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AgriBMPWater: systems approach to environmentally acceptable farming

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Abstract

To help local regulators mitigate non-point source agricultural pollution and implement environment-friendly agricultural practices, a comparison between different existing or simulated best management practices (BMPs) has been carried out within a pluridisciplinary project called AgriBMPWater (FP5 founded). The project has been imagined and built in a pluridisciplinary approach and framework. The approach developed corresponds to a cost/effectiveness assessment of several BMPs in several European watersheds, also including the study of their acceptability by farmers. Thanks to the integrated assessment of existing and potential BMPs, a selection grid contributes to provide assistance to regulators on how to conduct environmental, economic and sociological analyses for helping decision makers. Water quality problems encountered and dealt with in this project include nitrate, phosphorus, sediment, pesticide loads and acid water concerns. Thus, the developed framework allows for a large range of hydrological and economic models, depending on the environmental problem detected in each watershed.

Keywords: Best management practices; Non-point source pollution; Hydrological modelling; Economical modelling; Acceptability; Computable general equilibrium model; Asymmetric information

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1. Introduction

The merits of alternative pollution control policy instruments have been a major topic in the environmental literature since the 1970s. The increasing computer capacity developed in the last 20 years has led to the improvement of spatially distributed hydrologic models which seem to give sufficiently precise and reliable results to estimate diffuse nutrient losses at the watershed scale when the input dataset is precise enough (Vachaud and Chen, 2002). Sociologic approaches focus on analysing the social and institutional conditions for agri-environmental management and policy. Yet studies, focusing on the design and performance of input-based instruments and combining hydrologic, economic and sociologic approaches, are still needed (Shortle and Horan, 2001). AgriBMPWater is one such study. It aims to compare best management practices (BMPs) in a three dimensional space which is defined by environmental effectiveness, associated economic consequences and social acceptability by farmers and land-users.

The objective of this paper is to describe the framework that has been built within the AgriBMPWater project to compare the impact of BMPs in terms of hydrological effectiveness, costs for the farmers and society, and their acceptability. We shall firstly describe the framework, then the computer models that have been used in each discipline and what has been done to link them. An application of this framework is then proposed and discussed.

2. Framework

A comparison between different existing or simulated BMPs has been carried out through a cost/effectiveness assessment along with a study of their acceptability by farmers on eight European watersheds. This project is embedded within a multidisciplinary framework involving eleven research teams. These watersheds, their main production systems and pollution problems, are described in Table 1. Water quality problems encountered and dealt with in this project, for all eight watersheds, include: high nitrate loads and concentrations at the outlet of the two western French watersheds associated with dairy production; high loads of phosphorus into lake Vico (Italy) associated with hazelnut plantations; high nitrate concentration in groundwater for one watershed in Austria; high sediment loads at the outlet of a second Austrian watershed; acid water associated with artificial drainage of moraine soils in Finland; and pesticides contamination in Norway.

Because the watershed location, climate, size, agricultural production and pollution problems are widely different, the framework focussed not on the models themselves but on the objective that was being represented: the farmers' practices and their improvements, the BMPs. The comparison of different BMPs for a given watershed has been built as a 6 step framework (see Fig. 1):

- step 1: describing the watershed, the general problem (including the objective of different actors) and the main water quality problems;
- step 2: describing and modelling the hydrology. This included description of the model used, calibration and validation of the model, definition of critical areas and risky practices, assessment of their impact on total fluxes or concentrations, deduction of proposed BMPs, assessment of the *ex ante* effectiveness of each BMP;
- step 3: describing the economics. This included description of the diversity of farms, choice of the model to represent this diversity, results of model implementation, assessment of the consequences on introducing BMPs and *ex ante* cost of this introduction;
- step 4: using the results of steps 2 and 3 to derive a cost/efficiency ratio for each BMP;
- step 5: interviewing the farmers to assess the acceptability of each BMP;
- step 6: comparison of the cost/efficiency ratio and the acceptability to build a selection grid.

Table 1
Involved watersheds, environmental problem encountered and main agricultural activities

Country	Watershed	Area (km^2)	Environmental problems encountered	Main agricultural activities
France	Don watershed	650	Nitrates	Mixed crops Cattle breeding
France	St Léger watershed	1	Nitrates	Cattle breeding
Italy	Lake Vico	40	Erosion	Hazelnuts
Italy	Mincio	750	Nitrates	Arable crops
Norway	Heiabbekken	6	Pesticides	Vegetables
Finland	Rintala	59	Nitrates, acidity	Cereals
Austria	Grub	3	Nitrates	Cereals
Austria	Petzenkirchen	1	Nitrates	Cereals

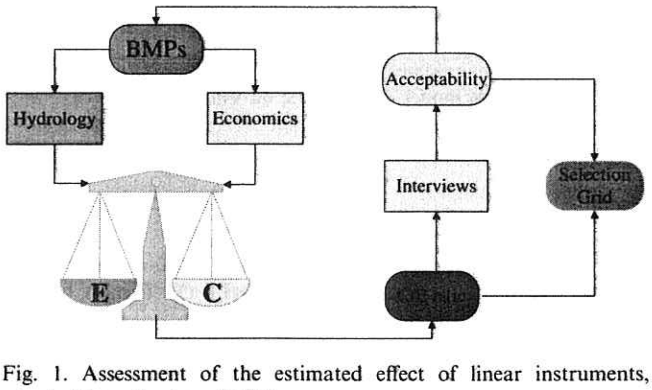

Fig. 1. Assessment of the estimated effect of linear instruments, adapted from Laplana (2001).

3. Environmental efficiency assessment

Environmental effectiveness has been assessed as the change of water quality resulting from BMPs' implementation. The effects on water quality of implementing BMPs have been assessed through hydrological modelling. Realistic estimation of the pathways of water flow in space and time is the great challenge of hydrological modelling. This is needed in order to examine environmental issues like surface- and groundwater pollution from point or non-point sources of nutrients, pesticides, acidity and erosion problems. Hydrological models can be classified in several ways (Roth et al., 1990; Abbott and Refsgaard, 1996):

- stochastic versus deterministic models;
- empirical, lumped, physically-based models;
- research versus management models.

Hydrological models are also used at different spatial scales starting with field sized areas or small watersheds up to mesoscale catchments. According to the various intentions of the application, different modelling approaches need to be used (Rudra et al., 1998; Strauss et al., 2002; Grunwald and Norton, 2000).

3.1. A panel of existing deterministic catchment models

A panel of available models has been used to deal with each specific problem (SWAT, BMP1top, HAPSU, EUROSEM, STOTRASIM, GLEAMS, POWER and EIQ). As they can take various forms, particular efforts have been carried out to improve the representation of BMPs in these hydrological models. Spatial modelling, at various scales, was used to define critical areas where efforts should be concentrated. The effectiveness of BMPs has been estimated through the simulation of previously validated models using pre-designed BMPs as alternative practices. The effectiveness of each BMP was determined as a non-dimensional value corresponding to the ratio between the initial state and the estimated state after BMP implementation. On each watershed and for each BMP, several model simulations were run and effectiveness values derived for increasing percentages of the total watershed area implemented. For small percentages, BMPs were implemented on the most critical areas and as the percentages increased, land implemented with BMPs became increasingly less critical.

The hydrologic models implemented include SWAT (Arnold et al., 2001) with some modifications, on one French and on the Italian watersheds, BMP1top (Bordenave et al., 2001) on one French watershed, HAPSU (Hutka et al., 1996) in Finland, EUROSEM (Morgan et al., 1998), STOTRASIM (Feichtinger, 1996) in Austria, GLEAMS (Leonard et al., 1987) in Italy, POWER (Haverkamp, 2002) in France, Italy and Austria, EIQ in Norway.

STOTRASIM is a field scale model for one-dimensional, vertical flow of water and nitrogen. It is mainly used for the flat areas of river basins and therefore interflow, preferential flow and surface runoff are neglected. Most attention is focused on the amount of water and nitrogen leaching to the groundwater.

EUROSEM is an erosion model which predicts soil erosion and runoff at the small watershed scale. For single events, the watershed is divided into grids, which may either be channels or planes, and both runoff and erosion are routed in a kinetic curve approach towards the outlet of the watershed.

GLEAMS is a continuous field-scale model and consists of four components or sub-models operating simultaneously: hydrology, erosion/sediment yield, plant nutrients and pesticides. This model simulates the loss of nutrients and pesticides at the edge of a field and out of the root-zone.

BMP1top is a spatially distributed model using an agronomy-based model for nitrogen (N) and phosphorus (P) in the root zone, and a semi-distributed hydrological model. BMP1 operates on a daily time step. Calculations are undertaken for all homogeneous surface units derived from a GIS. The sub-models for N and P are adapted from the GLEAMS model. The overland flow is directly transported to the stream.

The SWAT model -Soil and Water Assessment Tool- is a semi-distributed watershed model with a GIS interface (DiLuzio et al., 2002) that outlines the sub-basins and stream networks from a digital elevation model and calculates daily water balances from meteorological, soil and land-use data. SWAT simulates each sub-basin separately according to the soil water budget equation taking into account daily amounts of precipitation, runoff, riverbed transmission losses, percolation from the soil profile, and evapotranspiration.

POWER is a planner oriented watershed modeling system consisting of a hydrological watershed modelling system aimed at the simulation of integrated flow systems of stream and overland flow, soil water and solute movement (i.e. fertilizers and pesticides) in the unsaturated and saturated aquifer zones combined with plant root uptake. It is meant as a tool for integrated hydrological studies, suitable for coupling with planner oriented models allowing for impact studies of alternative management practices (BMP) in agriculture and land management.

3.2. The Don watershed as an example

For comprehension purposes, the general framework developed for this project will be illustrated using an example for this paper: the Don watershed. This watershed is located in the western part of France, in Pays de la Loire, the primary French region for cattle breeding (milk and meat production). The water coming from the Don watershed is connected to two pumping stations for drinking water, supplying around 150,000 people. The whole watershed covers 71,706 ha. The Departmental Council of Loire Atlantique monitors water flows and nitrate concentrations at the Conquereuil station (draining 59,306 ha of the whole Don watershed). The Don watershed is covered by brown soils resulting from the alteration of the underlying schist rock. The watershed being quite flat and soil hydraulic conductivities rather low, these thin soils (60–90 cm deep) are frequently hydromorphic. The weather is typically oceanic, with cool wet winters and warm drier summers. Farm production is mainly cattle breeding (dairy and meat productions), where cereals are grown for both grain and forage. Indoor breeding is still of low importance, but the number of pig and poultry farms is increasing. Grasslands, associated with dairy production, account for around 50% of total agricultural area. Cereals represent 18% and corn 15% of the total area. The average size of farms was 74 ha in 1999.

In the Don watershed, the environmental issue investigated for the AgriBMPWater project was nitrate concentrations and fluxes as nitrate concentration regularly reaches or exceeds the EU guidelines of 50 mg/l at the Conquereuil pumping station.

Local farming practices and economic processes as well as farmers' attitudes towards environmental policies were of primary importance in this project. As a result the population of farms in this watershed was extensively surveyed by an extension service in 1999. This inventory allowed for stratifying the whole population of 820 farms with production system criteria. A sample of 82 farms has been randomly drawn from among these strata (with sample size proportional to each stratum size). Data collected for the survey dealt with production, current, prior (from the last 5 years) and foreseen fertilising practices. Farmers' opinion towards the environment were also collected. The first preliminary treatment of these data allowed the determination of actual farming practices that have been introduced into the SWAT model. A second treatment of these data allowed the 68 farms which produced milk to be for isolated among the 82 surveyed farms. For these farms, the area devoted to forage crops for milk herd could be isolated. Thus the results presented here deal with dairy farms only.

3.3. Required data, calibration and validation

Apart from very specific data needed by some models (such as pH in the soil), most of the models used in the AgriBMPWater project require four types of data:

- The first type of data is the topography from which basin and sub-basins boundaries are drawn. Digital Elevation Models (DEM) were usually acquired for these purposes for most watersheds. The one used for the Don watershed was a 75-m resolution DEM forced in flat areas with the digitised streams.
- The soil map and data make up the second important type of data. A soil map for the Don watershed was kindly lent by extension services. Textural properties were associated with each soil unit using textural data obtained from soil pits. As pits were not dug for each soil type initially described, similar soil units were aggregated to create a map containing 7 soil units for the Don Watershed (from 47 initial soil units).
- Land use was derived from 1992 Landsat TM data at 30 m resolution. The simulations performed with other models on a sub-watershed have shown the importance of defer-effects of manure spreading operations during the 4 years before the estimation of the load (Turpin et al., 2001). As a result, it was decided to work with crop rotations. Rotations have been allocated to each land-use unit automatically using an expert system. The fertilisation practices and yields on each type of crop rotation on the Don watershed have been defined as a mean of all the similar rotations on the watershed. The data came from the 2000 survey.
- Climatic data were obtained through local official weather stations provided by the Departmental Council.

In addition to data available at the Conquereuil pumping station, water quality has been monitored at the outlet of a 3,500 ha subwatershed (Cétrais watershed) upstream of the Conquereuil station for at least 3 years. The first 2 years of data have been used for calibration purposes, the last being devoted to validation. On the Don watershed, three parameters calibrated in the SWAT model:

- The curve number, which by default was too high for the French watersheds.
- The Alpha base flow was calibrated for adjusting shallow aquifer after-event discharge.
- The groundwater delay parameter was also tested although it had little effect on the model results.

Although automatic calibration is available for SWAT (Eckhardt and Arnold, 2001), manual calibration was performed, because we wanted to be able to compare specific outputs from the model. The data used for calibration were daily flow rates measured at Don's outlet by the Departmental Council (and kindly provided) and daily flows measured at the outlet of Cétrais sub-watershed (monitored by Cemagref). The parameter estimation was multi-variable. This increased confidence in the model (Bergstrom et al., 2002).

3.4. BMPs definition

Interviews have been performed with professional representatives, administrations (departmental and regional agriculture administration, regional environmental administration), local advisors and elected representatives. These interviews have been conducted after a first contact during pilot operation committees. The synthesis of these interviews allowed us to describe the history of environmental operations tested on the watersheds and the details of management practices proposed to the farmers during these operations.

Several operations aiming at improving water quality have been or are currently being tested on the Don watershed. These operations do not introduce to farmers all the BMPs that could be scientifically assessed to reduce non-point source pollution (Turpin et al., 2000). A list of proposed BMPs has been built by describing to the local advisors the BMPs described in local agri-environmental management from other French regions, in the national schedule of conditions for Land Management Contracts, in national guides for 'good practices' (following EU Nitrate Directive), and by asking those interviewed to select the BMPs they thought could be proposed to farmers.

3.5. Assessment of the efficiency for each BMP

The spatially distributed hydrologic models, once calibrated and validated, allow determination of *critical areas* depending on pedo-climatic conditions, slopes, distances to ditches and rivers, and agricultural practices. The critical areas have been defined through collective work involving hydrologists, soil scientists, economists and sociologists. The following criteria are particularly relevant for good communication across disciplines:

> "the minimum area where feasible measures can be applied, measures needed to reach the desired quality standard of the considered pollutant at the receptor" (Natural Science theoretical aim),
>
> "the sets of areas where feasible measures can be applied, measures needed to reach the desired quality standard of the considered pollutant at the receptor" (operational aim)
>
> and "the set of areas where feasible measures can be applied to reach the desired quality standard of the considered pollutant at the receptor for the least social cost" (welfare economic aim).

Effectiveness has been estimated through the introduction of pre-designed BMPs as alternative practices in the previously validated models. Each BMP's effectiveness is determined as a non-dimensional value being the ratio between the initial state and the estimated state after BMP implementation (see Eq. (1) for an example).

$$\text{effectivity} = \frac{\text{soil loss}_{\text{conv}}(\text{t/ha}) - \text{soil loss}_{\text{BMP}}(\text{t/ha})}{\text{soil loss}_{\text{conv}}(\text{t/ha})} \times 100 \quad (1)$$

On the Don watershed, the BMPs have been tested in a two-stage process. First, mandatory BMPs, such as decreasing the use of mineral N or better spread manure over the different fields and crops, have been examined. Unfortunately, in this case, the hydrologic model does not estimate that these mandatory BMPs could decrease N loads enough: even for mean climatic years the loads would result in nitrate concentration over the EU guide of 25 mg/l on the Don watershed. Thus, more strict policies have been designed, such as taxes on mineral nitrogen, or breeding extensification. These policies have been introduced into the economic model, which assessed the modifications of management practices that the farmers would adopt following each policy; then the adopted management practices have been introduced into the hydrologic model for estimating their potential efficiency.

Fig. 2 depicts the potential reduction of N loads at the outlet of the Don watershed when BMP3 is applied on a mandatory basis. This BMP involves modification of production techniques, with better use of manure (manure is mostly spread on corn at rates in the status quo situation, the BMP requires spreading them at low rates on grasslands) and a decrease of mineral N used (most of the crops receive too high levels on mineral N

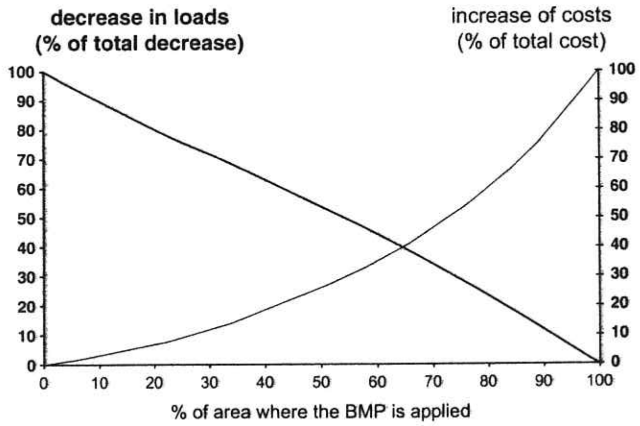

Fig. 2. Decrease of estimated loads and increase of estimated costs when the BMP3 (better use of manure and decrease of mineral N use) is applied, depending on the area of application, on the Don watershed.

in the statu quo situation). The potential reduction of N loads decreases almost linearly when the area where the BMP is applied increases.

4. Cost assessment

4.1. Model choice

Reducing non-point source pollution has several consequences for the farmers: yield losses when reducing the inputs (Yadav and Wall, 1998), increasing production costs when a greater amount of less polluting input (such as work) is required (Eiswerth, 1993), depolluting costs (Johnson et al., 1991), the need for increased knowledge on soil and manure (Trachtenberg and Ogg, 1994) and so on. Moreover, the regulator who implements a mitigating policy may have to allocate subsidies or to impose taxes. This allocation of means has a social cost, because when the regulator distributes money to one sector of the economy he has to restrain the subsidies provided to other sectors. Both on-farm and regulator's costs have been grouped into 'direct cost' of the policy. But the changes of the farmers' management practices also have consequences for the rest of the economy. For example, there can be an increase in costs (manpower, equipment) for pollution control, an increase in prices of goods and services in the focus area, which occurs as a result of an environmental program. These costs are determined as 'indirect costs' in our framework.

Three methods have been designed and initiated for the estimation of the costs: a computable general equilibrium model aimed at estimating indirect costs on large watersheds, a Principal-Agent model aimed at estimating direct costs on large watersheds and a linear-programming model aimed at estimating direct costs on small watersheds. The results are presented as a cumulative curve, which depicts the relation, on each watershed and for each BMP, between the costs and the contracted area and/or to the area of application on critical areas.

4.2. Main assumptions for economic modelling

4.2.1. Direct cost assessment

The models represent the farmers as price-takers (the prices of input and output are not affected by on-farm decisions) and profit maximisers (the farmers wish to maximise their profit, given some constraints on land, capital and labour, on their own farms). The linear-programming (LP) models describe several discontinuous on-farm activities (crops, breeding activities) with technical coefficients coming from the literature or based on expert knowledge; the modelled farmer selects some of the proposed activities in order to maximise his own profit, with respect to his own constraints. The BMPs designed during the hydrologic step of the process are represented as 'new' activities, with their own technical coefficient. Obviously, these new activities are more expensive than the previous ones (otherwise they would have been spontaneously implemented by the farmers). Thus, the BMP has to be combined in the modelling with an associated subsidy that renders the BMP cheaper than the previous activities. This subsidy is interpreted as the 'cost' of the BMP implementation.

The Principal-Agent models represent the farms in a different way, with continuous cost and yield functions, including heterogeneity among the environmental impact of different pollution sources (Wu and Babcock, 2001). The models focus on asymmetric information problems between a regulator (the Principal) and the farmers (the Agents) who are supposed to have more precise information on their own farm than the regulator, who has information on the density functions for each parameter only (Laffont, 1994). This representation allows the assessment of both the introduction of 'technical' BMPs (defined as a modification of the cost or the yield functions, or both) and the application of various policies: the modelled farms react to a given policy by moving along their profit function (Bontems et al., 2003).

4.2.2. Indirect costs assessment

The previous two partial equilibrium economic approaches (LP an PA models) only permit the determination of the direct costs induced by the implementation of regulation instruments. Dealing with a multiple usage good such as water, indirect costs should also be accounted for. These costs are the ones borne in other sectors of the economy than those for which the policy is directly intended to regulate.[1] In order to assess whether these costs might be significant, only a general equilibrium framework is appropriate (EPA, 2000). Therefore, a computable general equilibrium model (CGEM) has been developed which further integrates a spatial dimension in a distributed setting inspired from the multiregional CGE literature. Local policy implementation strategies can thus be tested for, and the distribution of impacts in space can be addressed. This model has been applied to the larger watersheds only where the general equilibrium linkages can no longer be neglected. An original multi-step procedure has allowed the necessary calibration data to be computed at the level of the study area from national input/output and accounting statistics. BMPs are introduced as alternative production technologies, which are initially at idle in the benchmark equilibrium; counterfactual simulations then consist of determining the minimum level of incentive instruments which enables a particular BMP technology to become profitable.

[1] See EPA (2000) for a discussion on the distinction between direct and indirect costs and for a detailed list of the latter which include changes in market structure, factors productivity, terms of trade, etc.

4.3. Calibration of the models and assessment of costs

The LP and CGE models required no calibration because they statistically model 'average' farms and use data from national accounting (thus no calibration was possible), respectively. The yield, cost and profit functions used in the Principal-Agent models have been statistically parameterised from data collected on the large watersheds. On the Don watershed in particular, the modelled on-farm dairy production does not statistically differ from the recorded value, but the aggregated milk production on the watershed is slightly (2%) overestimated (see Bontems et al., 2003, for details).

Three types of mitigating policies have been tested within the AgriBMPWater framework:

1. The mandatory application of new, less polluting techniques. The associated costs are mostly borne by the farmers. The costs are associated with an increased use of machinery or labour, or related to a risk of yield decrease when lower amounts of polluting inputs are used. Some benefits can be associated with the lower use of polluting inputs, if they are not replaced by more expensive ones.
2. Standard economic instruments, such as taxes or quotas applied on inputs or outputs. On the Don watershed a tax on the amounts of mineral N used by the farms, a quota of mineral N applied, and a linear extensification (decrease of milk yield per hectare) have been tested. These linear standard instruments can be associated with subsidies that increase on-farm profit, such that more farmers benefit from the policy.
3. Policies which are optimally differentiated and take into consideration the heterogeneity of farms on their cost and emission functions. The regulator proposes a contract to the farmers and designs this contract by maximising a welfare function, which is the sum of the farmers' profit, plus the sum of the tax-payers' surplus, minus the damage.

Fig. 2 depicts the evolution of costs when the BMP3 is applied on the Don watershed. In this particular case, requiring a larger area of BMP application tends to mandate it to farms that have higher associated costs (larger farms with higher spreading area). Thus the cost of mandating the BMP increases with its area of application. This may not be the case for other types of technical changes.

5. Acceptability

Agricultural innovations, such as BMPs, and their acceptability have been widely studied using an adoption-diffusion approach (Ruttan, 1994). This has focused on evaluating the causal relationships of the adoption of a new technology mainly with the help of behavioural models or social psychology. Nowadays many research efforts have recognised the limits of this paradigm (Buttel et al., 1990; Ward, 1993; Rogers, 1995). The study of BMPs acceptability in this project looks at the farm-level decision-making process as part of a wider actor network and institutional setting of the agri-environmental policy and planning. The focus is on the practices of different actors. The question to be raised is how the new agri-environmental policy gets institutionalised and how this process affects the spread of innovations and acceptability of BMPs and, hence, their environmental effectiveness. The starting point is that decisions that farmers take reflect the ways they perceive the social conditions (e.g. economic situation, history of management practices at the farm and in the farming community, environmental regulation) where they operate, but simultaneously a particular social condition provides means to be used in the interpretation (Hindess, 1986). Accordingly, the identity of actors is not fixed, but it is constituted in the networks within varied sets of resources.

The approach to social acceptability has concentrated on looking at farm-level decision-making processes. A qualitative method has been defined and applied in one watershed. For the others watersheds a simplified approach has been proposed. The studies concern the concrete related changes in management practices, the decision-making and contracting processes, the problem framing and the acceptability of the policy model. The results reveal how the representation of different interests in the implementation affects the spreading of BMPs. The social acceptability approach analysed the social conditions, which affect the decision making of a BMP contract both at the farm and policy implementation level. A first method, based on extensive case studies in Finland, examined the dynamics of farm level decision-making as part of the wider actor network and institutional setting of the agri-environmental policy. A simplified approach is conducted on the other sites and focuses on farm-level decision-making and farmer's views on the implementation of BMPs. In the Norwegian part of the project, focus group studies are in the process of being undertaken where farmers are asked about various aspects of policy instruments, including their opinion on the applicability of contracts. Of particular interest in this regard is farmers' acceptance of using models more actively in NPS settings (Romstad, 2002).

The farm-level analysis[2] shows that the implementation of agri-environmental policy brings new practices, spaces, time scales and networks through which agriculture's relationship to environment is being newly assessed. The policy has changed management practices,

[2] These results are based on the Finnish case studies (see Kaljonen, 2001, 2002).

and these changes happen step by step by a translation process where the new practices are adjusted to particular social and economic conditions of farms.

In general, farmers see agri-environmental policy as an important tool to diminish environmental impacts of agriculture. Despite this consensus, farmers also criticise strongly the environmental management practices, or BMPs, introduced by the agri-environmental policy. At a farm level, the goals of the agri-environmental policy are reflected through bureaucratic formulas. Strengthening environmental regulation at the same time as other structural changes have occurred in agricultural production has further increased the feeling that farm management decisions are being controlled by external forces in a top down manner.

Farmers look at environmental issues in relation to restructuring of agriculture and claim their rights to natural resources management. In their opinion, agri-environmental policy has undermined the local character of agri-environmental impacts as well as the farmer's social situation. Farmers' critics point to the standardisation built into routine structures of the definition of the good farming practice, or conversely, farm pollution. The universal units of agri-environmental policy practices are contradictory to farmers' practical oriented knowledge, which emphasises variation and uncertainty of the changing farming conditions in terms of soil characteristics, weather, economics and subsidies.

To diminish nutrient runoffs, is not just a simple adoption of a BMP, but – as far as a farmer is concerned – a complex reorganisation of several farming routines (van der Ploeg and Douwe, 1993) and, at the moment, an externally prescribed reorganisation of the agency (Wynne, 1996). Farmers' response can be interpreted as a cultural response to another cultural form of intervention - that is, one embodying particular normative models about human nature, purposes and relationships (Wynne, 1996). The other is not right, nor wrong, but the scale is different.

Evaluation of the experiences gained from the Lappajärvi restoration project indicate that the watershed level riparian zone planning has offered some bases for managing the uncertainties of environmental management, and hence, created also the potential for social learning (Kaljonen, 2002). The motivation for planning was derived from the need to manage both social, institutional and ecological uncertainties at local level policy implementation. Planning is based on agriculture's direct relationship to nature: environmentally critical areas have to be defined on a field basis, indicating also that the farmer's local knowledge is needed. Farmers have been given means to participate. The planners have been able to incorporate both farmer's local, contextual knowledge as well as environmental authorities' institutional knowledge on water protection watershed level plans. During the planning some of the problems discussed before have been overcome.

6. Integration

The different policies tested on each watershed have been compared using a two-dimensional graph: the first axis represents the cost-efficiency ratio (expressed in euros per kg of avoided pollutant) and the second axis shows the different acceptability levels associated with each BMP. For 'technical' BMPs, the acceptability level comes from surveys. The acceptability of linear and optimally differentiated policies is assessed by the models as being the percentage of farms who benefit from the regulation.

Fig. 3 depicts the estimated cost-efficiency ratio for several policies modelled on the Don watershed and their acceptability. This acceptability has been estimated with the simplified manner (survey) for the 'technical' policies, and assessed by the models as being the percentage of farmers who benefit from the regulation, for the linear and differentiated policies. On the Don watershed, the simulations suggest that the policies which mandate a technical modification of the production practices do not allow the European standard of 25 mg NO_3/l to be reached. Linearly designed instruments (taxes on N, quota on N, or linear extensification do not allow this level to be reached either if the level is quite low (for example, a tax rate of 0.23 euros/kg of mineral N used is considered as a 'low' level, even if it represents a high percentage of the status quo price of N fertiliser). With very severe levels, linear instruments may allow the EU standard for water quality to be reached, but the associated costs become very high for the tax on N. It is worth noting that optimally differentiated policies have a high level of acceptability, perform with an increase of welfare, and allow the EU standard for water quality to be reached.

7. Concluding remarks

Improving water quality altered by agricultural non-point source pollution requires multidisciplinary approaches. Combining these approaches raises important difficulties, mostly because each discipline uses its own concepts. Mutual comprehension has been enhanced with common definitions. Working together on the same modelling approach helps comprehension.

Although it would have been an interesting feat to use and provide a common modelling package in which most environmental problems and possible BMPs would have been taken into consideration, each partner used its own model. Such a package should eventually be built but, for this project, most models still required

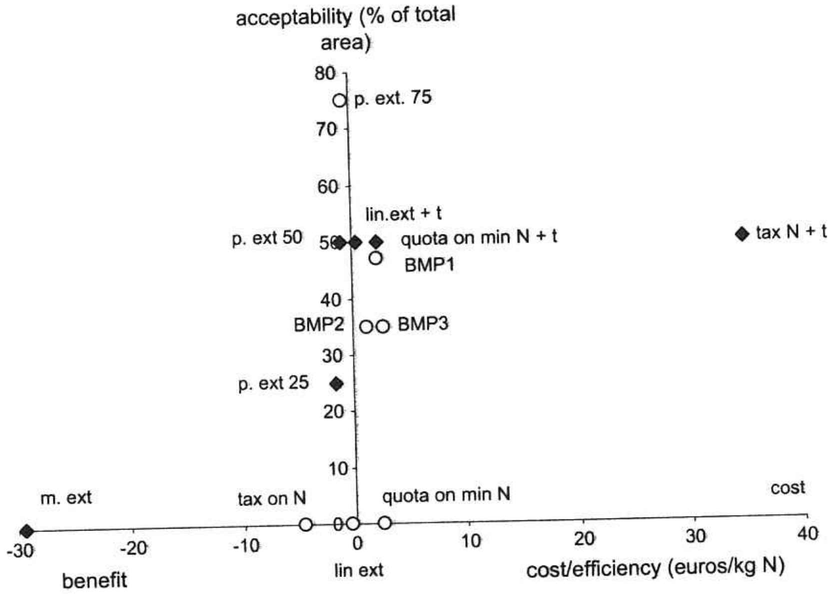

Fig. 3. Cost-efficiency for different policies on the Don watershed (adapted from Bontems et al., 2003). Legend: ○, Policy that can achieve the EU level of 25 mg NO_3/l for mean years. ◆, Policy than cannot achieve this level. *Technical BMPs mandatory applied*: (1) BMP1: mandatory decrease of mineral N use; (2) BMP2: mandatory better use of manures; (3) BMP3 = BMP1 + BMP2. *Linear policies*: Tax on N: linear tax on mineral N used (tax level: 0.23 €/kg N); Tax N + t: linear tax on mineral N used (tax level: 0.53 €/kg N) + subsidy to increase acceptability; Quota on min N: mandatory quota on min N (quota level: 89 kg N/ha); Quota on min N + t: mandatory quota on min N (quota level: 63 kg N/ha) + subsidy to increase acceptability; Lin. Ext: mandatory linear extensification (decrease of milk yield per ha of 2%); Lin. Ext: mandatory linear extensification (decrease of milk yield per ha of 4%) + subsidy to increase acceptability. *Differentiated policies*: M. ext: mandatory differentiated extensification; P. ext 25 (respectively 50, 75): differentiated extensification designed such that 25% (resp. 50, 75) of the farmers benefit from the policy.

further developments, which forced the use of several models in parallel.

Except when designing non-linear instruments, with the use of continuous functions that lead to an optimum (given the instrument), the overall approach of the project where the economic and the physical models are solved separately and successively, even though iteratively, fails to capture feedback effects between the economy and the environment. In particular, it does not allow a real and endogenous accounting of the quality of the environment in the measure of economic welfare. This is why an increasing number of CGE models are developed in what can be called a joint approach as they incorporate a (more or less expanded) physical modelling component. Readers are referred to Bandara and Coxhead (1999) or Coxhead (2000) for examples and to Petit (2002) for a review of the literature on this subject.

Many improvements can be foreseen: until now, we have only focussed on the potential effects and costs of particular BMPs. Obviously, the application of a specific BMP generates effects on other practices at the farm level. Some BMPs used for nitrogen control can also influence phosphorus and pesticides losses. Moreover, the first simulations suggest that one BMP by itself will most likely never be enough to achieve water quality standards, and it will be necessary to test combinations of BMPs. Last but not least, the implementation costs may be very high. As an example, on a 55,000 hectare watershed, our assessment is that lowering the mean nitrate concentration by 10 mg/l must be accompanied by a decrease of 11% of the milk production of the watershed.

The emphasis of agri-environmental policy should be directed to the management of uncertainties. Policy implementation should be seen as a non-linear and contextual learning process, in which the system's capacity for self-governance, enabling social learning, becomes crucial. To help this process, multidisciplinary modelling is of utmost interest.

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References

Abbott, M.B., Refsgaard, J.C., 1996. Distributed Hydrological Modelling. Kluwer Academic Publishers, ISBN 0-7923-4042-6.

Arnold, J.G., Neitsch, S.L., Kiniry, J.R., Williams, J.R., 2001. Soil and Water Assessment Tool – Theoretical Documentation, Grassland, Soil and Water Research Laboratory – ARS. Temple, Texas, 340 p.

Bandara, J.S., Coxhead, I., 1999. Can trade liberalization have environmental benefits in developing country agriculture? A Sri Lankan case study. J. Policy Model. 21, 349–374.

Bergstrom, S., Lindstrom, G., Pettersson, A., 2002. Multi-variable parameter estimation to increase confidence in hydrological modelling. Hydrol. Processes 16, 413–421.
Bontems, P., Rotillon, G., Turpin, N., 2003, Acceptability constraints and self-selecting agri-environmental policies, 12th annual conference of the European Association of Environmental and Resource Economists, Bilbao, 28–30 June 2003, 43 p.
Bordenave, P., Serrand, P., Bioteau, T., 2001. Pratiques Agricoles Durables et Qualité des Eaux Dans le Bassin Versant Expérimental de la Fontaine du Theil. Volet azote, phosphore, MES, Cemagref, 35 p.
Buttel, F.H., Larsson, O.A., Gillespie, Jr., G.W., 1990. The Sociology of Agriculture. Greenwood Press, Westport, CT.
Coxhead, I., 2000. Consequences of a food security strategy for economic welfare, income distribution and land degradation: the Philippine case. World Dev. 28, 111–128.
DiLuzio, M., Srinivasan, R., Arnold, J.G., Neitsch, S.L., 2002. ArcView Interface for SWAT2000 User's Manual. GSWRL Report 02-03, BRC Report 02-07. Texas Water Resources Institute TR-193y, College Station, TX.
Eckhardt, K., Arnold, J.G., 2001. Automatic calibration of a distributed catchment model. J. Hydrol. 251, 103–109.
Eiswerth, M.E., 1993. Regulatory/economic instruments for agricultural pollution: accounting for input substitution. In: Russell, C.S., Shogren, J.F. (Eds.), Theory, Modelling and Experience in the Management of Non-Point Source Pollution. Kluwer Academic Publishers, Norwell, pp. 69–90.
EPA, 2000. Guidelines for Preparing Economic analysis. US Environmental Protection Agency, Washington.
Feichtinger, F., 1996, Simulation of the Soil Water Balance and Nitrogen Dynamic by STOTRASIM for Irrigated Maize, Conference ICID/CIID-Workshop on Crop-Water-Environment Models, Cairo, Egypt, September 1996, pp. 150–162.
Grunwald, S., Norton, L.D., 2000. Calibration and validation of a non-point source pollution model. Agric. Wat. Manage. 45, 17–39.
Haverkamp, R., 2002. POWER a New Approach of Watershed Modelling, Conference Invited by Griffin University, Brisbane (Australia), 6–12 February 2002.
Hindess, B., 1986. 'Interests' in political analysis. In: Law, J. (Ed.), Power, action and belief: a new sociology of knowledge? Routledge & Kegan P, London, ISBN 0710208022.
Hutka, R., Laitinen, T., Holmberg, M., Maunula, M., Schultz, T., 1996. Happamien sulfaattimaiden ionivirtausmalli HAPSU. Title in English: ionic flow model for acid sulphate soils HAPSU (in Finnish). Suomen ympäristö 8, 154.
Johnson, S.L., Adams, R.M., Perry, G.M., 1991. The on-farm costs of reducing groundwater pollution. Am. J. Agric. Econ. 73, 1063–1073.
Kaljonen, M., 2002, Maatalouden ympäristötuen paikallisia sovellutuksia. Tapaustutkimus Lappajärven valuma-alueelta. (Local Dynamics of Agri-environmental Policy. A Case study from the watershed of lake Lappajärvi). Regional Environmental Publications 285. The West Finland Regional Environment Centre.
Laffont, J.-J., 1994, Regulation of Pollution with Asymmetric Information, Non-point source pollution regulation: Issues and analysis, pp. 39–66.
Laplana, R., 2001, AgriBMPWater, Conference ETCA Workshop: Protection of European Water Resources, Lille, May 23th 2001.
Leonard, R.A., Knisel, W.G., Still, D.A., 1987. GLEAMS: groundwater loading effects of agricultural management systems. Trans. ASAE 30 (5), 1403–1418.
Morgan, R.P.C., Quinton, J.N., Smith, R.E., Govers, G., Poesen, J.W.A., Auerswald, K., Chisci, G., Torri, D., Styczen, M.E., 1998. The European soil erosion model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. Earth Surface Processes Landforms 23, 527–544.
Petit, E., 2002. Les liens économie et environnement: l'apport des modèles d'équilibre général calculables mixtes. Title in English: The two-way link between the environment and the economy: the contribution of mixed applied general equilibrium models. Les Documents de Recherche du GRAPE-CEEP. GRAPE, Bordeaux, 34 p.
Rogers, E., 1995. Diffusion of Innovations, fourth ed. Free Press, New York.
Romstad, E., 2002, Non-point Source Pollution Contracts – Emission Based Regulations Through Models, conference paper presented at the World Congress for Environmental and Resource Economists, Monterey, CA, June 26–29, 2002. (Also available from http://www.nlh.no/ios/Publikasjoner/d2002/d2002-01.html).
Roth, K., Flühler, H., Jury, W.A., Parker, C., 1990. Field-scale Water and Solute Flux in Soils. Birkhäuser Verlag, Basel, 294 p.
Rudra, R.P., Dickinson, W.T., Wall, G.J., 1998. Problems regarding the use of soil erosion models. In: Boardman, J., Favis-Mortlock, D. (Eds.), Modelling Soil Erosion by Water. NATO Asi Series vol. 155, Springer Verlag, Berlin, pp. 178–189.
Ruttan, V.W., 1994. Constraints on the design of sustainable systems of agricultural production. Ecol. Econ. 209–219.
Shortle, J.S., Horan, R.D., 2001. The economics of non-point pollution control. J. Econ. Surveys 15, 255–289.
Strauss, P., Zessner,M., Schilling, Ch., Heinecke, U., Postolache, C., Sisak, I., Kosturkov, J., Kovacs, A., 2002, Nutrient management in the Danube basin at the example of selected case study watersheds – processes and problems, conference Proceedings International Conference on Diffuse Pollution, Amsterdam, 30.9. –4.10. 2002, pp. 201–208.
Trachtenberg, E., Ogg, C., 1994. Potential for reducing nitrogen pollution through improved agronomic practices. Wat. Resources Bull. 30, 1109–1118.
Turpin, N., Carluer, N., Kao, C., Piet, L., Arlot, M.-P., Boerlen, P., Bioteau, T., Chaumont, C., Gouy, V., Souiller, C., Vernier, F., Cast, P.S., 2000. Lutte contre les pollutions en milieu rural: démarche de diagnostic de risques sur le bassin versant du Cétrais. Ingéniéries – EAT 22, 3–16.
Turpin, N., Granlund, K., Bioteau, T., Rekolainen, S., Bordenave, P., Birgand, F., 2001. Testing of the Harp Guidelines #6 and #9, Last Report: Results, Cemagref and FEI, Rennes, 43 p.
Vachaud, G., Chen, T., 2002. Sensitivity of a large-scale hydrologic model to quality of input data obtained at different scales; distributed versus stochastic non-distributed modelling. J. Hydrol. 264, 101–112.
van der Ploeg, R.R., Douwe, J., 1993. Potatoes and knowledge. In: Hobart, M. (Ed.), An Anthropological Critique of Development, the Growth of Ignorance. Routledge, London.
Ward, N., 1993. The agricultural treadmill and the rural development in the post-productivist era. Sociologia Ruralis 33, 348–364.
Wu, J.J., Babcock, B.A., 2001. Spatial heterogeneity and the choice of instruments to control non-point pollution. Environ. Resource Econ. 18, 173–192.
Wynne, B., 1996. May the sheep safely graze? A reflexive view of the expert-lay knowledge divide. In: Lash, S., Szerzynski, B., Wynne, B. (Eds.), Risk, Environment and Modernity: towards a New Ecology. Sage, London.
Yadav, S.N., Wall, D.B., 1998. Benefit-cost analysis of best management practices implemented to control nitrate contamination of groundwater. Wat. Resources Res. 34, 497–504.