CHAPTER 7.3

Diffuse Groundwater Quality Impacts from Agricultural Land-use: Management and Policy Implications of Scientific Realities

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7.3.1 Why is Agricultural Land-use the Greatest Challenge Facing the New EC Water Directives?

In many regions of the European Union (EU) the main recharge areas of groundwater bodies form valuable tracts of farming land and are extensively utilised for agricultural production: either crop cultivation or animal husbandry. Very extensive land areas are often involved and this means that:

- large volumes of groundwater replenishment (originating as excess rainfall and excess irrigation infiltrating this agricultural land) are potentially affected by agronomic practices; and
- relatively large numbers of individual agricultural land-users (potential polluters) are implicated.

Agricultural land-use is an inherently "leaky activity," and one which is always potentially prone to leaching of nutrients and pesticides: especially when practised on the more permeable soils that tend to coincide with the most important aquifer recharge areas. And most of the EU has witnessed radical changes in agronomic practices over the past 20–40 years, associated with (largely successful) attempts at increasing agricultural productivity (to achieve self-sufficiency in grains, oils, milk and meat) and, in the case of Mediterranean Europe, to expand export production of vegetables and fruits. Common trends include the replacement of traditional crop rotations by near monocultures of higher-value crops across extensive areas: selected according to prevailing climatic conditions, guarantee price and/or market opportunities. This intensification of agricultural production (in some cases with increased cropping frequency) has been sustained by the application of ever-increasing quantities of inorganic fertilisers and a wide spectrum of synthetic pesticides, together (in areas of drier climate) with new irrigation schemes and increasing irrigation water-use efficiency.

Irrigated Cultivation in Mediterranean Spain

The most intensive land-use in Europe, in terms of water consumption and agrochemical application, corresponds to areas of irrigated multi-cropping. In Spain irrigated farmland represents 13% of the total cultivated area but contributes 50% of agricultural income.[1] Some 25–30% of this irrigated area uses groundwater, especially in the Mediterranean coastal zone. In most areas where irrigated land directly overlies an unconfined groundwater body, a substantial proportion of the total groundwater recharge is produced by "irrigation returns"—either representing supplementary recharge or recycled water depending on whether it is derived from surface water or groundwater irrigation. During the last 15 years or so, traditional flood irrigation has been widely replaced by more efficient systems (pressure tube distribution to microsprinklers or drip nozzles). Very high (but locally variable) application rates of (almost exclusively) inorganic fertiliser predominate, although rates appear to have stabilised or declined somewhat in recent years. In addition the use of plant protection products (notably insecticides) has increased greatly both in absolute quantity and in range of active ingredients.

Arable Farming in Eastern England

The land-use of this extensive region underwent major changes during the period 1950–1970 which had a number of components:

- *conversion of large areas of permanent pasture to tilled land under arable cultivation;*
- *major increases in the proportion of land dedicated to cereal cultivation, from rotations of less than 20% to monocultures of more than 60% in many areas; and*
- *substantial increase in the application of inorganic fertilisers to sustain more continuous cereal cultivation, on average from less than $50\,kgN\,ha^{-1}\,yr^{-1}$ to more than $100\,kgN\,ha^{-1}\,yr^{-1}$.*

The net effect of these changes during 1940–1980, coupled with some intensification of grassland-based livestock rearing, was a 20-fold increase in fertiliser nitrogen use to achieve a threefold increase in food production.

In subsequent years there has been a progressive move from spring-sown cereals (following autumn ploughing and winter fallow) to winter-sown cereals (with minimal tillage implying improved nutrient management but increased herbicide use), together with introduction of substantial areas of oil-seed rape and oscillating amounts of more traditional crops like sugar beet, potatoes and peas. Moreover, in recent years the amount of nitrogen fertiliser applied to winter-sown cereal and oil-seed crops has reduced somewhat, and an incipient trend towards the return of permanent pasture for sheep rearing is evident in some areas.

In the past agricultural land-use has been essentially "uncontrolled"—although over the past 50 years changes have been driven by government subsidies (as guarantee prices for certain produce), market opportunities and agro-technical innovation. Moreover, until the early 1980s there was general complacency about risks to groundwater quality. This was because field investigations by agricultural scientists produced misleading results since they were based on monitoring drainage from relatively heavy soils—for which a substantial proportion of nitrogen losses were gaseous (following soil denitrification) with much reduced leaching losses compared to those subsequently proven for more aerated soils (typical of groundwater recharge areas). There is thus a legacy of decades of *laissez faire* agricultural land-use to overcome: with a substantial proportion of the groundwater bodies defined during the initial phase of EC Water Framework Directive implementation not achieving "good chemical status" as a result of the effects of past agricultural land-use (Figure 7.3.1).

More recently, and in effect since the promulgation of the EC Nitrates Directive (1991), groundwater quality considerations have begun to enter into consideration, but as yet there has been little clear incentive for (and absolutely no constraint on) farmers in this regard. This situation arises because of:

- lack of understanding of diffuse groundwater pollution and individual capacity to influence it; and
- the fact that fertilisers represent a very small proportion of agricultural costs.

On a widespread basis across the main recharge areas of important groundwater bodies, there is a pressing need for more groundwater-friendly regimes of agricultural land-use to be promoted in the interest of future groundwater quality protection (and of significantly diluting existing diffuse pollution). For this it will be necessary to integrate groundwater considerations (and costs) fully into emerging action plans for EU Common Agricultural Policy (CAP) reform.

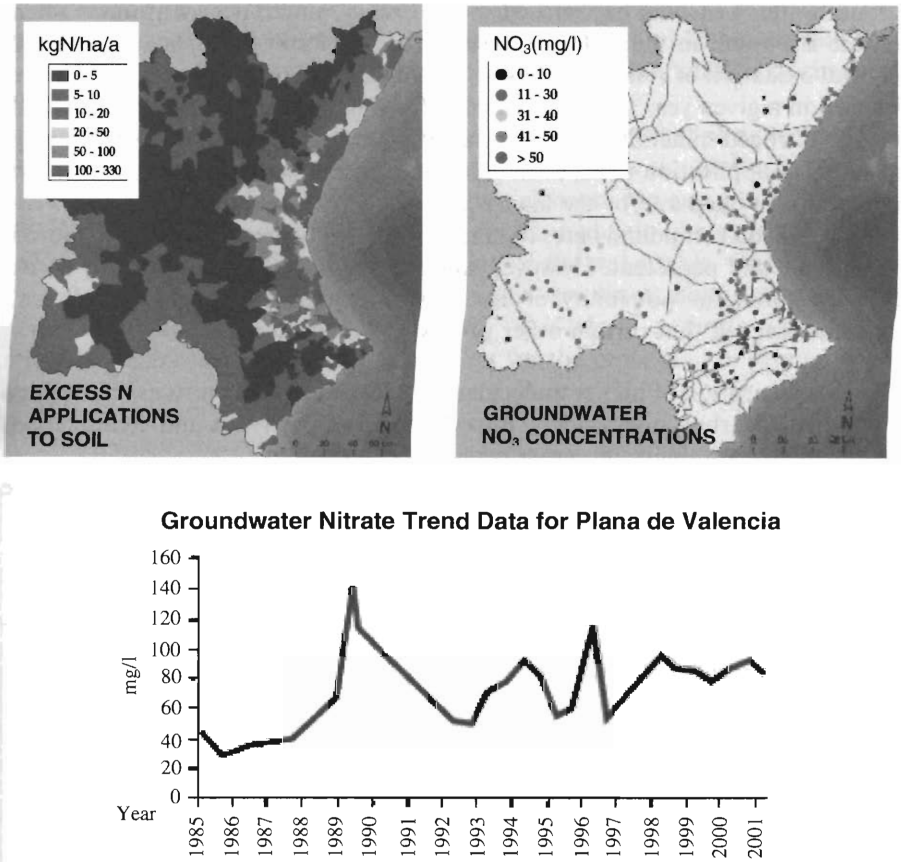

Figure 7.3.1 Preliminary assessment of excess nitrogen loading and groundwater nitrate concentrations in the Jucar Basin of eastern Spain.[2]

7.3.1.1 How does Agricultural Land-use Impact on Groundwater Quality?

Agricultural soils contain large, but widely varying, quantities of nitrogen in organic form: often amounting to more than 2000 kgN ha^{-1}. This is oxidised by soil bacteria to soluble nitrate (at rates varying with soil temperature and humidity) and is then susceptible to leaching below the root zone. Inorganic nitrogen fertilisers are added to increase the immediate availability of nitrate for plant growth, while manures (which also contain large quantities of less readily available nitrogen) are applied to replenish soil organic matter.

Nitrate applied to cultivated land is subject to complex soil processes: it may be taken up directly by the growing crop, incorporated into the soil nitrogen pool, reduced and lost either as NH_3 or N_2 gas or leached as NO_3 or NH_4 to groundwater. Leaching happens whenever excess rainfall occurs at times when nitrate is present in the soil, as a result of heavy fertiliser application and/or natural oxidation of residues. Thus while only a small proportion of the nitrate leached in a given year is derived directly from inorganic fertilisers, the overall rate of nitrogen mineralisation and leaching normally relates in a general way to fertiliser application rates, although some leaching will occur even when no nitrogen is applied and/or the land is fallow.

All pesticide compounds are, to greater or lesser degree, chemically tailored to be toxic and persistent. However, until the mid-1980s, there was not much concern about the possibility of leaching to groundwater, since agricultural scientists argued that certain other processes would predominate:

- soil sorption of higher molecular weight compounds (such as chlorinated hydrocarbon insecticides), introduced from the 1950s and characterised by low solubility but great persistence; and
- volatilisation of (subsequently introduced) lower molecular weight more soluble compounds (such as most herbicides).

Nitrate Leaching from Typical Crop Cultivation Regimes

On the Chalk recharge area of eastern England greatly increased rates of nitrate leaching result from the conversion of pasture land to continuous cereal cultivation, even in situations where both receive low applications of inorganic fertiliser. In arable soils, nitrate is readily leached by excess rainfall at times when it is present in excess of plant requirements, whereas the existence of soil compaction and a root system under pasture land lead to greater nitrate uptake and probably also to significant soil denitrification losses. The former conclusion was corroborated by many vadose zone profiles beneath long-standing arable land in the drier parts of England[3] with nitrate leaching usually much in excess of 50 mg $NO_3\,l^{-1}$. The leaching of nitrate from dryland agricultural soils is dependent on a complex interaction of soil type, cropping regime and rainfall infiltration. In intensive cereal cultivation 30–70 kgN $ha^{-1}\,yr^{-1}$ can be leached to groundwater from fertiliser applications of 100–150 kgN $ha^{-1}\,yr^{-1}$, and higher leaching losses occur from heavier applications to potatoes and oil-seed crops.

Nitrate leaching is particularly marked in areas of intensive irrigated agriculture (horticulture and citriculture) in Mediterranean Spain where sandy soils are predominant. In areas where irrigation rates exceed 1000 mm yr^{-1}, leaching to groundwater of 50–250 kgN $ha^{-1}\,yr^{-1}$ has been estimated to occur,[4] equivalent to 50% of that applied even given an irrigation efficiency of around 0.7. More traditional agricultural cropping has a fertiliser efficiency of less than 0.6[5] and the impact of this has already been experienced in the Valencia region, where the drinking water supply of 400 000 population exceeded the EC-MAC of 50 m $NO_3\,l^{-1}$.[6]

Moreover, in a "fertile soil" most modern pesticides have half-lives of less than 1 year (and many of less than 1 month), and thus it might be assumed that soil residues would thus be eliminated (by aerobic biodegradation or chemical hydrolysis) preventing groundwater contamination.

However, the property of greatest importance in respect of pesticide leaching is "mobility in soil solution," which varies inversely with affinity for organic matter and/or clay minerals.[7,8] If mobile pesticides are present at times of excess rainfall or irrigation, they are likely to be leached into the vadose zone or, where preferential flow is significant, rapidly to the water table. Once below the microbiologically active soil zone they will be very much more persistent than suggested by the manufacturer's quoted "half-life in a fertile soil."[9] This scientific reality has important implications for the protection of groundwater quality.

Pesticide Leaching From Typical Crop Cultivation Regimes

The EC-MAC for pesticides in drinking water ($0.1\,\mu g\,l^{-1}$) has already been considerably exceeded in many British public water supply boreholes, although concentrations in excess of $1.0\,\mu g\,l^{-1}$ have seldom been recorded. The pesticides most frequently encountered to date are all herbicides: atrazine, simazine, mecoprop and isoproturon.[10] *Detailed monitoring of the Chalk water table at sites in Hampshire under continuous arable cultivation using regular applications of isoproturon (to winter cereals) or atrazine (to summer maize) has revealed some penetration of these pesticides into groundwater via preferential flow immediately after the onset of recharge. Significant pesticide concentrations were also detected in the upper part of the vadose zone in matrix transport but were attenuated within 5 m of the surface.*[11]

In Mediterranean Spain insecticides are more heavily applied than other types of pesticide, as a result of the prevailing climatic conditions. The irrigated citriculture and horticulture belt has long used heavy applications of a range of insecticides and herbicides, and Beltrán et al.[12] *investigated the vadose zone mobility of organochlorine pesticides (such as tetradifon), organophosphorous pesticides (such as dimethoate) and phenoxyacid herbicides (such as MCPA), by installing soil suction samplers to depths of 3.5 m below orange groves. Concentrations up to $1.0\,\mu g\,l^{-1}$ of the more mobile compounds (notably dimethoate and MCPA) were recorded at depths of up to 3.5 m within 10 days of application, suggesting that some pesticide was reaching the water table at 4 m depth by preferential flow, although none was detected in the water wells of the area. A similar experiment in an intensively cultivated horticultural area northeast of Barcelona showed glyphosate presence in detectable concentration at more than 2 m depth*[13] *and Candela*[5] *has detected residues of organochlorine pesticides (such as lindane and heptachlor) in groundwater at concentrations of more than $10.0\,\mu g\,l^{-1}$ in the same area.*

7.3.1.2 Are all Types of Groundwater Body Equally Threatened by Agricultural Practices?

Across the EU different topographical, pedological and groundwater conditions, associated with different hydrogeological settings (or typologies), lead to wide variation in:

- the potential for generation of contaminant pressures from nutrient and pesticide leaching (as a result of differing types of agricultural and non-agricultural land-use in aquifer recharge areas); and
- the capacity for natural contaminant attenuation (or the intrinsic aquifer pollutant vulnerability), which depends largely on the thickness and character of the vadose zone.

In a broad sense this is illustrated by Figure 7.3.2, which is based on some widely occurring hydrogeological typologies in the EU countries, although in practice the range of typologies encountered is significantly greater that those illustrated.

Among groundwater bodies at most serious risk from agricultural activity are:

- the coastal and alluvial aquifers of Mediterranean Spain, because they have a coarse-granular vadose zone of less than 20 m thick and relatively low natural recharge rates, and their recharge area is often utilised for intensive irrigated agriculture with double or triple cropping; and
- the extensive outcrops of highly permeable fissured porous limestones and sandstones in northern Europe, which have been subject to increasingly intensive monocultures of cereal and oil seed crops sustained by heavy agrochemical applications.

The question of "how far can natural subsurface contaminant attenuation go in providing the required level of groundwater quality protection?" is an important component of the more general question posed above, and one which merits more detailed discussion in relation to:

- the extent and stability of natural subsurface denitrification in the aquifer system concerned; and
- the capacity of the aquifer concerned for subsurface pesticide retention and degradation.

Denitrification has been the subject of considerable research[14] because if active on a widespread basis (and without other complication) it can have a major beneficial effect on groundwater quality. Evidence comes from the confined parts of some British aquifers, but in the vadose zone of the major aquifers the generally aerobic conditions and persistence of high nitrate concentrations to depth imply that denitrification cannot be widely active, despite the presence of potentially denitrifying bacteria.[9] It has been suggested that denitrification is

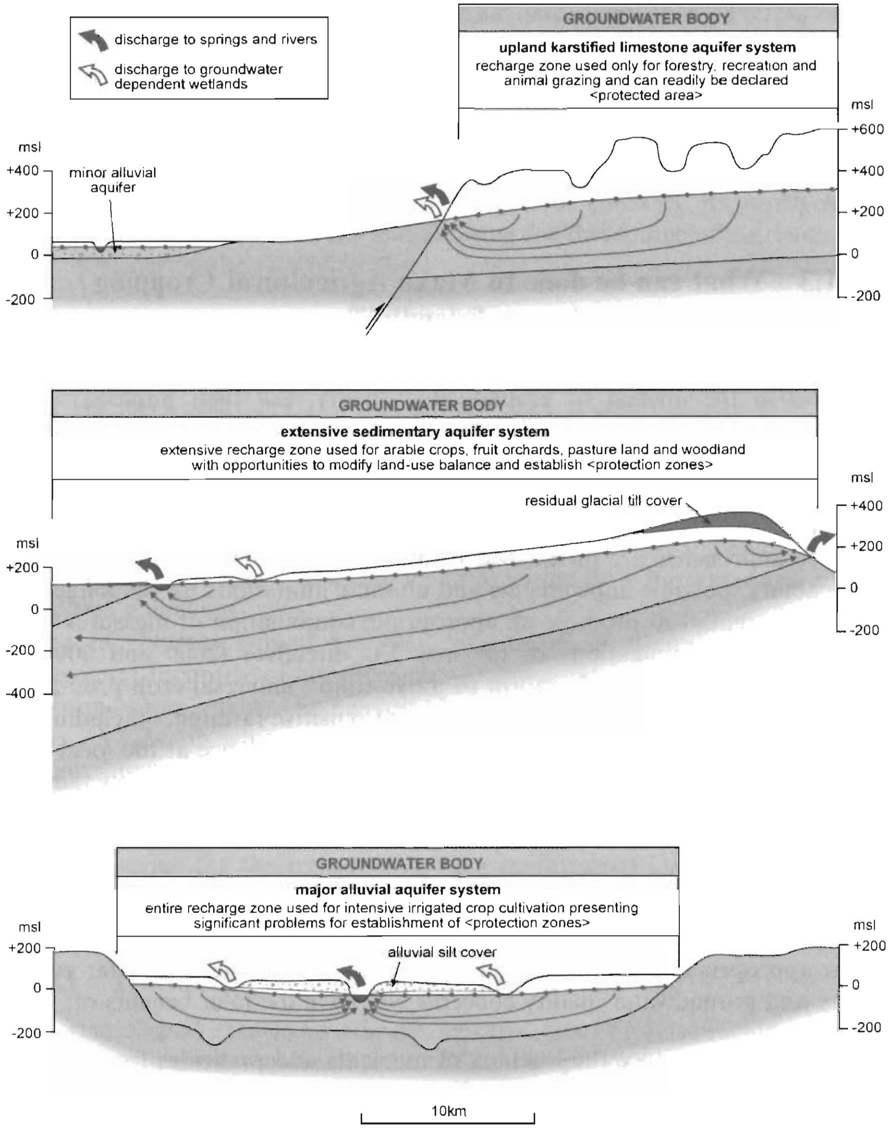

Figure 7.3.2 Effect of hydrogeological setting on the general susceptibility to agricultural impacts and the approach to groundwater protection.

more likely in the zone of water table fluctuation, but measurement of the normal gaseous products (N_2, N_2O) suggested that it is not significant in relation to the overall nitrogen flux. However, where the vadose zone includes strata rich in organic carbon, the process is likely to become more significant.

The factors influencing pesticide attenuation in the vadose zone are transit time and attenuation capacity, which interact with the persistence and mobility of the pesticide concerned. Leaching of pesticides into groundwater is to be expected under sandy soils of low organic matter with a water table within 5 m depth, where mobile and persistent pesticides are applied at a high rate. But there is considerable evidence that "natural preferential flow" is a major factor in the transport of mobile (and in some cases sorbed) pesticides through the vadose zone of a wide range of aquifer types (especially consolidated formations).[7,15]

7.3.1.3 What can be done to Make Agricultural Cropping more "Groundwater Friendly"?

A number of measures can contribute to constraining agricultural land-use practices in the interest of groundwater quality, but their implementation requires improved institutional capacity for cross-sectoral action. Certain amongst these are actually facilitated by the new EC directives themselves, whilst others will be required to fulfil the broader requirement of the same legislation.

These approaches are introduced below with comments on their potential applicability, possible impediments and ultimate limitations. In the longer run it will be essential to promote an appropriate combination of measures using the powers and obligations of the new EC directives (2000 and 2006) in combination with EC CAP reform to move from "universal crop production subsidies" to "selective support of catchment sensitive farming," including the introduction of land management regimes which on balance at the local scale are "groundwater quality friendly"—and in turn to keep under review the need for potential adaptation in response to accelerated climate change.

7.3.2 Guidelines on "Best Agricultural Practice"

The *dissemination of improved agricultural practices* (via rural extension services of the appropriate government agency) which take account of aquifer vulnerability and groundwater quality concerns will have the joint benefits of:

- tending to reduce the leaching of nutrients and pesticides from agricultural land to groundwater; and
- raising farmer awareness about their influence on groundwater and role in its protection.

In this context it will be important to have a groundwater quality monitoring system installed that is capable of demonstrating the corresponding improvements.

The sort of improved practices envisaged include:

- rationalising inorganic fertiliser regimes and reducing initial applications (*e.g.* avoiding nitrogen fertiliser application when sowing autumn cereals and oil seeds in view of the natural availability of soil nutrients at this time);

- reducing autumn ploughing and winter fallow, which are associated with high rates of soil nutrient leaching, by using autumn "cover crops" and direct drilling techniques;
- curbing the practice of "disposal" of agricultural manures and sludges to grassland (way in excess of normal fertilisation needs) in areas with intensive livestock rearing; and
- where groundwater is used for irrigation, checking its nitrogen and potassium concentrations and allowing for this source of nutrients when considering the rate of fertiliser application.

While an element of self-interest can usually be identified in *"selling" to farmers the need for control over leaching losses*—through reducing irrigation water and agrochemical use, avoiding pollution of their own groundwater supply, *etc.*—the reality is that these losses are usually only a minor item in overall crop production costs and the potential financial saving does not generally represent a significant incentive for control. Moreover even under "best agricultural practice," where intensive monocultures are practiced and aquifers are relatively vulnerable to pollution, this will generally not be sufficient alone to reduce the average rate of leaching losses to within drinking water and aquatic ecosystem guidelines.

The EC Nitrate Directive (1991) constituted an attempt to provide an instrument for control of nitrate leaching from agricultural soils in the interest of groundwater quality, and involved the *declaration of Nitrate Vulnerable Zones (NVZs)* in which constraints were placed on inorganic fertiliser and organic slurry application rates according to "best agricultural practice." But in most instances such measures were not sufficient alone to reduce the average nitrate concentration of groundwater recharge to below $50\,\mathrm{mg\,l^{-1}}$, since they did not provide for the introduction of a more mixed land-use regime with interspersed fields of lower cultivation intensity.[16,17]

7.3.3 Reducing Overall Cultivation Intensity

An earlier *English scheme for Nitrate Sensitive Areas (NSAs)* included stricter measures than those required by the NVZs with provision for:

- conversion of some intensively cropped arable land to low-intensity pasture land; and
- ensuring a high proportion of autumn-sown crops to reduce fallow during periods of excess rainfall.

These measures proved successful in significantly reducing nitrate leaching losses,[18] albeit that the benefits came with substantial time-lag in most aquifer systems and the negotiation of compensation paid to farmers was repeatedly contested.

Since pasture is less prone than cultivated land to nitrate leaching, it would appear to offer a useful option for reducing overall rates of nitrate leaching to a groundwater body. Where grass is cut and removed for animal fodder, the use of nitrogen is relatively efficient and leaching is modest even at relatively high fertiliser application rates—but leaching rates on well-drained soils increase abruptly to elevated levels when grassland productivity is intensified by high-density grazing sustained by large fertiliser applications. Moreover, organic nitrogen accumulates in pasture land and can be oxidised and leached at high rates following ploughing and reseeding.[19]

In some areas more direct action has been taken by water supply utilities, who have been prepared to enter into *private legal and financial agreements with the farmers of a specific groundwater protection area* to modify their activities in the interest of "harvesting" a high-quality groundwater supply through such actions as:

- converting existing arable land to permanent pasture or woodland;
- restricting animal grazing densities generally and not grazing certain fields; and
- reducing the application of agrochemicals or adopting a completely organic farming regime.

This type of agreement will be more readily negotiable if some form of financial support from government to encourage groundwater protection is also forthcoming.

To date the best examples of constraining or changing agriculture in the interest of groundwater quality in the EU countries have involved action in specific protection zones (*e.g.* historically in Sussex, England, and Bavaria, Germany, and more recently in Jutland, Denmark, and Lower Saxony, Germany) (*e.g.* Refs. 17 and 20). These zones have (variously) been established by regulatory action alone, by purchase and conversion of agricultural land to pasture or woodland, or by private financial and legal long-term agreements on land-use changes and cultivation practices.

7.3.4 Constraints on Pesticide Manufacture, Sale or Use

A wide range of pesticides are currently in use across the EU, with more than 600 different active compounds being applied on cultivated agricultural soils,[21] and there have been numerous reports of concentrations of "active pesticide compounds" in groundwater exceeding $0.1\ \mu g\ l^{-1}$ in most countries where intensive agriculture is practised.[22] The evaluation of associated groundwater quality risk is proving costly and problematic because of this wide range of compounds, the fact that some break down to toxic derivatives (metabolites) and the need to work at very low concentrations (with careful sampling to avoid volatile loss).

In view of these difficulties, an essential prerequisite is to identify the most likely types and sources of pesticide contamination, and the most probable mechanisms of transport from the land surface to groundwater.[7] Such information is essential for the specification of sampling protocols and monitoring networks, and to prioritise and rationalise investigation work.

The removal (or refusal) of pesticide registration on grounds of expected or proven mobility to (and toxicity in) groundwater is the most effective tool with which to protect groundwater quality in the interest of potable water supply and the environment. And although registration was originally introduced to protect crop consumers and agricultural workers, in recent years there have been examples of action on these grounds.

Some alternatives to a complete ban include:

- statutory or negotiated control of the application of a specific pesticide (often with an element of farmer compensation), but this can only really be implemented at a local scale (*e.g.* in public water supply "safeguard zones"); and
- systematic substitution of a given pesticide (which has been proven to be highly mobile and persistent in groundwater) for a certain application (*e.g.* atrazine and simazine for extensive defoliation, and some carbamates as soil insecticides).

Various mitigation measures to control the risk of groundwater pollution can also be used for specific individual pesticides compounds such as:

- changes in the recommended timing and rates of application; and
- improving the targeting of pesticide application through changes in spraying technique.

Given the formidable problem of adequate monitoring of large numbers of agricultural pesticides and their metabolites, numerical modelling is being increasingly applied to assess the potential mobility of pesticide compounds to groundwater, and thus priorities for constraint on use and for groundwater monitoring. Numerical codes (such as LEACHM, PRMZ, GLEAMS, SWAP, PEARL) have been used to classify the groundwater contamination potential from pesticides,[23] some having been developed by regulatory agencies for pesticide management. Certain problems have occurred with their use because of the limited amount of validation work that has been done and a tendency to underestimate the presence of preferential transport of pesticides from the soil to groundwater through the vadose zone.

7.3.5 Improving Irrigation Water Use Efficiency

Where irrigation is practised, there exists the possibility of controlling soil moisture so as to maximise nutrient uptake and to restrict deep percolation (thereby controlling agrochemical leaching). This is most practicable where most plant moisture requirements are provided by irrigation, and is less feasible where supplementary irrigation is required: but even here the maximisation of nitrate uptake can be assured by providing optimum moisture levels at times of rapid plant growth, and thereby reduce soil nutrient residues. Moreover, denitrification losses (rather than nitrate leaching) become more significant in irrigated cultivation, especially on finer-grained soils.

The *improvement of irrigation water use efficiency* (through the introduction of more advanced irrigation technology) can *reduce immediate nutrient and pesticide leaching*, and also improve crop yields and save on energy costs for pumping. It is *often advocated as the panacea to all groundwater problems*, since it also offers the opportunity for real water resource savings through reducing non-beneficial evaporation and other water losses.

However, the relation between irrigation practices and groundwater recharge is a complex one. It is extremely important to note that *irrigation returns often represent the major component of groundwater recharge* in the more arid climates—and this will represent "new recharge" in cases where surface water is the source of irrigation and in effect "recycled water" (reducing net groundwater abstraction) in the case where groundwater irrigation is practiced.

This scientific reality has very important implications for groundwater resource management, since in some cases improvements in irrigation water use efficiency may be largely achieved through reduction in irrigation returns to groundwater, and as such *do not result in "real water resource savings"*. Thus, in areas of intensive groundwater development, *future resource management should be based on accounting for "consumptive water use"* (rather than groundwater extraction *per se*) and this will pose new challenges for the administration and monitoring of groundwater use for agricultural irrigation.

Moreover, in the longer run improvements in irrigation water efficiency can result in major increases in the salinity of groundwater recharge.

7.3.5.1 What are the Main Policy Implications for Groundwater Body Quality Protection?

During the last 20 years or so it has become increasingly evident that *agricultural land-use practices exert a dominant influence on groundwater*. For example a recent British assessment showed that during 1973–2003 public groundwater supplies totalling more than 1500 Ml per day required treatment or blending or were abandoned (resulting in capital costs alone in excess of €500 million) as a result of quality deterioration due to diffuse agricultural pollution and tighter EC water quality standards.[24] Thus a major challenge to the *successful implementation of EC directives will be achieving improved harmonisation between agricultural practices and groundwater resource conservation*—on which only patchy progress has so far been made.

Various types of agricultural cropping (even if conducted under "best agricultural practice") will not achieve drinking water or ecosystem guideline quality as regards average quality of groundwater "harvested" from the corresponding land. Thus other more radical measures will widely be required to satisfy the "good chemical status" of groundwater bodies including:

- at farm level—more balanced land-use regimes and improved nutrient management plans;

- at groundwater supply "capture zone" level—a need to maintain or convert a proportion of land to low-intensity agricultural activity (woodland, pasture or recreational usage) with minimal agrochemical application; and
- at "groundwater body" level—similar land-use management approaches, but with less constraint on the precise location of areas under low-intensity use.

It will be evident that the introduction of appropriate measures to control diffuse groundwater pollution will be highly dependent upon the presence of monitoring networks (and supporting investigations) adequate to demonstrate unequivocally their effectiveness, not only in a direct regulatory sense but also to the stakeholders involved.[25]

The required constraints on agricultural land-use will normally have to be applied in "designated areas"—the EC Water Framework Directive makes specific provision for the *statutory declaration of "groundwater protected areas"* with the implication that:

- these are likely to comprise the main recharge area of groundwater bodies used as an important source of public drinking water supply; and
- additional *"safeguard zones" around individual groundwater sources* will be required to stabilise or reduce potable water-supply treatment needs, but these will not be mandatory.

The Critical Issue of Adequate Groundwater Quality Monitoring

The management objective of the EC directives, coupled with the large response times of many important European aquifers, means that substantial investment in groundwater quality monitoring networks will be required. Much of the routine monitoring that has been carried out in many countries to date has been focused on "external receptors" (mainly drinking water wells and springs), and in terms of groundwater body management has to be regarded as a "post-mortem" activity, since it is a very tardy and insensitive indicator of incipient pollution especially in the deeper aquifer systems.

This leads to the inescapable conclusion that monitoring and assessment efforts need to focus much more on the quality of contemporary recharge to groundwater bodies, since not to do so will:

- *compromise ability to obtain an early warning of potential new groundwater quality problems; and*
- *make the timely demonstration of the effectiveness of management measures impossible.*

Having said this the direct monitoring of groundwater recharge quality at field scale is not readily possible on a routine operational basis, and research-level techniques for soil leachate and vadose zone sampling in permeable *profiles (developed during 1975–1990) are required for this purpose, and even then the interpretation of results generated by these techniques may not be straightforward due to the potential complication of soil disturbance and preferential vadose zone flow. The favoured solution as regards routine monitoring is to put much more emphasis on sampling groundwater close to the water table in the "recharge zone" (Figure 7.3.3), which is a much more sensitive indicator of incipient pollution.*

Both exist to a varying degree (and based on variable criteria) in many EU countries, and clear benefits should accrue from a harmonisation of approaches. Such "protected areas" and "safeguard zones" could equally apply to important groundwater-dependent ecosystems (especially EU Natura 2000 sites), with the caveat that there is likely to be a much higher level of uncertainty in what will constitute a "significant impact" in terms of groundwater contamination.

Groundwater management measures involving the establishment of protection zones are of necessity long term, in view of the associated investment in water supply infrastructure, and thus need to be based on stable "groundwater-friendly" agricultural cultivation regimes. But complicating factors in this regard include:

- the long "response times" of many aquifers, which mean that the full benefit of control measures on agricultural activities will only be obtained in the long run and that the requirement of the EC Water Framework Directive (2000) of reversing negative trends in groundwater chemistry by 2015 will not be feasible for groundwater bodies of large storage (although this must not be accepted as a reason for not introducing appropriate control measures); and

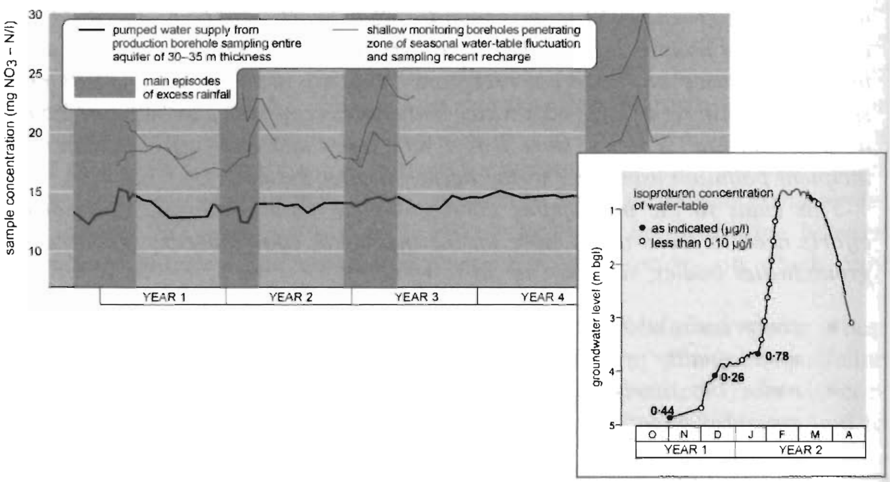

Figure 7.3.3 Detection of groundwater quality trends in aquifer recharge by sampling installations in the zone of water table fluctuation.

- the need to stimulate "adaptive capacity" in the water sectors to cope with the impacts of accelerated climate change on agricultural cropping and in turn on groundwater recharge and quality.

If adequate groundwater quality management measures are not (or cannot be) widely introduced, then the implication is that advanced treatment will be needed to secure the quality of public drinking-water sources and that wetland ecosystems will not be adequately protected. In reality water supply treatment should not be thought of as an alternative to source protection, but as a complementary measure to ensure drinking water quality depending upon the level of protection that can be guaranteed for raw water quality.

Certain other processes may also need to be taken into consideration to get a "fully rounded" picture of the diffuse groundwater pollution pressure arising from essentially rural areas:

- non-agricultural use of pesticides (usually at high rates) for railway, highway and airfield defoliation;
- effects of aerial fallout to agricultural land from industrial process (past and present) and the potential for soil accumulation and eventual leaching of certain types of synthetic organic pollutants; and
- irrigation of agricultural land with treated urban wastewater and/or the land application of sewage sludge, both of which could under some conditions result in the leaching of synthetic organic chemicals (such as industrial chemicals, cleaning solvents, antibiotics, hormonal compounds, disinfectants, fragrances, etc.).

Acknowledgements

The opinions and judgements expressed in this paper are those of the authors alone, but they wish to acknowledge the encouragement of many groundwater and agricultural specialists in England and Spain with whom they have worked over the past 30 years, and interest in the subject has been further stimulated recently by discussion with Dr Philippe Quevauviller (EC-DGE) and with various colleagues from the British Geological Survey at Wallingford (notably John Chilton) and from the Universidad Politécnica de Cataluña.

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