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MODELLING PHOSPHORUS INFLOW TO THE MOZHAYSKOE RESERVOIR WITH THE HYPE HYDROLOGICAL MODEL

ABSTRACT. Biogenic flow is the determining factor of ecological well-being of water bodies. It depends on a number of factors, such as weather conditions, soil and vegetation cover, agricultural use of the catchment area. Its simulation is possible based on a complex water quality model with parameters distribution. In this paper, we show that the model calculates the water flow with satisfactory accuracy and gives reliable values of phosphorus flow in the investigated river outlet. The influence of dryness of the year on the phosphorus flow is important and reduces dissolved phosphorus flow several times. The results of experiments with the model show a decrease of dissolved phosphorus flow subsequent to cease of fertilizing in range from 5 to 11%. The values of the surface and groundwater genetic components of phosphorus flow are comparable, while soil component amounts 65% of local phosphorus flow.

KEY WORDS: Phosphorus, HYPE, river flow modeling, nutrients, eutrophication, Mozhayskoe reservoir

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INTRODUCTION

Biogenic flow is an essential factor for hydroecological condition of water bodies. The influence of meteorological conditions, topography, agricultural development of the catchment area, soil and vegetation should be taken into account while modelling it. It should be much emphasized in our opinion, that the very models with distributed or semi-distributed parameters are the most adequate tool for assessment of agricultural development impact on biogenic flow. While choosing an appropriate model, the physical validity of the parameters, the flexibility of settings, volume, and complexity of obtaining input data hit the first place.

In this study, we have shown that the HYPE model could provide phosphorus flow simulation for a small river with an agricultural watershed, that can be used for analysis of phosphorus flow and its genetic components. The first part of the article presents the results of survey of the Mozhayskoe reservoir catchment area, used to configure the HYPE water quality model of the Swedish hydrometeorological Institute (SHMI) and hydrological and geographical features of the modeling object. The second part discusses the results of modelling the phosphorus flow and concentrations for the catchment of the upper Moskva river upstream the Mozhayskoe reservoir. The phosphorus annual and seasonal flow for dry and wet years was calculated from the simulation as well as its genetic components. The HYPE (HYdrologic Predictions in the Environment) is a dynamic, semi-distributed, physically based, watershed scale hydrological model for continuous simulation (Lindström 2010). The model has been being developed from 2005 at SMHI (Swedish Hydrometeorology Institute) and successfully used there for river flow forecasting. As for Russian Federation, the model was used in the research of great Siberian watersheds (Gelfan et al. 2017). Simple format of the input files, flexible customization, series of alternative built-in models for the calculation of main components of water and chemical balance, and transport processes of water and chemicals are the main advantages of HYPE.

Object of study

We have chosen the upper Moskva river catchment upstream of the Mozhayskoe reservoir as an object due to its natural and water management features, as well as to higher degree of knowledge of its territory, chemical and water runoff in common as compared with other watersheds of water reservoirs. It forms an inflow into the Mozhayskoe reservoir, which is a part of the drinking water supply system of the Moscow city.

The catchment area is situated in the central part of the Smolensk-Moscow upland and belongs to the province of glacial hilly and flat plains. The height of the catchment varies from 160 to 311 m. The highest point of the watershed, which divides catchments of the Moskva, the Ugra and the Protva rivers, is located within the Gzhatsko-Mozhaysky ridge of the Smolensk-Moscow upland being also the highest point of the Moscow region. The width of the Moskva River in the upper reaches is 2–15 m. The climate of the basin of the Mozhayskoe reservoir is moderately continental with cold winters and moderately warm summers.

The catchment area has a high degree of agricultural development. According to our estimates, the share of agricultural land in the total catchment area is 31%, 2% - floodplain meadows, 2% - rural settlements and household plots, the rest of the area - 65% is occupied by mixed forests. The land includes: intensively used arable land with growing potatoes, corn, feeding root crops with annual distribution of a large amount of organic and mineral fertilizers; moderately used arable land with grains and perennial grasses cultivation with occasional cattle grazing and fertilization in the part of the area; least intensively used arable land is the one with the predominant perennial grasses cultivation and regular fertilization in small quantities; pastures; hayfields which include floodplain water meadows.

The landuse data used in the work represents the situation of 1984-1985 (see Figure 1). Comparison of the landuse pattern of that period with modern satellite images indicates a slight change in the outlines of the fields. On the other hand, field studies have shown that about 2/3 of the land that was used as arable land in the 80s is now abandoned.

Currently, a number of enterprises of the agro-industrial complex, such as CJSC "Shinichino", CJSC "Uvarovsky" kolkhoz", CJSC "Porechye" and others, engaged in plant growing and animal husbandry, operate on the territory of the studied watershed. Also, in the catchment area there are several farms and peasant farms engaged in plant growing, animal husbandry, and poultry farming.

Fig. 1. Maps of the catchment of the upper Moskva river (left) and landuse with survey points (right).

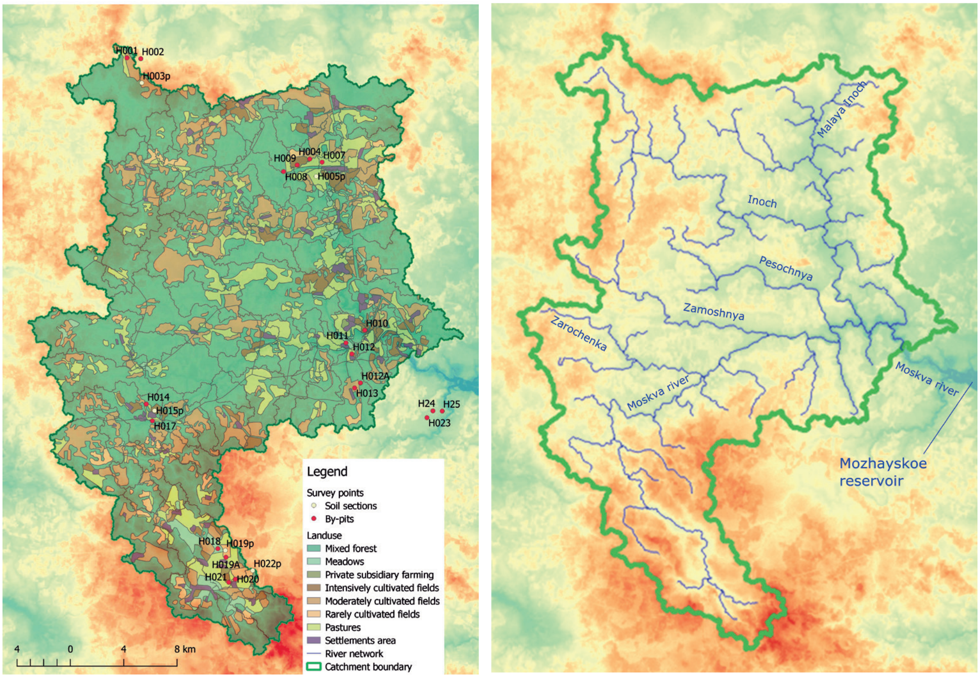

Fig. 1. Maps of the catchment of the upper Moskva river (left) and landuse with survey points (right)

The Mozhayskoe reservoir is experiencing a significant nutrient load almost since its creation, which is confirmed by studies of the primary production growth rate in the spring and summer period. In the 70s, the reservoir was second among all reservoirs of the Moskva River basin by average values of permanganate index in summer period (Edelshtein K. et al. 1978). Studies of the phosphorus flow from river bed sediments conducted in 1979 (Martynova 1979) and 1995 (Edelshtein 1995) indicate its increase. In 2009 year, under conditions of increasing water turnover, decreasing dryness of the year and low reservoir level high values of primary phytoplankton production and a slight predominance of destruction over primary production were observed (Kremenetskaya et al. 2015).

Due to the variability of ratio of the nutrient balance components during the year depending on weather conditions, stratification of the water column and the regime of water inflow into the reservoir, researchers note the importance of treating the components of the reservoir nutrient balance separately (Datsenko 2007). In this view modeling of nutrient runoff from the reservoir catchment becomes especially relevant.

Previous research

The observations of biogenic flow in the Moscow region have been being conducted from 1970s till now based on the Krasnovidovo laboratory of Moscow State University. They included biogenes, suspended materials, consumed oxygen water sampling at the outlets of the Moskva river and its tributaries. There were no trials of modelling the biogenic inflow into the Mozhayskoe reservoir, but several studies illustrate water inflow simulations made with ECOMAG model (Antokhina and Zhuk 2011; Motovilov et al. 2018) and GR4J model (Ayzel et al. 2019). Also, there are series of studies that are aimed at evaluating a modelling methodology of water masses transfer (the case of Uchinskoe reservoir (Datsenko 2019)) or characterize the variability of phosphorus and other hydrochemical parameters in the waters of Mozhayskoe reservoir (Sokolov et al. 2016).

Obtained data and methods used in the research

The series of temperature and precipitation at the meteorological stations of Mozhaysk, Gagarin, Volokolamsk, Staritsa, Klin, Maloyaroslavets for the period from 1997 to 2018 were used as meteorological information. Discharges, waterlevels and other hydrological information at the gauge Barsuki on the Moskva river were used for model calibration and verification.

We used the results of field research of the catchment, conducted by Yasinskiy N. in August - September 2017, for parameterization of the model (Yasinskiy and Belolyubtsev 2019). This comprised the initial level of phosphorus in soil, its distribution through the soil profile. Rates of residues degradation and mineralization as well as density of the soil solid phase were based on common values taken from academic books, study guides and some studies concerning in-stream chemical processes (Datsenko and Puklakov 2010; Kremenetskaya et al. 2015). Soil samples were studied in the laboratory of the Testing Center for Soil and Ecological Research of the Faculty of Soil Science at the K.A. Timiryazev University (RSAU-MAA).

The data on the phosphorus concentrations in the Moskva river, obtained by the authors and others in different years during the period from 1983 to 2012 at the Krasnovidovo Laboratory for Water Reservoirs Research, was used for calibration of the model's chemical block.

The map of agricultural land of the the Mozhayskiy Site (the territory of upper influents of the Mozhayskoe water reservoir) was developed at the Department of Physical Geography and Landscape Studies of the Geographical Faculty of Moscow State University in the 1980s by I.A. Gorbunova. It characterizes the landuse in the period before the general decline in agricultural production in the 1990s. For the purposes of our study, the map was georeferenced, digitized and corrected using modern satellite images for the period of 2015 - 2017, published in open sources. Digital elevation models with a resolution of 1 minute (30 m), formed with SRTM Mission Data, were taken from open sources (USGS). For some farms, we obtained statistical information on the amount and timing of fertilizer application.

The HYPE spatial approach is based on dividing the catchment area into subcatchments with an arbitrary degree of detalization and identifying non-localized landscape-landuse classes defined as an area fraction for each subcatchment (Pers 2014). Therein lies the core sense of parameters semidistribution (Xu 2002). Within each subbasin snow cover formation, movement of water and substances in different soil horizons (up to three) and movement of groundwater are modelled. The water runoff formed within a subwatershed comes first to the local and then to the main river network. Both networks have parameters independent of each other. The transport of nutrients in the model is divided into groups of processes related to fertilizer input, plant consumption, transformation in soil cover, removal with suspended solids and water runoff and transformations during its movement along the river network. Fertilizer supply is set explicitly, depending on the crop and alternation of agricultural activities. Plant growth is simulated according to the timing of plowing, planting and harvesting and is set for each class. The complex of processes occurring in the soil cover comes to the movement of substances between pools. So, for phosphorus, a pool of humus organic phosphorus, organic phosphorus, dissolved organic and dissolved inorganic phosphorus, as well as phosphorus adsorbed on soil particles can be distinguished.

The HYPE model, which is a hydrological model of water quality, makes part of the HYSS modeling system, which comprises loading input files, optimizing parameters and recording results. At the preliminary stage, text files with subwatersheds data and river network characteristics, and a file with classes description should be generated. We developed them in the GRASS GIS environment, so a digital river network, a layer of 86 subcatchments, a corrected landuse map and a soil map were created on the basis of the digital elevation model. Based on available landuse and soil types, a classification of 27 classes was compiled. After that, in the QGIS environment, GIS layers were superimposed on each other, the shares of the area occupied by each class in the area of each sub-collection were calculated. The final processing of the files was carried out in Excel and the RHYPE package written in R, designed by HYPE model developers to prepare, analyze and graphically display simulation results.

We have distinguished arable land with intensive, medium and low intensity of agriculture activity; meadows; pastures; kitchen gardens and territories of rural settlements among the landuse types. Mixed forest with undergrowth of deciduous trees, shrubs and grass cover was identified as a background type of vegetation. Meteorological series of air temperature and precipitation observations were interpolated into centroids of subwatersheds by kriging using variograms (Ly et al. 2013). The method development resulted in a Python program, which includes data preparation, error checking, filling in data gaps, interpolation using the PyKrige package (PyKrige, 2018) and time series generation in centroids. For the period of 1968 - 1980, the algorithm was simplified: now we have only to assign the values of precipitation and temperature at the meteorological station point located closer to the centroid, since for this period data only for Mozhaysk and Gagarin stations was used. Other input data such as hydrological series were converted to HYPE formats directly or used in parameterization files.

The evapotranspiration can be calculated in HYPE with 5 models, including Jensen-Haise, Hargreaves–Samani and FAO Penman-Monteith methods. Most of these models need additional data such as wind velocity, solar radiation, water vapor pressure etc, so we used the simplest model among those above, where the base potential evaporation is calculated when the air temperature is higher than corresponding threshold and then distributed exponentially between two upper soil layers. Potential evaporation depends on evaporation rate which is calibrated for each landuse type. The resulting evaporation depends on soil water content.

HYSS provides several different algorithms of parameter optimization, but the developers themselves recommend a method of differential evolution of parameters. The method consists in generating parameter vectors based on the latest values, choosing the best of the vectors, and accepting new parameter values with a given probability (Arsenault and Alcan 2019).

RESULTS AND DISCUSSION

At the first stage, the hydrological part of the model has been manually calibrated to determine the most sensitive parameters. The study has revealed two parameter groups that fundamentally affect the quality of modeling. The first group includes porosity of the upper soil horizons, coefficients and threshold values of infiltration and recession coefficients of the groundwater runoff; the second group includes the temperatures and snowmelt rates specified for each landuse type. At the second stage, these parameters were used in the process of automatic calibration by the method of differential evolution with the generation of 15 vectors in each of the 60 generations. At the final stage, the phosphorus concentrations calculated by the model were compared with those measured at the outlet gauge.

The simulation has been carried out for periods from 1966 to 1980, 1982 – 1987 and 1998 - 2015. The results for the first two-three years haven't been recorded for the model to warm-up. The period of 2002 - 2012 was used for calibration of the hydrological block. The need of dividing the period of 1966 – 1987 into two parts arose due to the absence of data for some rain gauges. So, we used different periods for validation in order to make sure that the model simulated waterflow satisfactorily acceptable. According to the results of manual calibration, the parameters that characterize the infiltration and leakage through the deep soil horizons, as well as the parameters characterizing the process of snowmelt, turned out to be the most sensitive parameters in the calculation of the water flow as variations of these parameters within the limits of 5 – 10% can result variations of output values by 50% and more.

The comparison of the optimal soil hydrology values and snowmelt parameters, and field measurements and data taken from literature has shown good agreement. The optimal value of melting rate ranged this way: for forest areas from 1.3 to 1.8 mm/°C day, for open areas from 1.5 to 2.2 mm/°C day and that agrees with the values given in literature (Alyushinskaya 1962; Zhidikov and Nechaeva 1982). The porosity of the upper soil horizons was 0.04 – 0.06. This value as a parameter does not take into account the presence of macropores, and rather corresponds to mesoporosity (Levkovskiy and Guber 2008). The measured water conductivity of soil ranged within the catchment from 100 to 500 mm/day and corresponded to the value of the mactrinf parameter (infiltration threshold), whose optimal value ranged from 90 to 120 for different catchment areas.

Within the watershed area according to FAO classification we have identified two soil types – Luvisols and Gleysols. The Gleysols occupied depressions and shadowed areas. The density of the upper soil horizon averaged was 1,430 kg / m^3 over the catchment area. In studied sections, soil included the following set of horizons: AY (or P – arable horizon on agricultural land) with a capacity of 30–40 cm gray and dusty (or brown and dense in case of horizon P), in most cases under a sod of 5–7 cm thick, whitish podzolic horizon EL with a capacity of 15–20 cm, light brown subeluvial horizon BEL and darker textural horizon BT with nutty structure with a common capacity of 40 - 50 cm, smoothly passing at a depth of 80 - 100 cm to the parent rock C, represented by heavy loam. The loam without inclusions belongs in this area to the Dnieper-Moscow and the Moscow region of water-glacial deposits. The indexes of soil horizons are given corresponding to the new Russian soil classification (Gerasimova 2019).

In total, there were carried out about 200 manual model launches and about 1500 launches during the automatic calibration, that together amounted to 56.6 machine-hours.

The model has shown satisfactory simulation accuracy in comparison with the water discharges observed at the outlet, which is confirmed by the values of the quality criteria given in Table 1. The result of the water flow simulation for the validation period is shown in Figure 2. The analysis of the graph shows a good accuracy of simulation, both the total volume of the flood and its maximum values. The values of the parameters in the above calculation give a sufficient basis for simulation of the biogenic flow.

The values of parameters related to the balance of nutrients, such as their content in various soil pools and fertilizer intake

Table 1. Simulation quality criteria for optimal values of model parameters for simulation of water flow

	r	KGE	NSE	PBIAS%	SDobs/2*	MAE
Acceptable value (Gupta et al. 2009; Moriasi et al. 2007; Waseem et al. 2017)	> 0.5	> 0.5	> 0.5	-10 < PBIAS< 10		SDobs/2
2002 – 2012	0.77	0.68	0.6	-9.3	5.51	3.42
2013 – 2015	0.93	0.75	0.85	-10.4	5.91	2.35
1968 – 1980	0.83	0.64	0.67	8	6.37	3.43
1983 – 1987	0.65	0.52	0.41	11.5	6.12	3.19

**less than a half of the standard deviation of the series*
r – Pearson correlation coefficient, KGE – Kling-Gupta efficiency, NSE – Nash-Sutcliff efficiency, PBIAS – percent bias, MAE – mean absolute error

were identified on the basis of chemical analysis of the catchment soils, standard fertilizer application rates and statistical data on fertilization in specific farms. Table 2 presents the average content of biogenic elements in the upper soil layer in areas with different land use types.

According to the data in Table 2 and distribution of landuse areas, phosphorus content generally corresponds to the intensity of landuse (moderate, medium or intensive), the distribution of nitrogen is opposite. Significantly higher levels of nutrient elements are observed at the sample points located on floodplains of the Moskva river due to high concentrations of phosphorus during floods and migration of elements to the depressions. On abandoned lands, the content of total phosphorus and nitrogen is 15–20% higher than on the used ones, the content of mobile phosphorus — 50–70% higher. It is not possible to establish the relationship of the content of nutrients with the altitude of land.

The formation of phosphorus runoff in the HYPE model is regulated by a number of parameters, among which one group concerns the transformation of soil phosphorus, including the initial levels of the element in different pools, the specific transition rates between pools, the Freundlich isotherm parameters. These parameters can be set based on the results of the analysis of the phosphorus content in soil samples. Another group of parameters relates to in-stream processes. These include specific rates of transition between different phosphorus forms in the water, half-saturation concentrations, and a production parameter. This parameter is the basic primary production, relative to which phosphorus degradation or production in a watercourse is calculated depending on the above

Table 2. Mean phosphorus content, P2O5, organic matter and nitrogen resulting from the watershed survey for different types of land-use

Landuse	Total phosphorus, g/kg		Mobile phosphorus, mg/kg		Organic matter (OM), g/kg		Total nitrogen, g/kg (conversion OM/20)	
	AY/P *	BEL	AY/P *	BEL	AY/P *	BEL	AY/P *	BEL
Fallow:	1980-e (landuse according to the map)							
Moderate	1,34	1,18	41,33	43,77	16,40	11,30	0,82	0,57
Medium	1,58	0,99	42,80	26,04	14,22	10,26	0,71	0,51
Intensive	2,30	1,38	57,00	32,58	12,84	9,42	0,64	0,47
Pasture	1,81	1,49	57,74	41,92	15,84	11,64	0,79	0,58
	2017 (landuse resulting from the survey)							
Non used	1,98	1,37	67,19	39,74	16,68	11,12	0,83	0,56
Used	1,74	1,12	35,44	26,63	12,34	9,49	0,62	0,47
	Not changed							
Meadow	3,44	2,27	54,70	63,40	18,60	12,45	0,93	0,62
Forest	1,19	1,08	23,87	23,90	17,40	9,50	0,87	0,48

** Soil horizons are given according to the New Russian Soil Classification: AY – gray-humic (soddy) – corresponds to layer H of FAO classification, P – agrohumic – corresponds to layer H, BEL – subeluvial – corresponds to layer E.*

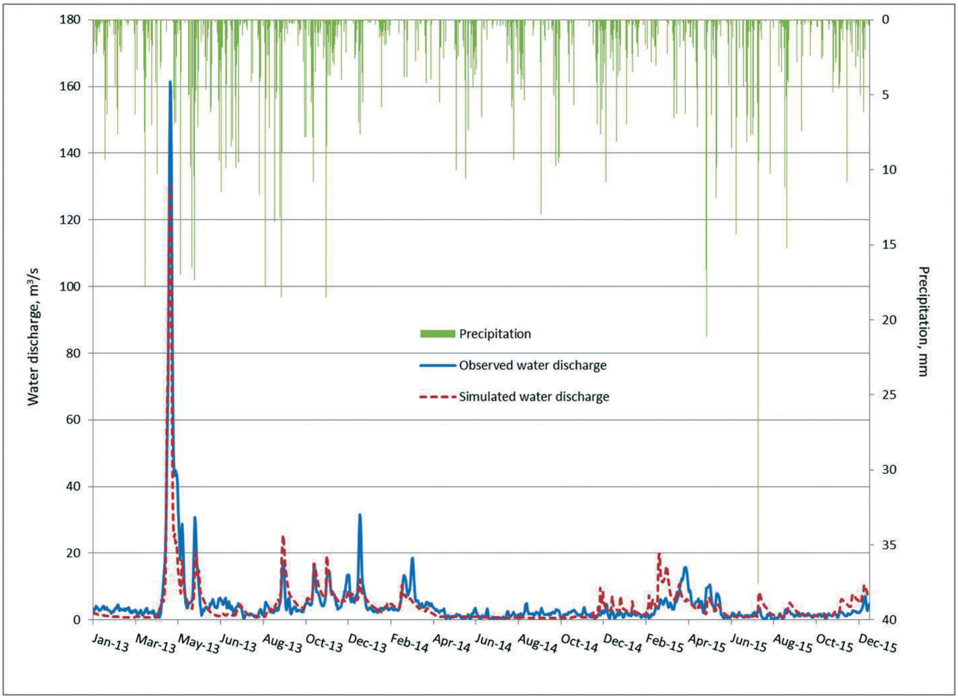

Fig. 2. Results of water flow simulation at the outlet of Moscow river in Barsuki village, compared to the observed flow and combined with the precipitation for validation period

mentioned parameters and temperature. The parameter values for the in-stream block can be refined based on those proposed in the literature. For example, in the research of Lindenshmidt (2006) and documentation concerning simulations with QUAL-2E (Cole and Wells 2013). When simulating phosphorus runoff, it is also essential to take into account the mode of mineral and organic fertilizers application, since they are the main sources of biogenic elements in catchments with intensive agriculture. In the HYPE model, it is possible to adjust the amount of fertilizer applied for each type of land use separately and the schedule of application of each type of fertilizer throughout the year.

Among parameters characterizing a specific catchment, it is worth paying special attention to those which are set separately for different types of landuse and the initial concentrations of elements in the soil. For flood periods, it becomes important to tune the parameters of soil erosion, since during these periods its transport with suspended matter contributes significantly to the phosphorus runoff (Yasinskiy and Datsenko 2018).

For simulation of phosphorus, the following initial contents were agreed: in slow phosphorus pool 100 g/m^3 for forested areas, 195 g/m^3 for open areas; in particulated phosphorus pool 80 g/m3 for forested, 150 g/m^3 for open areas. For initial phosphorus content in the pool with rapid turnover, 5 g/m^3 was agreed. The field survey findings about biogenic elements content in soils were also used for setting up parameters depending on distribution of elements in the soil profile and transition rates between pools.

Simulation of phosphorus concentrations was performed for the same periods, as the water flow simulation, but calibration and validation were made only for the years with data about phosphorus concentrations in the outlet: 1984 was used for calibration and 2010 and 2012 for validation. The values of the calculation quality criteria for the results of modeling the concentrations of phosphorus are given in Table 3. To assess the simulation quality of biogenic flow, a different set of indicators is used, since the time series of concentrations has a different statistical nature, and the observed values are available for comparison with a much greater discreteness. The results satisfy our standard error value only for 1984 for dissolved phosphorus, the correlation coefficient value for dissolved phosphorus in 2012 and 1984, and for total phosphorus in 2012. It is important to note that using of quality criteria for daily concentrations gives too detailed result and can be treated as additional information. When we compared annual and seasonal phosphorus flow, calculated from modelling results, observed data the relative error fell inside the limits of 0 – 76%. The essential point to remember is that the error of water sample analysis, which attains sometimes tens of percent, is comprised by the error of model calibration.

Combining the phosphorus concentrations hydrograph for total and dissolved phosphorus (Figure 3) shows the partial coincidence of peaks and accordance of simulated and observed concentrations in general. Concentrations overestimation within the region of summer and autumn floods and underestimation of spring hydrograph region can be explained for the most part by similar discrepancies in the simulation of water flow, since the form of concentration hydrographs is very sensitive to changes in flow. Important deviations of total concentrations are due to underestimation of suspended phosphorus. The suspended phosphorus flow mainly depends on suspended solids. So, during the calibration, the values of the parameters concerning soil erosion have been set to correspond the values, which were measured on the outlet gauge in 2016, which is the fact that the flow of suspended solids should not exceed 500 – 600 tons per day. We don't discuss the results for suspended phosphorus flow here a lot because on the current stage of the model calibration, we consider them as less reliable than the results for dissolved phosphorus due to the lack of the data on suspended solids concentrations in river water.

For 1984, we have performed an experiment to make an increase of the amount of fertilizer applied. Thus, before the experiment, the model was adjusted to apply mineral fertilizers only on arable lands with intensive use and kitchen gardens (48 and 60 kg / ha per year, respectively, in spring and 32 kg / ha at the end of summer only for arable lands). The experiment suggested that fertilizers are applied on all the fallows with proportional diminution by landuse intensity. This caused slightly worse values of simulation quality criteria, but, as a result, concentrations corresponded better to the extreme values of phosphorus concentrations observed. The common area of fertilized land for the experiment was three times bigger, since for current period it's three times smaller than during 1980 – 1985 years. It arises from the results of the field survey.

The parameterization of the latter experiment was used for the following research because it complies the most with the real situation in the watershed area. Based on it, the influence of mineral fertilizers on phosphorus flow has been studied. We have been divided years from 2000 to 2018 into groups of wet, medium and dry years using subtractive-cumulative curves method. For dry and wet groups, phosphorus flow has been calculated from the results of simulation. Dissolved phosphorus average flow in wet years was 24440 kg/year, in dry years it didn't exceed 6550 kg/year.

Table 3. Simulation quality criteria for optimal values of model parameters for simulation of phosphorus concentrations for separate years. SP – dissolved phosphorus, TP – total phosphorus

	RMSE		MAE		r		TEIL		SDobs/2	
	SP	TP	SP	TP	SP	TP	SP	TP	SP	TP
2010	57.3	76.4	41.6	61.2	0.28	0.22	0.33	0.23	29.1	28.6
2012	67.5	82.5	42.5	51.7	0.56	0.73	0.28	0.39	23.5	15.3
1984	82.2	98.7	43.5	56.8	0.50	0.30	0.43	0.37	39.3	26.2
1984**	85.3	105.2	47.4	63.0	0.50	0.31	0.42	0.38	39.3	26.2

**RMSE - root mean square error, TEIL – Teil criterion*
*** simulation with an increase of fertilized area*

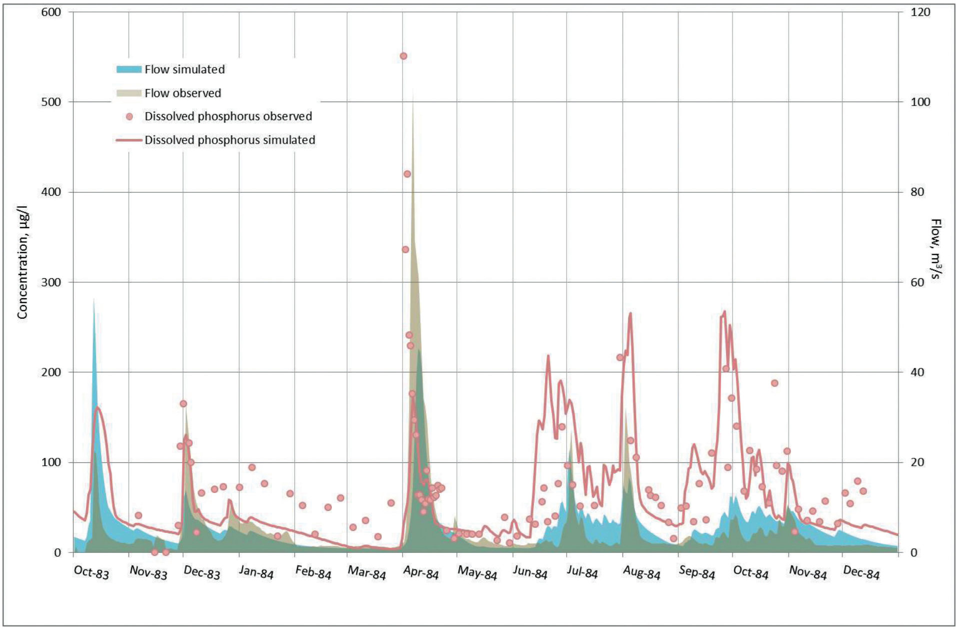

Fig. 3. Combining results of dissolved phosphorus concentration and water flow simulation at the outlet of the Moskva river (Barsuki village) in 1984

Then, we have performed another simulation having set values of mineral fertilization for every landuse to zero. The results of this simulation have been compared with the basic simulations for 1984 and 2012 years. This experiment has shown that applying no fertilizers results in decreasing of the dissolved phosphorus flow during spring flood by 5% (360 kg) in wet and by 11% (410 kg) in dry years. Average annual total phosphorus flow is decreasing then by 7 – 8%.

The genetic components of the phosphorus flow have been analyzed for 1984 and 2012 years, as they are both rather well covered with data.

Table 4. Total phosphorus average monthly flows with genetic components of water flow in 1984 compared with 2012 for summer and spring periods, kg/km²

Components	1984		2012	
	Spring	Summer	Spring	Summer
Average				
Surface	0.51	0.40	1.94	0.02
Subsurface	3.22	5.90	4.29	1.94
Groundwater	0.39	0.44	0.33	0.29
Summary	4.12	6.74	6.56	2.25
Maximum				
Surface	1.57	3.73	6.06	0.29
Groundwater	0.49	0.60	0.46	0.38

The phosphorus loads on 3 soil layer is rather constant, 0.65 kg/km^2 average and 1.4 maximum. It corresponds to 10 – 30% of local phosphorus flow for average and to 4 – 12% for maximum values. As it follows from the table 4, the surface and the groundwater components of phosphorus flow are comparable and the subsurface component in comparison is greater by value. It was estimated as 65% of summary flow. This corresponds well to the water flow by different soil layers, as in 1984 the surface component of water flow was 12% of total local flow, the groundwater was 21%. During the wet 2012 year, the surface component runs up to 25%. The analysis of different components of the phosphorus flow mapped for the watershed area shows higher groundwater flow for forested areas and higher surface flow for agricultural areas with intensive landuse.

CONCLUSION

The amount of unused land has increased 3 times since the 1980s. On abandoned lands, the content of total phosphorus and nitrogen is 15–20% higher than that of used ones, while mobile phosphorus is 50–70% higher. The highest content of all forms of phosphorus and nitrogen is observed on floodplain meadows.

Model HYPE satisfactorily reproduces water runoff from the catchment area of the Moscow river. Phosphorus concentrations have been simulated in conformity with observed phosphorus concentration changes, but some quantitative criteria of simulation quality yet are not satisfactory. However, the model can be used for calculations of phosphorus loads at the current stage of calibration on condition of good water flow simulation. Errors in phosphorus simulation are caused by extremely poor data on observed concentrations in water, by complexity and large errors of phosphorus observation methods themselves and high sensitivity of the shape of concentration plots to changes in water flow hydrograph.

The results of experiments with the model show a decrease of dissolved phosphorus flow subsequent to cease of fertilizing in range from 5 to 11%.

The values of the surface and groundwater components of phosphorus flow are comparable, while soil component amounts 65% of local phosphorus flow. It mainly corresponds to the distribution of components of the water flow.

It should be emphasized that the simulation of nutrient runoff with distributed or semi-distributed parameters is one of the best way to gain knowledge about the influence of the location and landuse, as well as of the change in forest area, on phosphorus flow. Further work with the involvement of more data could allow to get a more detailed analysis of nutrient concentrations carried out on the basis of the model.

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