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ESTIMATION OF NUTRIENT CONCENTRATIONS IN RUNOFF FROM AN AGRICULTURAL WATERSHED

INTRODUCTION

Surface waters remain still one of the most polluted elements of environment in Poland. This situation is the consequence of emission of large quantities of pollutants, including those, which originate from sewage waste inflow, and runoff from agricultural areas. Runoff from agricultural areas usually increases the amount of nitrogen compounds, while sewage inflow — the amount of phosphorus in the outflow. The resulting runoff can bring about eutrophication of waters and stimulate growth of autotrophic organisms. Concentrations of substances dissolved in surface waters are often subject to seasonal variations, increasing during high discharges, when a more intensive supply of material washed out from the watershed is taking place.

The present report concerns the estimation of concentrations of nutrient substances in surface waters of the watershed of Bełdówka (left confluent of the river Ner, in the basin of Warta river). The watershed of Bełdówka, with surface area of 160 sq. km, is under agricultural use. The watershed is covered by the glacial accumulation material, with well-permeable sands dominating on the surface, and only marginal parts of the watershed being covered by poorly-permeable forms. The potential pollution sources are constituted by cultivated fields and a small number of dispersed point sources from rural settlements. The pollutants in question are almost uniquely the nutrient substances, without any significant concentrations of heavy metals.

The Agricultural Non-Point Source Pollution Model (AGNPS Model), see Young et al. (1994), has been used to evaluate nutrient concentrations in river runoff from the watershed of Bełdówka. Simulation computations were carried out of the supply of nutrient substances from the watershed to surface waters in four variants. Different assumptions were made concerning precipitation and fertiliser use in the watershed.

The AGNPS model establishes the conditions for the evaluation of quantity and concentration of substances brought out of the watershed, including compounds of nitrogen, phosphorus, and the eroded material. It is a model with spatially distributed parameters. The quantitative and qualitative characteristics of river runoff are calculated within each element of the assumed calculation grid and at the watershed outflow node. Application of the AGNPS model requires carrying out of the analysis of physico-geographical parameters of the watershed, usually assessed with the use of the GIS methods (Fig. 1). The values of concentrations of the nitrogen and phosphorus compounds, obtained from the AGNPS model, were compared with the ones registered in the field. The estimation of the physico-geographical parameters of the watershed was done with the help of a digital model of the area, as well as the digital maps of the river network, soils, and land use, elaborated in the IDRISI for Windows software.

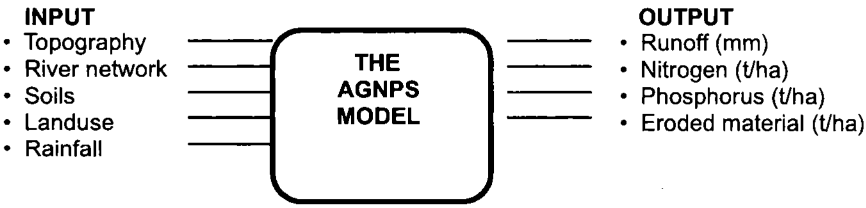

Fig. 1. Input and output elements of the AGNPS model.

THE AGNPS MODEL AND ITS STRUCTURE

The main calculation algorithms, which are included in the AGNPS model, correspond to the respective hydrological, erosion, and quality procedures (Young et al., 1989, 1994).

HYDROLOGY

The hydrological procedure makes it possible to determine the effective precipitation with the SCS method, as well as the peak runoff rate. The peak runoff rate is estimated using the following empirical equation:

$$Q_p = 3.79^{0.7} CS^{0.16} (RO/25.4)^{(0.903A \cdot 0.017)} LW^{-0.19}$$

where: A — drainage area in sq. km, CS — river channel slope in metres per km, RO — the surface runoff volume expressed in mm, LW — the watershed length-to-width ratio.

EROSION AND SEDIMENT TRANSPORT

Soil losses are calculated according to the universal soil loss equation, USLE, of the following form:

$$SL = EI \cdot K \cdot L \cdot S \cdot C \cdot P \cdot SSF$$

where: SL — the soil loss, EI — the erosive rainfall energy intensity, K —

the soil erodibility factor, L — the slope length factor, S — the slope steepness factor, C — the land cover and management factor, P — the support practice factor, and SSF — the slope shape factor. A detailed consideration of the quantities appearing in the equation can be found in Polish literature of the subject (Banasik, 1994).

CHEMICAL TRANSPORT

The chemical transport part of the model allows the estimation of concentrations of the general nitrogen and phosphorus in two forms: as the compounds contained in the soil brought out of the watershed, and as the substances dissolved in water.

Nutrient yield in the sediment-absorbed phase is calculated from the equation:

$$N_{ut-sed} = N_{ut-f} Q_s(x) E_R$$

where: N_{ut-sed} — the quantity of N or P transported in the sediment out of the watershed, N_{ut-f} — the N or P content remaining in the field soil, $Q_s(x)$ — the sediment load, E_R — the enrichment ratio. The loads of the soluble nutrients contained in runoff are estimated in accordance with the following relation:

$$N_{ut-sol} = C_{nut} N_{ut-ext} Q$$

where: N_{ut-sol} — the concentration of soluble compounds of N or P in the runoff, C_{nut} — the mean concentration of soluble N or P compounds in the surface layer of the soil during runoff episode considered, N_{ut-ext} — an extraction coefficient of N or P for movement into runoff, Q — runoff volume.

Tables 1 and 2 list the most important input and output parameters of the AGNPS model.

RESULTS OF THE SIMULATION CALCULATIONS

The analysis here reported was applied to the high discharges appearing in the watershed of Bełdówka at the Kałów control point in the years 1995/96 and 1996/97 and to their quality in terms of amounts and concentrations of nitrogen and phosphorus.

Figures 2 and 3 present the daily precipitation totals for the weather station of Puczniew, and the daily discharges of Bełdówka river at Kałów observed in 1995/96 and 1996/97. Particularly high precipitation occurred during summer months, when maximum daily precipitation totals ranged between 10 and 30 mm. These periods of intensive precipitation correspond to the registered peak discharges, reaching in the summer season the flow intensities of 0.6–1 cu.m per second. These values are daily averages, with instantaneous flow intensities reaching most probably much higher values.

Table 1.

Main input parameters of the AGNPS model

Topography:	Average land slope Average field slope length Slope shape factor Runoff direction
Soils:	Soil texture Erodibility factor Fertiliser use factor
Channel network:	Total network length Average channel slope Average channel side gradient Mannings' roughness coefficient for the channel
Land use:	Surface condition constant The SCS curve number Cropping factor Support practice factor
Rainfall:	Duration Intensity

Table 2.

Main output quantities of the AGNPS model

Hydrological output:	Runoff volume Peak runoff rate
Chemical output (nitrogen and phosphorus in suspended and dissolved matter):	Mass (kg/hectare) Concentration (ppm)

Average daily discharges in the spring season can even exceed 1 cu.m per second, but this is clearly dependent upon the nature of supply. Thus, in the winter season of 1994/95 the watershed was supplied with much more intensive precipitation in comparison with the same period of the year 1995/96, which found its reflection in a different character of runoff. During the winter months of 1994/95 discharges stabilised at the level of 0.5–1 cu.m per second, while in 1995/96 they oscillated around the values of 0.2–0.4 cu.m per second. It should also be mentioned that the discharges registered at Kalów remain under the influence of the periodical emptying of the ponds located in the watershed, marked by the abrupt peak discharges taking place in the autumn season without any relation to precipitation.

Taking into account the observed values of precipitation and the maximum discharges corresponding to them, precipitation levels of 10 mm and 30 mm were assumed for the purpose of simulation calculations. Low and average fertiliser use intensities were assumed. The results of the simulations performed are shown in Table 3.

The values of nitrogen concentration in the peak discharges, obtained from the simulation calculations, ranged between 5 and 10 ppm. The variability of phosphorus concentration was contained in the interval 0.35–1.15 ppm.

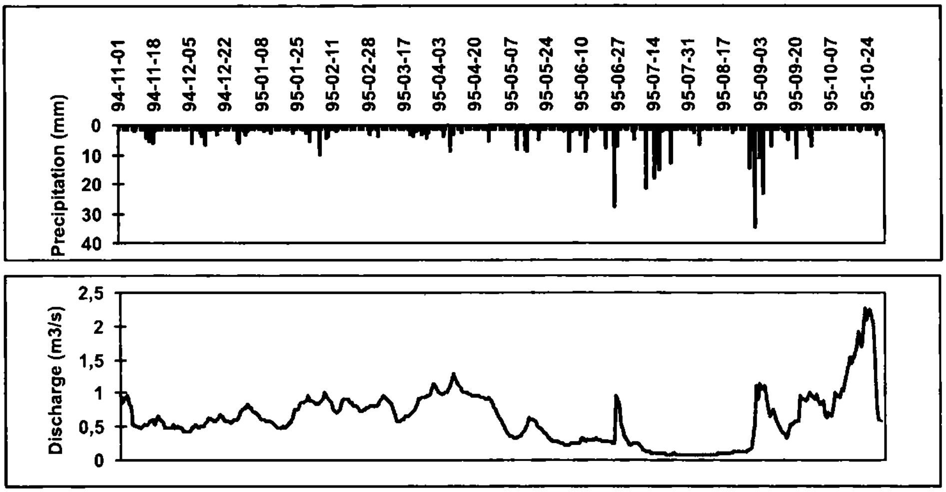

Fig. 2. Daily precipitation sums and average discharges in the watershed of Bełdówka river in 1994/95.

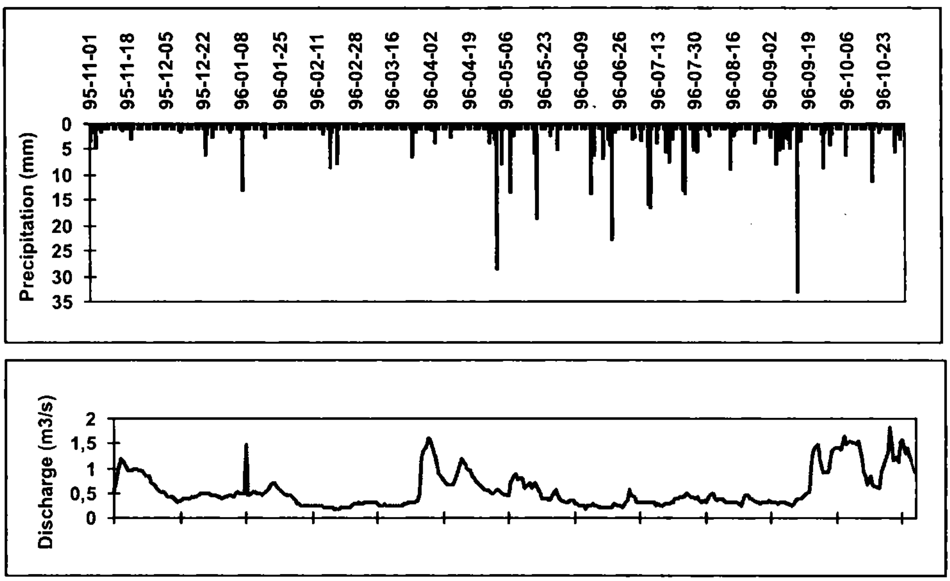

Fig. 3. Daily precipitation sums and average discharges in the watershed of Bełdówka river in 1995/96.

These values correspond to the maximum levels of concentrations observed in the years 1994–1996. The maximum observed concentrations of nitrogen in the period 1994–96 attain 10 ppm. The values of phosphorus concentrations observed at Kałów are lower than those obtained from simulation calculations. It must be emphasised, though, that the values of the

Table 3.

Results of simulation computations: Variant definitions: Variant 1 — low fertiliser use, low precipitation; Variant 2 — average fertiliser use, low precipitation; Variant 3 — low fertiliser use, high precipitation; Variant 4 — average fertiliser use, high precipitation

Selected model input parameters	Variant 1	Variant 2	Variant 3	Variant 4
Precipitation (mm)	10	10	30	30
Fertiliser use: N (kg/ha), P (kg/ha)	50/20	100/40	50/20	100/40
Selected model output quantities:				
Runoff (mm)	0.3	0.3	0.8	0.8
Peak discharge (cu.m per second)	1.1	1.1	3.3	3.3
Total load of nitrogen in runoff (kg/ha)	0.01	0.02	0.04	0.06
Concentration of nitrogen in runoff (ppm)	5.16	8.92	5.56	10.04
Total load of phosphorus in runoff (kg/ha)	0.00	0.00	0.00	0.01
Concentration of phosphorus in runoff (ppm)	0.35	0.66	0.62	1.15

concentrations observed, controlled only in selected time points and intervals, ought to be treated merely as reference points.

The values of the simulated concentrations largely depend — in view of the procedures applied in the model and commented upon before — on the value of surface runoff. That is why it is of primary importance to appropriately calibrate the model in its hydrological part, which sets the conditions for the calculations concerning water quality. Other publications concerning the possibility of applying the AGNPS model (Mitchell, Bingner, 1993) indicate also that this is the direction of future research, closely connected with the improvement of simulation quality.

CONCLUSIONS

The results of analysis, reported here, demonstrate the possibility of simulating the nitrogen and phosphorus load in the peak discharges with the use of the AGNPS model and the GIS technology, applied to identification of the model parameters. The AGNPS model can be used to estimate the area pollutant load transported to surface waters. This is of particular importance in case of watersheds not subject to water quality control. Simulation conducted for the different land use and fertiliser application variants provides information on the potential threats resulting from the supply of pollutants during high discharges. In addition, this can be the basis for elaborating the strategy of watershed use, so as to control the quantity of nutrients supplied to surface waters.

Concentrations of nitrogen and phosphorus observed in the period analysed in the watershed of Bełdówka correspond to the low and average fertiliser application levels. An increase of intensity of fertiliser use above the rates used currently would cause an increase of supply of area pollution and, consequently, the possibility of exceeding the limit values for the non-polluted waters.

The research results obtained are comparable with the values noted for the nitrogen and phosphorus compounds in the surface waters of the agriculturally used watersheds (Allan, 1998). Concentrations of nitrogen in the non-polluted American channels range between 1 ppm, in case of the forest watersheds with the share of forests amounting to 90% of the watershed surface, to approximately 9–10 ppm in case of the agriculturally used watersheds.

Further research ought to aim at a more precise calibration of the model on the basis of the field studies of increased frequency.

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