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Model based impact analysis of policy options aiming at reducing diffuse pollution by agriculture—a case study for the river Ems and a sub-catchment of the Rhine[☆]

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Abstract

In this paper an integration of the agricultural economic model RAUMIS with the hydrological models GROWA98 and WEKU is presented. The focus lies on an area wide, regionally differentiated, consistent link-up between the indicator "nitrogen balance surplus" and nitrogen charges into surface waters. The model network is used to analyze the status quo situation in the year 1999 for two river catchments in Germany that feature very distinct natural and socio-economic conditions. Regarding agriculture, the study areas include regions with specializations in cash crops, in intensive livestock featuring high nitrogen surplus, and extensive livestock production on permanent grassland. Due to regionally varying hydrological conditions quite different shares of agricultural nitrogen surpluses ranging from 25 to 92% enter surface waters. Furthermore, impacts of alternative nitrogen reduction measures namely a limitation of livestock density and a tax on mineral nitrogen are quantified. Measures of the nitrogen reduction potential and costs in terms of agricultural income forgone are taken into account in the assessment. Results regarding the effects of restricting the livestock density or tax mineral nitrogen highlight that the mitigation of diffuse water pollution problems requires regionally tailored measures.

Keywords: Diffuse water pollution; Model-based policy consulting; Interdisciplinary model networks; Agricultural sector model; Agri-environmental policy evaluation

1. Introduction

Water quality has improved throughout recent years in Germany. Total annual nitrogen emissions into German river systems in the period 1993–1997 sum up to 820,000 mt (metric tons), which is 25% less than in the previous decade (BMU, 2001). Most of the improvement can be explained by reductions of inputs from point sources (IKSR, 2003), e.g. by continuous waste water purification. As a result nutrients from diffuse sources represent at present the main contribution to the total nutrient load of rivers.

Until the late 1980s agriculture intensified mineral fertilizer and pesticide use which raised concentrations of nutrients and pesticides in surface and ground waters. Moreover regional concentrations of livestock increased manure supply aggravating diffuse water pollution in the areas concerned.

Since the end of the 1980s a decline in mineral fertilizer and pesticide use can be observed resulting in a decline of mean annual nitrogen surpluses from 120 to 80 kg per ha on agricultural area (AA) (see Fig. 1). However an impact of this trend on surface water

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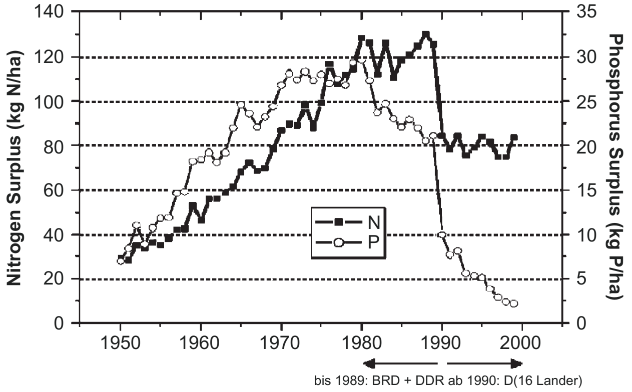

Fig. 1. Development of nitrogen surplus in German agriculture from 1950 to 2000 (kg N per ha AA). Source: BMU (2001).

quality can hardly be observed because of the residence time of water in the soil and groundwater systems (BMU, 2001). Thus at present, diffuse nitrogen emissions into ground- and surface waters still cause problems. In 2000 for instance 62% of nitrogen inputs into the river Rhine in Germany still originate from diffuse sources with an agricultural share of 86%.

The main German river systems will probably start to react to reduced nitrogen surpluses from agriculture within the next few years. In spite of the significant reduction of diffuse nitrogen surpluses in agriculture it cannot be expected that the political goals, namely a reduction of the nitrogen load of the northern sea by 50% (Nordseeschutzkonferenz) or the preservation of Water Quality Class II at the monitoring station network established by Germany's *Working Group of the Federal States on Water Problems (LAWA)*, will be achieved. According to recent scientific findings a further decline of annual nitrogen surpluses down to 50 kg N per ha AA and an increase of the denitrification potential (e.g. backwater or plugging of drainage systems, restoration of wetlands and improvements of morphological water structure) would be necessary to achieve this goal. The global implementation of such measures would have far-reaching impacts on agriculture. However, because of different site conditions it cannot be expected that the intended improvement of water quality may be achieved throughout Germany.

The objective of this paper is to present the integration of an agricultural economic model with hydrological models and use this model network to quantify and assess impacts of alternative nitrogen reduction measures.

2. Methodological approach

2.1. Agricultural modelling

The Regional Agricultural and Environmental Information System (RAUMIS) represents the whole German agricultural sector and has been developed by Henrichsmeyer et al. (1996) for continuous usage in the scope of medium and long-term agricultural and environmental policy impact analyses. Fig. 2 gives an overview of the methodological design of RAUMIS. The model consolidates various agricultural data sources and generates base model data with the national agricultural accounts as a framework of consistency. It comprises more than 50 agricultural products, 40 inputs with exogenously determined prices, and reflects the whole German agricultural sector with its sector linkages.

According to data availability, the spatial differentiation of RAUMIS is presently based on administrative bodies. A continuous spatial distribution of agricultural production is approximated by some 326 regions basically on a county level ("Landkreis"). These regions

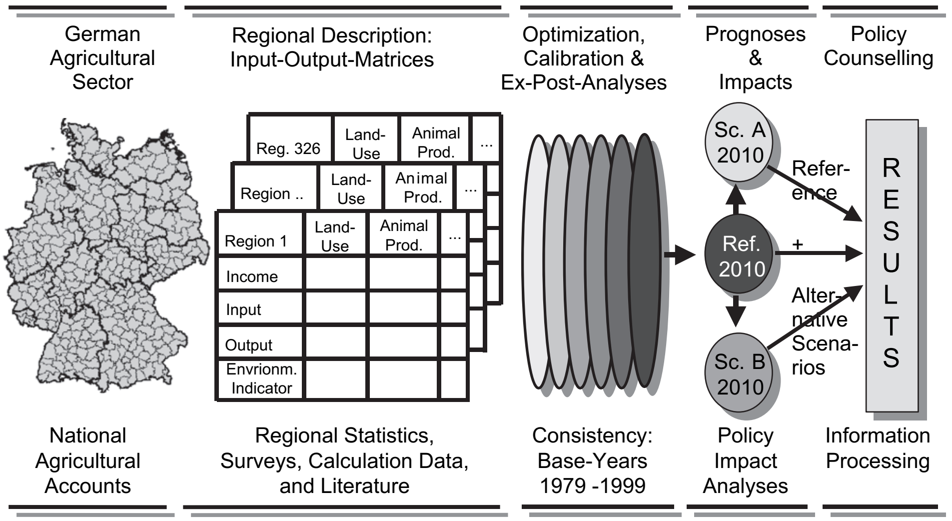

Fig. 2. Methodological design of RAUMIS. Source: FAA—Description and Layout.

are treated as single “region enterprises” that autonomously reach their production decisions. Hence, adjustments of production at the national level are based on aggregated responses of “region farms”.

Adjustments caused by changes in general conditions such as agricultural policies are determined using a mathematical programming approach with a non-linear objective function. This method uses an algorithm to model responses of producers to changes in relative profitability of production activities subject to technical, political and economic constraints. The calculated optimal production plan generates the maximum feasible farm income which is the objective function of this approach. However, the derived optimal production plan does not necessarily match exactly with the actual production being observed ex-post because of imperfect information about the true coefficients. This problem is overcome by applying the technique of positive mathematical programming (Howitt, 1995). This approach provides substantial advantages with respect to the long-term forecasting behaviour of the model. In the projection phase a variety of exogenous variables such as implicit costs resulting from positive mathematical programming, input–output coefficients, yields, capacities, and prices are forecast. Updates are partially based on trend and yield dependent regression analyses as well as on estimates provided by experts particularly relating to prices and the development of farm structures.

Comparative static policy impact analyses for a future target year require a scenario of reference because various parameters are changing in the long-run in addition to the variations of policy measures being investigated. Typically the scenario of reference is a projection of the development under “business as usual”.

Deviating from the reference scenario, alternative policies and regulations are imposed on the model keeping all other parameters and constraints constant. This procedure separates the policy impacts on agricultural production, land-use and agricultural income as deviations from the scenario of reference.

In RAUMIS, a set of agri-environmental indicators is linked to agricultural production. Currently, the model comprises indicators such as fertilizer surplus (nitrogen, phosphorus and potassium), pesticides expenditures, a biodiversity index, and corrosive gas emissions. These indicators help to evaluate direct and indirect environmental impacts of policy driven changes in agricultural production. Regarding diffuse water pollution the indicator *“nitrogen surplus”* is of particular importance.

Fig. 3 displays the RAUMIS concept of balancing nitrogen. It follows PARCOM-guidelines (PARCOM, 1993) where the soil surface represents the system border. The long-term nitrogen balance averaged over several vegetation periods is calculated following the methodology developed by Bach et al. (1997). In order to satisfy nutritional demands of plants, nitrogen is supplied by mineral fertilizer. Further exogenous sources are symbiotic and asymbiotic nitrogen-fixation, as well as atmospheric deposition. An internal fertilizer source is the nitrogen content in manure that is applied in plant production.

The primary demand for nitrogen is based on the nutrient uptake of plants that are removed from the soil

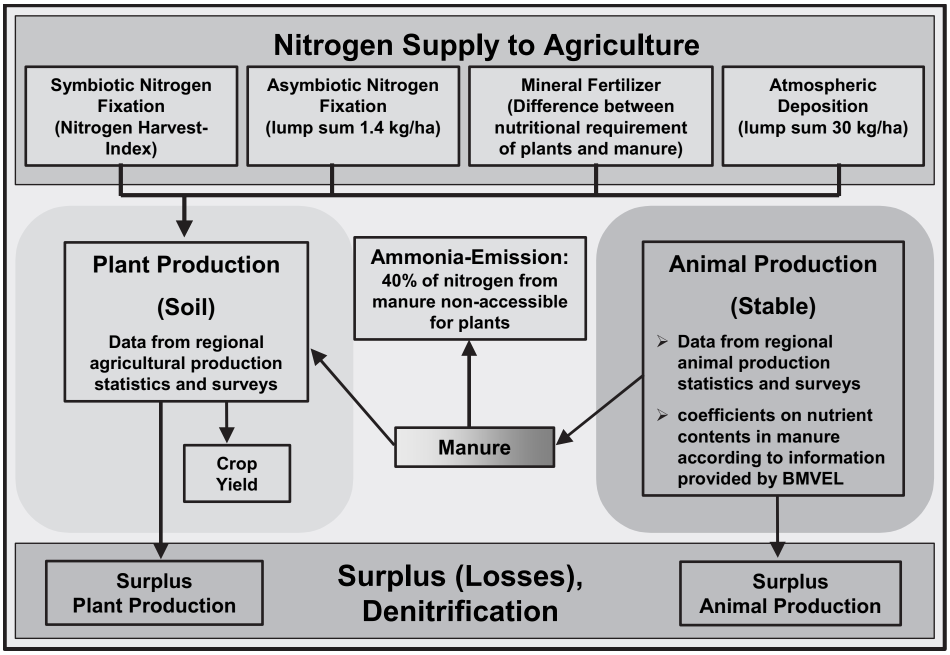

Fig. 3. Balancing nitrogen in RAUMIS. Source: Description and Layout—FAA.

during the harvest. A further reduction of nitrogen occurs as a loss of ammonia (NH_3) during storage and application.

The listed positions of the nitrogen balance are calculated by the activity-based framework in RAUMIS. In order to obtain regional input and output positions, activity-specific coefficients are multiplied with the level of each activity, e.g. area harvested or livestock units.

Nutrient requirements for each crop and region are based on expected crop-specific yields as well as soil and climate conditions. Nitrogen use for individual crops is calculated by linear yield-dependent requirement functions. The loss of ammonia during storage and application is based on the assumption that 40% of the nitrogen in manure that is inaccessible by plants is converted to ammonia during storage and application.

Nitrogen supply from manure is derived from nitrogen contents of the excrements of farm animals. RAUMIS differentiates between four processes of manure and its application, i.e. dung and liquid manure from cattle, hogs and poultry. Coefficients representing nutrient contents in manure as well as utilization factors of plants are taken from the literature and are also provided by experts of BMVEL. Following the concept that nitrogen from manure can replace nitrogen from mineral fertilizer, mineral fertilizer equivalents for manure are calculated based on different nitrogen utilization factors of dung and liquid manure from cattle, hogs and poultry. It is assumed that the mineral fertilizer equivalent for dung constantly amounts to 25%, implying that 4 kg of nitrogen from dung substitutes 1 kg of nitrogen from mineral fertilizer. Coefficients for liquid manure regionally vary between 16 and 25% for cattle, 20 and 30% for hogs, and 26 and 39% for poultry.

Because of high transport costs it is assumed that organic fertilizer remains in the region and substitutes mineral fertilizer in crop production subject to regional rates and thresholds of substitution. A regional excess demand for nitrogen in plant cultivation is equalized using mineral fertilizer. Calculated aggregate mineral fertilizer use in plant production matches national fertilizer sales figures of national agricultural accounts.

The positions asymbiotic nitrogen fixation and nitrogen entry from the atmosphere are included as lump sum amounts, namely 30 kg per ha for atmospheric entry and 1.4 kg per ha for asymbiotic nitrogen fixation. Calculations for symbiotic nitrogen fixation are based on expert information and depend on the production of pulses, clover and alfalfa.

As a rule, regional balances of nitrogen supplies and extractions result in a positive figure. The nitrogen surplus represents a risk potential since it indicates the amount of nitrogen potentially leaching into ground and surface water. Starting from these agricultural nitrogen surpluses hydrological modelling is required in order to get closer to the problem of diffuse water pollution, i.e. charges into water bodies.

2.2. Hydrological modelling

Diffuse nitrogen inputs into rivers take place via the runoff components. Nitrogen pathways are distinguished in direct runoff and ground water runoff. Starting points are nitrogen surpluses calculated by RAUMIS and reduced by denitrification losses in the soil. The nitrogen surplus is related to the ratio between ground water recharge and total runoff. This long-term annual ratio is determined on the basis of annual average precipitation levels from 1961 to 1990 (Kunkel and Wendland, 2002). For example, in areas, where ground water runoff is 90% of the total runoff, it is assumed that 90% of diffuse nitrogen surpluses are transported to surface waters via ground water paths. On its way nitrate degradation may occur. Thus, a calculation of ground water borne nitrate inputs into surface waters requires knowledge of ground water flow paths, total residence time of nitrate and denitrification kinetics in the upper aquifer. These processes are modelled in the models GROWA98 and WEKU that determine diffuse nitrate inputs into surface waters using an area-differentiated modelling approach on a supraregional scale. According to the applicability of the models to large river basins hydrological, pedological and hydrogeological input parameters needed for modelling are taken from thematic maps. The scale of these maps, ranging from 1:50,000 to 1:200,000, determines the degree of detail of model input values and defines, in connection with suitable model approaches, the validity range of model results.

GROWA98 (Kunkel and Wendland, 2002) is used to carry out area differentiated water balance analyses. The mean long term total runoff is modelled as a function of the regional interaction of climate, soil, geology, topography and land use conditions. The model separates total runoff into direct runoff (interflow and surface runoff) and ground water runoff (ground water recharge). GROWA98 calculates the ground water runoff using base-flow indices that depend on area characteristics (e.g. geology, depth for ground water). The ratio between ground water recharge and total runoff was taken as a measure for the extent diffuse nitrogen surpluses are displaced from soil to groundwater.

Nitrate degradation in soils is calculated according to a Michaelis–Menten kinetic applying the approach of Köhne and Wendland (1992). Denitrification losses occur mainly in the effective root zone of soils, and can be described as a function of nitrogen surpluses, average field capacity and site-specific denitrification conditions.

WEKU models the reactive nitrate transport in ground water. In the first step ground water velocities are calculated according to Darcy's law from hydraulic conductivity, effective yield of pore space of the aquifer and the slope of ground water surface (hydraulic gradient). Residence times of ground water runoffs are calculated in a second step. Based on ground water contour maps, a digital relief model of the ground water surface is generated. This is analyzed paying attention to information on the water network as well as ground water discharge or transfer areas with respect to lateral flow dynamics and ground water effective recipients. Residence times of ground water runoffs are then obtained for each initial grid by summation over individual residence times in the grids resulting from ground water velocities and individual flow distances along the flow path until they enter a surface water.

WEKU has been extended by a module quantifying nitrate degradation in ground water. According to extensive field studies by Böttcher et al. (1989) in a catchment area in the North German Lowlands and van Beek (1987) for a site in The Netherlands a first order denitrification kinetic has been assumed with a reaction constant ranging from 0.17 to 0.56 a^{-1}. This corresponds to a half life of nitrogen leached into ground water of 1.2 and 4 years. Rather simple indicators, such as the presence of Fe (II), Mn (II) and the absence of O_2 and NO_3 can be used to decide whether a ground water province has hydrogeochemical conditions in which denitrification is possible or whether such transformation of nitrogen can be neglected (Wendland and Kunkel, 1999).

In order to separate the fraction of nitrogen leached to ground water from total nitrogen leached from the root zone, total nitrogen leaching from the root zone is weighted by the base flow ratio calculated according to GROWA for the whole German area. Additionally, it has to be taken into account that a certain fraction of nitrogen leached from the root zone is coupled to direct runoff components. Whereas in most regions ground water runoff is dominant, some sub-regions, i.e. along the river valleys, reveal high direct runoff fractions.

The validation of ground water borne nitrate inputs into rivers is based on results of the MONERIS model (Behrendt et al., 2000). The model distinguishes between point source emissions from waste water treatment plants and direct industrial discharges and six diffuse pathways, including the inputs via groundwater. According to Behrendt et al. (2000) it is assumed that observed nitrogen concentrations in rivers under base flow conditions correspond to ground water borne nitrate inputs. Thus, modelled nitrogen inputs into surface waters from ground water were compared to corresponding MONERIS values. Given an overall satisfactory congruence between MONERIS values and calculated values by WEKU we conclude that the chosen procedure gives reliable estimates for the ground water borne nitrate input into aquifers.

3. Interface between RAUMIS and GROWA/WEKU

Coupling of agricultural economic and hydrological models is a scientific challenge. Regarding the differences and complexity between RAUMIS and GROWA98/WEKU the most suitable and efficient way to couple these models is the development of a model interface for data exchange. This interface has to guarantee a uniform definition (e.g. scope of representation, spatial and temporal dimension) of variables being exchanged within the model network.

A central interface between RAUMIS and GROWA98/WEKU are regional nutrient surpluses and land use patterns. Developing the model link according to requirements specified above, it has to be considered that the two models display different regional resolutions—raster cells in the hydrological models opposed to administrative units in RAUMIS. Additionally, the models use different data sources, e.g. in terms of agricultural area. While GROWA98/WEKU are based on data from the land register (cadastral maps), RAUMIS employs agricultural survey data. Hence, the models display significant differences not only with respect to spatial resolution but to acreages as well. For this reason, regional nitrogen balances per hectare AA calculated by RAUMIS cannot be directly used as input variables in GROWA98/WEKU. As a first step, nitrogen surpluses quantified by RAUMIS for individual regions are disaggregated on raster cells as required by GROWA98/WEKU.

4. Status quo in study area

Two German river basins shown in Fig. 4, namely the Ems and a sub-catchment of the Rhine, have been selected as study areas in order to cover a wide range of different landscape units with different hydrological, hydro-geological and socio-economic characteristics. Key features describing the status quo situation (1999) in the study areas are summarized in Table 1. Due to data availability indicators are based on a sample of administrative bodies "Landkreise" whose areas predominantly span the river basin. Selected regions that correspond to RAUMIS regions cover an area of 32,700 km^2 and over-extend the catchment areas that actually stretch across some 25,000 km^2.

The river Ems basin (12,900 km^2) is located in the North-German Plain. Agriculture plays an important role in comparison to the German average for two reasons: agricultural area (AA) accounts for about 62% of total area and production is dominated by intensive

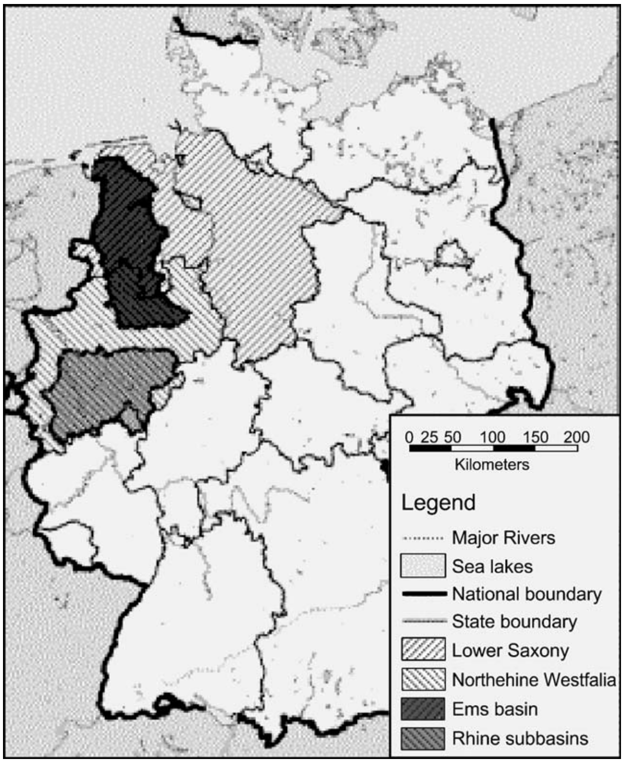

Fig. 4. Selected study area. Source: FZJ.

animal husbandry which is more competitive on the prevailing less fertile sandy soils than cash cropping. Farmers typically grow fodder crops, such as silage maize and corn-cob-mix on arable land. These generate higher yields than permanent grassland and enable a higher livestock production. This production structure explains the visible correlation between shares of arable land and livestock densities (LD) that are displayed in Fig. 5 for the regions within the Ems catchment.

Of course, the higher the livestock density the higher the nitrogen surplus that is discharged with the leachate out of the soil. Large annual nitrogen surplus per hectare AA ranges between 120 and 230 kg with an average of about 140 kg.

Table 1
Key features of the study area in the status quo situation 1999

		Ems	Rhine
Catchment area	1000 km^2	12.9	12.1
Area of sel. regions	1000 km^2	15.9	16.8
Population density	Inh./km^2	190	600
Agricultural area	1000 ha	989	497
Share of arab. land	% of AA	70	49
Livestock density	LU/ha AA	2.3	0.8
Nitrogen surplus	kg/ha AA	138	73
N in surface water	kg/ha AA	69	51
Agric. GVA	Mio. EUR	1473	644
Agric. labor force	1000 LFU	39.2	17.9

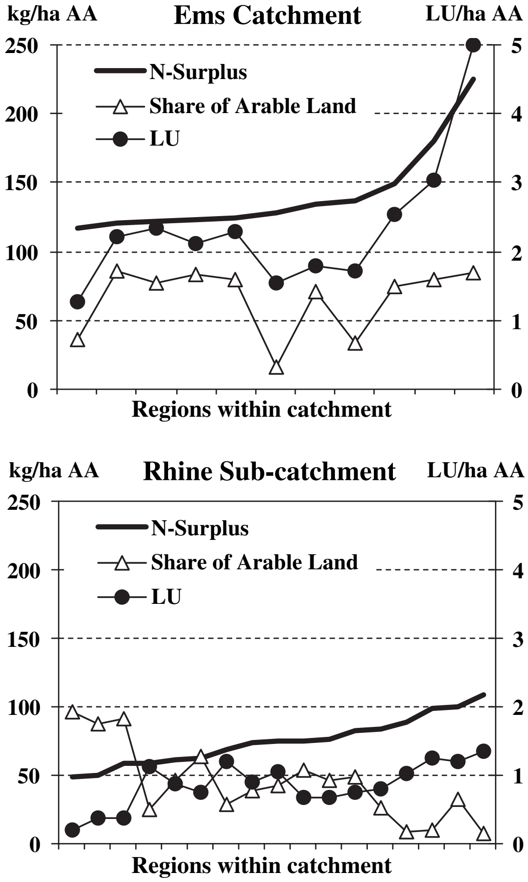

Fig. 5. Distribution of nitrogen surplus, livestock density and the share of arable land across regions within the river basins in 1999. Source: FAA and FZJ calculations.

Due to denitrification processes, about half of the calculated nitrogen surpluses enter surface water in the Ems basin. Fig. 6 displays supraregional differences. For example, in northern marshy parts of the basin with high ground water tables and/or artificial drainage, the ground water runoff accounts for 20–40% of the total runoff. Direct runoff is the dominant runoff component and likewise the main discharge pathway of surplus nitrogen and phosphorus fertilizer into surface waters. This leads to a comparatively lower denitrification and in turn to higher nitrogen emissions into surface waters.

The situation is quite different in the Rhine sub-catchment, i.e. Sieg, Wupper, Erft, Ruhr (12,100 km^2). A striking socio-economic difference is the population density being three times higher than in the Ems basin. Settlements, traffic, and industries, in addition to forests, play an important role such that agricultural area amounts to 30% of total area.

Eastern parts of the Rhine sub-catchment are located in consolidated Palaeozoic rock areas with high total area runoff levels, dominated by fast (direct) runoff components. These conditions hamper tilling of soil so that permanent grassland dominates land use. Farmers specialise in cattle and milk production on a fairly extensive level. However, some regions exhibit nitrogen surpluses of more than 100 kg per ha AA because

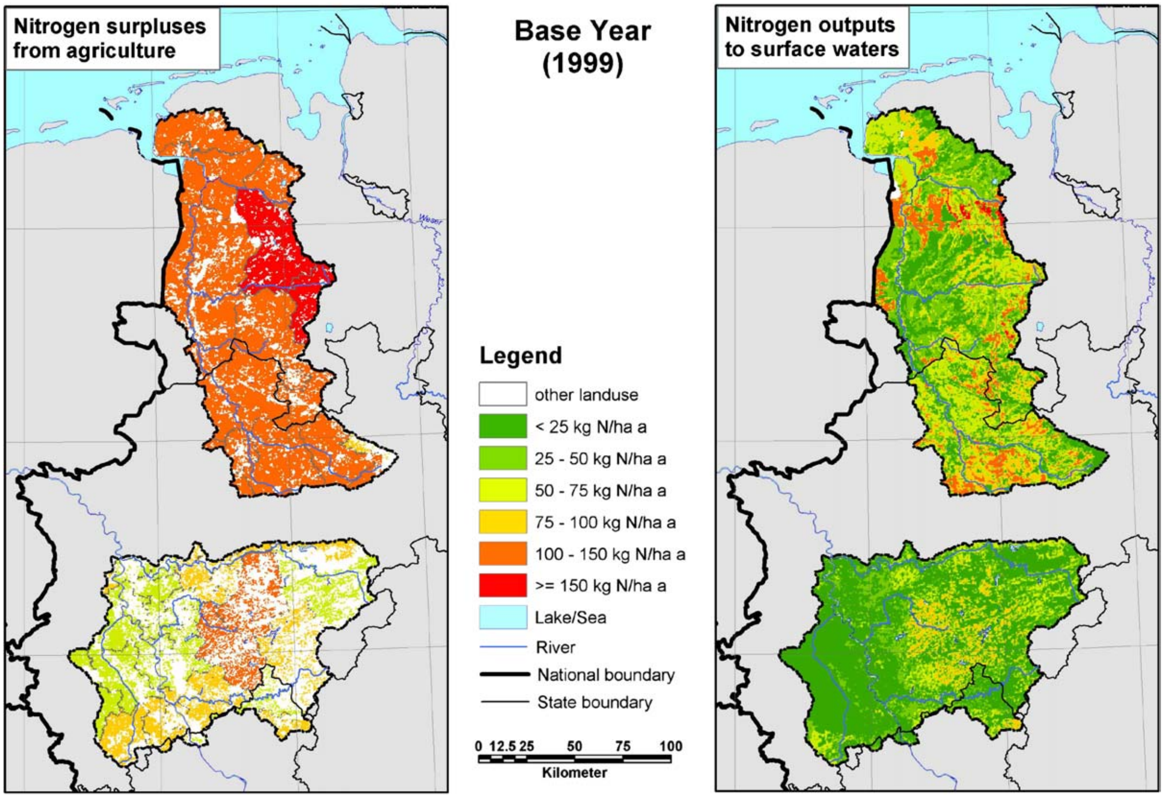

Fig. 6. Nitrogen surplus and nitrogen outputs to surface waters in the base year (kg per ha agricultural area (AA)). Source: FAA and FZJ.

manure supply is relatively high opposed to minor extraction rates due to low yields. As mentioned above, direct runoff is the main runoff component such that up to 90% of excess fertilizers enter surface water a short time after fertilizer application (see Fig. 6). On the one hand, all these regions can be classified as areas with a high risk of surface water pollution, e.g. of storage dams. On the other hand, it can be expected that nutrient reduction measures will improve surface water quality in these areas rapidly.

Western parts of the Rhine sub-catchment are located in the unconsolidated quaternary rock area of the lower Rhine bay with considerable ground water recharge levels. Because of the very fertile loess soil, intensive cash cropping is the main agriculture production activity. These regions feature a share of arable land of more than 90% of AA (see Fig. 5) and low livestock densities. Even though annual nitrogen surpluses are comparatively moderate, they average to about 65 kg per ha AA. Ground water runoff is to a large extent equal to total runoff and aquifer systems are the main pathway for nitrate into rivers. Because of the low flow velocity of ground water in aquifer systems, unconsolidated rock areas show a long term pollution risk. Actual displacement of nitrate from soil to ground water may be detectable in surface waters only after decades, even though denitrification amounts to more than 50% of nitrogen surplus. Consequently, remediation measures will be effective in the same time period. Regarding a classification and assessment of nitrate emission risk, however, it has to be taken into account that hydro-geochemical conditions exist in a number of aquifers especially in unconsolidated rock areas, which may enhance natural nitrate degradation.

As described a wide range of problems concerning nutrient pollution of water bodies are prevalent in both study areas. In particular, nitrogen surpluses significantly exceed 50 kg N per ha; a value that is considered necessary to achieve Water Quality Class II (see cap. 1). It is to be expected that possible methods of resolution will regionally vary with respect to the reduction of nitrogen and phosphorus in water bodies. The efficiency of measures has to be evaluated accordingly, taking into account the different historically evolved and partly established socio-economic conditions in the study areas such as agricultural farm structures, the structure of water protection, as well as water supply and sewage disposal.

5. Impacts of nutrient reduction measures

5.1. Policy scenarios

In line with the methodological approach of RAUMIS (see Fig. 2) policy measures are analyzed and assessed comparing their impacts to a *scenario of reference*. The scenario of reference is a medium term projection of the development until the year 2010 under policies of Agenda 2000 which constitute the current Common Agricultural Policy (CAP) of the European Union.

Among alternative policies aiming at reducing agricultural nutrient surpluses two distinct measures have been selected taking the following aspects into account: heterogeneity of study areas, relevance for practice and policy, applicability, sufficient potential for regional problem solution, and a minimum of social and political acceptance.

The description of the study areas shows that the Ems catchment reports extremely high nitrogen surpluses due to intensive livestock production. Reinforcing the linkage between animal production and agricultural land to overcome this problem is frequently discussed in public. This could either be reached by limiting the livestock density or by an improved regional distribution of manure supply. In this study introducing an upper limit of 1.0 livestock units (LU) per ha AA (Abbr.: LD $\leq$ 1.0 LU) is analyzed. The restriction seems to impose an extraordinarily high pressure on animal production because individual farms specialized in livestock typically exceed this threshold considerably. Since RAUMIS operates on “region farms” that exhibit lower livestock densities, a lower bound than on individual farm level is required to achieve a binding effect at all.

Nitrogen surpluses exceed 50 kg N per ha AA even in arable farm regions such as the analyzed Rhine sub-catchment. This is primarily due to growing cash crops on an intensive production level using mineral fertilizer. The high production intensity results from economic behaviour of farmers who determine the profit maximizing nitrogen use according to production functions and input–output price ratios. Under current conditions the application of one additional kg of nitrogen in wheat production is profitable as long as the yield increases by more than 4 kg. However, this yield increment extracts just 0.07 kg of nitrogen during harvest resulting in considerable nitrogen surpluses (Weingarten and Kreins, 2004).

Against this background increasing the price of mineral nitrogen by raising a tax is analyzed as a second measure. The *tax on mineral nitrogen* basically has two objectives: Firstly, a lowering of production intensity and secondly an improvement of competitiveness of manure nitrogen which would increase its utilization. Due to a rather inelastic demand for mineral nitrogen a tax of 200% is raised (Abbr.: N-tax 200%). Total N-tax revenues are reimbursed to farmers via a uniform direct area payment being independent from production.

5.2. Results

Results of primary interest regarding the evaluation of measures are impacts on nitrogen balances or nitrogen leaching into surface water and of course costs of the measures. Costs are represented by agricultural income changes. In RAUMIS income figures comply with the definitions of national agricultural accounts. While changes in agricultural Gross Value Added (GVA) indicate short term income effects, agricultural Net Value Added (NGA), that includes depreciations of fixed assets as well, expresses long run costs.

5.2.1. Scenario of reference

Agenda 2000 changes general conditions just marginally so that the situation in the reference scenario resembles the base year. Model analyses show minor changes of agricultural production resulting in a slight fall of average nitrogen surplus by 4 kg N. Still, nitrogen surpluses will exceed 50 kg N except for two regions in the Rhine sub-catchment (see Fig. 7).

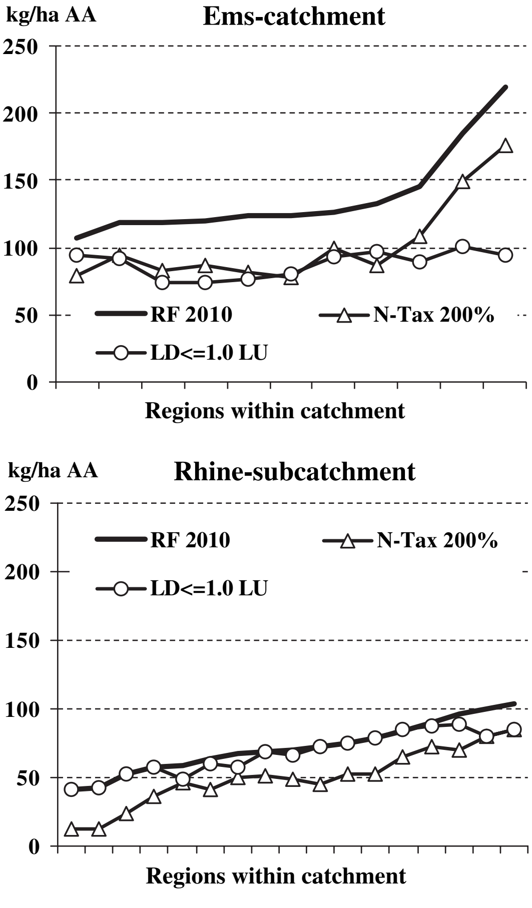

Fig. 7. Distribution of nitrogen surplus across regions within the river basins under alternative policies in 2010. Source: FAA and FZJ calculations.

5.2.2. *Limitation of livestock density*

Restricting the livestock density to 1.0 LU per ha AA will cause major adjustments of agricultural production with considerable regional variation. As expected, regions with the highest livestock densities in the reference scenario exhibit sharp cuts in animal production. The whole Ems basin and some regions in the Rhine area are affected. According to RAUMIS calculations average livestock will be reduced by 63% in the Ems catchment (see Table 2) with a peak of more than 80%. Regions will even fall below the imposed boundary because some crops, e.g. permanent crops, are excluded from manure application.

In spite of an almost two-third cutback in livestock total nitrogen surplus will decline by only 37% in the Ems basin. This is because manure represents just a fraction of total nitrogen supply. Since soil conditions are kept constant nitrogen emissions into surface water will drop by the same proportion as nitrogen surpluses.

In the Ems basin costs will amount to 20 EUR per kg reduced nitrogen charge into surface water (see Table 2). Differences among regions are considerable and range from no impact up to a drop of 53% in GVA. In a few regions of the Rhine sub-catchment the restriction puts only little pressure on animal production so that adjustments are accordingly moderate. Taking long run adaptations of production capacity into account, costs in terms of agricultural NVA (not displayed) will amount to about half of the short run costs.

5.2.3. *Tax on mineral nitrogen*

Prior to describing scenario results the effects of a tax on mineral nitrogen and how reactions are being modelled in RAUMIS are briefly explained. RAUMIS accounts for the following three important adjustments. In the first place, production intensities of all crops using mineral fertilizer are reduced. Depending on changes in input–output price ratios, the so called intensity module determines new optimal intensities. In the second place, the so called manure module upgrades utilization of manure because a higher mineral nitrogen price increases the profitability of investing in improved manure technology. Finally, the competitiveness of crops changes according to plant specific mineral fertilizer requirements which leads to a new optimal cropping pattern. A minor impact results from the enhanced competitiveness of animal production due to the increased value of manure.

In general, implementing a tax of 200% on mineral nitrogen will decrease nitrogen surplus in all regions within the study areas. Regional reductions will range between 13 and 46 kg N (see Fig. 7). This reflects differences relating to the total amount of mineral fertilizer being used locally. These differences depend on the specialization of agricultural production in the regions. On average, nitrogen surpluses decline by 27% in the Ems basin and 34% in the Rhine sub-catchment (see Table 2). While changes in livestock production will be negligible, the cutback of nitrogen surpluses will primarily come from a decreased intensity of crop production. Again, since soil conditions are kept constant the decline in nitrogen surplus proportionately reduces nitrogen leaching into surface water.

Agricultural GVA will drop by 1% in the Ems basin and 3% in the Rhine sub-catchment (see Table 2). Costs per kg of reduced nitrogen emission into surface water will amount to 1 and 3 EUR, respectively. These costs will not change subject to the time horizon since the tax mainly affects the intensity of crop production while production capacity is almost kept constant.

5.3. *Comparison and assessment of measures*

As expected, the measures result in different impacts on both regional agricultural nitrogen surpluses and

Table 2
Impacts of alternative nitrogen reduction measures in 2010

		Ems catchment			Rhine sub-catchment		
		Reference	LD ≤ 1.0 LU ha^{-1}	N-Tax 200%	Reference	LD ≤ 1.0 LU ha^{-1}	N-Tax 200%
Agricult. nitrogen surplus	kg ha^{-1} AA (% to Ref.)	135	85 (−37)	99 (−27)	69	65 (−6)	46 (−34)
Livestock density	LU ha^{-1} AA (% to Ref.)	2.5	0.9 (−63)	2.5 (1)	0.8	0.7 (−9)	0.8 (−4)
Agricult. gross value added	Mio. EUR (% to Ref.)	1.796	1.312 (−27)	1.781 (−1)	657	651 (−1)	636 (−3)
N-charges in surface water	kg ha^{-1} AA (% to Ref.) kg to Ref.	68	42 (−37) −25	49 (−28) −19	49	45 (−7) −3	34 (−31) −15
Costs of reduction	EUR kg^{-1} reduced N		20	1		4	3
Total N-charges	mt (% to Ref.)	64.062	40.128 (−37)	46.437 (−28)	23.373	21.792 (−7)	16.212 (−31)

Annotations: LD = livestock density; LU = livestock unit; AA = agricultural area; mt = metric ton.
Source: FAA, FZJ.

income. In regions with intensive animal production a reinforced linkage between livestock and agricultural area tends to ease problems of extraordinary high nitrogen surpluses. However, the measure has some shortcomings. Firstly, nitrogen surpluses due to intensive use of mineral fertilizer, e.g. in cash cropping, are of course not affected. Secondly, costs of the measure are relatively high. For example reducing nitrogen charges into surface water in the Ems basin by one-third, i.e. 21,000 mt N, long run annual costs in terms of agricultural income forgone will amount to 200 Mio. EUR. In spite of the nitrogen reduction the overall surpluses will still considerably exceed 50 kg N per ha AA. Thirdly, a cutback of livestock in regions with a specialization in animal production will not generally result in building up livestock in regions with low livestock densities. This requires a specialization in up- and downstream sectors as well. In fact, a shift of animal production to specialized livestock regions, where impacts of agricultural production on the environment are less regulated, is to be expected which will aggravate existing environmental problems in these areas. In addition, execution and monitoring of this measure will cause substantial administrative expenses.

In comparison to reinforcing the linkage between livestock and agricultural area, increasing mineral nitrogen price exhibits fundamental differences. Firstly, nitrogen surpluses will be reduced in all regions since mineral fertilizer is applied area wide. Thus, the overall nitrogen reduction effect is larger. However, in regions with intensive livestock production the decline is unsatisfactory regarding high nitrogen surpluses. Secondly, costs of a tax on mineral nitrogen are far less than those incurred by a limitation of livestock density. Thirdly, the execution and administration of the measure is comparatively simple since the bottleneck principle applies to supply and distribution of mineral fertilizer.

6. Conclusions and outlook

The methodology and results presented in this paper provide scope for conclusions and further research work in many respects.

Integrating the agricultural economic model RAUMIS and the hydrological models GROWA98 and WEKU into a network achieved the intended and anticipated methodological improvements. The risk indicator "nitrogen surplus" has been extended to account for actual depositions of nitrogen into water bodies. Detection, classification and monitoring of areas with nitrogen problems is more specific on the basis of this improved indicator because natural conditions are taken into account. A further development is the adjustment of the current spatial differentiation of RAUMIS according to natural sites. Depending on the availability of data, in particular land use information from remote sensing, a first step is to extend the model to a lower municipality level which is closer to the spatial grid cell resolution of the hydrological models. The next step is to assign "*homogenous natural sites*" below the community level, considering the homogenous sites as a farm, and model the adjustment behaviour of the farms.

An expansion and application of a similar model network to other catchments in Europe should in principle be possible without major problems. The advantage of a broader application of the model concept is to quantify subsurface nitrogen retention on a supra-regional level throughout Europe. In the same way, it would be possible to evaluate sensitive regions, i.e. areas with high nitrogen surpluses and low ground water residence times and hence incomplete subsurface nitrogen retention. However, it has to be taken into account that this generalization so far is a rough estimate relying on study results and on knowledge about the general geological structure in Europe. Statements about the applicability of the combined model for these areas can only be proved in the course of further selective studies. In this regard, the heterogeneity of selected areas provides a promising basis for calibrating the model network and application of the methodological approach to other landscapes and river basins.

Having accomplished a full model integration, a backward calibration of the model network will be possible. In this validation process, modelled nitrogen inputs into surface waters as well as pathway simulations will be compared with observed values, e.g. nitrogen concentrations from monitoring stations.

Concerning the modelling of adjustments of agricultural production, model-specific options will be developed. A first consists of calculating crop specific nitrogen balances. A second is improving the module that calculates the intensity of production. Input use being currently computed before the optimisation process should be endogenously determined. As a third improvement a manure transport module will be developed allowing for an interregional transport of manure.

Results of agricultural policy impact analyses point out that nitrogen reduction measures affect the regional nitrogen use differently. In particular, the investigated effects of restricting the regional livestock density or tax mineral nitrogen highlight that the mitigation of diffuse water pollution problems requires regionally tailored measures.

Regarding an overall evaluation of policy measures further topics such as the effects on land use, agricultural production and structural changes as well as the social acceptability have to be analyzed as well. These aspects will come to the fore in the context of the REGFLUD-project that aims at comprising all findings in a decision support system.

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