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# Estimation of influence of land management on river water quality based on model calculations

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## Introduction

In the introductory part of Water Framework Directive, the role of water is described as heritage which must be protected, defended and treated as such (Dz.U. UE.L.00.327.1 DIRECTIVE 2000/60/EC – so called Water Framework Directive). To avoid long term deterioration of freshwater quality and quantity, there is a need for Community legislation to cover ecological quality and prevention programs adopted for local and regional conditions. To achieve the good water status, it is necessary to define and implement the actions, within the frame of integrated activities programs complying with union requirements. However, it is important to be aware of the fact that the achievement of good water status requires long-term planned protection actions. Good water status is especially important when the considered areas are connected with Nature 2000 network or will become Nature 2000 in the future. The essential problems on Nature 2000 areas or areas designed for Nature 2000 network are non point source pollutions, which originate in human rural actives and which are transported from catchment areas to rivers either in soluble form or connected with soil particles. Not less important are short and long term hydro-meteorological phenomena like floods, droughts and climate changes. These phenomena are interconnected and only their integral consideration can allow achieving long-term aims like balanced development of rural areas situated on Nature 2000 areas and/or designed to Nature 2000. Poland is presently in such economic development stage, that its direction can define the ways of balanced management of Nature 2000 network for the next years. In comparison to west European countries, much area with little transformed environments still remains. The advantage of such situation is that it can determine the pattern for restoration of natural habitats changed by civilization grows as well as an impulse for economic development of these areas (by ecological tourism).

In hitherto existing environmental protection practice, including protection of water resources and pollution restraint, much more attention was paid to point source pollution, neglecting diffuse pollution, finding it difficult to register and control. Non-point source pollution is an important source of biogenic matter (nitrates and phosphates), pesticide and eroded soil coming into the water. Increased quantity of biogenic matter has an effect of intensified eutrophication. This problem is considered in the EU Water Framework Directive, where a demand of achieving "good surface water status" until 2015 is formulated. One of the crucial elements of the WFD is water protection of both surface- and ground-water, together with integrated water management on the base of watershed areas. Annex VIII of WFD – Indicative List of the Main Pollutants contain at the 11$^{th}$ position, substances that contribute to eutrophication (in particular: nitrates and phosphates). The very first step which should be taken to decrease biogenic matter transport from rural areas is to recognize the dependence between agriculture activity and chemical quality of water. Currently, in order to achieve this information, computer models are used increasingly, because those models describe known processes not only as simple regression, but they consider substantial relationships between particular processes. Optimization of the whole system of interdependences aiming to achieve intended effect (e.g. decrease of diffuse pollution with biogenic matter) is possible in models like SWAT (Soil and Water Assessment Tool) (Arnold and Fohrer 2005). The main limitation in application of such models are not fully recognized processes of land use-runoff-transport-accumulation and input data of low quantity and accuracy not high enough in the sense of time and space. However, this kind of models are currently the most sophisticated solution for determination of land changes and its impact on nutrient and pollutant transport. One of the advantage of SWAT is that is used all over the world for large (Qi and Grunwald 2005; Ndomba et al. 2008) and small basins.

In this study, the main aim was to estimate of diffuse pollution reduction ability in the way of various land use by application of SWAT model for Zagożdżonka catchment. The Zagożdżonka river catchment can be considered a representative catchment for Mazovian lowlands and is actually in the area Nature 2000 called "Ostoja Kozienicka". The advantage of this catchment is the existence of rainfall and runoff data for a period (Hejduk et al. 2010) which allows us to calibrate SWAT model for a reasonable time scale, which includes dry and wet periods. The results can be an example investigation for a neighboring, not observed small catchment.

# Materials and Methods

## Study area

The Zagożdżonka watershed is located in central Poland, about 100 km south of Warsaw. The Department of Hydraulic Engineering (former: Department of Hydraulic Structures) started its research in the watershed in 1962, with financial help of local chemical factory. Total area of the watershed with the outlet point at Płachty Stare gauging station (Figure 7.1) is 82.4 km². However, in this study smaller sub-watershed with the outlet at Czarna gauging station, area 23.4 km², was investigated.

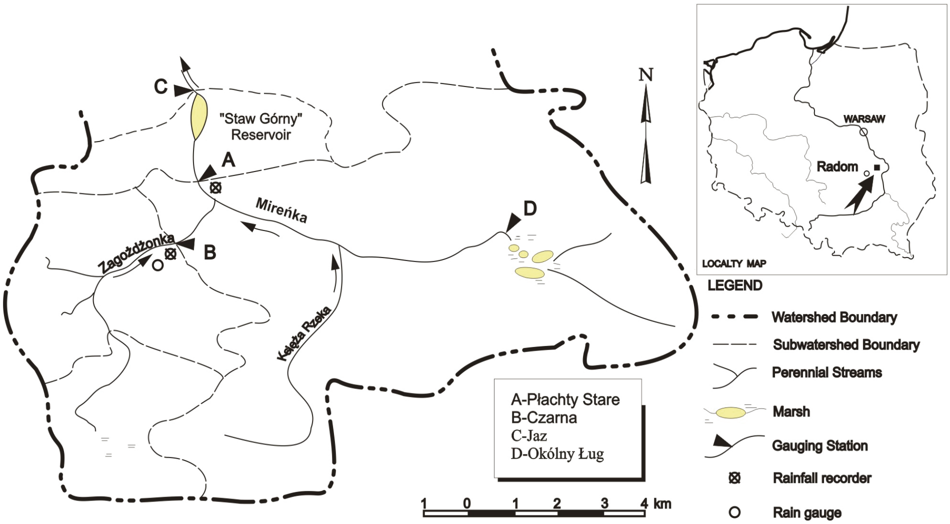


FIGURE 7.1. Locality of Zagożdżonka catchment

The average annual rainfall during considered period (2000–2010) is estimated at 605 mm and average discharge 0.069 m³/s which covers wet (2000–2002) and dry (2003–2005) period. The monthly distribution of rainfall shows a maximum volume in July and August for this period (Table 7.1). However, the monthly distribution of discharges shows high flows during spring periods – March and April (Table 7.1).

The dominant soil type is sand, ranging from almost pure to loamy sands. In depressions areas like river beds, peaty soils can be found. Generally sandy soil covers over 90% of watershed to Czarna gauging station.

The Zagożdżonka watershed is located about 170 m above sea level, and absolute relief of the sub-catchments is 16.5 m, so it can be considered of lowland type

TABLE 7.1. The monthly discharge and precipitation used for calibration (2000–2006) and validation (2007–2010) for Zagożdżonka catchment Czarna gauge

| Average discharges ($m^3/s$) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydrological year | XI | XII | I | II | III | IV | V | VI | VII | VIII | IX | X | Year avarage |
| 2000 | 0.040 | 0.068 | 0.072 | 0.147 | 0.174 | 0.179 | 0.028 | 0.024 | 0.051 | 0.040 | 0.040 | 0.028 | **0.074** |
| 2001 | 0.044 | 0.050 | 0.069 | 0.072 | 0.110 | 0.221 | 0.056 | 0.034 | 0.065 | 0.121 | 0.066 | 0.061 | **0.081** |
| 2002 | 0.062 | 0.051 | 0.132 | 0.165 | 0.113 | 0.060 | 0.039 | 0.082 | 0.033 | 0.051 | 0.021 | 0.051 | **0.071** |
| 2003 | 0.058 | 0.052 | 0.101 | 0.057 | 0.119 | 0.134 | 0.048 | 0.024 | 0.020 | 0.013 | 0.016 | 0.032 | **0.056** |
| 2004 | 0.037 | 0.043 | 0.064 | 0.105 | 0.120 | 0.109 | 0.047 | 0.038 | 0.041 | 0.030 | 0.024 | 0.038 | **0.058** |
| 2005 | 0.060 | 0.056 | 0.063 | 0.068 | 0.221 | 0.075 | 0.124 | 0.038 | 0.035 | 0.039 | 0.019 | 0.027 | **0.069** |
| 2006 | 0.033 | 0.063 | 0.073 | 0.053 | 0.161 | 0.142 | 0.041 | 0.031 | 0.010 | 0.038 | 0.034 | 0.038 | **0.060** |
| 2007 | 0.064 | 0.054 | 0.067 | 0.168 | 0.150 | 0.058 | 0.040 | 0.043 | 0.027 | 0.018 | 0.030 | 0.027 | **0.061** |
| 2008 | 0.045 | 0.045 | 0.059 | 0.053 | 0.066 | 0.062 | 0.056 | 0.020 | 0.014 | 0.015 | 0.026 | 0.037 | **0.042** |
| 2009 | 0.044 | 0.059 | 0.047 | 0.067 | 0.151 | 0.058 | 0.039 | 0.059 | 0.044 | 0.027 | 0.027 | 0.081 | **0.059** |
| 2010 | 0.100 | 0.092 | 0.070 | 0.167 | 0.175 | 0.077 | 0.235 | 0.070 | 0.044 | 0.098 | 0.375 | 0.095 | **0.129** |
| Avarage | **0.055** | **0.057** | **0.075** | **0.098** | **0.139** | **0.100** | **0.073** | **0.044** | **0.033** | **0.045** | **0.064** | **0.049** | 0.069 |
| Precipitation (mm) | | | | | | | | | | | | | |
| Hydrological year | XI | XII | I | II | III | IV | V | VI | VII | VIII | IX | X | Year sum |
| 2000 | 61.1 | 21.7 | 24.8 | 38.6 | 63.1 | 56.5 | 43.7 | 42.8 | 138.6 | 65.3 | 67 | 6.3 | **629.5** |
| 2001 | 39.2 | 38.7 | 20.2 | 25.3 | 34.2 | 97 | 25.6 | 55.8 | 146 | 97.6 | 83 | 21 | **683.6** |
| 2002 | 21.5 | 22.2 | 28.0 | 43.9 | 27.3 | 22.9 | 40.4 | 108.2 | 72 | 91.2 | 38.1 | 91.4 | **607.1** |
| 2003 | 26.9 | 14.7 | 15.3 | 23.0 | 26.0 | 59.9 | 46.9 | 29.8 | 86 | 50.4 | 60.8 | 58.6 | **498.3** |
| 2004 | 18.5 | 33.7 | 34.5 | 48.9 | 39.3 | 56.5 | 36.5 | 77.9 | 97.4 | 66.5 | 31.4 | 38.3 | **579.4** |
| 2005 | 44.0 | 15.7 | 36.4 | 35.7 | 40.9 | 11.2 | 86.1 | 30.7 | 89.1 | 28.2 | 22.0 | 4.0 | **444.0** |
| 2006 | 26.9 | 90.5 | 34.9 | 27.9 | 41.6 | 36.5 | 41.2 | 48.6 | 14.3 | 161 | 27.0 | 44.9 | **595.3** |
| 2007 | 40.1 | 20.7 | 67.8 | 56.8 | 43 | 18.1 | 69.0 | 61.6 | 75.7 | 30.8 | 73.7 | 14.7 | **572.0** |
| 2008 | 43.0 | 11.5 | 50.4 | 13.2 | 60.3 | 38.6 | 62.7 | 26.2 | 53 | 74.3 | 59.9 | 44.2 | **573.3** |
| 2009 | 29.0 | 38.5 | 22.8 | 54.4 | 82.3 | 0.3 | 68.0 | 101.8 | 84.7 | 59.7 | 36 | 83.4 | **660.9** |
| 2010 | 47.2 | 56.7 | 31.1 | 36.4 | 22.3 | 19.4 | 136.9 | 74.8 | 96.3 | 106.6 | 159.4 | 20.9 | **808.0** |
| Avarage | **36.1** | **33.1** | **33.3** | **36.7** | **43.7** | **37.9** | **59.7** | **59.8** | **86.6** | **75.6** | **59.8** | **38.9** | **604.7** |

TABLE 7.2. The consumption of fertilizer N and P in Poland and in the Mazovian Voivodship (GUS)

| Year | Poland | | Mazovian Voivodship | |
|---|---|---|---|---|
| | P (tons) | N (tons) | P (tons) | N (tons) |
| 2000 | 129423 | 861 266 | 18598 | 84 789 |
| 2001 | 138597 | 895 563 | 18449 | 83 334 |
| 2002 | 139495 | 861 775 | 18111 | 82 201 |
| 2003 | 131929 | 831 660 | 16184 | 74 215 |
| 2004 | 140351 | 895 024 | 17195 | 78 612 |
| 2005 | 141390 | 895 294 | 17335 | 79 446 |
| 2006 | 192619 | 996 464 | 24826 | 113 993 |
| 2007 | 179595 | 1 056 190 | 23154 | 127 730 |
| 2008 | 201579 | 1 142 275 | 23837 | 133 147 |
| 2009 | 163619 | 1 095 441 | 17550 | 118 578 |
| Avarage | 155860 | 953 095 | 19524 | 97 605 |
| 2010 | Data not available yet | | | |

and is typical for central Poland. The area is for 64% under cultivation, almost one forth (24.1%) is covered by forest and 10.7% is pasture land. The remaining 1.2% is occupied by other forms of land use (Banasik 1994).

It is difficult to estimate the use of fertilizers in this area due to the lack of precise data. One way is to recognize the consumption of mineral and chemical fertilizer, basing on Polish Statistical Yearbooks. The usage of N and P do not differ much during these years (Table 7.2) but it is a slight grow of fertilizers consumption since 2006.

The total area of the Mazovian voivodship is estimated for 35 598 km$^2$ so the average consumption of fertilizer P and N can be estimated for 5.49 kg/ha in case of P and 27.45 kg/ha in case of N. However, according to the Statistical Yearbook of Agriculture (2010), the area of agricultural land for Mazovian Voivodship is 20839 km$^2$. Hence, it makes it 58% of total Voivodship area. When the agricultural area is taken into consideration, the average consumption of fertilizer P and N can be estimated for 9.34 kg/ha in case of P and 46.72 kg/ha in case of N.

The nutrient monitoring in this catchments is conducted by State Environmental Monitoring service, although the frequency of sampling varied (usually once a month) and only during chosen year (Hejduk 2010). Additionally for more precise data gathering the chemical investigations were carried on out at Czarna in 1993–1995 (Banasik et. al. 1995), 1999–2000 (Hejduk 2001) and 2008–2010 as a part of these investigations. The average monthly concentration (mg P/dm$^3$) and (mg N/dm$^3$) calculated based on weekly data for period march 2008 December 2010 for soluble phosphorus and nitrate is shown o the Figure 7.2.

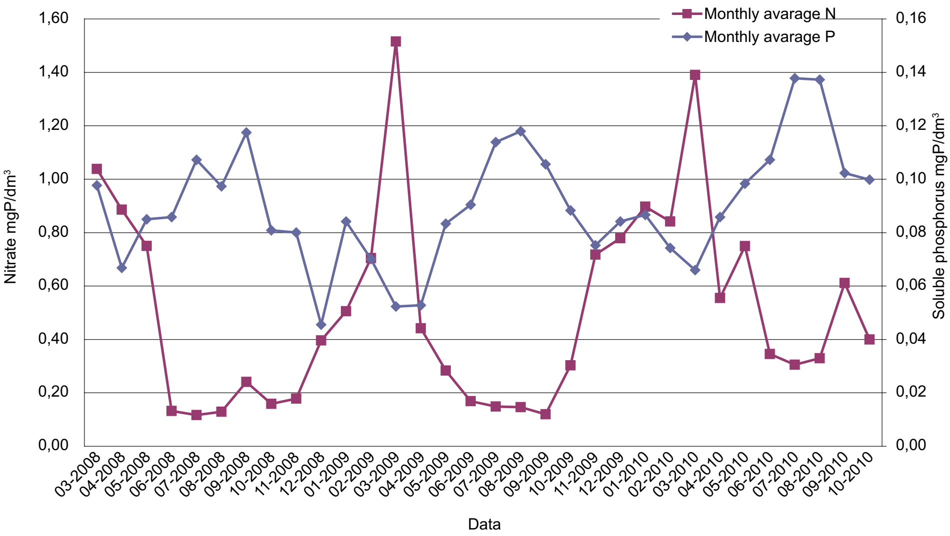


FIGURE 7.2. Monthly average nitrate and soluble phosphorus concentration at Czarna gauge calculated based on weekly concentration data

## SWAT model description

SWAT (Soil and Water Assessment Tool) is a long term continuous time model. The model was developed by Dr Jeff Arnold for USDA Agricultural Research Service (ARS) to predict the impact of management on water, sediment and chemical yields in a basin or watershed scale (Neitsch et al. 2005). The model is physically based, while the processes associated with water and sediment movement, crop growth, nutrient cycling are directly modeled using input data. The model is computationally efficient and allows us to model large basin and/or a spatial distribution of various land management by allowing the division of watersheds into smaller subwatersheds. The model enables to study long-term impacts and is not designed to simulate detailed single event flood routing (Neitsch et al. 2005). The model allows users to model watersheds with less monitoring data and to assess predictive scenarios using alternative input data such as climate, land-use practices, and land cover on water movement, nutrient cycling, water quality, and other outputs (Jha 2009).

For modeling purposes, a watershed can be divided into a subbasin, which benefits when the spatial distribution of soils and land use within the watershed have influence on hydrology of the watershed. Input for each subbasin is grouped into categories: climate, hydrologic response unit (HRU), pond/wetlands, groundwater and the main channel draining the subbasin. The important category is a HRU what is a area within subbasin, that comprise the unique land cover, soil and management combinations (Neitsch 2005).

The basis of the hydrologic cycle calculation in SWAT is a water balance. The model divides the hydrological cycle into two phases: the land phase, where the amount of water, sediment nutrient and pesticide is calculated as an input to main channel and the routing phase, where the movement of the water sediments etc. through the channel network to the outlet is calculated. In the land phase, based on water balance equation the model calculates the runoff separately for each HRU and afterwards is routed to obtain total runoff for the watershed (Neitsch 2005). The number of input data is needed to perform the calculations. Some of it is climate data consisting of: daily precipitation, maximum and minimum air temperatures, solar radiation, wind speed and relative humidity. All of this data can be incorporated as observed data or can be generated during simulations. Model simulates certain pathways for water movement in watershed. The rainfall can be intercepted by vegetation and held there, as well as be infiltrated to the soil or can flow as an overland flow. The SWAT model allows to model canopy storage, infiltration processes, redistribution (continuous movement of water through a soil profile after input of water), evapotranspiration (potential evapotranspitarin can be estimated by 3 different methods according to Hargraves, Priestley-Taylor and Penman-Monteith), lateral subsurface flow, surface runoff (can be estimated by SCS curve number method or Green and Ampt infiltration method), ponds, tributary channels (used for estimation of time of concentration for the subbasins), base flow (model estimate base flow with division into two aquifers – shallow (contributes return flow to the stream within watershed) and deep (contributes return flow to the stream outside watershed). The land cover and plant grow routine allow to distinguish between annual and perennial plants and is used for estimation of water and nutrient removal from the root zone, transpiration and biomass. The plant grow routine estimate potential growth, nutrient uptake and growth constrains. The erosion and sediment yield are estimated with Modified Universal Soil Equation (MUSLE). The phosphorus and nitrogen are governed in the model by nitrogen and phosphorus cycle in the soils. Nitrate and organic N may be removed from soil by the flow of the water and plant growth. SWAT is capable to model the nitrification and denitrification processes. Amounts of nitrates in runoff, lateral flow and percolation are estimated by volume of the water and average concentration in the particle soil layer. The organic N runoff is estimated basing on concentration of organic N in the top soil, sediment yield and enrichment ratio. The similar approach is applied for phosphorus cycle but the amount of soluble phosphorus removed in runoff is predicted using solution concentration in the top 10 mm of soil. The SWAT can simulate the pesticides by use of equation adopted from the GLEAMS model. Management practices are an important factor that has influence on water cycle. The model allows to implement the beginning and the ending of growing season, timing and amounts of fertilizers, pesticide and irrigation application and tillage operations.

In the routing phase of the hydrological cycle, two components are distinguished: routing in the main channel or reach and routing in the reservoir. Routing in the main channel can be divided into four components: water, sediment, nutrients and organic chemicals. Flow in the channel can be calculated using variable storage coefficient method or the Muskingum routing method. Sediment transport is calculated as a function of peak channel velocity. Nutrients routing are adopted from QUEL2E model. Only one pesticide may be routed through the channel network due to complexity of the simulated processes. The routing in the reservoirs includes inflow, outflow, rain flow on the surface, evaporation, infiltration from the reservoir bottom and diversions.

## Model data input

The land use for modeling purpose was prepared based on topographic maps in the scale 1:25000. Due to the use of more sophisticated GIS system, the form of previous, manually established division, differs to some extent from the current one. Based on this map the division for agricultural land, pasture, forests (deciduous and mixed), low density residential areas, water and wetlands were distinguished (Figure 7.3 and Table 7.3).

TABLE 7.3. Land use in Zagożdżonka

| Land cover type | Percentage of the watersched |
|---|---|
| AGRL (Agricultur land) | 48.82 |
| FRSD (forest deciduous) | 30.20 |
| FRST (fores tmixed) | 0.95 |
| PAST (pasture) | 14.14 |
| URLD (residential) | 2.24 |
| WATR (water) | 1.03 |
| WETL (wetlands) | 2.62 |

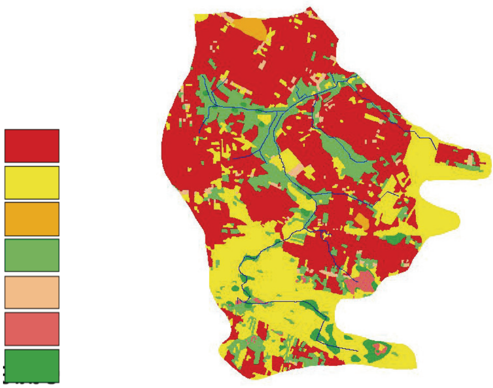

FIGURE 7.3. Map of Zagożdżonka land use

The three dominant soils were distinguished in the considered area. According to PTG standards (2008) the following soils are in the catchment: sands, loamy sands and peat bog soils.

Table 7.4 and Figure 7.4 shows the percentage of particular soils and distribution within catchment.

TABLE 7.4. Soil types in Zagożdżonka

| Soils | Percentage of the watershed |
|---|---|
| Sand | 48.55 |
| Loamy sand | 43.31 |
| Peat bog | 8.14 |

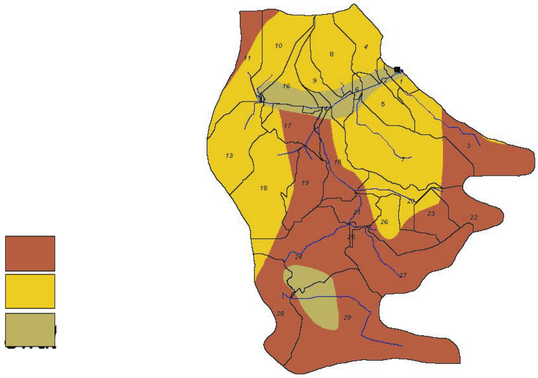

FIGURE 7.4. Map o Zagożdżonka soil types

The HRU distribution was done by use of dominant land use and soils what creates one HRU per one subbasin and assumed that the dominant type of land use and soil are used for particulate subbasin. Finally, the 29 subbasins were created and 29 HRU as well. This type of HRU generation has been chosen due to small area of the considered watershed and relatively uniform soil types.

For the modeling purpose, only the data from Czarna rainfall gauge were used due to lack of other rainfall data. According to the Statistical Yearbook of the Republic of Poland (2010) the dominant crop on this area on agricultural land is rye and this kind of the crop was chosen for the calibration, validation period and simulation purpose.

# Results and discussion

## Calibration and validation

The SWAT model was calibrated and validated for discharge data using the measured values from Czarna gauging station. The measured period was divided into two parts: 2000 to 2006 for calibration and 2007 to 2010 for validation. The first step of the application of SWAT model was calibration, which means the test of the model with known input and output used for adjust the model parameters. At this stage the flow data measured by WULS – SGGW staff gathered during year 2000 till 2006 has been applied. This period covers wet and dry years so it was possible to calibrate the model for different possible hydrological situation. The calibration was made only for water discharge due to lack of sediment and quality data for this period.

The next period from 2006 till the end of hydrological year 2010 was assumed as validation period, where comparison of model results with independent data set with no parameters adjustment has been done.

The quality of the model prediction, i.e. the accuracy of model estimation in comparison to the measured data is one of the most important step in model application. Among a number of statistical parameters, four of them are the most commonly used for determination of model predictions. In this case, the determination coefficient – $R^2$, Nash- Sutcliffe Efficiency, Root Mean Square Error – observations standard deviation ratio and percentage of BIAS were chosen.

The determination coefficient – $R^2$ describes the proportion of the variance in measured data explained by the model. $R^2$ ranges from 0 to 1, with higher values indicating less error variance and typical values greater then 0,5 are considered acceptable.

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the noise (residual variance) compared to the measured data information (variance) and indicates how well the plot of observed versus simulated data fits the 1:1 line (Moriasi et al. 2007):

$$\mathrm{NSE} = 1 - \left[ \frac{\sum_{i=1}^{n} \left( Y_i^{obs} - Y_i^{sim} \right)^2}{\sum_{i=1}^{n} \left( Y_i^{obs} - Y^{mean} \right)^2} \right] \tag{1}$$

where:

$Y_i^{obs}$ is a value of observation, $Y_i^{sim}$ is a simulated value and $Y^{mean}$ is a mean of observed data.

The recommended NSE for monthly time step are: values between 1,00 and 0.75 indicate very good performance rating, values between 0.75 and 0.65 good rating, values between 0.65 and 0.5 satisfactory rating and below 0.5 unsatisfactory rating (Moriasi et al. 2007).

The Root Mean Square Error (RSME) – observations standard deviation ratio ($STDEV_{obs}$) and index (RSR) is calculated as a ratio of root mean square error and standard deviation of measured data. RSR varies from optimal value of 0 which indicates zero RSME and therefore perfect model simulation to large positive values. The lower RSR the better model simulation performance is (Moriasi et al. 2007):

$$\mathrm{RSR} = \frac{\left[ \sqrt{\sum_{i=1}^{n} \left( Y_i^{obs} - Y_i^{sim} \right)^2} \right]}{\left[ \sqrt{\sum_{i=1}^{n} \left( Y_i^{obs} - Y^{mean} \right)^2} \right]} \tag{2}$$

The recommended RSR for a monthly time step values are: between 0.0 and 0.5 indicate very good performance rating, values between 0.50 and 0.60 – good rating, values between 0.60 and 0.70 – satisfactory rating and above 0.7 – unsatisfactory rating (Moriasi et al. 2007).

Percent of bias (PBIAS) measures the average tendency of the simulated model to be larger or smaller than their observed counterparts (Moriasi et al. 2007). Positive values indicate model underestimation bias and negative values indicate model overestimation bias:

$$\text{PBIAS} = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)\times(100)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right] \tag{3}$$

The recommended PBIAS for a monthly time step and discharge are: values below ±10 indicate very good performance rating, values between ±10 and ±15 – good rating, values between ±15 and ±25 – satisfactory rating and above ±25 – unsatisfactory rating (Moriasi et al. 2007)

During the calibration process, the model's input parameters were adjusted first by manual calibrating then by the sensitivity and auto-calibrating analysis, to match the observed and simulated streamflows. A time-series plot of the measured and simulated monthly streamflows (Figure 7.5) shows that the magnitude and trend in

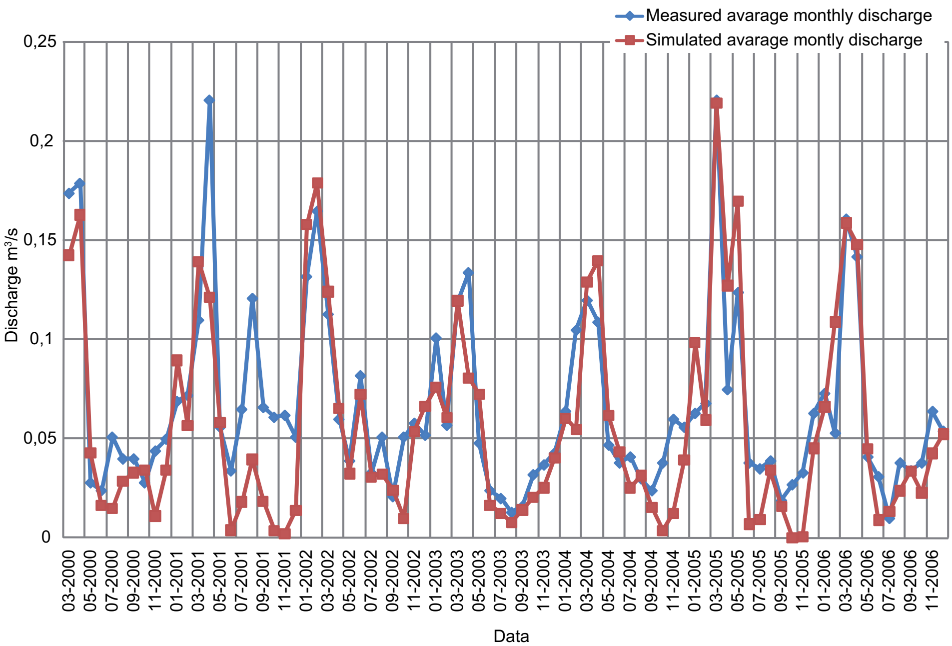


FIGURE 7.5. Comparison of measured and simulated discharges for the calibration period 2000–2006

the simulated monthly flows followed the measured data most of the time. The determination coefficient $R^2$ = 0.73, indicate a good correlation between the measured and predicted flows, the PBIS = +3.03 indicate very good performance rating, however two remaining indicators: NSE and RSR with the values 0.46 and 0.80 indicate unsatisfactory rating.

Figure 7.6 shows the time-series plot of monthly measured and simulated monthly streamflows and indicates an acceptable correspondence of simulated streamflows with the measured values for validation period 2007–2010. The determination coefficient $R^2$ = 41. indicates a satisfactory correlation between the measured and predicted flow the PBIS = +1.81 indicates very good performance rating. Similarly, during calibration periods, two indicators NSE and RSR with the values 0.34 and 0.81 indicate unsatisfactory rating.

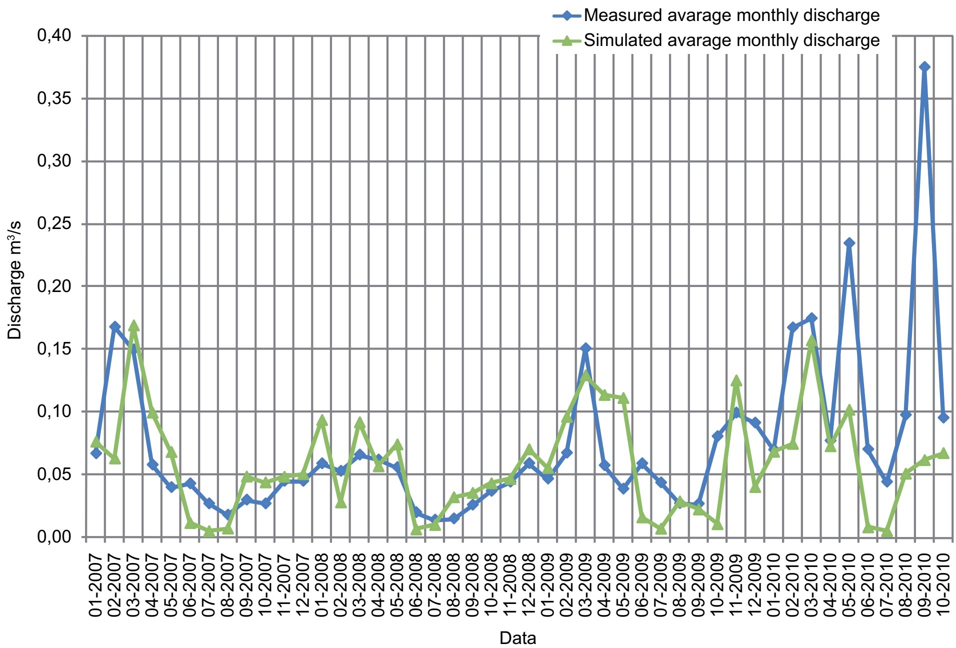


FIGURE 7.6. Comparison of measured and simulated discharges for the validation period 2007–2010

In the validation period, SWAT predictions were not accurate when the very high rainfall happened during in September 2010. During two days the amount of 99.5 mm were measured, what was a 62% of the total rainfall for this month and exceeded by 66% the 10 years average for the September. This extreme has a strong influence on calculated statistics.

## Results of nitrate and phosphorus simulation

The calibration and validation part of SWAT application, allowed us to simulate the influence of land use on water quality. Since march 2008, the chosen water quality indicator has been gathered for Czarna gauging station with the weekly time step. One of the most important water quality indicators at the rural areas are concentration of various form of nitrogen and phosphorus, especially those forms which have an important impact on eutrophication processes. In this case the soluble phosphorus and nitrate have been investigated. As the water quality data for Czarna gauging were available since March 2008 until October 2010, this period was chosen for further evaluation.

Among the factors influencing nutrients transport, the non-point source pollution and source pollution are the most important. Other factors connected with agricultural areas are soil type, land management and fertilizer applications. In Poland in case of the small catchment it is often very difficult to estimate all this factors precisely, however it is possible to simulate various land changes, fertilizer application (natural and artificial) based on data gathered by the statistical services.

In case of Zagożdżonka catchment, it was possible to calculate the monthly loads of soluble nitrates and phosphorus based on water content nutrients concentration and discharge measured in the same time during investigated period March 2008 and October 2010 (Figure 7.7).

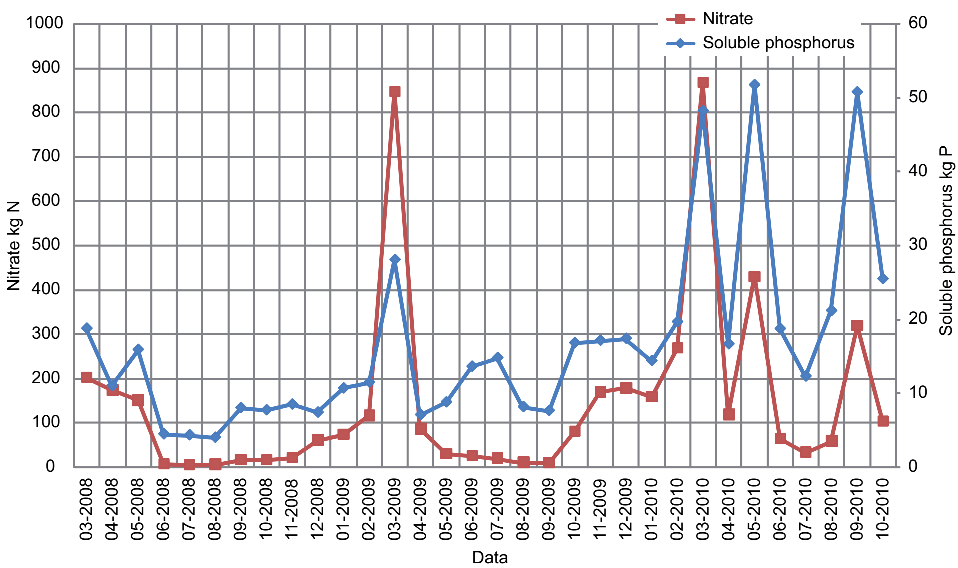


FIGURE 7.7. Monthly load of nitrate and soluble phosphorus during investigation period – March 2008 – October 2010 calculated based on weekly sampling

There is significant high load in March 2009 and 2010 of nitrates. Both values are results of high nitrate concentrations in the spring time measured in river. The pattern of soluble phosphorus load differ from nitrate pattern.

Data received from SWAT simulation for the same period indicate quite similar pattern of nitrate changeability during those years (Figure 7.8), but poor fit of the values, especially during period when the concentration of nitrate has been measured at very high level. Overall, the total values of nitrates for considered period has been underestimated about half of measured values (4710 kg N – measured, 2121 kg N – simulated).

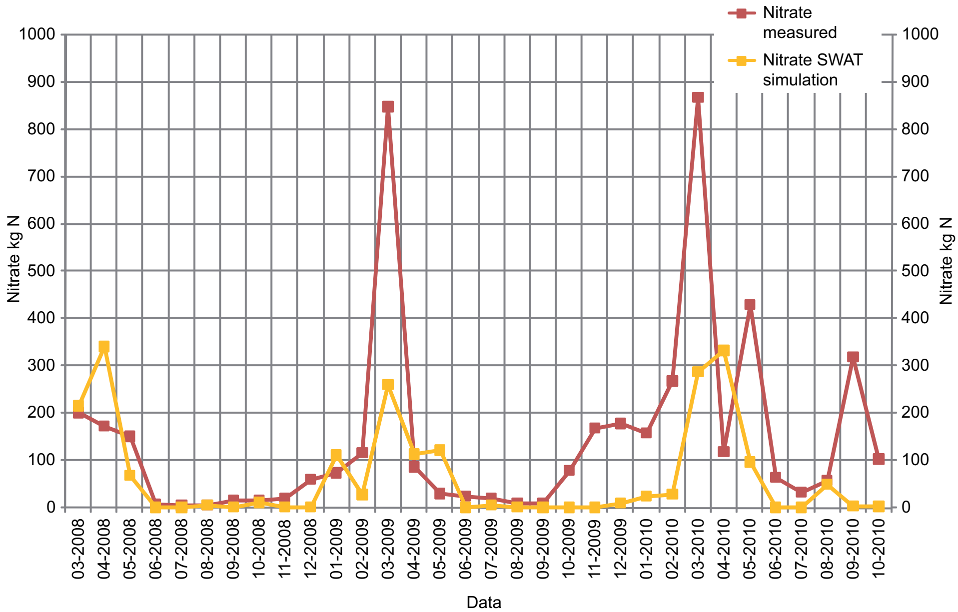


FIGURE 7.8. Comparision of monthly load of nitrate measured during the period March 2008 – October 2010 and simulated by SWAT model

The results of phosphorus simulation indicates the overestimation of loads during March 2008, 2009 and 2010 (months with the high runoff) and underestimation of loads during months with the relatively low flows (Figure 7.9). The total loads estimated by SWAT model was 321 kg P for investigated period what was the underestimation to measured values (530 kg P).

The results received from SWAT model was not satisfactory, but it is important to remember about some assumption made in this study, which have an impact on results. There is very little information on crucial inputs to the model in Zagożdżonka catchment: lack of precise data about fertilizers usage, lack of precise data about land management, especially about crop rotation, no data about point source pollution. The fertilizers application and land management inputs were chosen based on best

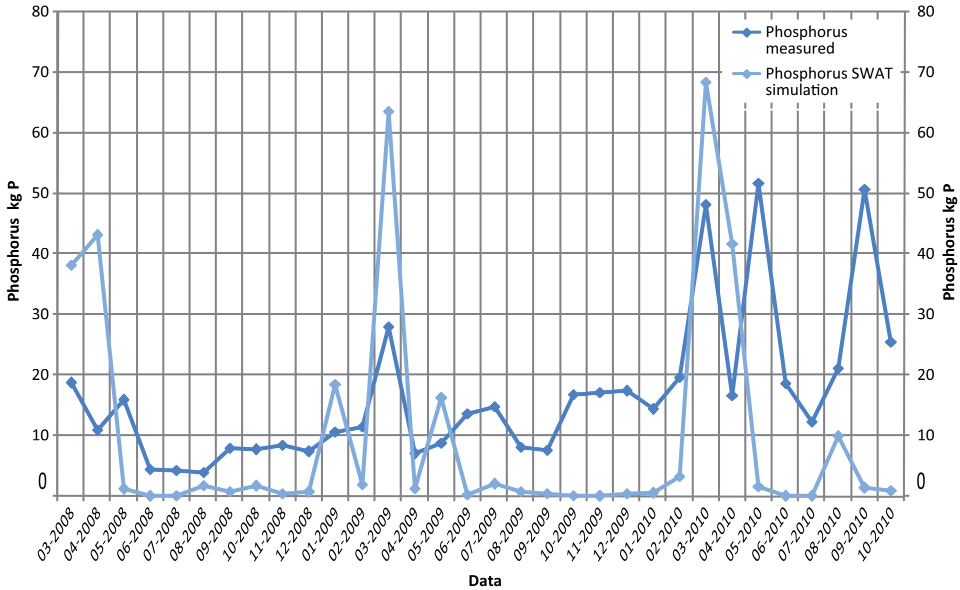


FIGURE 7.9. Comparison of monthly load of phosphorus measured during the period March 2008 – October 2010 and simulated by SWAT model

available sources like statistical data. The point source pollution was assumed not to have any significant impact on water quality. This is due to lack of point source data information. However, these assumptions have impact on model simulations and when this uncertainty is taken into consideration, the received results of nitrate and phosphorus loads can be assumed as satisfactory enough for Zagożdżonka river catchment.

## Simulation of different fertilizer application on nitrate and phosphorus loads

One of the forms of land management is an impact of different form of artificial fertilizers or natural manure application on water quality. In Zagożdżonka river catchment, that form of land management can be considered as a one of the possible way of increase of crop production due to poor soils. The SWAT give the opportunity of simulation of impact of amount fertilizers application on water quality and nutrients loads. In this study, the previous investigated period (March 2008 till October 2010) were applied. The aim of the simulation was to check what could be the nitrate and phosphorus load when various amount of fertilizer has been applied. According to the fertilizers recommendations (Jadczyszyn et al. 2010) the amount of mineral fertilizers depend on the crop and the crop forecast (Table 7.5). In this study, the recommendation for rye has been used for simulation and the assumption that all arable

TABLE 7.5. Simulation of fertilizers application and received loads at Czarna gauge station

| Crop yield (t/ha) | Amount of fertilizer applied Kg/ha (P recalculated from $P_2O_5$) | | Nitroge load kg – outflow during the investigation period | Phosphorus load kg outflow during the investigation period |
|---|---|---|---|---|
| | N | P | | |
| | No fertilizers | | 1020 | 567 |
| 4 | 60 | 7.6 | 9697 | 1814 |
| 6 | 100 | 12.0 | 17009 | 2222 |
| 8 | 140 | 16.4 | 29051 | 2405 |

land has been used for rye production. The table shows the results and summary of the simulation.

The results of the simulation indicate the increasing load of nitrogen and phosphorus with the increase of the fertilizers use.

## Conclusions

SWAT model needs tremendously precise data, which cover a wide range of catchment characteristics. Some of them are not available unless the special additional measurement is done. It is one of the main problem for Polish small catchment condition. Zagożdżonka catchment is quite well observed but still a number of input data were implemented from SWAT data base or estimated by use of internal SWAT estimators.

SWAT model is a distributed model which has a strong impact of data preparation for estimation of the good reliable modeling. It is very important to have an precise input data for the considered areas, which in Zagożdżonka catchment, just like in other small catchments, is difficult to obtain.

The received results show the usefulness of SWAT application in Zagożdżonka catchment. However, the lack of precise data, especially regarding the nutrient contents in particular soils and difficulties of identification of source point pollution, has the strong impact on received data especially concerning the nutrient concentration and time distribution.

In some cases the unexpected load of nutrient is rather connected to high water discharge which occurs for a short time (may 2010 ) due to load calculation schema.

As we use only one available rainfall station the spatial distribution of rainfall may have impact on catchment hydrological answer.

One of the most important data for estimation of nutrient output is the precise and careful estimation of land cover and fertilizers application.

The results from the pollution transport simulation indicate good but not very satisfactory predictions by the model. It could be due to lack of precise input data to the pollution part of the model.

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