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Construction of a model of nutrient export from the catchment using GIS-technologies for a transboundary river in Russia and Finland

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Abstract. GIS model SWAT to assess the nutrient load on the catchment area of the Gulf of Finland from the transboundary Seleznevka River (Rakkolanjoki) was applied. All stages of the model setup are considered: preparation of initial data, building the SWAT-model, its calibration and scenario calculations. We consider the possibility of using the SWAT-model for managing the quality of water bodies in Russia and the difficulties that arise while building a model for this catchment area.

1. Introduction

To solve one of the main environmental problems of the Baltic Sea and, in particular, of the Gulf of Finland – eutrophication, Helsinki Commission (HELCOM) adopted in 2007 the Baltic Sea Action Plan, according to which one of the primary goals of the countries located in the catchment area of the Baltic Sea is the development of measures to reduce the supply of nutrients to the marine ecosystem, which accelerate the processes of eutrophication. The availability of reliable information on the amounts of nutrients coming from the catchment areas of rivers is a key element for achieving this goal [1-4].

To assess the nutrient load from the catchment area of the Gulf of Finland, regular monitoring data are required. However, with an insufficient number of regular measuring stations on the rivers of the Leningrad Region and limited data series, it is promising to use mathematical modeling methods, including the use of GIS technologies [5].

One of the most widely used models in Russia for calculating nutrient removal based on mathematical modeling is the ILLM nutrient load model developed by the Institute of Limnology of the Russian Academy of Sciences. The model is a simple tool used to assess the external load from point and diffuse sources in conditions of scarce monitoring data and accounts for retention of nutrients by the catchment and water body; it allows to predict the nutrient load transformation due to anthropogenic and climatic changes [5-7].

The ILLM model was also used to scientifically support the implementation of the recommendations of the HELCOM Baltic Sea Action Plan for Russia. The model was used to calculate the nutrient load of total nitrogen and total phosphorus from different parts of the Russian catchment area of the Gulf of Finland (catchments of the Neva and Narva rivers, catchments of the Ladoga, Onega, Ilmen and Peipsi lakes). The model is also applicable for calculating the removal of some dissolved metals from river catchments. The calculation step is a year. The advantages of the model, besides its low requirements to resolution of the input data, include its easy-to-use mode and

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open access. To obtain the most accurate modeling results, it is recommended to make calculations for relatively large catchments [5-7].

An example of the application of geographic information systems (GIS) for mathematical modeling of nutrient load on the catchment is the dynamic model FyrisNP, developed by the Swedish University of Agricultural Sciences [8]. This model determines the load of total nitrogen and total phosphorus on the catchment of water bodies from natural and anthropogenic sources and the amount of removal of nutrients from the catchment into the receiving water body, including the retention capacity of the drainage basin.

The FyrisNP model was originally developed to calculate the distribution of nitrogen and phosphorus transport sources in the catchment of the Fyris River in central Sweden [8]. The model was also used to calculate the values of nutrient load from the drainage basin of the transboundary Pregolya River in the Kaliningrad Region, in the South-West Baltic (river flows through the territory of Poland and Russia into the Baltic Sea) and to identify priority sources of nutrients [9]. This model has higher resolution as compared to ILLM model: the time step of the model is one month. A relatively small amount of input data is required to run the FyrisNP model. The model is used for reservoirs up to 50,000 km^2 [8].

This paper discusses the possibility of using the SWAT (Soil and Water Assessment Tool) model to assess the nutrient load for the conditions of the coastal zone of the Gulf of Finland. The model is the most developed and tested geographic information system for complex predictive modeling of nutrient flows in the river's catchment area in the world [10]. For the successful implementation of the model, a large amount of high—resolution and high-quality input data is required, which allows the model to be used to solve a number of problems, and that is one and only disadvantage of this powerful tool, restricting its application in the Russian Federation. Depending on the given input variables, using the model, it is possible to predict the consequences of anthropogenic activities and agriculture on landscape components, bottom sediments, pesticide migration, yield and bioproductivity [11]. The main advantages of the SWAT model are: its open access; it solves a wide range of assessment tasks; effective modeling for long forecast periods; visual presentation of simulation results in the form of graphs and animated drawings, the time step of the model is 24 hours [10].

Successful implementation of the SWAT model with correctly specified initial data makes it possible to obtain model estimates of the load of all forms of nutrients coming from the catchment (including organic and inorganic forms), to determine the sources of excess nutrients, and is a powerful tool for predicting the impact of economic activities on the catchment, including the impact of climatic changes.

2. Materials and methods

The SWAT model was developed by the USDA Agricultural Research Service to quantify the impact of land management practices in large and complex watersheds. The model is widely used to study the impact of land use change and weather conditions within the studied model basins [10-13].

In this study, the SWAT model was used on the free Quantum GIS platform. The time step of the model is one day.

The object of research is the transboundary Seleznevka River (Rakkolanjoki), which originates in Finland and flows into the Vyborg Bay of the Gulf of Finland on the territory of Russia. This is a relatively small river 33 km long, has a catchment area of 215 km^2, the territory of which is mainly covered with forests, to a lesser extent agricultural land, urbanized areas, water bodies and swamps. The following types of soils are characteristic for the territory of this catchment: rocks, moraines, coarse soils, clays, peat soils. The largest point source of pollution of the river is the Finnish city of Lappeenranta with a population of 72 thousand people.

Since November 2018, regular hydrological and hydrochemical observations have been carried out on the Seleznevka River as part of the Russia-South-East Finland 2014-2020 Cross-Border Cooperation Program. At two monitoring stations, once a month, water samples are taken to determine the physical properties, main ions, gas composition, organic and pollutants, nutrients and pollutants of inorganic origin.

Table 1. The initial data for SWAT model.

The initial data	Format
Digital elevation map (DEM)	Raster file (.adf, .tiff)
Soil and landuse maps	Raster files (.adf, .tiff)
Stream network	Shapefile (.shp)
Wastewater discharge source	Shapefile (.shp)
Lookup tables for soil and landuse maps	.csv
Station information	.txt
Daily climatic data: — Temperature (min and max value) [ºC] — Precipitation [mm] — Solar radiation [MJ/m²/day] — Relative humidity [%] — Wind speed [m/s]	.txt

The monitoring data made it possible to prepare the necessary baseline data, which, with a high degree of detail, describe the various characteristics of the system within the catchment. These data made it possible to identify the corresponding sub-basins, and then - elementary hydrological units (HRUs), each of which is homogeneous in terms of soil cover, relief element, type of land use or vegetation cover. The initial data (table 1) in the form of maps with a high degree of detail made it possible to identify each elementary hydrological unit, and then calculate the nutrient load for each HRU, taking into account the volume of fertilization, surface runoff, growing crops, weather conditions and other factors. At the next stage, the model includes a database of weather conditions, created on the basis of daily data from hydrometeorological monitoring. Ultimately, the simulation results were visualized.

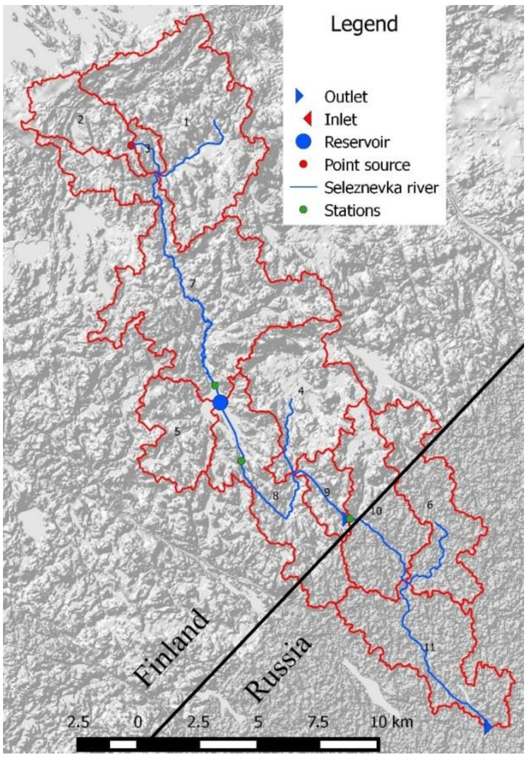

Figure 1. Catchment of the Seleznevka (Rakkolanjoki) River with delineated 11 sub-basins.

Thus, the SWAT model was tested for the conditions of the Leningrad Region in the catchment of the Gulf of Finland, and also identified the limitations of using the model and creating files with initial data that meet the requirements of the model. At the next stage, verification and calibration of the model and scenario calculations were performed.

3. Results and discussion

As part of the work with the SWAT model for the catchment area of the Seleznevka River, the initial data with the necessary extensions were prepared, which were used when starting the model. Figure 1 shows the catchment area of the Seleznevka River, divided into 11 sub-basins and 278 HRUs.

One of the advantages of the SWAT model is a good visualization of the results and the ability to present the obtained values of the parameters calculated by the model in the form of graphs and animated drawings. Figure 2 shows one of the options for the visual representation of the calculated parameter values (river runoff values (m^3/s), total nitrogen and total phosphorus load (kg)).

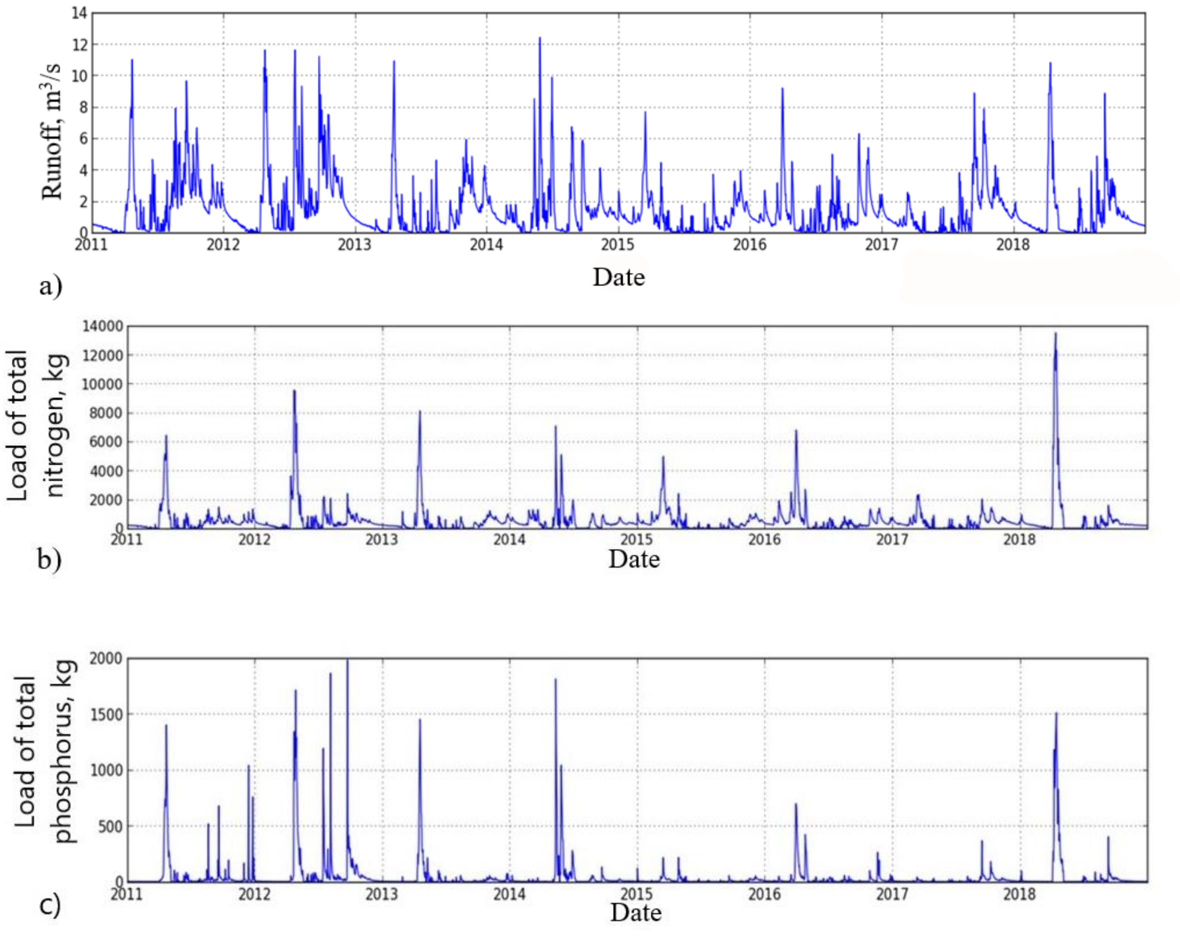

Figure 2. Parameter values calculated using the SWAT model for the period 01.01.2011-31.12.2018: a) river runoff values (m^3/s), b) load of total nitrogen (kg) and c) load of total phosphorus (kg).

At the stage of model testing in 2020, and in the absence of a sufficient amount of field data due to epidemiological constraints, for the calibration of the SWAT model the calculated values of the characteristics (values of river runoff (m^3/s), loads of total nitrogen and total phosphorus (kg)) were compared with values from the Finnish model Vemala, which has been successfully used to estimate nutrient loading in Finnish river catchments of the same size and characteristics. When calibrating, a large number of parameters were enumerated, depending on the load of point sources, the number of fertilizers applied, the underlying surface, the value of total evaporation, etc.

From table 2 it can be seen that the values of the parameters calculated by the SWAT model are overestimated, which may be due to insufficient knowledge and debugging mechanisms for calculating individual characteristics in the model. In this case, you can observe the realistic dynamics of changes in the calculated parameters. At the next stage, at the end of the field observation period in 2021, the SWAT model will be calibrated based on field data.

Table 2. Average values of parameters calculated by SWAT model after calibration.

	Runoff, m^3/s	Load of total nitrogen, kg/ha	Load of total phosphorus, kg/ha
Model Vemala	1.4	12.6	0.3
Model SWAT	1.4	12.8	1.2

Also, during the study, the first scenario calculations were made: reducing the load from a point source by half (50%) and in full (100%); the presence of buffer zones; allocation of new wetlands. These calculations were performed to identify the overall impact of the given parameters on the nutrient load on the catchment of the Seleznevka River. Implementation of the selected scenarios will lead to a decrease in the nutrient export from the catchment area.

4. Conclusion

The application of the SWAT model to the conditions of the coastal zone of the Gulf of Finland revealed some limitations of its application.

Firstly, this is the lack of baseline data due to insufficient coverage of the monitoring network in Russia, which necessitated additional monitoring studies by the North-West Department on Hydrometeorology and Environmental Monitoring in 2019.

Secondly, the input data for the model in the form of digital maps requires a high resolution, an appropriate degree of detail and specification of characteristics in accordance with the encodings of the SWAT model.

At this stage of the study, the calculation mechanisms on the SWAT model for the catchment area of the transboundary river Seleznevka are being finalized, and also the SWAT model will be calibrated based on monitoring data, and scenario calculations will be completed.

After all the necessary modifications, the SWAT model will allow the planning of economic activities in the transboundary catchment, taking into account various scenarios reflecting changes in economic activities in the catchment and future climatic changes. Ultimately, the model may be used as a universal method of planning economic activities in the catchments of the North-West of Russia.

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References

[1] HELCOM Baltic Sea Action Plan 2007 (Helsinki Commission Publ. Helsinki) pp 103

[2] Korobchenkova K D and Ershova A A 2020 Postroyeniye modeli vynosa biogennykh elementov s vodosbora s primeneniyem GIS-tekhnologiy dlya rek Leningradskoy oblasti [Building a model for nutrient export from the catchment area using GIS technologies for rivers of Leningrad region] *Sbornik tez. Mezhdunarodnoy nauchno-prakticheskoy konferentsii, posvyashchennoy 90-letiyu RGGMU* [Proc. of the International scientific-practical conference dedicated to the 90th anniversary of the RSHU] pp 617-618

[3] Ershova A A, Korobchenkova K D and Agranova Yu S 2018 Otsenka sostoyaniya Finskogo

zaliva po indikatoram evtrofirovaniya KHELKOM [Assessment of the state of the Gulf of Finland based on HELCOM indicators of eutrophication] *Uchenyye zapiski Rossiyskogo gosudarstvennogo gidrometeorologicheskogo universiteta* [Scientific Notes of the Russian State Hydrometeorological University] **51** pp 137-149

[4] Kondratyev S A, Shmakova M V, Bryukhanov A Yu, Viktorova N V, Ershova A A and Oblomkova N S 2018 K otsenke biogennogo stoka v Finskiy zaliv Baltiyskogo morya [To the evaluation of nutrient removal to the Gulf of Finland of the Baltic sea] *Uchenyye zapiski Rossiyskogo gosudarstvennogo gidrometeorologicheskogo universiteta* [Scientific Notes of the Russian State Hydrometeorological University] **51** pp 109-120

[5] Kondratyev S A 2015 Otsenka sovremennoy biogennoy nagruzki na rossiyskuyu akvatoriyu Finskogo zaliva I yeye sootvetstviye mezhdunarodnym trebovaniyam [Assessment of the current nutrient load on the Russian water area of the Gulf of Finland and its compliance with international requirements] *Trudy Vserossiyskoy nauchnoy konferentsii Nauchnoye obespecheniye realizatsii Vodnoy strategii Rossiyskoy Federatsii na period do 2020 g.* [Proc. of the All-Russian Scientific Conference Scientific support for the implementation of the Water Strategy of the Russian Federation for the period up to 2020] (Petrozavodsk) **1** pp 439-446

[6] Kondratyev S A, Ignatyeva N V, Shmakova M V, Ershova A A, Minakova E A and Terekhov A V 2020 Model-based assessment of nutrient load into water bodies from different landscape types *Landscape Modelling and Decision Support. Ser. Innovations in Landscape Research* pp 299-310

[7] Kondratyev S A, Ershova A A, Ekholm P and Victorova N V 2019 Nutrient load from the russian territory on the Gulf of Finland *Fundamentalnaya I prikladnaya gidrofizika* [Fundamental and applied hydrophysics] **12** 2 pp 77-87

[8] Hansson K, Wallin M, Djodjic F and Lindgren G 2008 The FyrisNP model. Technical description (Uppsala: Dept. of Aquatic Science and Assessment SLU) pp 17

[9] Gorbunova Yu A, Chubarenko B V and Domnin D A 2018 Metodika vydeleniya prioritetnykh istochnikov biogennoy nagruzki s vodosbornogo basseyna reki Pregoli [Methodology for identifying priority sources of nutrient load from the drainage basin of the Pregolya River] *Izvestiya KGTU* [Proceedings of KSTU] **50** pp 13-25

[10] Gassman P W, Reyes M R, Green C H and Arnold J G 2007 The Soil and Water Assessment Tool: Historical Development, Application, and Future Research Direction *SWAT.American Society of Agricultural and Biological Engineers* **50** 4 pp 1211-1250

[11] Lychak A I 2011 Prognoznoye modelirovaniye geoecologicheskikh situatsiy v Krymu s ispolzovaniyem SWAT-modeli [Predictive modeling of geoecological situations in Crimea using the SWAT model] *Uchenyye zapiski Tavricheskogo natsionalnogo universiteta imeni V I Vernadskogo* [Scientific notes of the Tavricheskiy National University named after V.I. Vernadsky] **24** 2 pp 116-121

[12] Soil and Water Assessment Tool: Input/Output Documentation 2012 (College Station, Tex.: Texas A&M University) pp 649

[13] Soil and Water Assessment Tool Theoretical Documentation 2009 (College Station, Tex.: Texas A&M University) pp 647