Combining agricultural economic and hydrological models with the aid of remote sensing data

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ABSTRACT: The EU Water Framework Directive (WFD) aims at maintaining and improving the aquatic environment and at establishing the basic principles of a sustainable water policy in the European Community. For this reason the impact of agricultural emissions into the hydrological system is analysed and modeled both for inventory and policy advisory purposes. In the case of nitrogen, regions with a high exposure of eutrophication are characterised on a high precision level and changes in discharge paths are identified.

In this study a coupling of the agricultural sector model RAUMIS (Regional Agricultural and Environmental Information System for Germany) with the hydrological model GROWA is illustrated. The area of investigation is the catchment basin of the Ruhr river in the west of North Rhine – Westfalia, Germany.

RAUMIS places emphasis on the economic aspects of agriculture and assesses the impact of agricultural-environmental policies. Essential elements are environmental indicators such as the potential diffuse agricultural nitrogen or pesticide emissions into the groundwater. These data are available for crops in an averaged form on the district level. The raster-based model GROWA calculates the main water balance components: the actual evapotranspiration, total discharge, direct runoff and groundwater recharge. One result of the model is an estimation of diffuse agricultural nitrogen emissions into water bodies. However besides soil data the model makes use of CORINE Land Cover which has an insufficient spatial resolution and which does not differentiate between individual crops such as wheat, sugar beet, potatoes, etc.

Because of this difference in scale and attribution, the output data of RAUMIS cannot be inserted into GROWA in a simple way. LANDSAT ETM+, SPOT and ASTER data of the Ruhr catchment are used in order to solve this problem. After a panchromatic sharpening and further standard pre-processing methods, a Kalman filter based neural net classifies the images into the specific land use categories. A post-classification filtering with probabilistic label relaxation is availed for correction of misclassified pixels. The images of consecutive years are analysed to define the regional crop rotation for each parcel of land. This precise land cover information then serves as the interface between the two models. Nitrogen balance surpluses estimated by RAUMIS are disaggregated from district scale to a raster level of 15-20m. Furthermore the land cover class probabilities themselves are included as improved input data into GROWA.

1 INTRODUCTION

In the scope of the Water Framework Directive (WFD) the European Union has made water protection one of the priorities of its work. It demands effort to obtain cleaner rivers, lakes,
groundwater and coastal regions. Since agriculture is reckoned as main diffuse polluter of the aquatic environment with nutrients, research focuses on analysing and balancing matter fluxes to give policy options. Nitrogen containing mineral fertilisers and manure from livestock farming are main sources for an increased N-concentration in watercourses (Pau Vall & Vidal 1999). This can cause eutrophication with generation of toxic substances for microorganisms and fishes on the one hand and economic losses for drinking water management on the other.

The agroeconomic model RAUMIS, developed at the Federal Agricultural Research Centre Brunswick (Weingarten 1995), analyses the agricultural sector for, among other things, labour, capital and fertiliser input. An environmental indicator system assesses the potential nitrogen surpluses of farmland on the district level in a database. These data are available either as a single average value for a district or on a crop-by-crop basis for the main crops in the district. The methodological background is a balancing of applied fertilisers with the extracted nitrogen content of the yield. In contrast, the hydrologic model GROWA, which was designed at the Programme Group Systems Analysis and Technology Evaluation in the Research Centre Juelich, works on a variable raster basis (Kunkel & Wendland 2002). In this study a 25 m grid is used. It aims at separating the incoming precipitation into further components of the water balance. Depending on the runoff components direct runoff and groundwater recharge nitrogen balance surpluses are routed through soil with different decomposition and conversion processes.

A direct coupling of these models is possible (Gömann et al. 2003), e.g. with a stochastic distribution of nitrogen surpluses over the agricultural area of a district, but such a distribution is fictitious and unsatisfactory for detailed hydrological modelling. The aim is to identify area accurate risks for pollution. This is possible with remote sensing data. For this reason the main focus of this study is the link between the models, rather than the models themselves.

2 CONDITIONING OF REMOTELY-SENSED DATA

The catchment basin of the river Ruhr, a subcatchment basin of the Meuse in the Belgian-Dutch-German borderland, was chosen as area under investigation (Fig. 1). It is characterised by the bedrock of the Eifel in the south and rank loess areas in the north (Juelicher Boerde). The greatest possible variety of natural resources should be represented to analyse possible restrictions with heterogeneity.

In this region it is a problem to get cloud free scenes of high resolution remote sensing images in the relevant phenological phase and for consecutive years. For this reason a set of different sensors – Landsat 7 ETM+, SPOT 1/2 and ASTER – had to be consulted for the years 2000 – 2004. A Wavelet Fusion using the ARSIS concept developed by (Ranchin & Wald 2000) was performed to pan-sharpen the LANDSAT and ASTER images, whereby the SWIR bands of the ASTER data are fused with the first principle component of the VNIR bands. A panchromatic SPOT band is not available.

To obtain land cover on crop level, a Kalman filter based artificial neural net (ANN, Shah & Palmieri 1990) classifies the images into 14 categories. The advantage of an ANN compared to other algorithms is that it models the probability density functions of each class directly (Bishop 1997). The significant agricultural classes are wheat, sugar beet, potato, corn, barley and grassland, whereas industry and settlement are classified for determining impervious areas. The ANN also determines individual class probabilities. Accordingly a Probabilistic Label Relaxation can be used to analyse neighbourhood relationships in order to generate internally homogenous land use segments (Richards & Jia 1999). The accuracy of the classifications after filtering are evaluated with $\kappa$-indices (Congalton & Green 1999) of $>0.95$.

3 DISAGGREGATION OF NITROGEN SURPLUSES

To combine the RAUMIS output with landcover information, disaggregation has been conducted up until now with Corine data. Without any crop information only an average value of nitrogen
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surpluses for a district was compiled (Fig. 3c). In contrast a remotely sensed crop inventory is capable of constructing diffuse nitrogen surpluses on a 14.25 m – 20 m pixel basis (Bogena et al. 2004), depending on the sensor used. Administrative units and located crops are present in a Geographic Information System so that the output database of RAUMIS can be distributed on this raster (Fig. 3d).

With the aid of remote sensing data such as landcover and imperviousness information not only a disaggregation is simplified but also the input data for the hydrological model GROWA are enhanced (Fig. 2). Landcover-dependant input parameters such as effective field moisture capacity of the root zone, capillary rise and maximum evapotranspiration are also adopted. The separation into the discharge pathways real evapotranspiration, total runoff \(Q_t\), direct runoff \(Q_d\) and groundwater recharge \(Q_{gw}\) is achieved that way. Imperviousness has an especially high significance in this step.

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4 MODEL LINKING

The intrinsic coupling of agroeconomic and hydrological schemes, in this case the disaggregated nitrogen surpluses, is shown in Fig. 2. With a module based on GROWA called DENUZ (Wendland & Kunkel 1999) denitrification and retention is calculated on the basis of soil data. The remaining nitrogen is leached out with direct flow and groundwater recharge (Fig. 3e and 3f). The concurrently calculated groundwater residence times reflect the impact periods and, together with the amount of nitrogen charging into the aquifer, a pollution map can be generated.

With this map a link back to RAUMIS for scenario analysis is possible and planned to the future (Fig. 2). The question how the structure of the agricultural sector should be changed to reduce nitrogen pollution can be answered. A conceivable study would be a hypothetic tax on nitrogen fertilisers: What influences would a tax have on the agricultural sector and indirectly on the resulting nitrogen surpluses and the nitrogen charge into groundwater respectively? With this new combination of the agroeconomic sector model and the hydrological models, effects on the environment can be evaluated. This will give information for decision support purposes.

5 CONCLUSIONS

A combination of agroeconomic and hydrological models is certainly possible without remote sensing data, but with the aid of satellite images the level of detail is much higher with regard to content and spatial resolution. Especially the area-wide crop information for several years provides the missing link between the two different kinds of models. The result is a detailed map of hot spots of agricultural diffuse nitrogen pollution with prospect for decision support, e.g. for river basin management plans in context of Water Framework and Nitrates Directive.

Some problems persist, such as the different intensities at district borders that one can observe.
Combining agricultural economic and hydrological models with the aid of remote sensing data in the result, even though agronomists manage cross-district. On the other hand the full potential of this model network is conceivable to be adopted for phosphorus and potassium surpluses and loads as well.

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REFERENCES


