An IWRM approach in western Ukraine: Integrated eco-hydrological modeling and diffuse pollution simulation strategies.

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ABSTRACT

Pollution of surface and groundwater, due to improper land management, has become a major problem worldwide. It has been predicted that, as pollution can no longer be remedied by dilution in many countries, freshwater quality will become the principal limitation for sustainable development in these countries early in the 21st century. Therefore, there is a need to adapt land management to minimize leaching of nutrients and other chemicals. This requires the development and successful implementation of new concepts of land management.

The work presented here was carried out within the framework of the ongoing project IWAS, the "International Water Research Alliance of Saxony – Water Research in the Ukraine". Within this project a wide range of fields are investigated. The overall aim of our working group was to assess how severe the diffuse pollution has impacted the Western Bug catchment by means of spatially distributed water and matter modelling. The models resultant from the IWAS project research will be then combined and extended in order to address coupled processes in the hydrosphere in the IWAS-Toolbox. This water related research counts with studies e.g. focusing the impacts of climate change to studies focusing the modelling of urban drainage systems. In the Western Bug catchment, data insufficiency hinders the modelling process. Therefore, in this study we present a strategy to simulate long term diffuse pollution trends while dealing with the socio-economic modifications and system dynamic brought by the political turnover in 1991.

KEY WORDS: *Watershed modelling, land management, western Bug, water quality .*

INTRODUCTION

The aim of the Water Framework Directive is to achieve clean water across the European Union. Under this directive, water management is based on river basins. Some of these basins cross from the European Union to neighboring countries. The Western Bug basin is an example of it. This basin is situated in the north-west part of Ukraine, south-western Belarus and the central eastern part of Poland. The Western Bug is the second largest tributary of the Vistula which drains into the Baltic Sea. This watershed stands representative for many catchments in Central and East Europe which have gone through a political turnover. After the independence of Ukraine in 1991 the catchment experienced large societal changes (Schanze *et al.*, 2012). Due to out-of-date sewage treatment infrastructure as well as diffuse sources from agricultural activities the water resources of the Bug are currently characterized by water scarcity and remarkable water pollution (cf. Ertel *et al.*, 2012). Therefore, there is a need to adapt land management to minimize leaching of nutrients and other chemicals while taking into account the complexity of the economic, social, and ecological processes. The integrated project IWAS "International Water Research Alliance of Saxony – Water Research in the Ukraine" aims to contribute to an Integrated Water Resources Management in hydrological sensitive regions by developing specific system solutions as a response to some of the most pressing water-related problems of our time. Within the IWAS Framework the overall aim of our working group was to assess how severe the diffused pollution has impacted the Western Bug catchment by means of spatially distributed water and matter modeling. The objective of this study was to assess to applicability of the eco-hydrological SWAT model to reproduce the water balance and nitrate flux under scarce availability of input and calibration data. Subsequently, the methodology is presented as it is currently being applied to our study site.

METHODS

Study site

The Western Bug river basin is situated in the north-west part of Ukraine, south-western Belarus and the central eastern part of Poland and is within the Baltic sea catchment area. The total area of the Bug basin is 39.4 thousand km2, which is 19.3% of the Vistula basin. The total length of the river is 755 km, of which 184 km are located on Ukrainian territory and further 185 km mark the border between Ukraine and Poland (TACIS, 2001). In our work we focus on the Ukrainian part of the Bug river basin particularly in the Dobrotvir Reservoir catchment (Figure 1). The study area, covering about 3700 km2, is predominantly a wavy plain with elevations between 200–250 m, which has a hilly topography and elevations of 300–400 m at its western and southern periphery (Schanze *et al.*, 2012), a temperate continental climate with an average precipitation of 800 mm per year and an average temperature of 7.1 °C.

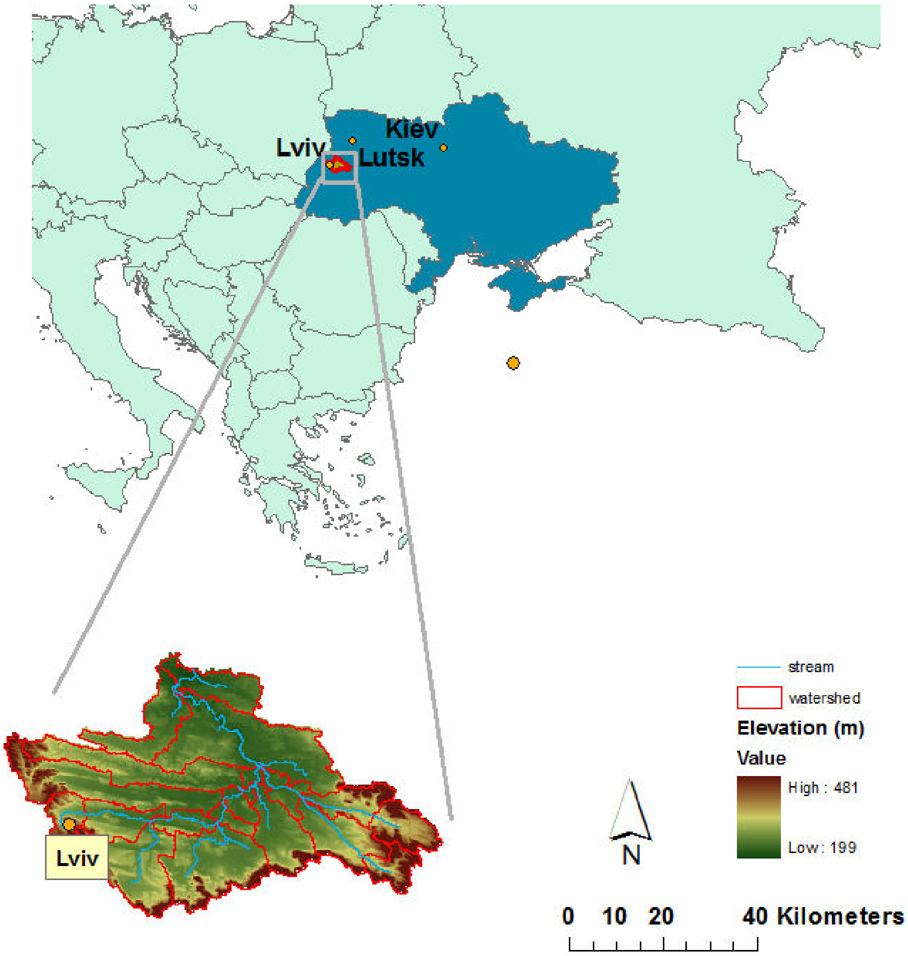

Figure 1. Dobrotvir catchment study area in Western Ukraine and watershed delineation.

Highly cracked and karsted limestone, marls and loess from the Upper Cretaceous form the hydrogeological structure of the Dobrotvir catchment (Terekhanova, 2009).

In the past, due to the presence of fertile soils, deforestation took place at large scale leading to new land use schemes where agricultural activities predominate occupying about half of the catchments area. There is one important tributary on the east, the Poltva which flows through the city of L'viv. L'viv with 3/4 million population is the biggest city within the catchment. In the study area nutrients entries, to the river systems, from agricultural activities and obsolete or overloaded waste water treatment plants (WWTPs) diminish the surface water quality. In contrast to the poor water quality status, the river's hydromorphology is of mainly good quality for large stretches (Ertel *et al.*, 2012; Scheifhacken *et al.*, 2012; Zingstra *et al.*, 2009).

Land management and diffuse pollution

Diffuse pollution and consequently water quality problems go hand by hand with the agricultural practices in Ukraine. In the former days of the Soviet Union the Ukraine with its fertile Chernozems had a high competitive grain, livestock and poultry production. Following the independence in 1991 Ukraine's agricultural sector entered a decade of decline as a result to the severe financial crisis (USDA, 2002). With the decline in consumer purchasing power and farm inputs including fuel and fertilizer (Figure 3) the agricultural production decreased. Of great importance to the water quality is the fertilizer usage. Mineral fertilizer use fell by 85% over a ten-year period after the political turnover. Furthermore, with the sharp-fall of livestock production, the availability of cattle manure was greatly reduced (FAO, 2005; Stalnacke *et al.*, 2003).

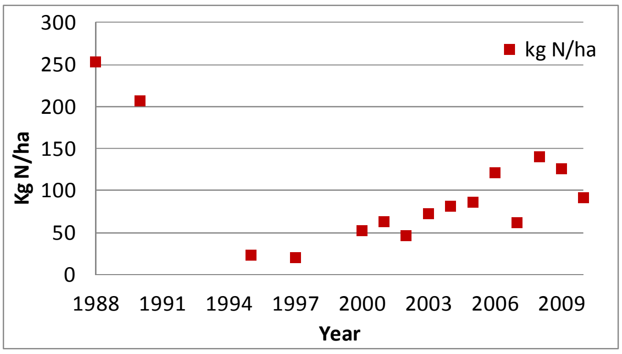

Figure 2. Mineral nitrogen fertilizer consumption on arable + permanent cropland for the time period 1988 – 2009. Source: Department of statistics for the Lviv region.

Such socio-economic modifications were observed in several other eastern European countries undergoing similar transitions during this time period by Mander *et al.* (2000) and Pekarova and Pekar (1996). These studies show that the changes brought about by the political turnover inevitably affected the nutrient export to water bodies. In the Western Bug River similar trend can be observed. After the year 2000 the reorganization of the agricultural sector took place. Farm property was divided among farm workers in the form of land shares and most new shareholder leased back their land to private agricultural associations (FAO, 2005). This resulted in a significant growth of the private sector which led to increased fertilizer usage and therefore higher nutrient exports to water bodies.

Data availability

Data availability and reliability is a major issue in the Ukraine (Blumensaat *et al.*, 2012, Tavares Wahren *et al.*, 2012). In our previous work we dealt with the difficulties brought by limited spatially distributed soil information. In this paper we evaluate the data satisfactoriness for the representation of diffuse pollution sources.

A constraint to model development and verification is that water quality and discharge data are rarely simultaneously collected in a satisfactory resolution. In fact, there are only two monitoring point (Busk and Kamianka-Buska) for which there are both daily discharge measurements and water quality measurements available. Yet, the water quality measurement were conducted only once per month to once per quarter year. Further, during the monitoring period of 1978 to 2009 there were 4 responsible institutions for the water quality measurement program. Figure 3 shows measurements of total phosphorus (mg/l) at the Kamianka-Buska outlet for the whole time period. The question arises if the development of the water quality is due to the land-use and system dynamic caused by the political turnover or if the measuring technique of each institution plays a role. Hence, as for the discharge calibration and validation of nutrient fluxes will be carried out in the period 1980 to 1990.

Integrated eco-hydrological modeling

SWAT is a basin-scale, semi-distributed, and continuous time model that operates on a daily time step. It was designed to simulate the impact of various agricultural management practices on water, sediment, and nutrients in large and complex watersheds, over long periods of time (Arnold *et al.*, 1998; Neitsch *et al.*, 2005). Main model components consist of weather, hydrology, soil temperature, plant growth, nutrients, pesticides, land management, bacteria and pathogens (Arnold *et al.*, 1998; Neitsch *et al.*, 2005; Gassman *et al.*, 2007). The majority of soil management practices can be simulated in SWAT through direct changes in parameter values (Ulrich and Volk, 2009). Many studies have used SWAT to assess the effects of land use change and management practices (Shanti *et al.*, 2001; Ulrich and Volk, 2009; Lam *et al.*, 2010). SWAT monitors five different pools of nitrogen in soils: two inorganic (ammonium, NH^{+}_{4} , and nitrate,NO^{-}_{3}) and three organic;

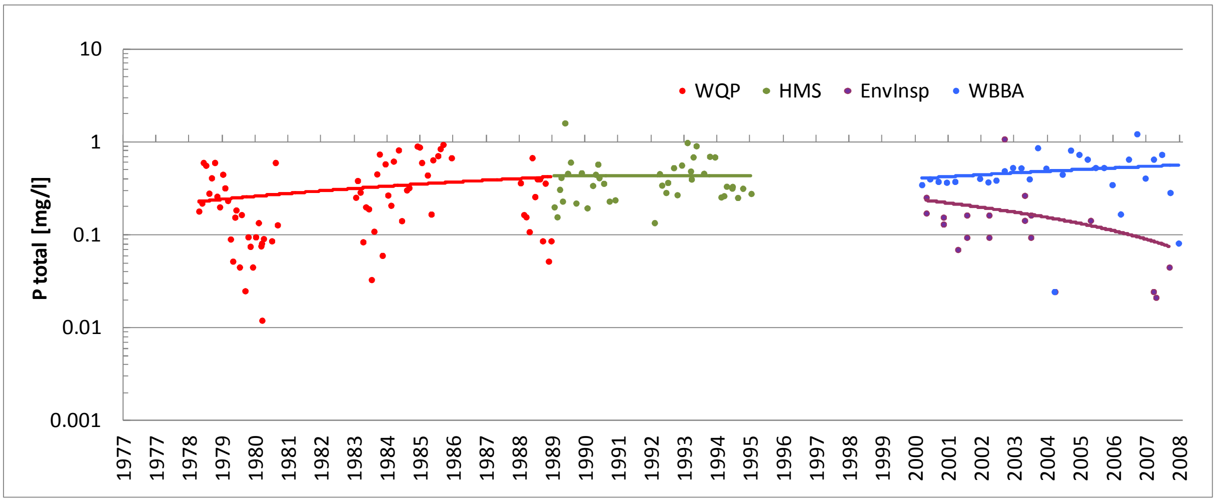

Figure 3. Time series of total phosphorus (mg/l) at the Kamianka-Buzka outlet. (Legend: WQP = Water Quality Project (monitoring campaign: 1980-1990); HMS = Hydro-Meteorological Services (monitoring campaign: 1990-1995); WBBA = Western Bug Basin Authority (monitoring campaign: 1994-2008) and EnvInsp = Environmental Inspectorate (monitoring campaign: 2001-2008)).

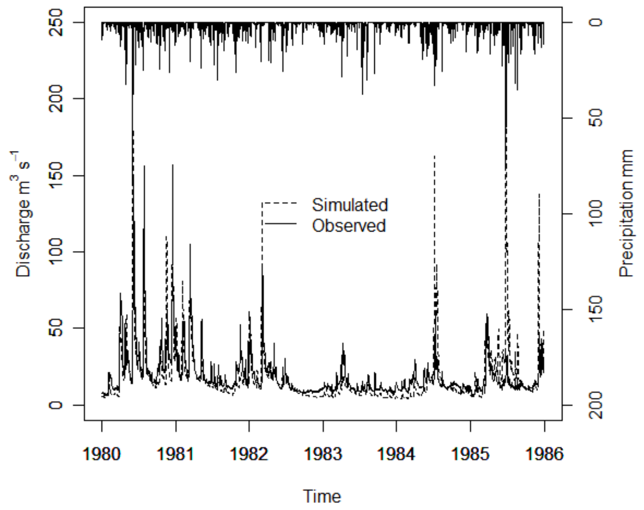

Figure 4a Comparison of daily observed and simulated discharge during the calibration (1980-1985) in the Dobrotvir catchment area at the gauge Kamianka-Buska

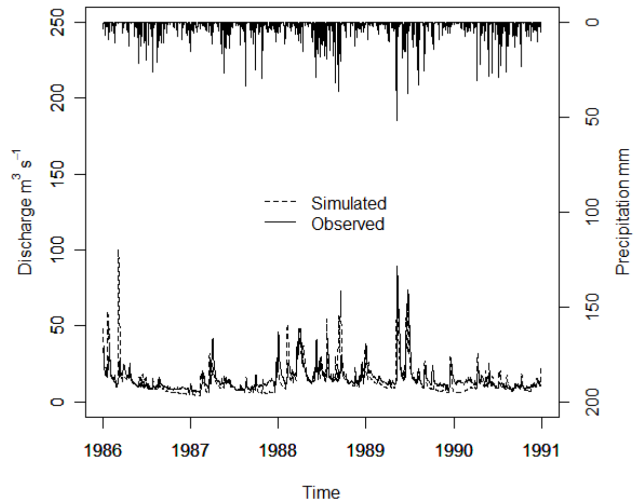

Figure 4b. Comparison of daily observed and simulated discharge during the validation period (1986-1990) in the Dobrotvir catchment area at the gauge Kamianka-Buska.

fresh organic nitrogen associated with crop residue and microbial biomass, and active and stable organic nitrogen associated with soil humus (Ulrich & Volk, 2009). Nitrogen is added to the soil through fertilizer, manure or residue application, fixation by bacteria, and precipitation (Neitsch *et al.*, 2002). Nitrogen losses occur through plant uptake, transport with surface runoff, lateral flow, percolation and with eroded sediment (Neitsch *et al.*, 2002; Ulrich & Volk, 2009). In this study, we applied ArcSWAT version 2009.93.7b in the ArcGIS (version 9.3) environment.

The Dobrotvir catchment was divided into 20 sub-basins, and calibration and validation of the water balance was conducted using data from the gauge at Kamianka-Buzka. For the period until 1991, we assumed a traditional agricultural management scheme; including corn silage, wheat, barley, sugar beet and potato cultivation. Conventional plough tillage and disk bedder operations were applied. Both daily fresh and mineral fertilizers were applied to the agricultural field according to the approach of Pospelova (1997) and Pospelova and Schinke (1997).

RESULTS

Figure 4a and 4b show the results of discharge calibration and validation respectively. Both Nash-Sutcliffe Index (NS) and Correlation Coefficient (R2) for the calibration (NS=0.46, R2=0.52) and validation (NS=0.51, R2=0.47) periods indicate a reasonable fit of water balance. The fact there is only one precipitation station inside the catchment area may be one of the motives for the low NS and R2 obtained. Strauch et al. (2012) states that spatial rainfall variability may result in added model uncertainty. The overestimation of the peaks in 1984 and 1985 may be a consequence of that. Improvement in the precipitation input data set would allow better model fit.

CONCLUSION

The SWAT model was successfully fitted to simulate runoff. Difficulties to the calibration were brought by the scarce rainfall data and the watersheds hydrogeological characteristics. In the following an improved rainfall dataset will be tested. The first nitrate simulation shows plausible load ranges and dynamic. Both further calibration as a strategy to overcome the measured data insufficiency must be further conducted. From the calibration point of view nitrate percolation and humus mineralization processes will be following target of investigation. To bridge the gap brought by the data scarcity, nutrient exports will be studied by means of a simple mass balance.

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