

# The challenges of agricultural diffuse pollution

*Emilio Custodio<sup>1</sup>, Alberto Garrido<sup>2</sup>,  
Carmen Coletto<sup>3</sup> & Gloria Salmoral<sup>2</sup>*

<sup>1</sup> Department of Geotechnical Engineering and Geo-Sciences,  
Technical University of Catalonia, Barcelona, Spain

<sup>2</sup> Water Observatory of the Botín Foundation;  
CEIGRAM, Technical University of Madrid, Madrid, Spain

<sup>3</sup> General Directorate for Water, Ministry of Agriculture,  
Food and Environment, Madrid, Spain

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**ABSTRACT:** Agricultural diffuse pollution is of concern in Spain, as it is in most European countries. The mountainous nature of the Iberian Peninsula and the Spanish islands explain the coexistence of areas little affected by nitrate with others in which this pollution is intense, especially where there is intensive cropping and livestock production, mostly pig farms. The use of chemicals in agriculture and intensive livestock production do not differ from other European countries, although the different climate and soil conditions explain differences in fertilizers and pesticides application rate and chemicals used. The enforcement of different European Directives poses specific technical and also administrative coordination problems due to the different authorities responsible for water resources and the environment at national and regional level. Many aquifers and the related springs and surface watercourses will not reach the good quantitative and chemical status by 2015 required by the European Water Framework Directive. This means that new terms have to be negotiated, with action that needs to be well defined in technical, economic, social and administrative terms. Most of the work carried out concerns nitrate pollution, vulnerable zones and good agricultural practices, but there is also saline pollution due to the evapoconcentration effect when irrigation water has originally high solute contents, something that is not rare in Spain. Pesticides and emergent pollutants in groundwater and the related surface water are being studied, but results are still in the early stages; their presence may become a serious future challenge for water supply and care of the environment.

*Keywords:* agricultural diffuse pollution, nitrate, European Water Framework Directive, good groundwater chemical and quantitative status, vulnerable zones

## I INTRODUCTION

The total agricultural land surface area in Spain is about 20 Mha [Mha = million hectares =  $10^6$  ha] (40% of the territory), of which close to 3.4 Mha are irrigated. About 70% to 75% of the total water consumption is for crop irrigation (see Chapter 6).

Water planning has traditionally focused on quantity issues, with reduced attention to water quality, a serious affair in some rivers and aquifers. Pollutants reach water bodies from point and non-point sources. Non-point sources are mainly due to agriculture, livestock and the related airborne contaminants, which cause diffuse pollution, mostly nitrate excess from fertilizers and in some cases salinity increase from return irrigation flows. This pollution has environmental and social consequences and often a significant associated cost to users.

The effect of agriculture and animal breeding on water quality is the subject of the European Union (EU) Nitrate Directive (ND) (OJEU, 1991). After previous efforts from water and environmental administrations in several European countries, a final decisive push to consider water quality and the environmental implications of pollution came from the Water Framework Directive (WFD) (OJEU, 2000), which is developed and complemented in what refers to groundwater by the *Daughter* Groundwater Directive (GWD) (OJEU, 2006). These Directives have already been transposed into the Spanish water law.

Spain is politically and administratively divided into 17 Autonomous Communities, here called Regions. They are responsible for their territorial resources and environment. Besides, for water management, 16 River Basins Districts have been defined, of which 7 are inside a particular region and depend on each region's own Administration, and the other 9 comprise territories over two or more regions and are under the responsibility of the Government of Spain for water planning, although the regional Governments have their shared responsibility inside their territory in relation to water quality and the environment.

Spain has a varied geology (which includes soluble salt formations), is mountainous, has a long coastline, numerous aquifers (many of them of small size, although thick and yielding), and climatic conditions vary from sub-humid to semiarid and even arid. Thus very different recharge and natural quality conditions can be found in the aquifers. In general terms, groundwater, and consequently springs and river base flow, have moderate to good quality for most uses, although naturally brackish or saline water can be found, and in some cases inconvenient solutes may appear, such as F excess and the presence of Fe and Mn, rarely of As and B. Large areas of river headwaters and aquifer recharge are in the highlands, which are little affected by agriculture and feedstock breeding.

This chapter presents an overview of non-point (diffuse) source pollution in Spain, with emphasis on agrochemicals. The nitrate monitoring network and recommended codes of best management practices are considered. Finally, the current economic, social and management issues relating to non-point pollution are briefly commented. Only general references are given. Some statements come from the direct experience of the authors.

## 2 USE OF AGROCHEMICALS IN SPAIN

Agricultural fertilizers are widely used in Spain, in both rainfed and irrigated areas. The common nutrient elements (N, P and K) are applied in different forms. Since 1998 the total fertilizer consumption shows a decreasing trend (Figure 1), as well as nutrient consumption per unit of crop production value (Figure 2). Improved technology,

the increasing cost of fertilizers and in their application, and more strict farming rules help in reducing fertilizer application, especially when plots are large or there is cooperative action. Soil correctors are applied in sandy soils. The production of manure from intensive livestock is about 75 Mt/year [Mt = million tonnes =  $10^9$  kg], although only a fraction is used as fertilizer.

Average N application as manure and in inorganic form over the total agricultural area of Spain is about 40 to 60 kg/ha/year. In rainfed areas average values are about 10 kg N/ha/year, up to 60 kg N/ha/year. N application is much larger in irrigated fields: average values increased from about 60 kg N/ha/year in 1950 to a maximum of 360 kg N/ha/year around 1985, and in year 2005 decreased to about 250 kg N/ha/year. According to the Spanish nitrogen balance in the year 2008 (MARM, 2010), average doses in kg N/ha/year were 350 for flowers and citrus, 280 for vegetables and potatoes, 220 for industrial crops, 90 for cereals and leguminous plants, and 50 for vineyards and olives, although actual values vary over a large range.

Pesticides are widely used. The largest consumption over the period 1995–2009 took place between 1999 and 2005 (MARM, 2011). The basic components are variable and diverse, and change from period to period and according to the area. Methyl bromide was widely applied in sandy soils before plantation of some intensive crops but since the 1990s it has been banned.

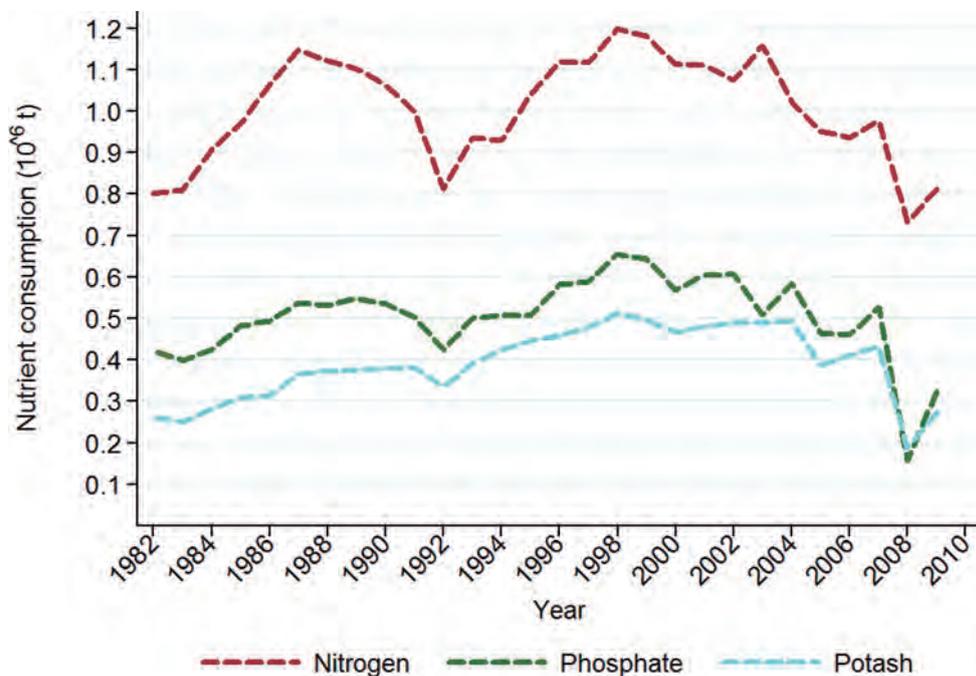


Figure 1 Consumption of nitrogen (as N), phosphate (as  $P_2O_5$ ) and potash (as  $K_2O$ ) fertilizers in Spain. Period 1982–2009. (Source: IFA (2011)).



Figure 2 Ratio between nutrient consumption and crop production (kg/€). (Source: Own elaboration based MARM (2011) and IFA (2011)).

### 3 AGRICULTURAL DIFFUSE POLLUTION IN SPAIN

Diffuse agricultural pollution in Spain refers mostly to nitrate. In some areas irrigation return flows may be brackish and even saline due to application of relative high salinity irrigation water, especially in coastal areas. Diffuse pollution affects primarily groundwater, which is mainly considered here, but also surface and coastal waters through groundwater discharge and agricultural drainage. Besides, intensive aquifer use for irrigation produces hydrodynamic changes in the aquifer and in the related surface waters, which may enhance quasi-diffuse effects in some areas due to ground salt dissolution, enhanced mixing with saline or poor quality groundwater, large-scale seawater intrusion, and in some of the new irrigated arid areas the downward displacement of saline waters held in the unsaturated zone.

$\text{NO}_3$  is easily leached to groundwater, while ammonia, urea-based fertilizers and manure-N are less leachable. However they may be partly volatilized in relatively warm, acidic soils, and later on deposited into the soil over a wider area than the fertilized one. This has been noticed around the Doñana National Park, in south-eastern Spain.

Nitrate leaching is a concern in Spain, as it is in many other European countries. Although average application intensity is lower, nitrate is more unevenly distributed due to the varied climate, soils, depth to the water table, land elevation, crops, and fertilization practices. The average agricultural N excess (surplus) in Spain is

estimated to be 20–25 kg/ha/year, varying from less than 25 to more than 150 kg/ha/year (MARM, 2010). However local studies may show higher values. For example, in Valencia (eastern Spain) studies show leaching rates of 230–250 kg N/ha/year for open-air cultivated vegetables, whereas for orange trees they are 90–160 kg N/ha/year. In many cases the N actually applied may be greater since nitrate in irrigation water is generally not accounted in Spain. In the European Union (EU) N average excess values are about 50 kg/ha/year, up to 125 kg/ha/year in Germany and 225 kg/ha/year in the Netherlands (Cuevas Navas, 2008).

In arid areas, even low fertilization rates may lead to high  $\text{NO}_3$  concentration in recharge; for example a recharge of 10 mm/year and a low N application of 10 kg/ha/year, used by plants at 50% efficiency, leads to a concentration of about 280 mg/L  $\text{NO}_3$  in recharge water. In some hot spots in Spain, more than 500 mg/L  $\text{NO}_3$  are found in groundwater; they often coincide with areas intensively irrigated with local groundwater where the  $\text{NO}_3$  has been progressively accumulating in the aquifer due to recycling (input exceeding output over a long time), often evolving towards a high steady state value.

Under common scenarios, nitrate behaves as a non-retarded, conservative solute, since the underground ambient is generally oxidizing, even for many of the thick carbonate aquifers in Spain. Nitrate reduction in the ground is a rare circumstance in most Spanish aquifers.

In some of the semiarid and arid areas, the combination of low recharge and deep water table means long transfer times of conservative solutes from the surface to the aquifer, from decades to centuries, even longer for solutes affected by retardation, as is the case for many pesticides. In some areas nitrate and especially pesticide pollution is still in the unsaturated zone, above the water table. Besides, deep wells in thick aquifers produce mixed groundwater, so arriving nitrate is diluted in the abstracted water and this delays the early recognition of diffuse pollution severity. However nitrate pollution is already a serious problem in some areas, forcing to look for alternative water sources (a difficult task in small islands like Menorca), or to mixing with other waters, or even membrane treatment, as in the area of Denia, in Valencia Region.

Little information is available on agricultural groundwater pollution by phosphorus. Most of the reported surface water contamination is due to household chemicals. Phosphates are highly retained in the widespread carbonate-rich soils and aquifers of Spain, so they do not tend to appear in springs and river baseflow in many areas. This explains the relative good trophic conditions of some groundwater-dependent lakes, reservoirs and wetlands, in spite of the high  $\text{NO}_3$  content of agricultural origin in the groundwater that feeds them, when surface runoff contribution is low and livestock is sparse in the area. This is the case of the Lagunas de Ruidera Natural Park (lagoons in central-southern Spain) or S'Albufera wetland in north-eastern Mallorca Island.

The behaviour of pesticides and similar agrochemicals in soils and groundwater bodies is little known. This is due to patchy studies, variable behaviour in soils, changing active principles and poorly documented field application. The European Directive 2008/105/EC (OJEU, 2008) on environmental quality standards of priority substances gives limits on pesticide concentrations between 0.04 and 1.8  $\mu\text{g/L}$  in inland surface water, depending on the substance, but they do not legally apply to groundwater. Some regions and river basin districts report that their waters are pesticide-free, but this refers mostly to surface waters. Modern herbicides have been reported in

groundwater, in spite of their assumed high retention and fast decay in soil, such as glyphosphate. In recent years there have been events in which the pesticide content in reservoirs and aquifers have exceeded the quality standards and have caused closing down sources supplying water to many towns in Andalusia; residues of herbicides used in olive groves led to temporary cuts in supply of drinking water between 2001 and 2004 to 135 municipalities with a total population of about 2 million inhabitants. Many supply systems have had to install expensive activated carbon filters to address these pollution episodes (J. Corominas, pers. comm., 20th January 2012). Pharmaceuticals used for feedstock have been identified in some intensive pig raising areas of Catalonia (northeastern Spain), as sulphonamides in high  $\text{NO}_3$  content groundwater. The importance of these organic compounds can become a major water quality problem in the future since they are difficult to monitor because of the frequent substitution and introduction of new compounds, and the slow transit time in the ground.

#### 4 NITRATE MONITORING AND VULNERABLE ZONES

The water sampling monitoring networks provide data on  $\text{NO}_3$  concentration in natural waters all over Spain. Results are available in the four-year reports requested by the Nitrate Directive (ND). Except in the north-western area, the 50 mg/L  $\text{NO}_3$  is exceeded in about 30% of groundwater sampling points, or about 17% of the surface area, with a slight increasing trend. Surface water tends to be stable with respect to average and winter values, although maximum values tend to increase slightly (MARM, 2008). This is small compared with the average 40–45% of points above limits in the sampling points of the EU, but the values are similar when inhabited, flat areas are compared. The most deteriorated aquifers are along the Mediterranean coast, in Andalusia (southern Spain) and in the Canarian and Balearic archipelagos.

After the ND, Vulnerable Zones to Nitrate Pollution (VZN) due to agricultural activities have been officially declared in Spain, based on available information. This includes the identification of the affected waters, the formulation of codes of good agricultural practices, the designation of the vulnerable zones, the development of action programmes, and the analytical monitoring to be carried out. In total 57 VZN have been declared, which cover about 13% of the national territory. This will be commented on further in Section 6.

#### 5 CODES OF GOOD AGRICULTURAL PRACTICES

In pursuance of the ND, each EU Member State has to produce and enforce codes on good agricultural practices, both for agriculture and livestock, in order to reduce nitrate losses to aquifers, especially in the VZN, and consequently into inland and coastal surface waters. This is a very sensitive issue due to the economic, social and political implications. In Spain this is the responsibility of the Regions, which are in charge of producing, enforcing and controlling the compliance. The preparation and publication of the codes has been slow.

These codes should take into account local circumstances and consider 1) a common upper limit of N application (from 150 to 170 kg/ha/year), 2) periods and areas in

which fertilization is forbidden or subject to more strict limitations, 3) the convenience of maintaining a plant cover on the fields during the cold months, 4) limits to total use of fertilizers and the mode of application, 5) rules for a. calculating fertilization rates and methods, including fractionating their application; b. use of alternating crops; and c. performing soil analysis before fertilization; this allows for calculating maximum acceptable yearly irrigation depths and methods, 6) maximum animal density in extensive feedstock breeding, 7) required conditions against leakage and storage tank capacity to hold manure and liquid animal wastes, 8) obligation to keep a book on fertilizer use, and on production, storage, and distribution of animal wastes. Economic studies to help in fertilizer use and application are not included, except preliminary in Catalonia.

In the codes there are no explicit provisions and methods to account for the  $\text{NO}_3$  already in the irrigation water, which may be significant in the case of groundwater in some areas. Taking this  $\text{NO}_3$  into account will contribute to reducing nitrate losses and their accumulation by recycling, but this is not an easy task since the right timing for fertilization and water application usually do not coincide. The codes of La Rioja region (central-northern Spain), which has easy access to surface water, recommend abandoning the use of groundwater with high nitrate content and irrigate with surface water, which contains lower concentrations of  $\text{NO}_3$ . This measure is intended to alleviate the  $\text{NO}_3$  concentrations in local aquifers and springs, as well as to save energy. What seems sound from the Region's point of view, is not so for the whole river basin, due to less good quality and the different time distribution of  $\text{NO}_3$  available in downstream surface water.

High application of irrigation water may be beneficial when it comes from external sources since this helps to sustain aquifer recharge in intensively exploited aquifers, and may reduce the use of herbicides. This is the case of the fruit tree plantations in the Lower Llobregat river alluvial plain (Barcelona, north-eastern Spain). However, an integrated water balance is needed.

In some cases nitrate pollution is not strictly dependent on good agricultural practices, but on the convenience to apply out-of-season irrigation to limit frost damage to crops in critical days, but this leaches  $\text{NO}_3$  already in the soil. This is the case of the Inca-Sa Pobla plain in eastern Mallorca Island. To reduce this leaching, the application of water as mist is advisable but this increases the operational cost to the farmers.

The application of the codes has encountered some practical pitfalls: 1) high cost and complex inspection and control, 2) difficulty in enforcing the guidelines when agricultural plots are small, or the plot owner is not the person who is cultivating it, or the application of the rules is rejected by farmers, 3) complaints by farmers on unfair treatment and over-charges, especially those inside the VZN with respect to neighbours just outside it, 4) poorly coordinated action of involved authorities and political foot-dragging.

## 6 SOCIAL, ECONOMIC AND MANAGEMENT ISSUES

Spain is responsible to the EU Commission for the enforcement of the Directives. The River Basin Districts produce 4-yearly reports on nitrate issues and yearly reports on groundwater. The EU monitors the application of the Directives and issue procedures

of infringement to the Member States when regulations are not satisfactorily accomplished.

In relation to nitrate pollution, the designation of VZN is a complex task due not only to poor knowledge and data scarcity but also to the high economic and social costs involved, the reluctance of farmers, sometimes plain rejection. So, the number and surface area of VZN initially declared in Spain were short in some regions. In 2002 the European Commission filed an infringement procedure against Spain for breaching the Directive on Nitrates, which has been pending for almost nine years. It was required to increase nitrate monitoring due to agricultural sources and to review the number and boundaries of the VZN, as well as some of the programmes of action, including the small storage capacity of animal wastes and their excessive application. Through coordination between the Central Government and the regional administrations, in particular in Catalonia where there are many large pig farms, new vulnerable zones were designated and their programmes of action were modified. The result was accepted by the European Commission.

The slow evolution of groundwater makes difficult attaining the WFD good quantitative and chemical status of aquifers by the year 2015. To cope with this, the WFD allows for agreed delays, following the 6-year period between successive water plans (2021 and 2027), if supported by studies and accompanied by proposals for action. Several EU Members have already applied for such delays, but not yet Spain, although this is currently considered in some of the recent River Basin Management Plan drafts.

Not every Spanish River Basin Authority or responsible institution has enough knowledge, staff, economic and technical means for due action since this is costly and often limits their actual possibilities. In some cases this is worsened by excessive political interference and giving the responsibility to politically appointed, technically unskilled persons, since water is a very sensitive political and social issue (See Chapter 4). Water mobilizes people and especially farmers' lobbies, which are able to create high media pressure and may influence the polls, even if jobs in agriculture affect only quite a small fraction of the population. Currently the main issue is water quantity, although the concern on water quality is increasing.

As has been already mentioned, agricultural pollution appears long-delayed in wells, springs, streams and coastal waters. For this reason, the recovery of aquifer quality after a diffuse pollution source ceases or slows down often takes decades. This is well known by specialists but not by decision-makers, water administrators and the public in general, who often expect prompt and visible responses. Enforcing actions that are economically, socially and politically costly becomes difficult when the expected improvements will be noticed much later and sometimes with further deterioration over some time. This is already mentioned in some of the River Basin District Water Plan drafts of Spain.

The social cost of agricultural pollution is not known. Studies are rare and incomplete. In some areas, getting drinking water is difficult and suppliers have to mix local groundwater with waters of other origins, often imported from long distances, or they have to treat the  $\text{NO}_3$  excess by means of expensive ion exchange or reverse osmosis plants. There is research on effective and cheap new treatments, but applicable results are not yet at hand. The related cost increase is fully transferred to the population, which is not directly responsible for the water quality deterioration. Some

unpublished preliminary data tend to show that treatment costs are possibly one order of magnitude higher than the cost to reduce nitrate losses.

The involvement of water users and stakeholders is very important for water quality management, particularly for agriculture, and this seems the best way to get positive results. Experience on users associations is just beginning, slow to build, and limited, although there is some encouraging and pioneering progress in Spain, mostly as a civil society initiative. About 20 groundwater users' associations already exist, as well as a national association linking them. They have a legal status recognized in the Water Act. Most current action refers to water quantity since farmers are still reluctant to consider quality issues.

Implementing the codes of good agricultural practices is not an easy task since this means an additional cost to farmers, who have to sell their production in highly competitive markets. The increased cost is not accompanied by an immediate benefit for them, apart from possible but unproved savings in agrochemicals and water use. This implementation is also poorly attractive for politicians since in many cases results will only appear after a much longer time than normal political life, and thus enforcement is not palatable for them. Giving subsidies for pollution abatement looks better, but is expensive and, if continued, may often lead to perverse results. This is a general issue that in some areas of Spain may be serious. However, since farmers have a wide margin of error in the rate of N application, some room for N savings are possible with little change in profitability. Some studies under way on the economics of nitrate pollution reduction and environmental improvement show that efficient irrigation and fertirrigation (incorporation of fertilizers to irrigation water) may produce good results at low or no cost, and even with some benefits, but field-scale experience is needed. Reducing fertilizer use through taxes is rarely considered. Most efforts refer to irrigated agriculture, but rainfed farming, although less polluting, also produce significant diffuse pollution over a large territory in the semi-arid areas of Spain, but this is poorly documented.

For feedstock wastes, improved collection and storage is at a cost that greatly depends on local circumstances. There is some experience in the EU, with costs crudely evaluated at a few €/kg of N leaching reduction. The disposal of wastes from feedstock is a growing serious problem in Spain if nitrate load to groundwater has to be limited. The control by water authorities is poorly feasible in practice since they lack staff, resources and means. Then, important progress is needed to get the participation and co-responsibility of farmers, groundwater users and water stakeholders in the control and monitoring, and also to help water authorities to find solutions to existing problems and how to comply with legislation, but this needs time and continuous backing and help, and this is just starting. In the meanwhile a mix of enforcement of rules and compensations has to be applied in Spain. Policy makers and people should be aware that what is not compensated by those causing the problem, means passing the cost to third parties, such as neighbours, urban supply and future generations. How measures are applied affect the EU economy as a whole and the balance among Member States, and should not be at the expenses of socially unacceptable loss of natural resources, ecological services and inheritance. In Spain this message is still poorly internalized and politicians and media avoid dealing with it.

In difficult-to-solve situations there is the possibility of declaring some aquifers as too costly to be brought into good condition, and using them only for low water

quality uses, but this should not cause damage to other water resources, coastal waters and the environment, nor maintain comparative temporary economic privileges with respect other areas. Good quality water has to be guaranteed for demanding uses, especially for drinking purposes, looking for other water sources or treating carefully low quality groundwater before distribution, as is currently done in the area of Barcelona. But this vision may be incomplete since the environment and the economic contribution provided by nature are not duly considered, nor is there equity in the distribution of the economic costs of pollution. The principle of *the polluter pays* needs to be reformulated and adapted to diffuse pollution by agriculture, according to actual circumstances and taking into account inherited situations. This is an ethical and moral issue still not adequately addressed in Spain.

## 7 CONCLUSIONS

Agricultural diffuse pollution in Spain is variable according to the diverse characteristics of the mainland and the islands. From aquifers, pollutants are transferred to springs and river base flow, as well as to littoral water. Most study and monitoring efforts refer to nitrate, which is of concern in many areas where the concentration limits are exceeded, though pesticides and some substances added to them are the next challenge to be faced. According to the European Directives many aquifers will not attain the good quantitative and chemical status by 2015. Thus delays are needed and exceptions have to be negotiated taking into account not only the slow turnover time of groundwater, but also the role of pollutants in the soil and in the unsaturated zone, and the delaying effect of sorption. Action is rather delayed. Spain has specific problems that have to be faced not only by means of regulations and good agricultural practices, but also considering its specific circumstances, and the economic, social and environmental impacts. Improvements come slowly but can be achieved. A combined action of water, environmental and land use authorities on one hand, and water users' associations on the other, are needed as a key issue for governance and water planning. Steps are being implemented.

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