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SWAT Model Application for Simulating Nutrients Emission from an Agricultural Catchment in Ukraine

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Abstract

For the first time in Ukraine, a process-based watershed model SWAT was applied for the analysis of a surface water body contamination by nitrogen and phosphorus compounds. The model was applied in a small Holovesnya River Catchment (area 30.4 km^2) located in the forest zone of Ukraine on the territory of the Desna water-balance station. The model run was in daily step for years 1985–1988, 2007, 2009, 2010, 2012. The calibration and validation within SWAT-CUP showed good results for streamflow (NS, R2 > 0.6, PBIAS < 4%), acceptable for nitrogen and phosphorus loads (NS > 0.6, RSR < 0.6, PBIAS < 43%).
Streamflow and removal of nitrogen and phosphorus mineral compounds were to estimate the dependence of nutrient wash-off on the amount and practice of fertilizing were evaluated to provide recommendations for agricultural management. Increase of the amount of fertilizer results in the reduction of its efficiency. Divided application of fertilizer leads to the nitrate wash-off reduction by 66%.

Keywords: *nitrogen, phosphorus, SWAT, fertilizer, eutrophication*

Rezumat. Aplicarea modelului SWAT pentru simularea emisiilor de nutrienți într-un bazin hidrografic agricol din Ucraina

Pentru prima dată în Ucraina, o modelare SWAT a fost aplicată într-un bazin hidrografic pentru analiza contaminării unui corp de apă de suprafață, cu compuși cu azot și fosfor. Model a fost aplicat într-un bazin hidrografic mic, Holovesnya (suprafaţa de 30,4 km^2), situat în zona forestieră a Ucrainei, in teritoriul stației de pentru studiul bilanţului apei „Desna". Modelul a rulat, la pas de timp de o zi pentru anii 1985-1988, 2007, 2009, 2010, 2012. Calibrarea și validarea în cadrul SWAT-CUP, au arătat rezultate bune pentru râuri (NS, R2> 0,6, PBIAS <4%), acceptabile pentru azot și fosfor (NS> 0,6, RSR <0,6, PBIAS <43%). Curgerea și evacuarea compușilor minerali cu azot și fosfor au estimat dependența de diluția nutrienților, iar cantitatea și practica fertilizării au fost evaluate pentru a oferi recomandări managementul agricol.
Creșterea cantității de îngrășăminte determină reducerea eficienței sale. Utilizarea separată a fertilizatorilor conduce la reducerea cu 66% a îndepărtării nitraților.

Cuvinte-cheie: *azot, fosfor, SWAT, îngrășăminte, eutrofizare*

Introduction

The surface water pollution by nutrients still remains an important problem, which requires further scientific research on improving methods of the water management in river basins. As a result of excessive loads of nitrogen and phosphorus compounds into the water ecosystems the balance of the aquatic organism's development is disturbed. This leads to their excessive production, which is known as eutrophication (Dodds, 2006). Despite the significant long-term efforts of many countries eutrophication remains to be the challenge, and many water bodies are still at risk of not achieving a "good" ecological status (ETC, 2012).

The main factors causing the inflow of nutrients into water bodies are wastewater discharges of municipal, industrial, and agricultural enterprises, damming of the river flow, and uncontrolled use of fertilizers.

The European Union established the following key legislation to minimize eutrophication: the Water Framework Directive which requires the development of integrated watershed management plans based on the evaluation of their pollution, the Nitrate Directive which regulates the flow of nutrients from agricultural sources and the Directive concerning urban waste water treatment which introduces mandatory wastewater treatment for settlements with a population equivalent of more than 2,000 inhabitants. By signing the Association Agreement with the EU in 2014, Ukraine also made commitment for the implementation of the above directives. The directives are since then being actively implemented. Nutrients sources consist of municipal and industrial wastewaters (the point sources) and, water flow formed within the catchment area (the non-point or diffusion sources). Reduction of pollution from the point sources is carried out by the inventory of discharges and improvement of waste water treatment methods. Evaluation of pollution from the non-point sources is a more complex task which solved mainly by modeling. Sequential commissioning of sewage treatment plants in the settlements with population over 2000 led to a significant reduction of the pressure on aquatic ecosystems in most EU countries.

However, the water pollution by nutrients is still high. This is associated with very little progress in the control of pollution from the non-point sources. As indicated by the European Environmental Agency (EEA, 2015), food consumption will demand even

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greater intensification of the agricultural production, which will result in the increased use of fertilizers. At present, 46% of the nitrogen compounds and 28% of the phosphorus compounds in the Danube river basin come from agricultural production (ICPDR, 2015).

Ukraine is an agricultural country. The agricultural sector is among the leading sectors in the economy of the country and arable lands cover about 70% of the territory. This is an important factor contributing to a significant impact on surface and ground waters. At the same time, the data to carry out an analysis of the national river systems is insufficient. The state system of monitoring of surface water bodies is outdated, has an inadequate spatial coverage and an insufficient sampling frequency of water quality. Many potential areas of contamination are not investigated at all. In this regard, Ukraine faced an urgent need for the development or implementation of existing instruments to assess the input of nutrients from diffusion sources.

Mathematical modeling is commonly used worldwide to solve this task. The number of models based on different principles has already reached more than seven dozens (EPA, 2005). Three models are commonly used in Europe: the conceptual MONERIS and GREEN models and the, process-based SWAT model. Comparative analysis of the approaches used by different models showed that the results do not significantly differ (Malago et al., 2015).

The analysis of publications showed that the SWAT is worldwide the most frequently used the tool for modeling of the nutrient pollution (Wellen et al., 2015). The inputs required by the model are available also in Ukraine from the Ukrainian national monitoring system. For these reasons, we have decided to test model performance in Ukraine.

The objectives of this work were to apply the model in simulation of streamflow, nitrogen, and phosphorus concentrations in runoff from a small catchment and elaborate recommendations for fertilizers use.

Materials and methods

Study area

The Holovesnya River Catchment with area of 30.4 km^2 is situated in the Northern Ukraine on the south-western spurs of the Central Russian Upland. The surface area has an undulating terrain; the elevation varies between 69–199 m a.s.l. (Fig. 1, A).

The river has a length of 6.3 km and a mean slope around 0.3%. The average annual precipitation is relatively high (670 mm) for the north-east part of Ukraine. The annual runoff distribution is characterized by a sharp spring maximum which represents 20 to 40% of the total annual runoff, and summer-autumn and winter low flows, which are often interrupted by runoff events caused by rainfalls.

The catchment is located in a mixed forest zone. About 48% of its area is cultivated while the rest is covered by the forest (35%) with a dominance of oak and pine, meadows (13%), orchard (2%), water (1%), buildings (0.7%) and roads (0.2%) (Fig. 1, B). Every year over 50% of cultivated lands was accounted for winter wheat; the rest was accounted for barley, oats, and corn (CGO, 1983-2013).

There are three types of soils according to the former USSR 1977 (Egorov et al., 1977) and FAO (FAO, 1998) classification there: the Dark-grey forest soil (Haplic Greyzems) (54.2%), the Grey forest soil (Haplic Greyzems) (40.2%), and Chernozems podzolized soil (Luvic Phaeozems) (5.6%) (Fig. 1, C) (SSUGCC, 2016).

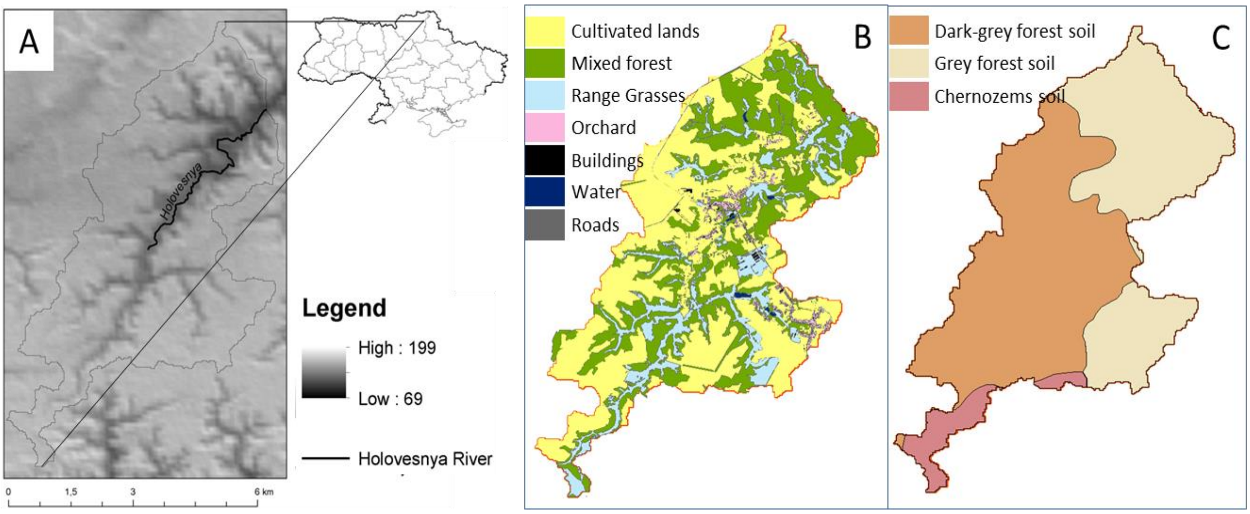

Fig. 1: Topography (m a.s.l.) (A), land cover (B), and soils of the Holovesnya River Catchment (C) Source data: CIGAR, Google Maps, SSUGCC

Data set

The U-notch water level recorder is installed at catchment outlet. Precipitation (6 points), air temperature, humidity, wind speed and, solar radiation are measured in the catchment since 1956, but there are breaks in the data series (CGO, 1983-2013). Samples for water chemistry were collected 9–16 times per year in period 1985-1989 and 4 times per year in period 2007-2012.

The digital maps with resolution 90 m are used for the work (CGIAR, 2013). The land use was digitized from the Google Map satellite image. Map of soil types was taken from the public cadastral map of Ukraine (ETC/ICM, 2012).

SWAT model

SWAT is a process-based, continuous time model. It was developed to predict the impact of land management practices on the water, sediment, and chemical yields in complex catchments with varying soils, land use and management conditions over long periods of time (Arnold et al., 1998). The user has an opportunity to specify agricultural management practices including a detailed agricultural land planting, tillage, irrigation, fertilization, grazing, and harvest procedures (Arnold et al., 2011).

SWAT divides a catchment into Hydrologic Response Units (HRUs). HRU is a unique combination of slope, soil, and land use. SWAT simulates hydrology, a vegetation growth, and management practices at the HRU level. Water, nutrients, sediment, and other pollutants from each HRU are routed through the stream network to the catchment outlet. SWAT was first used to simulate the nutrients loads in the stream. Then, effect of fertilizer application was studied. In this study cultivated lands specified as AGRC (Agricultural land close-grown crops), crops that are generally drill-seeded or broadcast, such as wheat, oats, rice, barley, and flax. For this land cover SWAT inputs plant growth values used for winter wheat (Arnold et al., 2011).

Model calibration procedures

The daily data of streamflow runoff was analyzed from 1983 till 2013, except 1992, when the observations were missing. The average annual values of runoff were characterized by a falling trend (Fig. 2, up). On the other hand, the corresponding trends for total annual precipitations were not found (Fig 2, down).

The closer look showed that the runoff coefficient has a tendency to reduce for the snowmelt-discharge and the precipitation-discharge relations, especially last 7 years. The reason for these changes is a topic for another study. But in general the long-term fluctuations in the water flow are a widely known phenomenon caused by climatic and/or anthropogenic factors (Szolgayova et al., 2014). For example, long-term monitoring (20 years) of water permeability have shown that multiple passes of the truck reduces the permeability by 60%, the use of mineral fertilizers in high doses by 7%, irrigation by 24% with respect to the plowed etalon (Medvedev, 2012; p. 172). Therefore, two periods "past" (1985–1988) and "previous" (2007–2012), characterizing different hydrological conditions were selected for modeling.

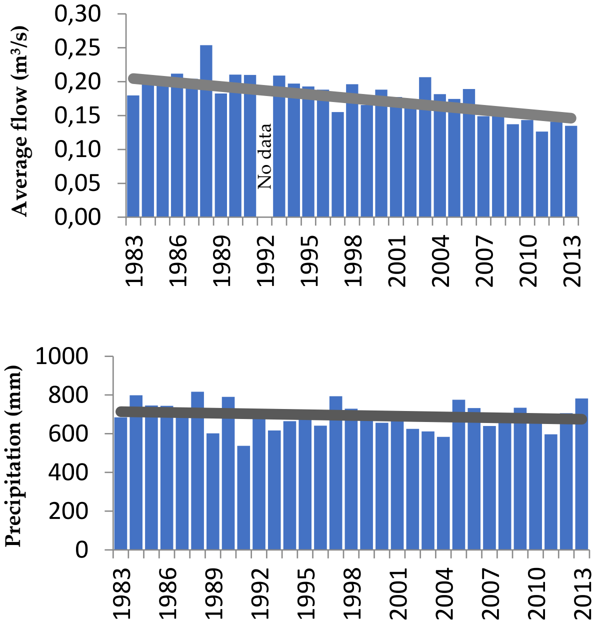

Fig. 2: Average daily runoff values (A up) and total annual precipitation (B down)

The SWAT was calibrated against measured runoff, nitrate, and phosphorus data using the Sequential Uncertainty Fitting (SUFI-2) algorithm available in SWAT-CUP (Abbaspour, 2007). The model was first calibrated to the runoff data. Then, the calibration for nitrate and mineral phosphorus compound loads was carried out. The sensitivity analysis was used to identify the insensitive parameters. Further calibration was carried out only with sensitive parameters.

Hence, 18, 7 and 5 parameters were used for runoff, nitrate and phosphorus calibration, respectively. The selected parameters and their ranges are shown in Table 1.

Efficiency criteria

The Nash–Sutcliffe coefficient (NS), coefficient of determination (R^2), percentage of bias (PBIAS) and

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the RMSE-observation standard deviation ratio (RSR) were used to assess the model performance.

The NS coefficient is a normalized statistical value which indicates the relative value of a residual variance as compared to a measured value variance (Nash and Sutcliffe, 1970).

$$NS = 1 - \frac{\sum_i (Q_o - Q_s)_i^2}{\sum_i (Q_{o,i} - \overline{Q}_o)^2} \quad (1)$$

where: Q_o and Q_s are observed and simulated values respectively, $\overline{Q}_o$ - mean observed values; NS varies from -∞ to 1 (1 indicates a perfect fit for observed/calibration values).

Table 1: List of SWAT's calibration parameters and their ranges and fitted values for "past" (1985–1988) and "previous" (2007–2012) period

Variable	Definition	Min value	Max value	1985–1988 value	2007–2012 value
ALPHA_BF	Base flow alpha factor (1/day)	0	1	0.0029	0.0018
RCHRG_DP	Deep aquifer percolation fraction	0	1	0.4	0.52
GW_DELAY	Groundwater delay (days)	0	500	9	12
CN2_AGRC	SCS runoff curve number for crop-lands	35	98	75.8	66
CN2_FRST	SCS runoff curve number for forest	35	98	59.2	55.7
CN2_RNGE	SCS runoff curve number for grasses	35	98	78.3	62.8
CNCOEF	Plant evapotranspiration CN coefficient	0.5	2	0.82	0.76
SOL_AWC	Available water capacity of the soil layer, mm H_20/mm soil	0	1	0.13	0.106
SOL_K_AGRC	Saturated hydraulic conductivity for crop-lands, mm/hr	0	2000	139	107
SOL_K_FRST	Saturated hydraulic conductivity for forest, mm/hr	0	2000	157	165
SFTMP	Snowfall temperature, °C	-5	5	0.43	0.27
SMTMP	Snow melt base temperature, °C	-5	5	0.47	0
SMFMX	Maximum melt rate for snow during year, mm H_2O/°C-day	0	20	2.57	1.27
SMFMN	Minimum melt rate for snow during the year, mm H_2O/°C-day	0	20	0.64	4.92
TIMP	Snow pack temperature lag factor	0	1	0.63	0.73
SURLAG	Surface runoff lag time	0.05	24	3.5	2
ESCO	Soil evaporation compensation factor	0	1	0.7	0.8
EPCO	Plant uptake compensation factor	0	1	0.35	0.42
Parameters sensitive to nitrate only					
RCN	Concentration of nitrogen in rainfall, $mg \cdot NL^{-1}$	0	15	1.3/0.15	0.2
CDN	Denitrification exponential rate coefficient	0	3	2.61	
SDNCO	Denitrification threshold water content	0	1	0.995	
NPERCO	Nitrogen percolation coefficient	0	1	0.3	
ANION_EXCL	Fraction of porosity (void space) from which anions are excluded	0.01	1	0.144	
CMN	Rate factor for humus mineralization of active organic nitrogen	0.001	0.003	0.1	
N_UPDIS	Nitrogen uptake distribution parameter	0	100	81	
Parameters sensitive to mineral phosphorus only					
PHOSKD	Phosphorus soil partitioning coefficient	100	200	128	
ERORGP	Organic P enrichment ratio	0	5	4.24	
SOL_SOLP_AGRC	Initial labile P concentration in surface soil layer for crop-lands, $mgP \cdot kg^{-1}$	0	100	8.5	
SOL_SOLP_FRST	Initial labile P concentration in surface soil layer for forest, $mgP \cdot kg^{-1}$	0	100	1.1	
P_UPDIS	Phosphorus uptake distribution parameter	0	100	72	

The coefficient of determination is calculated as:

$$R^2 = \frac{\left[\sum_i (Q_{o,i} - \overline{Q}_o)(Q_{s,i} - \overline{Q}_s\right]^2}{\sum_i (Q_{o,i} - \overline{Q}_o)^2 \sum_i (Q_{s,i} - \overline{Q}_s)^2} \quad (2)$$

where: Q_o and Q_s are observed and simulated values respectively. R ranges from 0 to 1, the closer the value to 1, the smaller the error is.

Percent bias (PBIAS) shows the mean inclination for simulated values is greater or lower than observed values (Gupta et al., 2013). PBIAS is similar to a percent streamflow volume error (PVE), a prediction error (PE), a percent deviation of streamflow volume (D_v), which are also used in international publications. Positive values indicate that simulated variable is underestimated and vice versa. The optimal value of PBIAS is 0. It is calculated as:

$$PBIAS = \frac{\sum_{i=1}^{n} (Q_o - Q_s)_i}{\sum_{i=1}^{n} Q_{o,i}} \cdot 100 \quad (3)$$

where: Q_o and Q_s – are observed and simulated values respectively.

RMSE-observation standard deviation ratio (RSR) labels the ratio of the deviation of simulated values against observed values. It is calculated as:

$$RSR = \frac{\sqrt{\sum_i^n (Q_o - Q_s)_i^2}}{\sqrt{\sum_i^n (Q_{o,i} - \overline{Q}_o)^2}} \quad (4)$$

where Q_o and Q_s are observed and simulated values, respectively; RSR varies from 0 to +∞, the closer the value to 0, the smaller the error.

The selection of these criteria is determined by their widespread use and therefore by the possibility of comparing the results obtained with other studies. NS and PBIAS are also recommended by the ASCE (American Society of Civil Engineers) (ASCE, 1993). The general performance ratings for the above criteria are shown in Table 2.

Table 2: General performance ratings for criteria ASCE (1993) and Moriasi et al. (2007)

Performance rating	NS & R^2	PBIAS, % (streamflow)	PBIAS, % (nitrogen, phosphorus)	RMSE (RSR)
Very good	0.75<NS≤1	PBIAS±10	PBIAS±25	0<RSR≤0.5
Good	0.65<NS≤0.75	±10≤PBIAS<±15	±25≤PBIAS<±40	0.5<RSR≤0.6
Satisfactory	0.5<NS≤0.65	±15≤PBIAS<±25	±40≤PBIAS<±70	0.6<RSR≤0.7
Unsatisfactory	NS≤0.5	PBIAS≥±25	PBIAS≥±70	RSR>0.7

Note: NS = Nash–Sutcliffe coefficient; R^2 = coefficient of determination; PBIAS = percentage of bias; RMSE (RSR) = observation standard deviation ratio

Results and discussions

Streamflow calibration

For the "past" period the SWAT model was calibrated with daily step for period 1985-1986 (Fig. 3, A) and validated for 1987-1988 (Fig. 3, B). For the "previous" period the calibration was carried out for 2007 and 2009 (Fig. 3, C), the validation for 2010 and 2012 (Fig. 3, D). 2008 was excluded because of missing a daily minimum and maximum temperature during the snowmelt period. The snowmelt modeling is very sensitive and a daily average temperature is not enough. The ice jam in 2011 contributed unpredictable changes to the hydrograph, therefore it was also excluded. The calibration parameters corresponding to the best iteration are shown in Table 1. According to the common performance ratings of calibration/validation efficiency (Table 2), the calibration showed a good result for both periods. The validation results are lower but still satisfactory (Table 3).

The calibration efficiency primarily depends on the accuracy of seasonal maximum modeling. In our case, it's a period of a spring flood. At the same time, it is the most difficult period for the simulation, due to some additional uncertainties associated with a snowmelt process: sleet, the ratio of a soil freezing, a rain influence on snowmelt.

Nitrate and mineral phosphorus loads

Comparison of simulated and measured nitrogen and phosphorus loads is shown in Fig. 4. Model parameters for nitrogen and phosphorus simulations

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obtained from the calibration period remained constant throughout the whole observation period (1983–2012) except for the parameter giving nitrogen concentration in precipitations (Table 3).

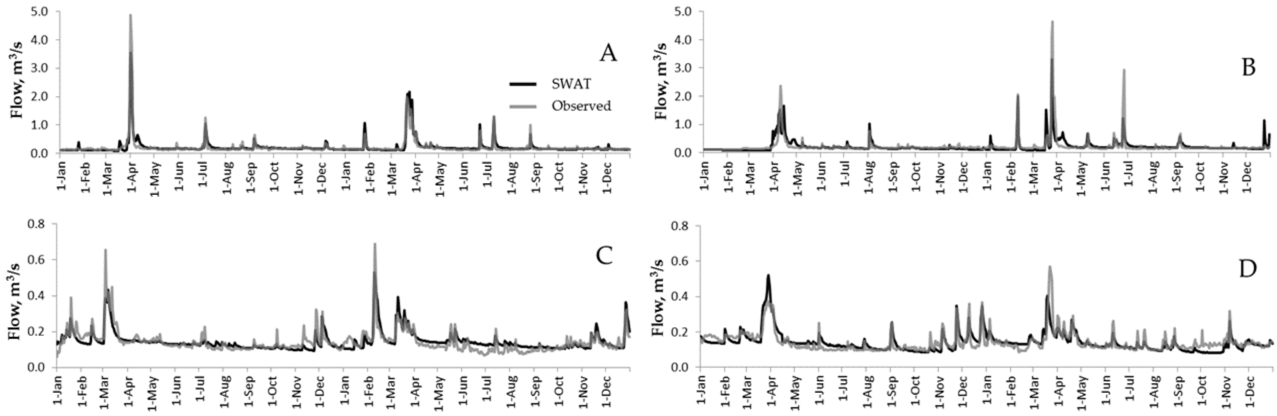

Fig. 3: Daily streamflow (A) calibration (1985-1986) and (B) validation (1987-1988) for the "past" period and (C) calibration (2007 and 2009) and (D) validation (2010 and 2012) for the "previous" period

Table 3: Goodness-of-fit criteria for daily streamflow calibration/validation

Criteria	C 1985–1986	V 1987–1988	C 2007, 2009	V 2010, 2012
NS	0.86	0.6	0.68	0.6
R^2	0.87	0.6	0.68	0.63
PBIAS	-4	1.5	2.2	0.5

Note: NS = Nash–Sutcliffe coefficient; R^2 = coefficient of determination; PBIAS = percentage of bias; C = Calibration; V = Validation

Validation of simulated nitrate loads was carried out for years 1987 and 1989 (1988 was excluded because of the absence of observations during a spring flood) as well as for years 2007 and 2009 (Fig. 5, A). The validation of mineral phosphorus loads was carried out for a 1987–1988 period (Fig. 5, B).

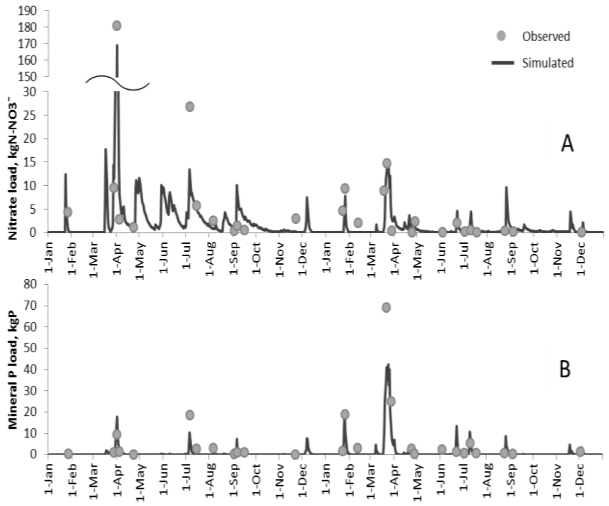

Fig. 4: (A) N-NO_3^- and (B) mineral P calibration for the period from 1985 to 1986

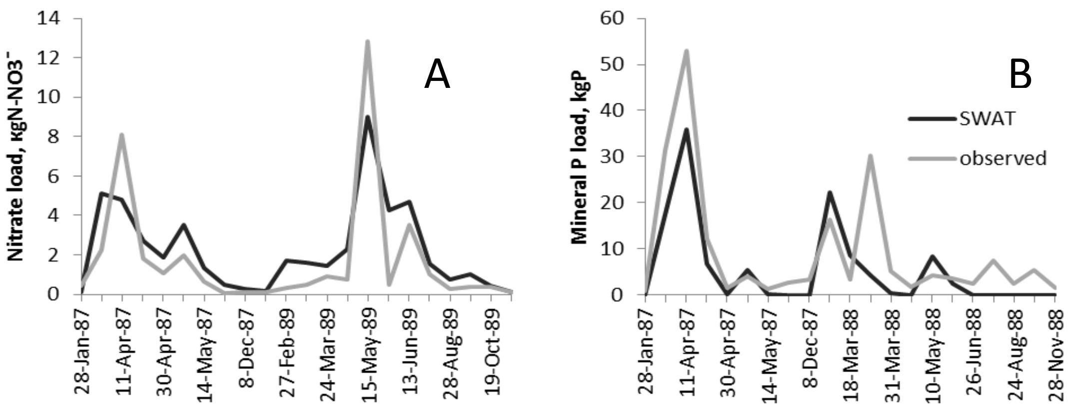

Fig. 5: N-NO_3^- validation for years 1987 and 1989 (A) and mineral P validation (B) for the period from 1987 to 1988

Results of nitrate and phosphorus simulations during calibration and validation periods are shown in Table 4. Phosphorus simulation in the validation period was lower, but still satisfactory (Table 4). NS and R^2 are more sensitive to high values than RSR. Therefore, RSR is included to assess the calibration efficiency since NS and R^2 overestimate the results (NS=0.97) not taking into account differences in the field of small values.

During the year, the first significant input of nitrates to the river is observed at a spring flood period due to their accumulation in the snow cover in winter. The peak value depends on the $N\text{-}NO_3^-$ concentration in precipitation which is accumulated in the snow cover. The nearest meteorological station where the observations of this parameter were carried out is situated at 60 km east from the catchment. The data shows that the concentration of $N\text{-}NO_3^-$ ranges from 0.1 to 1.5 $mg \cdot L^{-1}$ and may significantly vary from month to month. That is the reason of the significant difference between the nitrate removal during the floods in 1985 and 1986. It was found through the calibration that the average concentration of $N\text{-}NO_3^-$ in precipitation is 1.29 $mg \cdot L^{-1}$ in 1985 and 0.16 $mg \cdot L^{-1}$ in 1986. In 1985 crop lands were fertilized by mineral nitrogen during planting, the third decade of April.

Table 4: Goodness-of-fit criteria for nitrates and mineral phosphorus calibration/validation

Criteria	Nitrates			Mineral Phosphorus	
	C	V		C	V
	1985–1986	1987, 1989	2007, 2009	1985–1986	1987–1988
NS	0.97	0.69	0.71	0.73	0.6
RSR	0.15	0.56	0.54	0.52	0.63
PBIAS	10.2	-29.3	10.4	21	42.5

Note: NS = Nash–Sutcliffe coefficient; RSR = standard deviation ratio; PBIAS = percentage of bias; C = Calibration; V = Validation

The exact amount of fertilizers is not known therefore a standard recommended value for this type of soil - 200kg $N\text{-}NO_3^-$ ha^{-1} is conditionally accepted (Marchuk et al., 2010). All the nitrate compounds have a high solubility in water and are practically not subjected to the sorption. In this regard, they are almost entirely washed off by precipitation within three months after the application of fertilizers. In 1986 nitrogen fertilizers were not used. Therefore, the nitrate wash off in May to July was low compared to 1985 and caused only by flash floods.

Unlike nitrate, phosphorus compounds have high adsorption properties and a low mobility and are washed off only during high-runoff events. That is why phosphorus fertilizers applied at planting in the third decade of April in 1985 are mainly observed in the streamflow during the spring flood in 1986. The estimated amount of phosphorus fertilization was also taken as recommended norm (200kg $P \cdot ha^{-1}$).

As opposed to past years, the precipitation has smaller influence on nutrients inputs to the rivers for two reasons.

Firstly, the emissions decreased after the Soviet Union collapse. Present concentration of $N\text{-}NO_3^-$ in precipitation rarely exceeds 0.8 $mg \cdot L^{-1}$. Secondly, the proportion of the precipitation flowing into the mainstream with a surface runoff decreased, presumably due to higher average temperature recent years (e.g., higher evapotranspiration). According to the estimates of many studies the main cause of nitrate pollution is currently application of fertilizers. Therefore, we studied fertilizing more detailed through the example of the application of nitrate fertilizers on AGRC.

Influence of fertilizer application on nutrient loads in river systems

Figure 6 shows the SWAT model results of AGRC fertilization. Sequential increase of the fertilizer amount (kg $N\text{-}NO_3^-$ ha^{-1}) is not proportionally related to an increase in the crop yield. The rate of a crop yield increase goes down (curve A) while the proportion of non-production losses increases which is reflected in the loads of nitrate into the stream (curve B). Without the fertilizer application, the calculated crop yield would be 0.82 ton ha^{-1}.

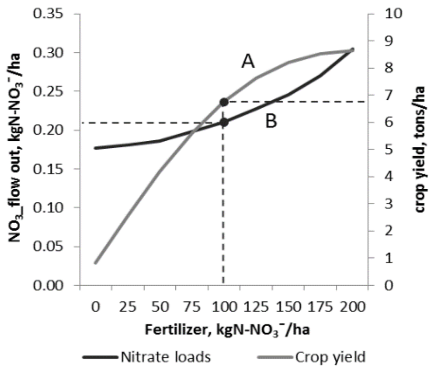

Fig. 6: Crop yield (A) and $N\text{-}NO_3^-$ load (B) relationship simulated in SWAT

Fertilization using 100 kg $N\text{-}NO_3^-$ ha^{-1} will result in the crop yield increase to 6.75 ton ha^{-1}. Accordingly, the crop gain would equal 5.93 ton ha^{-1}. Further increase of the fertilizer to 200 kg $N\text{-}NO_3^-$ ha^{-1} would lead to a crop yield of 8.66 ton ha^{-1}; the crop gain will equal 7.84 ton ha^{-1}. Hence, doubling the fertilizer amount increases the crop yield only 1.28 times. Without application of fertilizers the loads of nitrate into the stream would amount to 0.176 kg $N\text{-}NO_3^-$ ha^{-1}. If fertilizer amount is 100 kg $N\text{-}NO_3^-$ ha^{-1}, nitrate wash-off would increase only by 19%. However, increase of the fertilizer amount to 200 kg $N\text{-}NO_3^-$ ha^{-1} would result in the nitrate load

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gain 73%. This example shows that by reduction of fertilizer amount from 200 to 100 kg $N\text{-}NO_3^-$ ha^{-1} it is possible to reduce the wash-off of nitrates significantly while the crop yield would not significantly decrease. This practice may be appropriate in the areas vulnerable to nitrate pollution.

Further reduction of nitrate loads can be achieved through the practice of a split fertilizer application during the first month of the crop growth. Consider as an example the split-application of environmentally reasonable fertilizer amount of 100 kg $N\text{-}NO_3^-$ ha^{-1} for 2007 year, which has similar hydrological regime with the present conditions. Division of the fertilizer amount of 100kg $N\text{-}NO_3^-$ ha^{-1} into two equal parts reduces the nitrate wash-off during the growth period (April–August) by 33% (Fig. 7, B). Division of the same amount of fertilizer to three and four applications leads to the nitrate was-off reductions 52% and 66%, respectively (Fig. 7, C, and D). Application of the same fertilizer amount over a longer period leads to a slight reduction of the crop yield and slight increase in the nitrate load (Fig. 7, F).

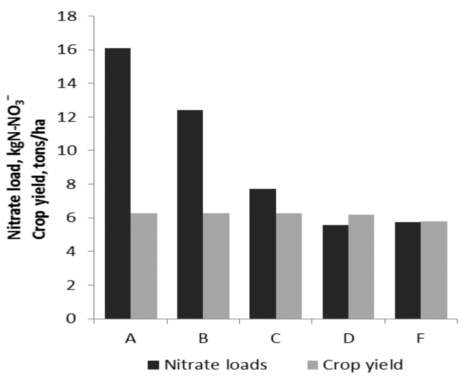

Fig. 7: Influence of divided application of the same amount of fertilizer on nitrate loads (April-August) and a crop yields (A – 1 application in a month; B – 2 applications; C – 3 applications; D – 4 applications in a month; F – 4 applications in 40 days)

Field experiments in Ukraine of divided nitrogen application focused on assessing the economic impact (kg crop yield/kgN fertilizer) (Nosko, 2013, p. 86-87). The positive effect is greater for soils with low reserves of mineral nitrogen and for areas with high precipitation, compared with the average value in Ukraine (e.g., western forest-steppe). The influence of divided nitrogen application on fertilizer loss or nitrogen loads in the stream wasn't assessed, because it's difficult to measure in practice and such goal wasn't placed before.

The choice of the crop also has an influence on the nitrate removal. The most positive effect is observed in case of winter crops. It is most likely due to an earlier development and accordingly a longer period of a culture growth (Fig. 8). Analysis of other studies in Ukraine shows that, in general, the nitrogen consumption for crops ranges: winter wheat > spring cereals, potato > corn, sunflower (Nosko, 2013, p. 105).

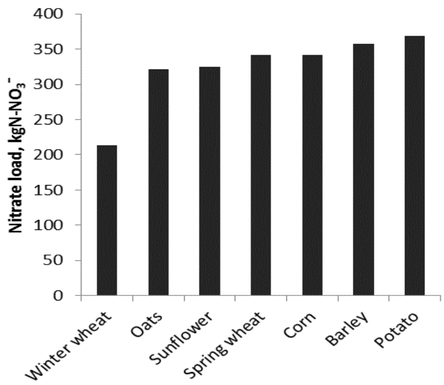

Fig. 8: $N\text{-}NO_3^-$ load – crop type relationship for one year simulated in SWAT

Conclusion

We have conducted the analysis of nutrient loads to the river from the non-point sources in the small agricultural Holovesnya catchment by means of hydrological process-based SWAT model.

The model well simulated catchment runoff although the simulation in the validation period was worse than in the calibration period. Acceptable results were achieved also for nitrogen and phosphorus loads. Small number of water quality observations during the year hampers a more detailed evaluation of model performance.

The nature of nitrate and phosphorus leaching has different characteristics due to the physicochemical properties of these compounds. Nitrate compounds are washed off during the first months after the fertilizer application because of their high solubility. Mineral phosphorus compounds are well kept in the soil due to the high absorption and enter the stream network only during heavy rains and especially during spring floods.

A more detailed analysis of the nitrate fertilizer with the help of the SWAT model has shown that increase of the amount of fertilizer results in the reduction of its efficiency. The rate of a crop yield gain reduces but the proportion of the washed off fertilizers increases. Divided application of fertilizer has a positive effect during the month after planting. Winter crops reduce nitrate loads into the streams more effectively than other crops because of longer period of the growth.

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