Study Present Measurement Strategies And The Application Of The SWAT Model For Its Suitability To The European Water Framework Directive (EU-WFD) Within A Large-Scale Catchment In Germany

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EXTENDED ABSTRACT

The European Water Framework Directive (EU-WFD), implemented in the year of 2000, requires the general ecological protection and a minimum chemical standard to be achieved in all European surface waters based on the watershed scale. All member states of the EU mandate to develop river basin management action plans to achieve these goals within the year of 2015.

In Germany, this procedure is regulated by several administrative units through the legislation of federation and state laws defining different stages of responsibility. Thereby the administration is positioned by the spatial scale of 10 major water basins (Danube, Rhine, Maas, Ems, Weser, Elbe, Eider, Oder, Schlei/Trave and Warnow/ Peene).

Being part of the Elbe River system the 843 km² Gera catchment was selected for a pilot study. The study was announced by the 'Thuringian environmental, agency' (TLUG) to develop a method to target the aims of the EU-WFD for establishing a good water quality within one of the main tributaries of the Elbe River.

The Gera basin is located in the Thuringian middle mountain range area of Germany. Physiographic and climatic factors, such as topography, landuse and soils as well as precipitation varying strongly. They are resulting in a highly complex of variable water and nutrients turnover processes. One of the main water quality problems occuring in the Gera basin is related to nutrients. Therefore the main goal of this pilot study was to assess the suitability of the available data bases for achieving the goals of the EU-WFD in case of nitrogen. The study was applied for the Gera catchment by

(i) Evaluation of the feasibility of the present data related monitoring system for providing spatial informations on the detecting of local water quality areas and their relation to sources of pollution;

(ii) Applying the SWAT model to regionalise areas contributing a high release of nitrogen to the Gera River by utilising basin related spatial informations;

(iii) Investigation and assessment of comparability of monitoring and model application for accomplishing the goals of the EU-WFD.

In summary it can be concluded that the present monitoring system of the Gera River system has to be improved (frequency and number of gauging stations) for *Phase II* of the EU-WFD according to the proposed areas through applying the SWAT model. Although it has to be pointed out that modeling results have to be improved this application has tested to be suitable for identifying key system properties of spatial and temporal variability of nutrient release within the catchment. This knowledge is of highly importance if dealing with the development and the assessment of management action plans according to the *Phase III* of the EU-WFD.

1. INTRODUCTION

With the commencement of the ‘Common Implementation Strategy’ of the European Framework Directive (EU-WFD) in the year of 2000 a European wide law has been implemented to protect all kinds of water systems (Directive 2000/60/EC). Hereby water systems are defined into five categories which are groundwater, surface water, lakes, coastal areas and ‘crossover waters’. Hence new considerations are implemented like

(i) Providing clear guidelines for water management actions at the watershed scale,

(ii) Including economic criteria such as proving the efficiency of action plans, cost-covering prices of water etc., comprehension of environmental resources costs,

(iii) Involving the public within the local decision procedures.

In Germany the spatial base for managing and implementing the EU-WFD is based upon five major basins independent of administrative boundaries (Figure 1).

Figure 1. Major river systems of Germany managed by the EU-WFD (BMU 2004)

2. EUROPEAN FRAMEWORK DIRECTIVE AND WATER QUALITY ASSESSMENT

On that base action plans according to the EU-WFD are structured as illustrated in Tab.1. *Phase I* is disposed within a four year period to assess watersheds and to what extent the goals of the EU-WFD could or could not be reached. Hereby the actions plans are oriented along the dominant impacts within the watersheds (Figure 2.).

Action	Time schedule	Reference
Phase I: Inventory and classification of local water systems, determination of anthropogenic influences, reporting	2004	Article 5
Phase II: Definition and construction of observational network, monitoring of water systems	2007	Article 8
Phase III: Development of management action plans for local basins, public hearings	2009	Article 11, 13
Phase IV: Implementation of management action plans for local basins	2012	Article 11
Obtaining EU WFD goals for local basins	2015	Article 4

Table 1. Stages of management planning to achieve WFD goals

Thereby the water quality inventory for each basin comprises the detection of all kinds of sources and the evaluation of the potential risks of these sources, their potentially cumulative effects as well as their long-range effects.

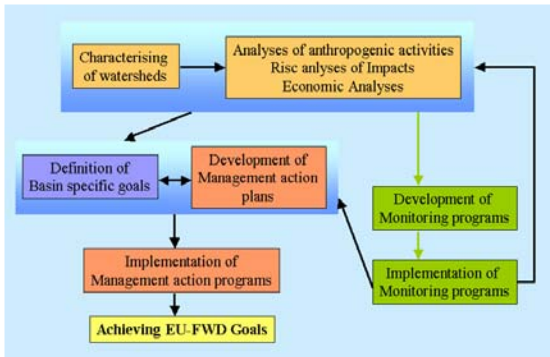

Figure 2. Steps of *Phase I* of the EU-WFD (BMU 2004)

Phase II contains the enhancement and completeness of consisting monitoring progams until the year of 2007. On the evaluation of the water quality inventory the regional management action plans will be developed within *Phase III* up to the year of 2009 and will be implemented in *Phase IV*.

At that present stage (*Phase I*) the assessment of consisting monitoring programs is essential to prove its ability on assessing impacts on watersheds. Therefore the 843 km² test catchment of the Gera River in Thuringia (Figure 1), Germany was selected for a pilot study to develop a practicable method for assessing areas with a high potential to reduce impacts by analysing the present data bases, such as water quality measurements and spatial datas.

3. STUDY AREA

The study area is located on the northern bound of the middle mountain range of the Thuringian forest mountain, Germany, about 50 km south of the city of Erfurt (Figure 1 & Figure 3).

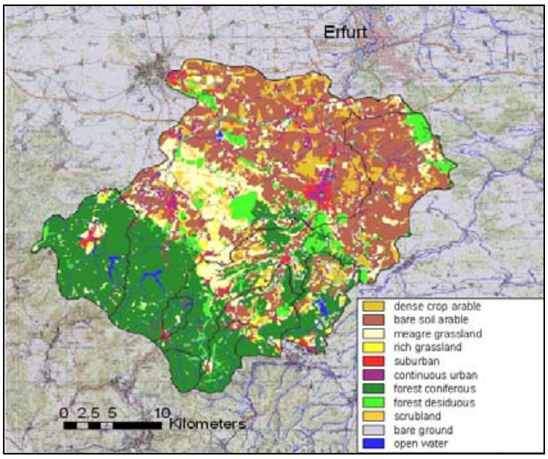

Figure 3. Landuse (September 1999) of the geographic regions of the 843 km² large Gera river system

The Gera River drains into the Saale, which is a tributary of the main Elbe River. The catchment covers three landscape units from southwest to the northeast given the natural conditions:

- The 'Thuringian Forest' (up to 980 m asl) is underlain by impermeable granite and porphyry stones (Seidel 2002). Dominant landuses are forests, mainly coniferous. Evapotranspiration adds up to less than 30% of the annual precipitation and runoff is clearly dominated by interflow (Table 2);
- The 'Ilm-Saale-Ohrdrufer-Shell-Limestone' (300 – 600 m asl) is mainly based on the limestone's, dolomite and calcite shale where locally karst phenomena are appearing. Landuse accounts for forests and pasture and meadows;
- 'Innerthuringian agricultural hill-land' (200 – 300 m asl): geology shows an alternating stratification of marl and sandstones. It is drifted up by loess that provides a high soil fertility resulting in productive crop landuse system. Hereby groundwater recharge is dominant.

Hydrochemical datasets of interest comprises, besides major cations and anions, nitrogen components, such as ammonia, nitrite and nitrate

Geographic Region	Precipitation (P) [mm]	Evapranspiration (E) [mm]	Discharge (Q) [mm]	Discharge-quotient (Φ)
Thuringian Forest	1300	400	900	0,69
Ilm-Saale-Ohrdrufer- Shell-Limestone	800	460	340	0,43
Innerthuringian Agricultural Hill-Land	635	540	90	0,15

Table 2. Regional long-term water balance of the three landscape units within the Gera catchment

4. WATER QUALITY ANALYSIS

The Gera River is instrumented by a water quality-monitoring network, which is advised by the TLUG. Within the watershed there are 13 water quality gauging stations (Figure 4).

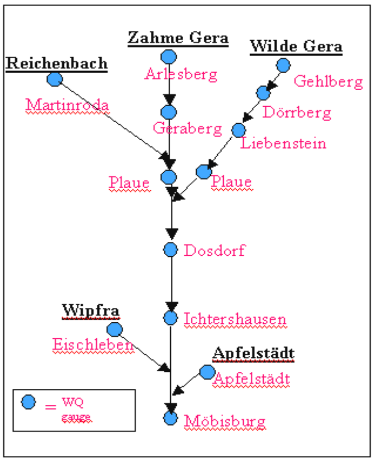

Figure 4. Water quality gauging station within the Gera River catchment

for a time period of 1995-2004. Frequency of data sampling intervaling 4-6 weeks depending on the order of the tributaries.

As illustrated in Figure 5 and Figure 6 the headwater catchments of the Gera River like Wilde Gera and Zahme Gera (see stations Gehlberg, Arlesberg and Geraberg) showing up the lowermost medium nitrogen concentrations along with low variances and maxima. Observed values are below the require standards for surface waters in Germany of 10,0 mg/l NO_3, 1,0 mg/l NH_4 and 0,1 mg/l NO_2 (Worch 1997). Given the fact that solute dynamics are driven by atmospheric impacts and internal turnover the observed values are related as natural hydrochemical background within these headwater catchments. Urban impacts are detected in the ongoing tributaries of the Wilde Gera and Zahme Gera (see stations Liebenstein, Geraberg) as well as in the basin of the Reichenbach (see station Martinroda). Nitrite- and ammonia-concentrations are above the exceed threshold values for surface waters (Worch 1997). These parameters are referred to impacts of house sewages that are still a problem.

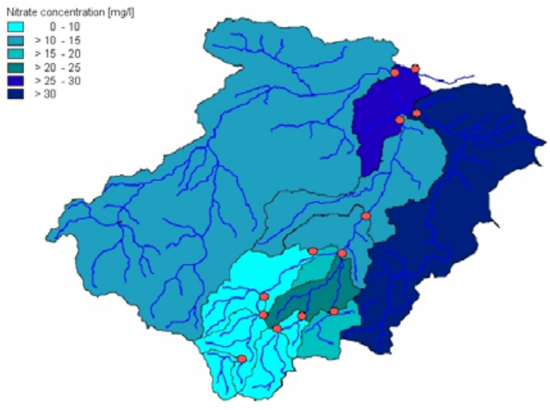

Figure 5. Regional distribution of observed median nitrate concentrations of the Gera River basin (1995 – 2004)

Shortly before the confluence of Wilde Gera and Zahme Gera (see stations Plaue) rising nitrate concentrations are observed towards an average of 22,0 mg/l.

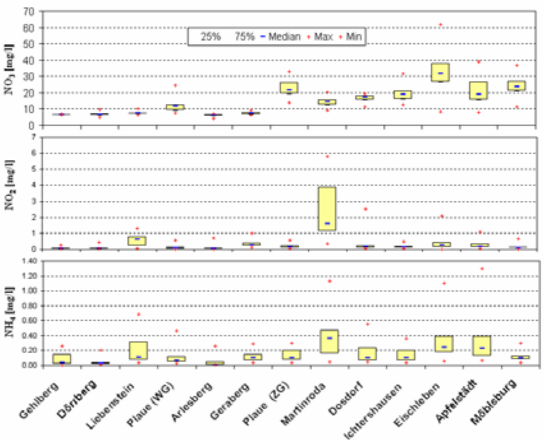

Figure 6. Variability of the nitrogen measurement values for the Gera basin (1995 – 2004)

This might indicating the release of diffuse source from agricultural landuse. That assumption is confirmed by the appearance of additional fertilizer ingredients such as potassium that are applied in the catchment (Figure 7).

In the following river sections the median concentration of nitrate declines (see station Dosdorf, Ichtershausen). A remarkable nitrate impact on the Gera River system is observed by the confluence from the Wipfra (see station Eischleben) and the Apfelstädt (see station Apfelstädt). Therefore the minimum concentrations are above the referenced standard for surface waters in Germany (Worch 1997) and the maximum concentration exceeds the European drinking water regulation standard of 50 mg/l NO_3 (TVO 1990).

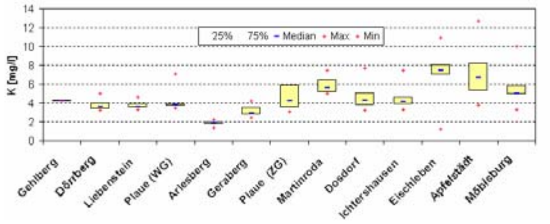

Figure 7. Variability of the potassium observed values for the Gera basin (1995 – 2004)

Similar to the confluence of Wilde Gera and Zahme Gera it is assumed that nitrogen sources are related to intense agricultural landuse within those areas.

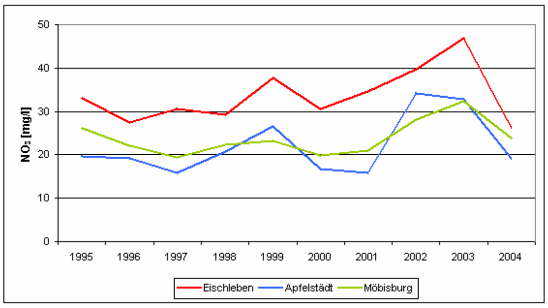

Figure 8. Yearly based average nitrate concentrations of the Gera River outlet, Apfelstädt and Wipfra sub-basin (1995 – 2004)

These trends are undetermined unless for the years of 1999 and 2003 rising trends of the nitrogen concentration are observed. They are supposedly resulting from concentration effects due to surpassing dry conditions within these years. In contrast to this dilution effects are observed in 2000 and 2004.

In summary it can be concluded that different nitrogen indices can be mapped for different land uses within the Gera River. Problems are indicated within areas of intense agricultural use while sources of nitrogen impacts can not be regionalized. With respect to this the use of the SWAT model was suggested to detect and model dynamics of areas contributing high releases of nitrogen.

5. SWAT MODEL APPLICATION

The Soil Water Assessment Tool (SWAT) (Arnold et al. 1998) was assumed and tested for identifying and quantifying nutrient source areas by simulation of key bio-geo-chemical processes and interactions, investigating nutrient delivery from land to water by main transport pathways as well as for evaluating of potential management scenarios in meso- or large-scale catchments which is required by the EU-WFD (Arnold & Fohrer 2005; Haverkamp 2005; Hörmann et al. 2005).

5.1. Data Input

The application of SWAT requires GIS-based data such as relief, geology, soils and land use information. Therefore a 25*25m DEM with was available to derive subcatchments, slope and exposition. The soil map “Die Leitbodenformen Thüringens” 1:100000 (Rau et al. 1995) provided soil informations. Thereby soil horizons, field capacity and the hydraulic conductivity were delineated. Additionally the geological map (“Geologische Übersichtskarte 1:200000”) was used to distinguish regions where karst phenomena are located. The information of land cover was derived from two landuse classifications (Figure 3) originating from Landsat TM images of the years 1999 and 2002. Moreover the information for the landuse management has been delineated according to the classification of the year 2002. Consumption of crop specific fertilizer was estimated through literature studies (Thüringer Landesanstalt für Landwirtschaft 2001) and from farmer interviews by a catchment nearby (Fink 2004). Therefore the results are shown in Table 3.

Crop	kg N/ha*a “intense“	kg N/ha*a “less intense“
Winter wheat	178	164
Maize	202	
Summer barley	106	
Winter barley	178	164
Rape	202	176
Peas		50
Fallow		0
Meadow	60	60

Table 3. Crop types and fertilization for different regions of the Gera catchment.

Hence two variants of agricultural uses have been distinguished: ‘intensive’ and ‘less intensive’. The ‘intensive’ farming system is located in the ‘Innerthuringian agricultural hill-land’ given the excellent natural conditions. The other landscape units are parameterized as ‘less intensive’ fertilization. Climate values originated from 11 rain gauges and 3 climate stations. In total 527 HRUs were modeled within 120 subcatchments in a semi-distributive way.

5.2. Modeling Results

In Figure 9 the predicted and measured runoff for the period of 1/1994 to 11/2000 is shown. It is noticeable that in low flow periods the predicted flow has some peaks, which are not represented by the observed values. This could be caused by the water consumption of several reservoirs in the catchment that could not represented well in the SWAT model. The average predicted discharge is 6.8 m³/s whereas the measured one is 5.9 m³/s. This difference could be explained by the karst phenomena in the catchment, which is not described adequately in the model as well. The efficiency R_{eff} (Nash & Sutcliffe 1970) for the showed period is 0.51. It comprises R_{eff} 0.27 for the calibration period (1998 - 2000) and 0.60 (1994 - 1997) for the validation period.

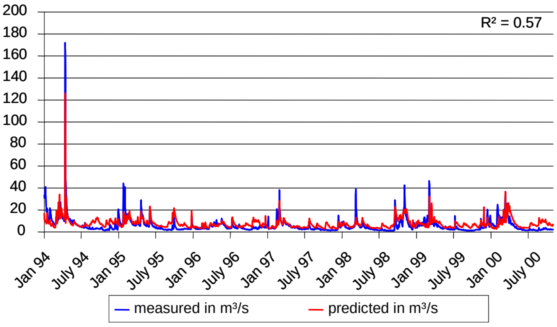

Figure 9. Predicted and modeled discharge at the catchment outlet (Möbisburg)

Figure 10 shows the contributed predicted discharge. Thereby the different behavior of the 3 major landscape units can be identified. In the northern part (‘Innerthuringian agricultural hill-land’) almost no discharge takes place.

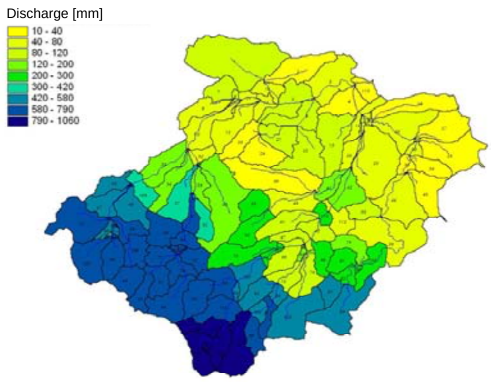

Figure 10. Predicted average annual discharge of the derived subcatchments in the Gera catchment

In contrast to this discharge rates within the ‘Thuringian Forest’ adds up to 70% of the discharge (Table 2). The modeling results of the nitrogen concentration dynamics is shown in Figure 11. Obviously the general level of the prediction fits in some extend to the measured values. The prediction of the nitrogen dynamic on a daily basis is poor ($R^2 = 0.29$). This result comprises for the calibration period (1998 - 2000) a coefficient of determination of $r^2 = 0.36$ and for the validation period (1995 - 1997) $r^2 = 0.28$. Hereby it has to be marked that a comparison between sparse measured values and the modeled continuum is in general questionable. However the average modeled nitrate concentration is 20.1 mg/l

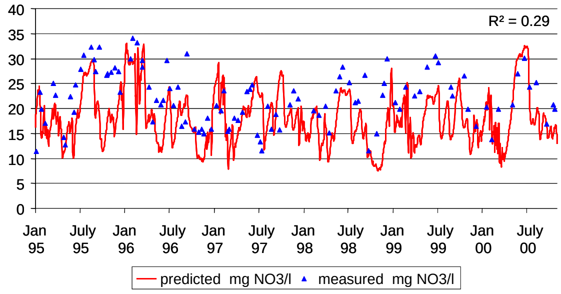

Figure 11. Predicted and measured nitrate content at the catchment outlet (Möbisburg)

and fits to the observed value of 22.1 mg/l NO_3. Thereby predicted value included additional 50000 kg N/a of the wastewater treatment plants.

The predicted distributed nitrogen load as illustrated in Figure 13 shows low values in the north with intensive fertilization applications (Figure 12) which relates to very low discharge rates (Figure 10). In contrast to this the landscape of the 'Thuringian Forest' (in the south) showed relative high loads of nitrogen (up to 20 kg/ha*a) originating from atmospheric deposition. As compared to the predicted average annual nitrate concentrations (Figure 14) a high correlation to the observed values (Figure 6) is found. Thereby high discharge rates followed from high precipitation and low evapotranspiration rates as well as high permeable soils in these areas.

Highest values of nitrogen load are in subcatchments were fertilization takes place and the discharge rates of water are significant. The leached nitrogen concentration (Figure 14) had a quite similarity to the spatial distribution of the fertilization (Figure 12). A comparison between the modeling results in Figure 13 and 14 with the results of the measurements (Figure 5) show that the measurement network is to coarse to regionalise areas releasing high amounts of nitrogen, especially in the northern parts of the

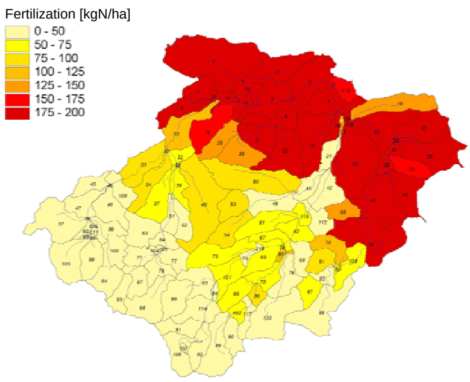

Figure 12. Parameterized average annual nitrogen input from fertilization and atmospheric deposition

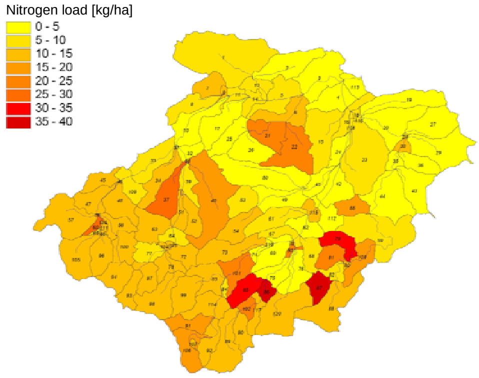

Figure 13. Predicted average annual nitrogen load leached within the derived subcatchments in the Gera catchment

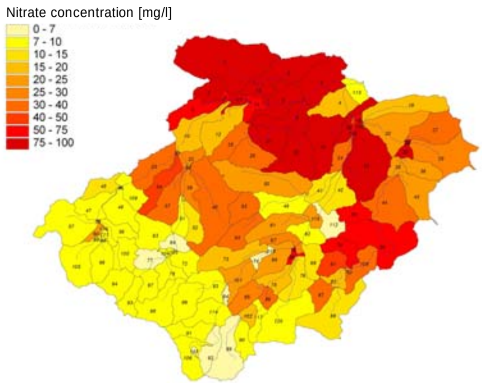

Figure 14. Predicted average annual nitrate concentrations leached by the modeled subcatchments in the Gera catchment

intensive agricultural used areas.

Especially in the northwestern part of the subcatchment (Apfelstädt) medium concentrations are indicated by the measurements (up to 15 mg/l NO_3). In contrast to this the modeling results show for the same subcatchments high amounts of nitrogen contributing to the total load as well as nitrate concentrations up to 100 mg/l NO_3. Despite of these high concentrations the total load to the Apfelstädt is related to very low discharge rates up to 100 mm/a (Figure 10).

6. CONCLUSIONS

The pilot study was attempt to proof if the goals of the European Water Framework Directive (EU-WFD) can be met by the present measuring strategies as well as available data sets and model applications for the 843 km² large heterogeneous Gera catchment. Hence the analyses of observed data indices different nitrogen pollutants which could have been mapped for different landuses but for effective implementation of *Phase II* of the EU-WFD the present water quality network has apparently to be improved due to its spatial and temporal resolution. Therefore it can be concluded that the monitoring frequency is not suitable to cover different hydrologic conditions and therefore to analyze key system properties of spatial and temporal variability of nutrient release within the catchment. Precisely that knowledge is a premise if dealing with the development and the assessment of management action plans according to the EU-WFD. Moreover the monitoring network is not capable to detect spatial relevant diffuse source of agricultural pollutant enrichments and fluxes whereas especially in the areas of intense agricultural use (Wipfra, Apfelstädt) merely one observation station exists. Particular within these areas high fertilization coupled with low discharge resulting in high nitrate concentrations within the river stretch. It is therefore suggested to expand the measuring gauges within these areas by operating on a daily timescale. This will additionally be sufficient for validation purposes of model applications.

To optimize these lacks of information the SWAT model was applied for the Gera catchment. Improvements of the simulation are directed to better modeling of karst dynamics as well as water supply routines. Additional better understanding of the model will be achieved through sensitivity analysis of significant parameters like ESCO, SOL_AWC etc.. To bridge the gap of a higher spatial resolution it is proposed to use a fully distributed hydrologic model such as J2000 (Krause 2001). Further investigations will couple this model with simulation routines of the nitrogen turnover as well as landuse management options on the base of SWAT. With respect to these further requirements of the EU-WFD, such as assessing different landuse management action plans will be met satisfactory.

ACKNOWLEDGEMENT

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