European Water 17/18: 3-16, 2007.

Constructing scenarios of agricultural diffuse pollution using an integrated hydro-economic modelling approach

N.Graveline and J-D Rinaudo
Brgm (French Geological Survey), Water Department,
1039 rue de Pinville, 34000 Montpellier, France.
Ph: (+33) 4 67 15 79 90.
E-mail: jd.rinaudo@brgm.fr

Abstract: In the Upper Rhine valley, as in many other areas in Europe, agriculture is generating a significant nitrate diffuse pollution. This paper presents an integrated modelling approach to simulate future evolution of groundwater quality. The models, which were developed as part of the Interreg project MONIT (Modelling Nitrate in Groundwater in the Upper Rhine), combine economic farm models (on which this paper focuses) with soil and groundwater models. The models are coupled and used to simulate long term evolution of agricultural production and of its impact on nitrate pollution for a range of global change assumptions (CAP reform, oil price changes, etc.). The models are also used to assess the effectiveness (in terms of reduction of nitrate emission) of two alternative nitrogen tax systems.

Key words: Upper Rhine, groundwater, nitrate, diffuse pollution, economic instruments, tax, scenario, linear programming model, farming sector, Common Agriculture Policy reform

1. INTRODUCTION

Recent studies conducted to characterize groundwater quality at river basin district level reveal that, in many European Member States, nitrate pollution is likely to be a major cause of non compliance with the objectives of the Water Framework Directive (WFD). The programs of measures implemented by European Member States to comply with the Nitrate directive of 1991 (91/676/EEC) have clearly not been sufficient to reverse pollution trends and to achieve the targeted nitrate concentration of 50 mg/L in all declared vulnerable areas (European Commission 2002). The situation is not likely to improve rapidly given the strong inertia of groundwater systems, possibly resulting in a high number of groundwater bodies not achieving the targeted 50 mg/L by 2015.

Assessing the risk of non compliance with the WFD objectives for each and every groundwater body is however not a trivial task, as future evolution of nitrate concentration in aquifers depends on complex interrelated bio-physical processes (transfer, transport and attenuation) and economic processes (emissions from the farming sector). To account for all these processes, forecasting future evolution of groundwater quality should ideally be carried out using integrated models able to simulate the evolution of pollution sources, pathways and receptors. The integrated models should ideally be able to simulate future evolution of agriculture in terms of cropping patterns and practices (inputs), as this is a key factor determining groundwater quality change. Moreover, integrated models can also be used to simulate the effect of pollution control measures, considering not only technical measures (imposed on farmers via regulatory constraints) but also economic measures providing positive or negative incentives through the use of environmental subsidies or taxes.

This paper presents an example of integrated hydro-economic model used to simulate future evolution of nitrate pollution under different scenarios of economic and regulatory change. The results presented were produced as part of project conducted at the regional level in the Upper Rhine valley. This project, coordinated by the LfU Baden Württemberg aims at assessing the baseline trend of nitrate evolution in the aquifer and the effectiveness of possible nitrogen management measures through the development and use of an integrated modelling platform. This platform comprises a soil-plant model (simulation of nitrate transfer in the unsaturated zone), a nitrogen balance model (simulating nitrogen infiltration in the aquifer), a hydrogeological model simulating water and nitrogen flows in the aquifer and an economic model (simulating farmers' decisions in terms of crop choices). The present paper focuses on the farm economic model. It presents the results of two years of collaborative research between economists, policy makers and stakeholders conducted as part of the economic Working Group" of the InterReg III MoNit project.

The remainder of this paper is organised as follows: section 1 gives a brief description of the case study area (water resources, pollution trends, agricultural sector) and a quick overview of groundwater water protection policy implemented at the regional level in the Alsace region (France) and the Land of Baden Württemberg (Germany). The paper goes on (section 2) with a presentation of the economic methodology developed and implemented to assess the impact of various measures on farming practices and the associated impact on farm income. The third section of the paper presents the farm typology which was conducted in parallel in the French and German part of the case study area, using a similar methodological approach. Scenarios are then developed (section 5) using a participatory approach and their impact simulated using the economic farm models. The same sections shows how the economic models developed have been coupled with a nitrogen balance model and a hydrodynamic model to simulate the long term impact of the scenarios envisaged on nitrate concentrations in the aquifer. The effectiveness of various environmental tax systems is then estimated using the economic models (section 6).

2. PRESENTATION OF THE CASE STUDY AREA

2.1 Nitrate groundwater pollution in the upper Rhine valley

The Upper Rhine valley aquifer extends over 4200 square kilometres between Germany and France. With a reserve of approximately 45 billions cubic meters of water, it is one of the largest freshwater reserves in Europe. The water supply of more than three millions inhabitants of the Alsace (France), Baden (Germany) and Basel (Switzerland) regions directly depends on this resource. Approximately 300 millions cubic metres are extracted every year for drinking water, 45% being used in France, 35% in Germany and 20% in Switzerland. Groundwater also fulfils 50 % of industrial water needs (approximately 300 millions cubic metres pumped every year).

Since the 1970's, it has increasingly been affected by diffuse nitrate and pesticide pollution, mainly due to agriculture intensification. The nitrate pollution problem is particularly acute on both sides of the Rhine. While the nitrate concentrations were lower than 50 mg/L in the entire aquifer in the early 1970s, 15% of the 1100 monitored points showed in 1997 a nitrate concentration exceeding 50 mg/L. The European guide value of 25 mg/L was exceeded in 36% of the monitored points. Groundwater shows high nitrate concentration levels in areas where intensive crops (corn or vine) are cultivated. And the area of such crops rises whereas the area occupied by grassland steadily declines: between the two last agricultural censuses (1988 and 2000), the area under vine has increased by 13%, the area under corn by 60% whereas area under wheat and grassland decreased by respectively 25% and 13%. This trend is likely to change after the implementation of the reform of the Common Agricultural Policy (in 2006 in Germany and 2013 in France) or other major economical or regulatory trends.

Nitrate contamination of groundwater causes significant economic damages at the regional level. It has lead to the closure of an increasing number of drinking water wells, it contributes to the decline of consumer trust in tap water and the raise of bottled water consumption, and it creates technical and economic constraints for the industry. In the Alsace region, the total cost due to nitrate contamination between 1988- and 2002 has been estimated at €20 to 22 millions for drinking water utilities (investment), €160 millions for households (bottled water purchase, installation of filtering devices at home). The cost borne by the industrial sector could not be assessed but the example of one large brewery, which spent over €10 millions in ten years for the construction and operation of a nitrate removal plant reveals the significance of the cost (Rinaudo et alii, 2005). The regional authorities are therefore increasingly concerned by the consequences on the local economy of further degradation of groundwater.

2.2 Groundwater protection policies in Alsace and Baden-Württemberg

In response to the mounting threat represented by nitrates (and more recently by pesticides), a variety of measures aiming at modifying farming practices have been implemented on both sides of the Rhine. The first type of regulatory measures ensues from EU regulations and in particular from the Nitrate Directive and from the Integrated Pollution Prevention and Control Directive (IPPC) (constraints related to manure storage). Concerning the Nitrate Directive, reference farming practices have been defined by Government agencies in collaboration with professional organization (in Alsace) or with the Extension Services (in Baden Württemberg) and they are imposed to farmers located with vulnerable areas. Constraints imposed to farmers are related to dates of land preparation or fertilizing, maximum quantity of fertilizer allowed, cultivation of autumn cover crops (nitrate sink). Constraints are relatively more stringent in Baden Württemberg than in Alsace. And on both sides of the Rhine, these regulatory measures are accompanied by information and training programs, called Ferti-mieux projects in France and Nitrate Information Services (NID) in Baden-Württemberg.

The second type of measures is related to the implementation of the environmental pillar of the Common Agricultural Policy. In Alsace, farmers are offered the possibility to sign 5 years Sustainable Agriculture Contracts (CAD) with Agriculture Government Agency (DDAF) in which they commit to adopt specific farming practices (8 type of CAD related to nitrate pollution reduction) against a financial compensation ranging between 91 and 374€/ha (see Graveline and Loubier, 2004). In Baden Württemberg, a similar system is implemented (MEKA), farmers being entitled to select environmental friendly practices within a list of 30 measures, each one opening financial compensation rights (possibility to cumulate subsidies). Additional subsidy programs are implemented in Alsace and Baden Wurttemberg to encourage investment in manure storage equipment for instance[i] or the conservation of grassland (subsidies granted by Region Alsace and Water Agency in Alsace)[ii].

The third type of measures aim at modifying farming practices in Drinking Water Protected Areas. In Alsace, such measures are implemented on a voluntary basis and they are formalized by contracts between farmers (who commit to follow certain practices) and Drinking Water Utilities (who pay compensation); the technical and the financial aspects of the agreements are determined by the Chamber of Agriculture. The authorities have gone one step further in Baden Württemberg with imposing by regulation that specific farming practices be followed in all protected areas (SchALVO: "Schutzgebiets- und Ausgleichsverordnung"). Farmers used to be financially compensated during the first years of the program which was initiated in 1988 but the subsidy has been removed and farmers are now charged with a financial penalty if the residual nitrogen content of the soil exceeds a certain threshold value. Since the SchALVO program applies to all drinking water protected areas, and given that these areas are much larger than their equivalent in France, its impact on groundwater quality is significantly higher than in Alsace (for a description of the situation in Alsace, see Bosc et al., 2005).

Although nitrate pollution trend seems to stabilise in the Upper Rhine valley aquifer (see Rinaudo et al., 2005), policy makers are increasingly aware that additional measures must absolutely be implemented to reach the objectives of the Water Framework Directive by 2015. A survey of policies implemented in different countries has enabled to identify innovative approaches which could be implemented in the Upper Rhine valley (Graveline and Loubier, 2004). Economic tools such as fertiliser tax, nitrate emission quotas or the development of a marker of tradable pollution rights (for an illustration, see Jensen et al. 2002) have been implemented in certain countries or investigated in research study. For instance, different nitrogen tax systems are currently implemented in Denmark, Norway and Sweden (see for instance Schou et al., 1999). In the

Netherlands, farmers are taxed according to the nitrogen surplus according to a system called MINAS (Minera Accounting System) and they can sign agreements involving some transfers of manure and a financial compensation (MTAS – Manure transfert agreement system; see Berntsen et al., 2003). However, the effectiveness of these measures might be site specific. The modelling platform developed in MoNit is intended to allow the exploration of the impact and effectiveness of some of the alternative innovative nitrogen management policies in the Upper Rhine valley.

3. METHODOLOGY

The economic methodology developed and implemented consists in eight steps interlinked as shown in figure 1 below. The first steps consists in dividing the study area into a limited number of small agri-environmental regions homogeneous in terms of geographical and environmental characteristics (slope, type of soils, climate) and land use (share of forest, arable land, grassland, etc). The coupling of the economic and nitrogen balance models will be carried out at this geographic level. While an existing zoning is used on the French side, the definition of zones is carried out by a group of experts on the German side.

The second steps consist in constructing a farm typology. A large number of experts were first consulted to identify and describe major farm types and to construct a classification procedure (specification of criteria and threshold values) on German side, while an existing typology were used and adapted on the French side. Farm statistical data were then used to classify the 23,000 farms of the study area; the statistical analysis was performed by Agriculture Government agencies on both sides of the Rhine (for data confidentiality reasons) using different data sources (2000 agriculture census in France, CAP data in Germany) and slightly different classification methods. In France, the classification work was carried out by the Agriculture Government Department (DDAF) on the basis of classification criteria specified by the Chamber of Agriculture (Chambre d'Agriculture d'Alsace, 2003). As a result, we estimate the relative weight of each farm type in terms of percentage of farms, percentage of total agricultural land, cropping pattern and risk of nitrate leaching in each of the small agricultural regions ("Petites Régions Agricoles").

Real farm representative of the typology are selected in collaboration with local extension offices and interviews carried out in order to describe farmers' production strategy, assets and constraints (step 3). A linear programming (LP) model is then developed for farm types having the highest contribution to total nitrate leaching risk (step 4). LP models assume that farmers select the combination of crops which maximises their income under a set of technical, regulatory and economic constraints. They simulate crop choices, input consumption (fertiliser, labour, energy) and farm income for different input parameter values (agricultural prices and subsidies, regulatory constraints, changes in the price of input such as energy, fertiliser, labour, minimum set aside constraint, etc). In their current version, the models incorporate constraints related to crop rotations, labour availability, production quotas (sugarbeet and milk), manure storage and management (for livestock oriented farms). A corn production function, constructed using values provided by the results of agronomic field trials is also introduced into the model to represent the yield and nitrate residual content response to nitrogen input. Gross margins values and technical coefficients are based on figures reported by farmers, cross checked with standard values used by agricultural experts and published by farm professional organisations. The LP models representing the production choices of each of these representative farms are calibrated at the farm level by comparing the simulated with the current cropping pattern. They are implemented using a mathematical solver (MLP) and a simulation engine developed using Visual Basic which allows running repeated simulation for a range of input parameter values.

A group of expert is consulted (step 5) to identify major driving forces (or factors of change) likely to influence farm decisions in the medium term (2015). These factors of change are sorted according to the impact they might have on diffuse pollution, their uncertainty, the time horizon when the change is likely to occur and the ability of the farm models to simulate their impact. Expected evolution trends are then described by experts and using published documents for a limited number of driving forces: the CAP reform, the risk of proliferation of the corn rootworm, fuel price increase and a baseline scenario, consisting in a combination of trends, is developed. Policy makers (who are full members of the project) are then consulted to identify possible responses to the anticipated evolution (step 6); a list of regulatory, contractual and economic measures is developed, taking into account: the existing regulatory framework at EU, national and regional levels; existing local policy instruments; and a review of measures implemented in EU Member States to reduce nitrate pollution levels.

A global simulation plan is then developed and the models are run (step 7, work in progress) to assess the changes in cropping patterns and farm income associated to (i) each component of the scenario separately, (ii) the combined baseline scenario and two more extreme scenarios (A1 and B2) and (iii) the impact of each of the pollution abatement measures identified. Selected examples of simulation runs are presented in the last section of this paper: (i) the CAP scenario, (ii) the global scenarios, (iii) the tax simulation on both fertilizer use and on the post harvest nitrate residual content for two farm types (large cereal oriented farm and milk production oriented farm, in France and Germany).

Finally, the results of the farm models are extrapolated to the small agricultural regions and used as input by the nitrogen balance model (step 8).

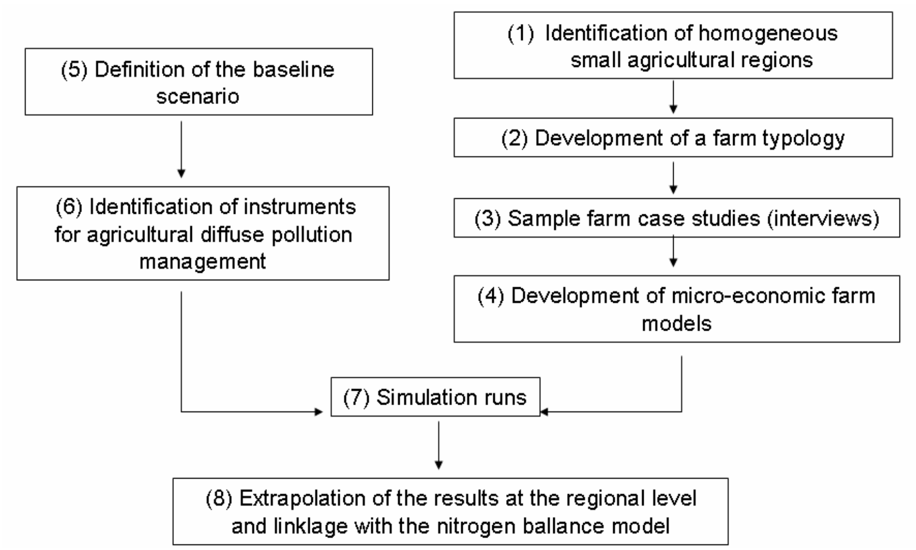

Figure 1. Major steps of the methodology.

4. FARM TYPOLOGY AND ASSESSMENT OF THE RISK OF NITRATE LEACHING

4.1 Farm types identified

In Alsace and Baden-Württemberg respectively, 16 and 11 farm types were identified, with some correspondence between most of the types and some specific types are only present in Germany or France (see Graveline et alii., 2004). Approximately 80% (France) and 66% (Germany) of the farms, representing between 85 and 81% of the total farming area, could be classified into one of the types. The remaining farms which did not correspond to any of the types defined by experts are left out of the sample for the rest of the study. The major types identified are the following:

Five cereals oriented farm types (C1, C2, C3, C4 and C5), differing in size, level of diversification and intensification, represent respectively 64% and 54% of the total arable area in Baden and Alsace region respectively (Farms C1 and C2 are large production units (80 ha on average in France, and 102 ha in Germany) specialised in corn production (74% - 62% of the cultivated area), other cereals representing less than 10% of the cropped area. The French type C1 has a significant irrigated area whereas C2 is mainly growing rainfed corn. No distinction is made between C1 and C2 in Germany (very little irrigated area). Farm type C3 is composed of large production units (95 ha) which diversify their production with cereals (36% Alsace, 27% Baden) and other crops such as rape, sugar-beet, oilseeds, etc (22% in Alsace, 5% in Baden). This type covers a large area in Baden (4% of total agricultural area) than in Alsace (1%). Farm type C4 is composed of very small part-time production units (15 ha in Alsace, 12 ha in Germany) which represent 27% and 34% of the total farm sample in Baden and Alsace. In Baden, farmers of this type grow more cereals than corn (respectively 31% and 27% of the total area) whereas French farmers are specialised in corn (67% - with only 15% of cereals). Farm type C5, which is specific to Baden region, is also specialised in corn and cereals (49% and 15% of its area) but it derives a significant share of its income from intensive special crops: vegetables cover 4% of its area, asparagus 3% and tobacco and other perennial crops 6% (orchards, vines). This type does not exist in Alsace, due to the difference in labour legislation (no minimum wages in Germany for temporary labour which is widely used for intensive special crops). In general, all these types (C1 to C5) have a much larger area under grassland in Germany than in France (23% for C3, 13% for C1/C2 in Baden).

Farm type D1 (D1-M in Germany) is composed of medium size diversified farms (50 ha on average) cultivating a significant area of high added value crops such as sugar-beet, hops, tobacco on a significant area. German farms are much more diversified than the French ones, probably due to the difference in labour legislation: special crops represent 14% of the group area in Alsace and 62% in Germany (53% of vegetables, 3% of vine, 3% orchard, 3% of berries). Corn only occupies 30% of the area in Baden and 67% in Alsace. Farm types M and H, which are specific to Alsace, are also specialised in vegetable (M) and horticulture (H) production but unlike their German counterpart D1-M, they operates very small areas (4 and 2 ha). These farms, which represent a very small total area (0,8 and 0,1% of the total area in Alsace) are not analysed further.

Farm type L1 and L2, specialised in milk production, only represent 5% of the sample in Alsace and 1% in Germany (covering 15% and 2% of the total agricultural area in Alsace and Germany). In Alsace L1 are more intensive than L2 (respectively 0,7 and 0,4 milk cows per ha), most of the area being used for fodder production. In Baden, only one type was identified (L, 0,76 cows per ha). Grassland represents 25% of the area in Alsace and 40% in Baden. Winter nitrogen trap crops are cultivated in 28% of the area in Alsace, probably as a response to the regulatory constraints related to manure spreading.

Table 1. Number of farms and area of each farm types (Alsace and Baden regions)

ALSACE	total	C1	C2	C3	C4	D1	DG	DS	H	L1	L2	B1	B2	O	V1	V2	M
Part of farms in each type (%)	100	5,9	3,0	0,6	34,3	5,0	0,9	0,9	2,0	2,4	3,1	0,8	2,3	0,3	26,7	11,2	0,8
Part of type area in total area (%)	100	21	9,7	2,1	21	12	1,6	2,1	0,1	5,6	9,5	2,1	4,39	0,7	2,3	6	0,1

BADEN	total	C1 /C2	C3	C4	C5	L1	B1	B2	D2 -S	T p	VD	D1 -M	out of types
Part of farms in each type (%)	100	4,9	4,1	26,7	10,4	0,6	0,5	0,4	0,4	1,9	14,5	2,9	34,0
Part of type area in total area (%)	100	17,0	13,8	10,7	22,5	1,8	1,6	1,6	0,7	0,7	8,2	4,9	19,1

Farms of types B1 and B2 are specialised in beef production, B1 being more intensive than B2 which operates more area than what is strictly needed for fodder production. These farms are even fewer than the milk production oriented farms, they hardly represent 6,5 % and 4% of the total area in Baden and Alsace. Overall, German farms operate more grassland than their French counterpart (respectively 40% and 30%). French farm also grow more corn (24 / 37% of the area of B1 / B2 in Alsace against 13 and 18% in Baden).

Farms of types V1, V2 and VD, which mainly depend on vine (Alsace) or vine and orchard (Baden), represent very large groups (38% of the farms in Alsace, 14% in Baden) but a moderate percentage of the total area (8%). Type V1 is more diversified than V2, farms of this group cultivates cereals (9% of its area) and corn (24%), the total representing 3% of the total cereal and corn area of the region.

Finally, a few marginal farms types specialised in animal production have been identified: sheep breeding (type O, Alsace), pig production (DS, D2S) and poultry farms (DG).

4.2 Contribution of farm types to the risk of nitrate leaching

The next step of the work consisted in assessing the relative risk of nitrate leaching generated by the different farm types described above. The use of detailed nitrogen balance models – such as the CORPEN model in France – was not possible in our case, given the aggregate level at which the analysis is carried out and the lack of information on farm practices (quantities of fertiliser used, manure spreading practices, etc). We therefore used a much simpler indicator to assess the relative contribution of each farm type to the overall risk of nitrate leaching. This indicator was defined as follows:

$$R_i = \sum_{j=1}^{N} .S_{i,j} k_j \qquad (1)$$

where: "i" is a farm type index, "j" a crop index;
R_i the indicator of nitrogen leaching risk;
$S_{i,j}$ is the area of crop j cultivated by farm type j
k_j is the post harvest residual nitrogen for crop j.

The post harvest nitrogen residual values used are estimated using the results of the 2001 – 2003 campaigns of the SchALVO program implemented in the land of Baden Württemberg. This program consist in analysing nitrogen residual in soil (90 cm depth) after harvest in all the fields located within drinking water protected areas ("Wasserschutzgebiet"). Since farmers are charged with a fine if the residual exceeds a certain threshold value, it is expected that the nitrogen residual content of the soil is lower in these protected areas than in other regions[iii], nevertheless these values can be used in order to assess comparative and relative impact between crops.

The results show that 7 farm types contribute to respectively 78 and 85% of the total post harvest nitrogen residual in the soils in Baden and Alsace. The total contribution of the five cereal oriented types is very significant (59% in Baden and 56% in Alsace). Diversified vine oriented farms in Alsace (V2) and vine-orchard farms in Baden are also significant contributors (11% in Baden and 10% in Alsace) as well as diversified farms (9% in Baden, 12% in Alsace). These farm types therefore represent a priority target and specific measures should be implemented to reduce their nitrogen emission. Based on this result, it was decided to concentrate the economic modelling work on these farm groups which represent the major potential sources of nitrate diffuse pollution. The following section illustrated how the models developed following the methodology presented above have been used in simulation.

5. ESTIMATING FUTURE EVOLUTION OF NITRATE EMISSION

5.1 Identification of driving forces and elaboration of scenarios

Five major driving forces likely to have an impact on farming systems and on the risk of nitrate leaching were identified by the group of experts: the reform of the Common Agriculture Policy (CAP); the risk of proliferation of the corn rootworm; the increase of oil price; the development of bio fuels; and the enlargement of the EU which could have an impact on labour markets (increase of temporary labour costs – which is widely used in fruit and vegetable farms in the Baden region). Other driving forces identified by the experts were not included in the model, either because it was difficult to quantify the associated trend or because their impact may not appear during the period considered (climate change).

The CAP reform (Luxemburg agreement of 2003) clearly represents a major driving force likely to determine future evolution of cropping patterns, farm practices and the risk of nitrate leaching in the study area. The direct payment subsidy system introduced by the reform will significantly modify economic incentives in the farming sector in Europe. After the reform, each farmer will be allocated a fixed number of rights (expressed in hectares), each right being eligible for a fixed premium, which amount is independent from the crops cultivated. This decoupling of subsidies from production will not be implemented similarly in France and Germany (see Graveline et al., 2004 for a detailed description), with two major differences. Firstly, while Germany has adopted a total decoupling system (Deutscher Bauernverband, 2003), France has decided to keep a 25% coupling system for main crops (75% of the premium is fixed and 25% depends on the cultivated crop) (MAAPAR, 2004). Secondly, in France, the amount of the fixed part of the premium is specific to each farmer[iv], whereas a regional average amount was defined in Germany, implying a subsidy increase for extensive farmers at the expenses of intensive farmers (a temporary decreasing compensation payment is however implemented – top-up premiums). Overall, the reform will modify the relative profitability of the crops and it could result in changes of cropping patterns, such as a decrease of area under corn (corn was benefiting from a premium higher than other cereals until 2003) if the effect of the new subsidy system is higher than the remaining relative benefit of corn towards other crops for the farmer. A decrease in the area under corn would lead to a reduction of the level of nitrate emission in the environment.

The second driving force identified by the group of expert is the risk of proliferation of the corn rootworm (Dibrotica virgifera)[v] which has been observed for a few consecutive years in the region of Mulhouse – Basel (the southern part of the study area). Although significant measures have been adopted to keep the parasite development under control, experts consider that the risk of proliferation is real. Would the parasite spread in the entire Rhine valley, farmers would have to implement a three years corn crop rotation – implying a reduction of the corn area to a approximately 30 to 40% of the total arable area. This adjustment in cropping pattern would be spontaneously adopted by farmers after a few years of observed damages.

Experts have also considered that the fluctuations of international oil price could have an impact on cropping patterns. An increase of oil price would significantly raise the variable machinery costs and the drying cost of corn (and to a lesser extent of other cereals) and, reducing the gross margin of these crops and possibly changing their relative profitability. Also, an increase of oil price could generate a new demand for bio-fuel at an industrial and farm scale (development of raw oil on-farm productions), offering new cropping possibilities to farmers and an alternative to the corn-cereal specialisation.

Experts have also considered that labour cost could increase in Germany where there is currently no regulation imposing minimum wages. This change could be due to a possible evolution of the German legislation and the rapid increase in the way of life of new European Member states which currently supply most of the temporary labour force employed in agriculture.

Other factors of change were identified but the experts considered them as very uncertain, both in terms of expected trends and time horizon. Technology is expected to evolve, possibly leading to a reduction of diffuse pollution (development new crop varieties, genetically modified varieties, development of new machinery for instance for sowing without tillage). Agricultural prices could also evolve due to changes in the structure of the entire agricultural industry. The implementation of new environmental policies could also affect agricultural systems: the Water Framework Directive could for instance result in implementing the costs recovery principle (increase of taxes on water), the future soil directive could also introduce new constraints and costs on land management practices, etc. Public budget allocated to the farming sector could evolve downwards, at the

European, national and regional level. Finally, the farming sector could be drastically affected by the evolution of farmers' population demography (insufficient young farmers installation to replace retired farmers). And the social demand for environment protection could result in an increasing pressure on agriculture, resulting in a spontaneous evolution of practices towards more sustainable production practices. All these changes are however perceived as very uncertain by experts, they are therefore not considered in the present work.

5.2 Simulating the impact of the CAP reform

To simulate the impact of the CAP reform, the price vector of the model is modified to take into account new subsidy values. Additional constraints are also inserted to take into account the decoupling principle and the activation of rights for payment. These changes differ between German and French farm models to take into account CAP reform specific implementation. Simulation results show that crop choice is only slightly affected by the reform. In France nearly no changes in cropping patterns are observed, except for tobacco which disappears (reduction of 1400 ha) due to a drastic decrease in subsidy, and which is replaced by corn. As a result, mineral nitrogen consumption and the estimated post harvest nitrogen residual content of the soil remains constant. Water consumption slightly decreases (-8%). These simulated evolutions are confirmed by observed changes in 2006 harvest (first year after CAP reform implementation) which showed nearly no changes in farmers choices. The impact of the CAP reform on farm income is much more significant, in particular in Germany where total gross margin reduction is close to 10% for certain farm types (-9% for large cereal oriented farms, -12% for milk oriented farms). The impact is less marked in France where corn oriented farms lose less than 2% of the total gross margin and milk farms lose 7%.

5.3 Simulating the impact of integrated scenarios

The economic models were then used to simulate the impact on cropping patterns of three global change scenarios. Given the uncertainty associated with future changes, three contrasted scenario were developed, a baseline scenario and two variants inspired from the scenario developed by the International Panel on Climate Change (IPPC, 2000). More details on these scenarios can be found in Graveline et al. (2007). Economic models simulations show that the common trend for the 3 scenarios is the fall of corn areas to the benefit of wheat and in one case of rape (biofuels). This trend is moderate for A1, but more extreme for the baseline scenario and even more accentuated for B2 where the three year rotation – corn, wheat, rape – has become widespread for large cereal farms.

The consequences on water quality of these changes in cropping patterns were then estimated using the other components of the modelling platform described above. Simulation results show that future nitrate concentration in the aquifer will not significantly differ from one scenario to the other in the short term (estimated at 19 mg/L for the baseline and A1 scenarios, and 19.5 mg/L for the B2 scenario). More significant differences are expected in the longer term (average concentration of 16 mg/L for baseline and A1 scenarios, 18.2 mg/L for B2 scenario). The area where nitrate concentration exceeds the drinking water thresholds (50 mg/L) will drastically fall from 17000 hectares in 2005 to around 4000 ha for the baseline and A1 scenarios, and to 6000 ha for the B2 scenario. Surprisingly, scenario B2 which depict a world with more stringent environmental constraints is also the worst scenario in terms of water pollution due to the increase in areas under industrial crops used for producing bio fuels.

Table 2. Simulated evolution of the agricultural cropping pattern for the whole area (Alsace and Baden)

	2003	Baseline 2015	A1 2015	B2 2015
Wheat	39 000	90 000	76 000	90 000
	16%	36%	30%	35%
Barley	6 000	5 000	5 000	5 000
	2%	2%	2%	2%
Summer cereals	5 000	9 000	7 000	9 000
	2%	4%	3%	4%
Silage corn	11 000	10 000	10 000	10 000
	4%	4%	4%	4%
Corn	146 000	85 000	108 000	48 000
	58%	34%	43%	19%
Rape	3 000	14 000	6 000	52 000
	1%	6%	2%	20%
Sugar beet	5 000	5 000	5 000	5 000
	2%	2%	2%	2%
Oleaginous/ Leguminous	2 000	2 000	2 000	2 000
	1%	1%	1%	1%
Fallow	24 000	23 000	25 000	23 000
	9%	9%	10%	9%
Tobacco	2 000	2 000	2 000	2 000
	1%	1%	1%	1%
Vegetables	4 000	3 000	3 000	3 000
	2%	1%	1%	1%
Tabac	1 000	1 000	1 000	1 000
	1%	0%	0%	0%
Total arable area	**250 000**	**250 000**	**250 000**	**250 000**

Table 3. Simulated evolution of nitrates concentration in the aquifer. Source LUBW (2006)

	2015 (cropping patterns from 2003)	**2050** (simulated cropping patterns)			
	Ref	Ref	Baseline	A1	B2
Mean Nitrate concentration in the aquifer [mg/L]	19,4	17,4	16,0 (-8%)	16,4 (-6%)	18,3 (+5%)
Area that exceeds NO3 threshold (50 mg/L) [ha]	10 963	5 637	-38%	-31%	5%

6. SIMULATING THE IMPACT OF ECONOMIC INSTRUMENTS: THE CASE OF NITROGEN TAX

6.1 Theoretical background

Technical measures have traditionally been preferred by policy makers to reduce nitrate emissions. They consist in imposing constraints on crop production, such as restricting the total quantity of fertiliser use, covering soils in winter with an intermediate crop (nitrate sink), etc. Incentive based economic instruments such as environmental taxes or subsidies are less frequently used although they can also, in some cases, lead to water quality improvement (Rinaudo and Strosser, 2007).

The principle of the environmental tax in agriculture consists in shifting the economic optimum from high to low intensity cultivation practices. For a given crop, yield generally follow a curve as shown on *Figure 2* bellow, the maximum yield being achieved at point A, called the agronomic optimum. In absence of tax on inputs, farmers will generally tend to maximise their production and adopt intensive practices which allow maximising the gross margin. The economic optimum corresponding to this situation is noted E1 on *Figure 2*. The effect of a tax on inputs (fertilisers in particular) will consists of shifting downwards the profit curve, the economic optimum moving towards E2, E3, E4 as the tax level increases. This does not only result in a reduction of fertilise use but also in a decrease of farm income (more costs).

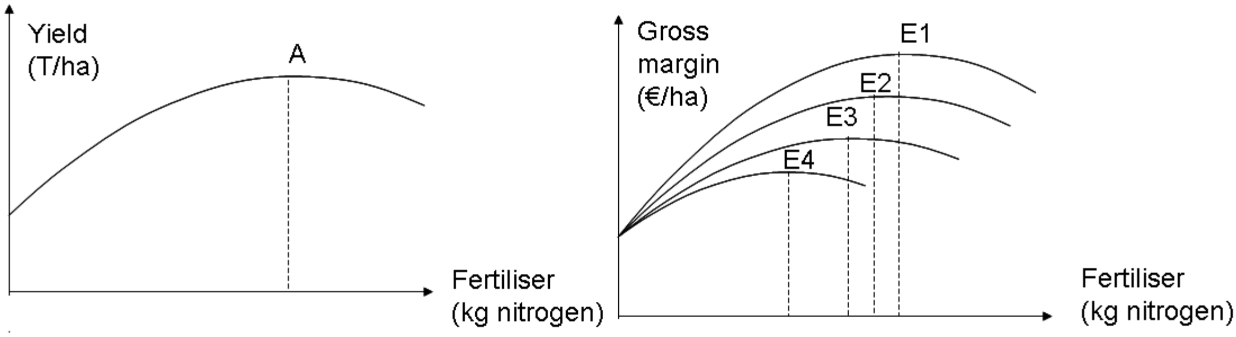

Figure 2. Representation of agronomic and economic optimum for different tax levels.

Table 4. Relationship between yields, fertiliser use and post harvest nitrate residual in soils.

	Thin gravel soils (Hardt region)				**Deep silt soils**		
	Irrigated corn fert level 1	Irrigated corn fert level 2	Irrigated corn fert level 3	Non irrigated corn	Non irrigated corn fert level 1	Non irrigated corn fert level 2	Non irrigated corn fert level 3
Fertiliser dose (kg)	190	210	230	165	150	170	190
Yield (T/ha)	10,6	11,1	11,4	6,5	10	10,3	10,5
Post harvest N residual	47,6	50,4	53,3	44,0	41,3	47,8	54,3

The economic models presented above were used to simulate the effectiveness of different environmental tax on nitrogen. A production function, linking crop yields with nitrogen input was first developed and integrated in the linear programming models, using agronomic field test conducted on different soils in the region. This allows the model choosing not only crops but also the intensity of fertiliser used. Due to data availability constraints, the production function could only be developed for corn, which represents the main source of nitrate input in the aquifer. The STICS soil plant model is then used to simulate the value of post harvest nitrate residual in soils for the different level of fertiliser use (Table 4 and LUBW, 2006).

6.2 Simulating the impact of a tax on fertiliser use

A first series of simulation were conducted to assess the impact of a tax that would be charged on fertilisers use (per quantity in kg of nitrogen). The simulations presented below correspond to the typical C1 French corn oriented farm. In the reference situation (2003), the farm is mainly growing irrigated corn (71 ha) and wheat (6 ha).

The simulation shows that, with the 2003 current economical environment (before CAP reform, low energy prices), farmers would not change their cropping pattern significantly until the tax reaches 1 €/kg. When this level of tax is reached, the tax becomes effective and farmers reduce the level of corn fertilisation (Figure 3). When the tax reaches 1.75 €/kg, the area under corn drops to about half of its initial level and is replaced by cereals (wheat). With an additional increase of the tax (2 €/ kg), farmers reduce fertilisation to the lowest fertilisation level on corn.

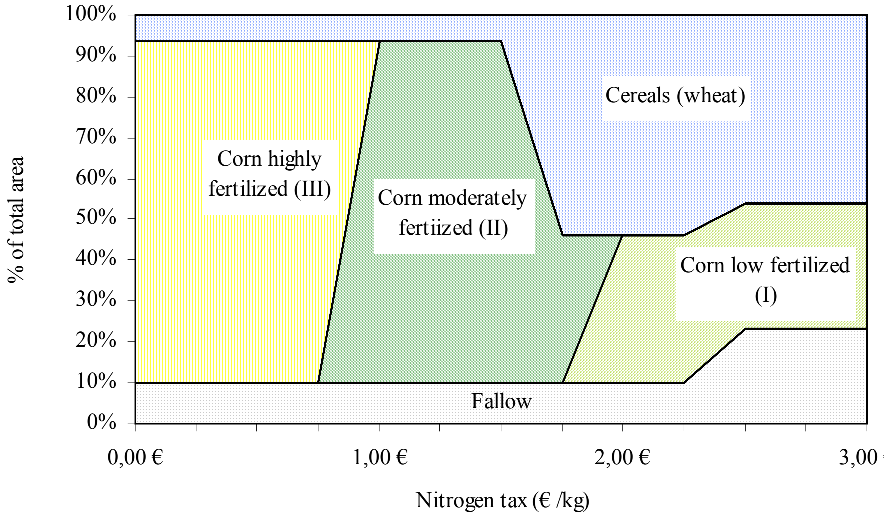

Figure 3. Simulation of the evolution of cropping pattern for various levels of nitrogen tax for farm type C1 in the reference situation (2003)

Figure 4 shows the evolution of fertilizer use associated to changes in cropping patterns and fertiliser use practices, as well as the impact on post harvest nitrogen residual in soils. With a tax of 3€/kg, the total fertiliser use drops at about 50% of the initial level and the total farm income is reduced by half. To reduce the income effect of the tax, a marginal tax system could be designed, where farmers would only be taxed at high level for fertiliser used above a given threshold, considered as good practice.

6.3 Simulating the impact of a tax on nitrogen post harvest residual

We then simulated the impact of a tax that would be proportional to the average post harvest nitrogen residual at the farm level. With this system, inspired from the practical experience of the German SchALVO program and from theoretical considerations presented in Spaeter and Verchère (2004), farmers are taxed on the basis of the actual impact of their activity and not on the quantity of fertiliser they use. This implies that soils analysis are carried out every year to estimate actual nitrogen residuals for a number of fields representative of the farms, entailing much higher transaction costs than with a simple tax on fertiliser use. The simulation results show that the tax becomes effective after 3 €/kg of residual per hectare for farms of type C1 where corn is partly replaced with wheat. The effect of the tax is different for farms of type C2, which start reducing fertiliser use for corn crops after the tax exceeds 1 €/kg of residual. This highlights that the effectiveness of this type of tax may differ significantly between farm types but also soils. The tax also has a strong impact on income, which could be mitigated through the definition of a threshold value below which the tax is not charges (for instance 30 kg/ha considered as the unavoidable nitrogen loss occurring with good practices).

7. CONCLUSION

In the Upper Rhine valley, as in many other areas in Europe, agriculture is generating a significant nitrate (and pesticide) diffuse pollution. Past efforts to manage this risk have not been entirely successful which compels policy makers to anticipate future evolution and identify measures able to bend past trends.

This paper presents an economic methodology developed as part of the InterReg project MONIT (Modelling Nitrate in Groundwater in the Upper Rhine) and illustrates it with some of the results obtained. The methodology consist in constructing a farm typology and developing linear programming models at the farm level, the models being used to simulate the impact of various economic development scenarios on cropping patterns, farm income and the risk of nitrate leaching. One specific characteristic of this research is that it focuses on a transboundary region – where the same policies might have a different impact in different countries, due to environmental, economic and regulatory differences. The analysis highlights the differences which exist between the French and the German part of the case study area in terms of farming systems, water protection an agricultural policy and simulated responses of the farms to various nitrogen management instruments.

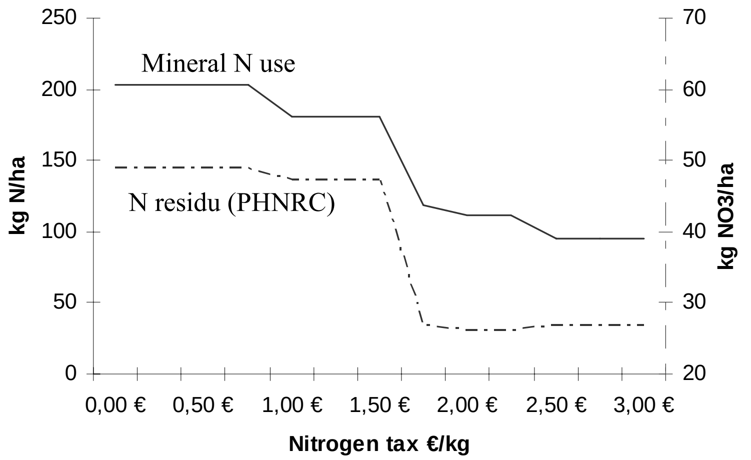

Figure 4. Evolution of post harvest nitrogen residual content of the soil with various levels of nitrogen tax for two farms

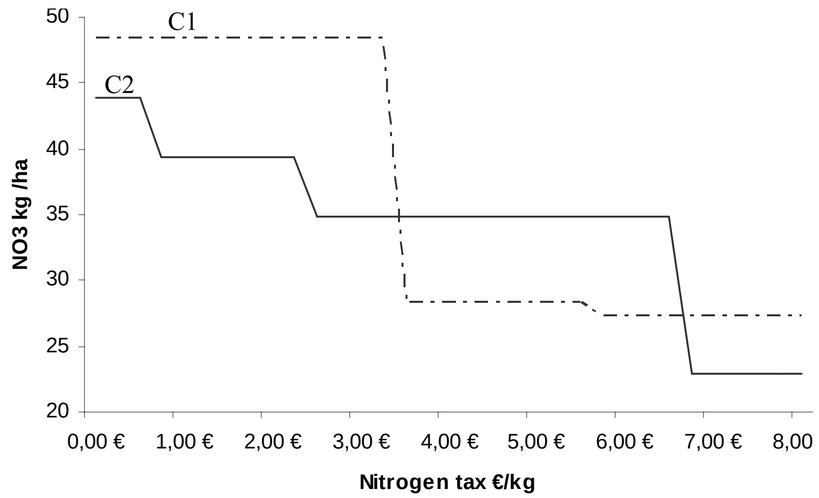

Figure 5. Simulated evolution of post harvest nitrogen residual in soils for farms of type C1 located on gravel soils and farms of type C2 located on silt soils.

The simulations conducted show that the CAP reform is not likely to result in a significant reduction of the risk of nitrate diffuse pollution. The simulation of more complex scenarios accounting for different economic and environmental changes suggest that nitrate contamination should progressively decrease. The potential offered by environmental taxes as a tool to reduce contamination is also explored through economic simulations. The results obtained show that the tax has to be set at a relatively high level to be effective.

The methodological approach presented here also has some caveats and limitations which must be stressed. Firstly, the extrapolation of the results obtained with modelling a limited number of real farms to the entire sector (23,000 farms) generates an uncertainty which – although difficult to quantify – should be fully considered. Secondly, LP models are not able to account for the possible changes of farm structure, they assume that farm assets and constraints remain constant over time; in reality, the changes provoked by the CAP reform for instance might lead to the concentration of the sector, the specialisation of some farms; the typology elaborated in this project being static by nature, the methodology does not allow to describe the dynamics of farming systems.

REFERENCES

Berntsen, J., Petersen, B.M., Jacobsen, B.H., Olesen, J.E., Hutchings, N.J., 2003. Evaluating nitrogen taxation scenarios using the dynamic whole farm simulation model FASSET. Agricultural Systems 76 817–839.

Bosc C., M Bourblanc, J-D Rinaudo, A Roussary, and C. Viavattene (2005) EVEC project (Town water and Field Water): A French approach to mechanisms protecting potable water catchment areas menaced by agricultural pollution. Paper presented at the EWRA conference, Menton: September 7-10, 2005.

Casper M., J. Grimm-Strele, Th. Gudera, S. Korte, H. Lambrecht, B. Schneider, P. van Dijk, J-D. Rinaudo & M. Finck (2005) EU-Project MoNit: Decision support system to assess the impact of actions and changing frameworks on the nitrate load in the Upper Rhine Valley aquifer. Models and scenarios. Paper presented at the EWRA conference, Menton: September 7-10, 2005.

Deutscher Bauerverband (2003)- Die Reform der Gemeinsamen AgrarPolitik

European_Commission. 2002. Implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources. Synthesis from year 2000 Member States reports. COM (2002) 407 fin. European Commission, Brussels.

Graveline N., Rinaudo J-D, Segger V., Lambrecht H., Casper M., Grimm-Strele J, Van Dijck P, Koller R., Gudera and Elsass P. (2007) Integrating economic with groundwater modelling for developing long term nitrate concentration scenarios in a large aquifer. In Aquifer Systems Management: Darcy's legacy in a world of impending water shortage, Chery L and de Marsilly G (eds). AA. Balkema Publisher

Graveline N., Segger V. and Rinaudo J-D. (2004) – The 2003 CAP reform : comparative analysis of implementation in Alsace (France) and Baden Württemberg. Report BRGM/RP-53542-FR. Orléans. (in French)

Graveline N. and S. Loubier (2004) – Policy instruments for diffuse nitrate pollution reduction : a literature review. Report BRGM/RP-53170-FR. 65p. Orléans. (in French)

Graveline N., Rinaudo J-D, Gerberth F. and Segger V. (2004). Analysis of farming systems in the upper Rhine valley. Report BRGM/RP-53171-FR. Orléans. (in French)

Inter-governmental Panel on Climate Change, Emissions scenarios - Summary for policy makers. IPCC special report, 2000.

Jensen, J.D., Huusom, H., Rygnestad, H., Andersen, M., Jørgensen, S.H., 2002. Economic impacts of transferable quotas in pesticide regulation - data, model and scenarios. Rapport 145 fra Fødevareøkonomisk Institut. December 2002.:87.

LUBW (2006). Simulating future groundwater nitrate contamination – final report of INTEREG III A MoNit project (in French and German). Karlsruhe, LUBW, Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg.

Ministère de l'agriculture de l'alimentation de la pêche et des affaires rurales (2004)-La nouvelle politique agricole commune (PAC)-Les modalités d'application nationale 2005-2006-2007

Rinaudo J-D, Blanchin R., Arnal C., Elsass P., Meilhac A., and Loubier S. (2004) Assessing the cost of groundwater pollution : the case of diffuse agricultural pollution in the upper Rhine valley aquifer. Water Science and Technology 52 (9) - pp. 153-162.

Rinaudo J-D and Strosser P. (2007) Groundwater management and planning: how can economics help? ; In: Quevauvillier P/ (ed). Groundwater science and policy. Willey.

Schou, J.S., Skop, E., Jensen, J.D., 1999. Integrated agri-environmental modelling: A cost-effectiveness analysis of two nitrogen tax instruments in the Vejle Fjord watershed, Denmark. Journal of Environmental Management 58 (3):199-212.

Spaeter S. and A. Verchère, (2004), "Politiques d'audit optimales dans le cadre de la pollution agricole de l'eau", Cahiers d'Economie et Sociologie Rurales 71, 5-35

---

[i] In Baden Württemberg, investment related to manure management are determined (and partly financed) by the Landschaftspflegerichtlinie, the national REG programme and the regional Agrarforderungsoprogramm – AFP in only. In Alsace, similar investments are subsidised by Agence de l'Eau as part of the PMPLEE programme (Programme de Maîtrise des Pollutions Liées aux Effluents d'Elevage).

[ii] This subsidy is called "Prime Herbagère Agro-Environnementale (PHAE).

[iii] This indicator is very imperfect for two main reasons: firstly, it does not take into account the risk due to manure spreading (this caveat is however not very significant since animal production oriented farms are not very well represented in the study area); secondly, it assumes that the risk is directly proportional to the nitrogen residual and ignores the key role played by climate variability and the type of soils. It is however perceived as a satisfactory simple indicator to assess the relative contribution of the different farm types of the entire area to the overall risk of nitrate leaching.

[iv] For each farm, the amount of the premium associated to each right is equal to the total subsidy received during the reference period (2000-2002) divided by the number of rights.

[v] See Zagatti P and Derridji S (2002). La chrysomèle du maïs est en France. *Insectes* (127). INRA Editions. pp:5-7.