Enhanced cost-effective agri-environmental measures for groundwater protection - an economic and ecological modelling approach

Thomas Schmidt[a], Ralf Kunkel[b], Bernhard Osterburg[a]

[a]Johann Heinrich von Thünen-Institut (vTI), Federal Research Institute for Rural Areas, Forestry and Fisheries, Bundesallee 50, 38116 Braunschweig, Germany;
[b]Agrosphere Institute, Research Centre Jülich, 52425 Jülich, Germany
Corresponding author: Thomas Schmidt, Phone: ++49 (0) 531 596 5507,
Fax: ++49 (0) 531 596 5599, E-mail: thomas.schmidt@vti.bund.de

Abstract: The EU-Life-project ´Water Resources Management in Cooperation with Agriculture (WAgriCo)´ outlines and implements voluntary water protection measures to reduce diffuse nitrogen (N) pollution from agricultural activities in accordance with the EU Water Framework Directive (WFD). Outcomes of the ongoing project are presented in this paper.

Well proven action-oriented agri-environmental measures, in combination with an innovative result-oriented approach that rewards increased N-use efficiency, are tested within pilot areas in Lower Saxony, Germany. The objective of the project is a successful combination of two different approaches to reduce N losses from agricultural activities and to increase cost-effectiveness. To improve the water quality of ground and surface water it is necessary to reduce leaching, especially under arable land, and to reduce the N surpluses as far as possible.

This paper describes two related tasks of the WAgriCo project (NLWKN, 2006): one is to select agri-environmental measures in terms of water protection and optimise their allocation in the study area, the other task is to simulate the current pressure of agricultural nitrogen pollution on groundwater and postulate the required reduction of N-leaching to reach an adequate, ecological target level.

Keywords: agri-environmental measures, cost-effectiveness, groundwater, modelling

1 INTRODUCTION

Germany’s water-related agri-environmental policy for implementing the EU Water Framework Directive (WFD; EU, 2000) consists of basic measures such as the implementation of the EU Nitrates Directive through the Fertilising Ordinance with mandatory standards for nitrogen use in agriculture. Beyond the level of good farming practice, voluntary agri-environmental measures with compensation payments are promoted as supplementary measures. The selection, design and implementation of water protection measures in Germany are within the responsibility of the federal states. Water protection measures can be implemented through EU co-financed schemes within the Rural Development Plans, as well as independently from the EU with regional or local funding, the latter mainly in water protection areas. A key problem for implementing the WFD in Germany is diffuse pollution resulting from a high nitrogen surplus of the farming sector, and nitrate leaching into the groundwater.

For co-financed agri-environmental measures, the EU sets the general objectives and provides rules for administrative procedures for design and implementation. Design of measures is restricted in terms of maximum payments, calculation of payments, controllability and the duration of at least five years. The EU regulation provides a wide scope for the content of supported measures. For EU co-financed measures, the incorporation into the Integrated Administration and Control System (IACS), which was created for direct payments of the so-called first pillar of the CAP, is mandatory. This includes precision in determining the size of eligible area, and a minimum number of on-the-spot controls per measure at a rate of 5 % of beneficiaries (Nitsch et al., 2005). While the payments to the farmers are EU co-funded, administrative costs for agri-environmental programs have to be borne entirely at the member-state level. For member states and regions with limited administrative personnel, measures with low costs for administration and control are thus more attractive. Today, there is a dominance of standardised, horizontally-offered action-oriented agri-environmental measures (AEM) with flat-rate payments (Osterburg and Runge, 2006).

Research activities support the policy decision process for the implementation of WFD. The development of model tools is still the weakest area of the modelling (Lindenschmidt et al., 2007). First steps in this direction have already been realised in a project conducted in the river Ems basin and sub catchments of the river Rhine basin. In these projects, a combined emission model was developed by coupling results from N-balancing using data from agricultural statistics with the hydrological model GROWA (Kunkel and Wendland, 2002), the DENUZ model approach (Kunkel et al., 2004) for assessing denitrification rates in the soil and the reactive nutrient transport model WEKU for groundwater (Kunkel and Wendland, 1997). Further developments in agricultural N-balancing are described by Schmidt and Osterburg (2006). The modelling in the ongoing WAgriCo project (NLWKN, 2006) is based on these experiences and outcomes are presented in this paper.

2 OBJECTIVE

The WAgriCo project investigates an innovative program of voluntary measures. Ecological effects as well as the economic impacts are analyzed using a spatial modelling approach. The WAgriCo project outcomes demonstrate a new strategy that deals with measure combinations and considers both the agricultural structures regarding the farm management systems as well as natural site conditions. Objective of this paper is to describe the combined agroeconomical-hydrologic modelling approach that can be applied for macroscale areas. It is a powerful tool to analyse the actual pollution loads and ´hot spot´ areas and predict the impact of reduction measures.

3 METHODS

The central objective of the WAgriCo project is to define, select and develop cost-effective measures or measure combinations having a high ecological impact to reduce the nitrate load to groundwater that can be easily integrated in the farming process. Therefore, an approach has been chosen that deals with action-oriented measures on the one hand, and a new result-oriented measure on the other hand (Schmidt et al. 2007). The first step – how to allocate action oriented measures – is the content of this paper.

Selection and allocation of action-oriented measures: 49 farmers in Lower Saxony, Germany, signed an agreement in autumn 2006/ spring 2007 to participate in WAgriCo water protection measures. The specific water protection measures are restricted to vulnerable zones. All of them have their farm land in target areas with high nitrogen surplus within one of three selected project areas. The project farms differ considerably, ranging from intensive livestock farming to cash crop. The farmers could sign contracts for eleven selected action-oriented measures targeting green cover crops over the winter and on the use of improved techniques. The management conditions can be easily applied. As the cost will not vary substantially between farms and regions for those measures requiring additional operations or inputs without major impacts on land use and productivity (e.g., green cover crops with additional cost for seeds and establishing the crop) flat-rate payments were defined. The selected measures are easy to control and achieve a good ecological effectiveness as the required farm activities are strongly linked to the desired ecological effects. Farmers participate with about 1,300 ha contract area. After a final discussion between farmers, advisors and other experts, the nine most appropriate action-oriented measures were defined and proposed for further promotion:

1 Catch cropping after harvest (winter-hardy, late ploughing)
2 Catch cropping after harvest (standard)
3 Three-year fallow with active greening
4 No soil tillage/ploughing in autumn after maize/sugar-beet
5 Restrictions for farm manure application in autumn (application only to catch crop, rape, grassland with time restrictions)
6 Improved slurry application techniques (to winter cereals, winter rape, grassland)
7 Turnip (brassica rapa sylvestris) as catch crop before winter cereals
8 Reduced tillage of volunteer rape seedlings
9 Organic farming according to Council Regulation (EC) No 834/2007

These measures were used to simulate the potential regionalised effect of N-reduction strategies. Four scenarios have been calculated and will be presented at the conference (final results are not ready for publication yet). The scenario simulations, using an LP model, calculate the environmental effect and corresponding financial resources for each sub-region and summarize the single values. In the first scenario *A*, the ecological effect of measures is maximised and no financial restrictions are specified. In scenario *B* the maximum ecological effect is calculated at a given budgetary maximum for the selected voluntary measures, scenario *C* deals with the required N-reduction according to the ecological modelling results and calculates the corresponding budget, and scenario *D* is focussed on the regional allocation of measures with given restrictions of N-reduction, budget and acceptance. The acceptance represents the estimated percentage of farms that participate in the water protection program. Study region is ´Lower Saxony´ which is located in the north-western part of Germany. The agricultural land use is about 2.8 mio. hectares.

Modelling nitrate flow through the soils: Denitrification losses in the root zone are calculated using Michaelis-Menten kinetics with the DENUZ model (Kunkel and Wendland, 2006) as a function of diffuse N-surplus; denitrification conditions and related maximal denitrification rates per year, and the residence time of percolation water in the soil. The maximal denitrification rates have been assessed on the basis of observed denitrification rates in German soils (NLfB, 2005) according to their geological substrate, the influence of groundwater and perching water and the average residence time of perching water in the soil as differentiation criteria.

The coupling of the N-surpluses occurring in the soil after denitrification with hydrological input pathways is carried out based on the grid-based water balance model GROWA (Kunkel and Wendland, 2002). The model was developed to support practical water resource management issues of large river basins, and has already been applied in different regions of different sizes with different perspectives (Bogena et al., 2005; Kunkel et al., 2005; Tetzlaff et al., 2007; Wendland et al., 2005; Wendland et al., 2007; Wendland et al., 2003). It employs an empirical approach with a temporal resolution of one or more years. Annual averages of the main water balance components in mm/a have been quantified as a function of climate, soil, geology, topography and land use conditions. The calculated total runoff can be separated into direct runoff (i.e., surface runoff, interflow and drainage runoff) and groundwater runoff (Wendland et al., 2007). Percolation water rates are modelled as mean long-term averages by subtracting mean long-term surface runoff rates from total runoff. Based on the calculated percolation water rates, N surpluses and denitrification rates in the soil, the nitrate concentration in the percolation water can be calculated directly.

Input data of the geohydrological model approach: A prerequisite for the integrated modelling is the compilation, updating and harmonizing of a digital data basis for the study region. The agrarian statistical data necessary to run the N-balancing model were provided by the Federal Ministry of Food, Agriculture and Consumer Protection or taken from the literature. The input data for the GROWA and DENUZ model, i.e., data on climate, topography, soil cover, soil parameters, hydrogeological parameters, water quality and groundwater bodies, have been made available for the entire federal state of Lower Saxony and the German Meteorological Service. Many of these parameters were derived from digital maps, whose scale ranged from 1:50,000-1:200,000.

General description and visualisation of the modelling approach: Figure 1 shows one virtual region with 24 subregions. Six illustrations of this region represent the ecological situation of nitrogen balances or nitrate concentrations in the seepage water. First of all, the current situations of nitrogen balances were calculated for each subregion (1) (comp. Schmidt and Osterburg 2006). The nitrate concentrations were simulated in the next step (2), using N-surplus of step (1) and information about land use, soil and climate. Each region with more than 50 mg/l of potential nitrate concentration is included into the target area for implementing water protection measures. Step (3) highlights the target area and the ecological objective of 50 mg nitrate per litre. Within the target area, a recursive calculation provides the maximum of tolerable N-surplus (4) depending on soil conditions and precipitation, followed by a simulation study of the implementation of measures (5). Some regions can be brought into a good ecological state of ≤ 50 mg/l after implementing measures (6), others fail the target so that additional measures are required.

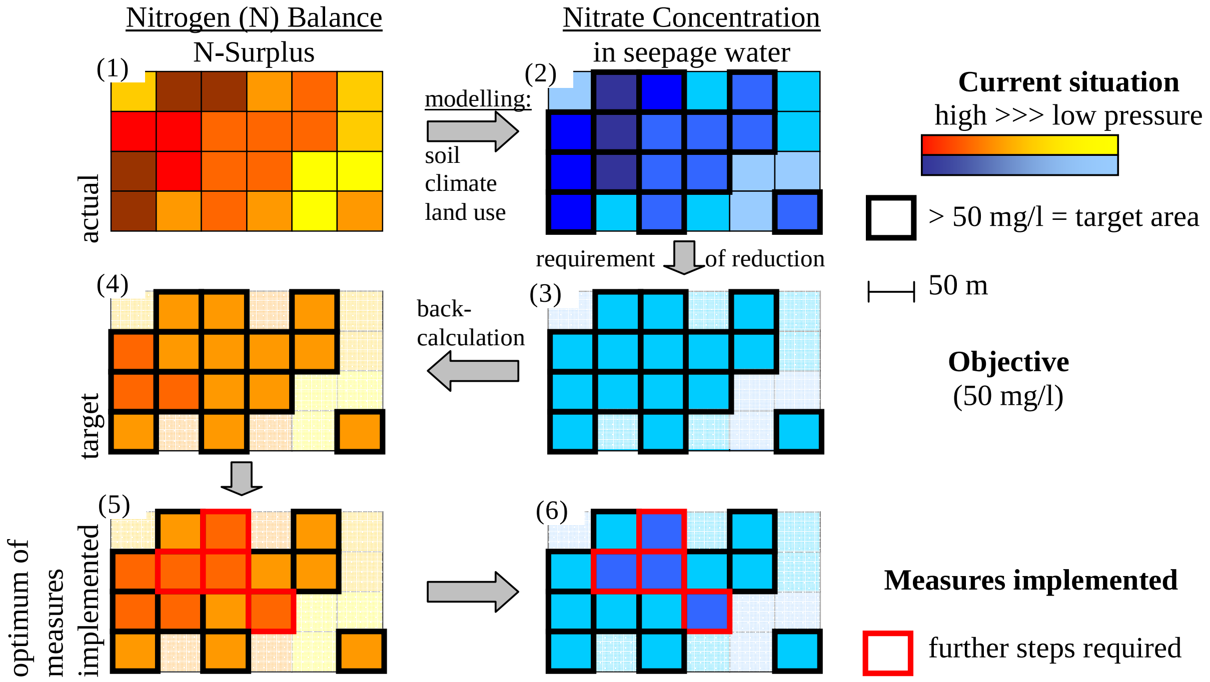

Figure 1: Regional modelling approach - from nitrogen balances to the nitrate concentration in seepage water and vice versa

Further steps could be new action- or result-oriented measures, an increase of advisory services as well as legal consequences such as stricter regulatory laws.

4 RESULTS

The presentation of the results is divided in two chapters. One presents the outcome of the simulation of action-oriented measures and the other describes the design of the hydrological modelling approach.

The measures selected are specified in Table 1. Costs are the amount paid out to farmers for implementation (governmental transaction costs such as costs of administration are not considered yet). The ecological effect reflects the potential N-reduction of the measure. Consequently there is a calculated cost-efficiency for each measure. The specifications about acceptance are expert-estimations and reflect the ratio of participation at the potential area after three years of promotion.

Table 1: Costs and ecological effects of selected action-oriented measures

Measure	**costs** [€/ha]	**ecological effect** [kg/ha]	**cost-effective-ness** [€/kg]	**accep-tance** **[%]**
1 Cover cropping (winter-hardy)	120	30	4	45
2 Cover cropping (standard)	80	30	2.7	70
3 Follow with active greening	120	55	2.2	90
4 No soil tillage/ploughing in autumn after maize/sugar-beet	25	8	3.1	30
5 Restrictions for farm manure application in autumn	15	15	1	30
6 Improved slurry application techniques	35	13	2.7	45
7 Turnip as catch crop before winter cereals	60	20	3	15
8 Reduced tillage of volunteer rape seedlings	40	15	2.7	15
9 Organic farming	170	45	3.8	3

These numbers represent the most probable values of the whole study area on average resulting from an extended expert discussion. Measure 5 has the best cost-effectiveness of 1 €/kg. This means that each Euro of expense reduces the N-losses by one kilogram. The range of cost-effectiveness on this list also includes the cover crops which demand four Euros per 1-kg-N-reduction. The LP-model allocates the most effective measures to the available area. Projections will be presented at the conference.

The LP-Emission model characterizes the present status of the N-emissions to groundwater and for the study area of the WAgriCo project. All input data have been presented and discussed with local stakeholders and have been approved.

Modelling the potential nitrate concentrations in the leachate: Percolation water rates, nitrogen surpluses and nitrate degradation rates in the soil are used for the calculation of nitrate concentrations in the leachate. First results show high concentrations of 150 mg NO_3/l and more (see conference contribution by Kunkel et al., 2008). This is due to the intensive agricultural use, i.e., high N-surpluses. Especially in sandy areas, significant denitrification in the soil is not possible, thus leading to high nitrate concentrations.

5 CONCLUSION

The modelling approach delivers an economic and ecological projection of agri-environmental measures at a large scale. It is determined by expert knowledge, project results about measures effectiveness and the model in use itself. The outcomes show the most appropriate adaptation of the selected measures, and also steps for optimising programs of measures with limited public financial resources.

Until now, few attempts have been made in Germany to substantially change the existing system of voluntary horizontal action-oriented measures with flat-rate payments despite several recommendations from economists. Once having introduced this system, path-dependency might play a role, as well as expectations that administrative costs (public transaction costs), would increase when changing the existing system. Furthermore, there is a risk of higher decision-making costs and lower acceptance of voluntary measures. If EU requirements are not complied with completely, there is also the risk of disallowances regarding EU co-funding, thus leading to less willingness of public administrations to test innovations.

The ecological effectiveness of water protection measures in conjunction with levels of payment and the corresponding acceptance by farmers were evaluated in the WAgriCo project. Further steps involve an analysis of administrative costs of the approach as well as of the multiple objectives of most agri-environmental measures and the quantification of their contribution. For example, reduced tillage does not only influence the nutrient turnover but also reduces soil erosion. This should be evaluated in an integrated approach. In addition, a result-oriented approach (Runge and Osterburg, 2007), combined with an advisory service, is in discussion in the WAgriCo project. Within the ongoing project, the ecological modelling approach will not only calculate the current and tolerable N-surplus-level but also the effects of the measures implementation.

As the discussions on environmental targets proceed, it may be necessary to modify the trigger value of 50 mg NO_3/l in percolation water depending on the agricultural and hydrological site conditions in the groundwater bodies. In general, however, this procedure is perceived to be particularly innovative since the political relevance of conclusions of this type of approach is gaining importance for better spatial targeting of measures, and the accuracy of recommended environmental policy instruments is improved.

Acknowledgements: The WAgriCo project is supported by the EC instrument ´LIFE-Environment´ (DG Envi)., It does not, however, necessarily reflect the views of the European Commission and in no way anticipates the EU’s future policy in this area.

REFERENCES

Bogena, H., R. Kunkel, T. Schobel, H. P. Schrey and E. Wendland (2005): Distributed modeling of groundwater recharge at the macroscale. Ecological Modelling, 187 (1), 15-26.

EU - European Parliament and Council of the European Union (2000): Directive 2000/60/EC of the European Parliament and the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. , edited, Official Journal of the European Communities.

Kunkel, R., M. Bach, H. Behrendt and F. Wendland (2004): Groundwater-borne nitrate intakes into surface waters in Germany. Water Science and Technology, 49 (3), 11-19.

Kunkel, R., H. Bogena, H. Goemann, P. Kreins and F. Wendland (2005): Management of regional German river catchments (REGFLUD)impact of nitrogen reduction measures on the nitrogen load in the River Ems and the River Rhine. Water Science and Technology, 51 (3-4), 291-299.

Kunkel, R. and F. Wendland (1997): WEKU - A GIS-supported stochastic model of groundwater residence times in upper aquifers for the supraregional groundwater management. Environmental Geology, 30 (1-2), 1-9.

Kunkel, R. and F. Wendland (2002): The GROWA98 model for water balance analysis in large river basins - the river Elbe case study. Journal of Hydrology, 259 (1-4), 152-162.

Kunkel, R. and F. Wendland (2006): Diffuse Nitrateinträge in die Grund- und Oberflächengewässer von Rhein und Ems. Schriften des Forschungszentrums Jülich, Reihe Umwelt/Environment, Vol 62. Forschungszentrum Jülich GmbH, Jülich, Germany.

Kunkel, R., M. Eisele and F. Wendland (2008): Evaluation of strategies to reduce nitrate pollution of groundwater – assessing the needs and efficiencies of agri-environmental measures for selected groundwater bodies in Germany. Proceedings of the 13th World Water Congress, Montpellier, France.

Lindenschmidt, K.-E., F. Hattermann, V. Mohaupt, B. Merz, Z. W. Kundzewicz and A. Bronstert (2007): Large-scale hydrological modelling and the Water Framework Directive and Floods Directive of the European Union. Proceedings of the 10th Workshop on Large-Scale Hydrological Modelling, Advances in Geosciences, 11, pp. 1-6.

Nitsch, H., B. Osterburg, V. Beckmann and A. Lütteken (2005) Inventory of institutional arrangements of agri-environmental schemes in Europe. Integrated Tools to design and implement Agro Environmental Schemes, Document number: ITAES WP4 D8 P51 P5

NLfB (2005): Grundwasser: Methodenbeschreibung, EG-WRRL Bericht, Niedersächsisches Landesamt für Bodenforschung, Niedersächsisches Landesamt für Ökologie, Bezirksregierung Hannover, Hannover, Germany.

NLWKN - Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (2006): WAgriCo, LIFE Project LIFE05 ENV/D/000182, Progress Report No. 01, Hannover, Germany (http://www.nlwkn.niedersachsen.de/servlets/download?C=38838826&L=20).

Osterburg, B. and T. Runge (2006): Agri-environmental measures in Germany – their evolution in practice and new approaches to strengthen efficiency. Paper presented at OECD-workshop on information deficiencies in agri-environmental policies. Paris, 6 June 2006

Rohmann, U. and H. Sontheimer (1985): Nitrat im Grundwasser: Ursachen, Bedeutung, Lösungswege. DVGW-Forschungsstelle am Engler-Bunte-Institut der Universität Karlsruhe (TH), Karlsruhe, Germany.

Runge, T. and B. Osterburg (2007) A result-oriented approach to reward N-efficiency improvements, Proceedings 15th Nitrogen Workshop, Lleida (Spain)

Schmidt,T.G. and B. Osterburg (2006): Improving Regional Soil Surface Nitrogen Balances. Proceedings of the IWA DipCon 2006: 10th International specified Conference on diffuse Pollution and Integrated Basin Management, Istanbul.

Schmidt, T. G., B. Osterburg and T. Runge (2007): A new strategy for agri-environmental measures to reduce N-losses more effectively. Proceedings of the 35. IAH Congress Groundwater and Ecosystems, Lisbon, Portugal, 17.-21. September 2007, Internatinal Association of Hydrogeologists.

Tetzlaff, B., R. Kunkel, W. Schäfer and F. Wendland (2007): Determination and ranking of target areas in catchments for the implementation of nitrogen reduction measures. Advances in Geosciences, 11, 69-75.

Wendland, F., H. Bogena, H. Goemann, J. F. Hake, P. Kreins and R. Kunkel (2005): Impact of nitrogen reduction measures on the nitrogen loads of the river Ems and Rhine (Germany). Physics and Chemistry of the Earth, 30 (8-10), 527-541.

Wendland, F., R. Kunkel, H. Gömann and P. Kreins (2007): Water fluxes and diffuse nitrate pollution at the river basin scale: Interfaces for the coupling of agroeconomical models with hydrological approaches. Water Science and Technology, 55 (3), 133-142.

Wendland, F., R. Kunkel, B. Tetzlaff and G. Dorhofer (2003): GIS-based determination of the mean long-term groundwater recharge in Lower Saxony. Environmental Geology, 45 (2), 273-278.