigation totals 2.530 hm^3, while 870 hm^3 are lost through percolation. Nitrogen emissions through nitrate leaching totals 16.300 tones N-NO_3^-, with an average of 67 kg N-$NO3^-$/ha.

The Ebro, Cinca and Arba watersheds have the highest nitrogen emission levels, due to their large irrigation surfaces. The counties that generate the highest levels of nitrogen emissions are Monegros, Cinco Villas and Zaragoza, again because of the size of their irrigation surfaces, while the counties of Zaragoza, Ribera Alta and Bajo Aragon top the table in terms of nitrogen emissions per hectare.

These data relating to diffuse nitrate pollution from agricultural sources are of great importance for the establishment of pollution abatement measures. The policy instruments typically considered for the abatement of diffuse pollution include taxes on the pollutants used in production, such as nitrogen fertilizers; irrigation water taxes; limits on the use of nitrogen fertilizer and water; pollutant discharge permits; and the application of sanctions when nitrate concentrations in watercourses exceed certain predetermined standards.

A water tax is the type of measure advocated by the Water Framework Directive in order to apply the principle of "full cost recovery", which ultimately means increasing the price of water for farmers. Water pricing is the measure currently being promoted by both the Environment Ministry and ecological organizations. Martinez and Albiac (2004 and 2006) reject the water-pricing alternative, showing water price increments to be a highly inefficient measure that generates a high cost to farmers in terms of net income, while having very little impact in reducing diffuse pollution. Any other measure is preferable to raising water prices. Potential alternatives include regulating the use of nitrogen fertilizer, raising the price of nitrogen fertilizer, introducing nitrogen emission permits, or imposing sanctions for excessive nitrogen concentrations in watercourses. All of these are more cost-efficient, less detrimental to farmers, and more beneficial to general public welfare.

In conclusion, to design and implement the Program of Measures of the Water Framework Directive, the water authority needs reliable data concerning the generation of nonpoint source pollution, the transport and fate of these pollutants, and an assessment of the harm to aquatic ecosystems from pollutants in watercourses. Without such data it is impossible to devise rational strategies to control diffuse pollution.

Neither the Environment Ministry nor other administrative bodies with authority over water resources are currently generating these crucial data, the collection of which requires resources and time. The danger that exists therefore is that, in the absence of the necessary data, the Environment Ministry will opt for the "simple" solution, which is to raise water prices: a measure that not only harms farmers but is also inefficient in curbing pollution.

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