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SEVIRA modelling report 1

Output 2.2. Calculation of runoff and nutrient load under present conditions

Output 2.3. Output 2.3. Building up the scenarios and estimation of future nutrient loads

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Content

Introduction 2
Site descriptions 2
Virojoki 2
Rakkolanjoki 3
Sestra (Rajajoki; Siestarjoki) 4
Land use change during 2000-2018 5
Calculation of runoff and nutrient load under present conditions 7
Short description of the ILRAS models 7
VEMALA model 9
ILRAS model's calibration and testing 10
Building up the scenarios and estimation of future nutrient loads 13
Climate scenarios 13
Climate scenarios based on VEMALA model 20
Land use changes 22

Conlusions and discussion....24
References....25

Introduction

In the SEVIRA project, two models developed in Russia / ILRAS (ILHM = Institute of Limnology Hydrological Model, ILLM = Institute of Limnology Load Model) (Kondraytev, 2007; 2019) were applied to all three pilot areas and one operational Finnish model, called VEMALA was applied to one pilot area (Huttunen et al., 2016). Of the pilot areas one was located entirely on the Finnish side, one entirely on the Russian side and a third on the transboundary area.

The modeling was used to study the impact of climate change and land use changes on hydrology and nutrient loading in the pilot areas. The flow and water quality data collected in the SEVIRA project were utilized in the calibration and testing of the models. The model results were also compared with the results of the VEMALA model developed in Finland. We used climate scenarios which were calculated using the Institute Pierre Simon Laplace climate model (IPSL-CM5A, 2010 – until now, see IPSL Climate Models – My CMS). Changes in land use over the last 20 years were also investigated using spatial data sets (CORINE land use data, Büttner et al., 2004)).

Site descriptions

Virojoki

The Virojoki catchment (357 km^2) in south-eastern Finland belongs to the cold boreal region. The 43-km long Virojoki river drains the watershed into the Gulf of Finland of the Baltic Sea. The average annual precipitation in the area during the last decade was 728 mm. Land elevation ranges between 0 and 122 m a.s.l., the highest altitudes being in the northern parts of the catchment. Rock (<1m soil layer) is the dominant (42%) soil type, followed by clayey (16%), moraine (15%) and peat (14%) soils. In terms of land use, forest (79%) is by far the dominant class. Agricultural areas (13%) are concentrated in the central and southern parts of the catchment on mostly clayey soils. The rest of the Virojoki catchment area is covered by urban areas (3%), water (3%) and wetlands (2%) (Figure 1).

Table 1. Pilot area summary table.

Catchment	**Area km2**	**Agricultural area %**	**Urban %**	**Dominant soils**	**Mean flow m3/s**

Virojoki	357	13	3	Rock, clay	4
Rakkolanjoki	215	11	7	Rock, coarse	2,2
Sestra	381	7+5	9	Podzol, peat	6

At the Salmen Silta measurement station near the Virojoki river outlet, the average (2000–2019) flow was 4.0 $m^3 s^{-1}$ and it ranges between 0.1 and 33 $m^3 s^{-1}$. The Virojoki river flows into the Vironlahti Bay, which is a bordering body of water between Finland and Russia. In the upper reaches of the catchment there are two peat mining areas and at the river outlet there is the wastewater treatment plant of the Vironlahti municipality (3 100 inhabitants). However, these point sources account for a negligible part of the anthropogenic nutrient loading from the Virojoki catchment into the Gulf of Finland, the largest shares (87% of total P and 67% of total N loading) being from agriculture (Vemala-model, Huttunen et al. (2016)). Within the catchment there are 1 133 people living in properties not connected to the sewer networks, i.e. with onsite wastewater treatment. On top of this there are 476 summer cottages.

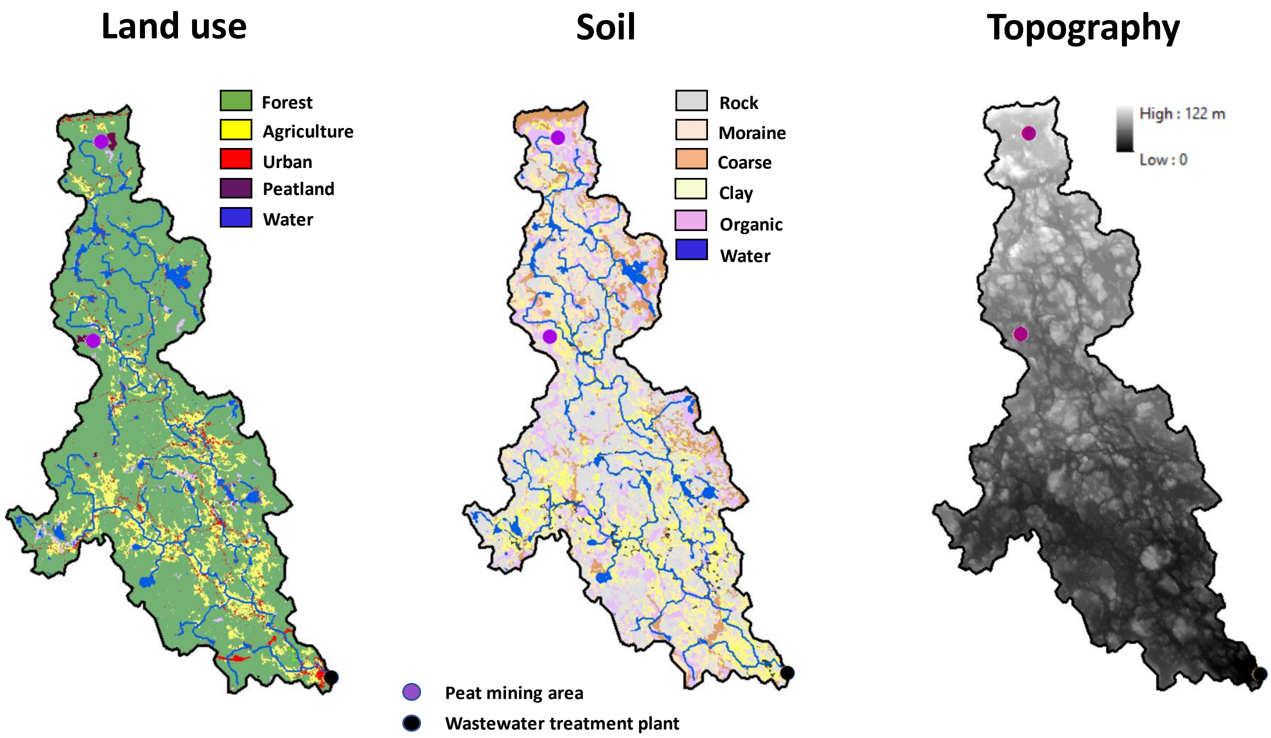


Figure 2. Land use, soil and topography of the Virojoki catchment.

Rakkolanjoki

The Rakkolanjoki cross-border catchment (215 km^2) is located in south-eastern Finland and north-eastern Russia, and it belongs to the cold boreal region. The 33-km long Rakkolanjoki river drains the watershed into the Bay of Vyborg in the Gulf of Finland. The average annual precipitation in the area (Lappeenranta) during the years 1981–2010 was 648 mm. The land elevation ranges between 0 and 115 m a.s.l., the highest altitudes being in the northern parts of the catchment. Rock (<1m soil layer) is the dominant (37%) soil type, followed by coarse (20%), clayey (17%), moraine (11%) and peat (11%) soils. In terms of land use, forest (62%) is the dominant class. Agricultural areas (11%) are concentrated in the northern parts of the catchment in the Finnish side, on mostly clayey soils. Urban areas – mostly by the Finnish town of Lappeenranta – cover 7% of the Rakkolanjoki catchment. Water occupies 6%) and wetlands 2% of the catchment.

The average (2000–2016) flow was 2.2 $m^3\,s^{-1}$ and it ranges between 0.3 and 19 $m^3\,s^{-1}$. The Rakkolanjoki river flows into the Vyborg Bay in Russia. In the Rakkolanjoki catchment there is one major source of point pollution, i.e. the wastewater treatment plant of the Lappeenranta town (72 000 inhabitants). This large point source accounts for the bulk of the nutrient loading from the Rakkolanjoki catchment into the Russian side and finally to the Vyborg Bay; 56% of total P and 82% of total N loading (Vemala-model, Huttunen et al. (2016)). Within the Finnish side of the catchment there are 1 343 people living in properties not connected to the sewer networks, i.e. with onsite wastewater treatment. On top of this there are 72 summer cottages.

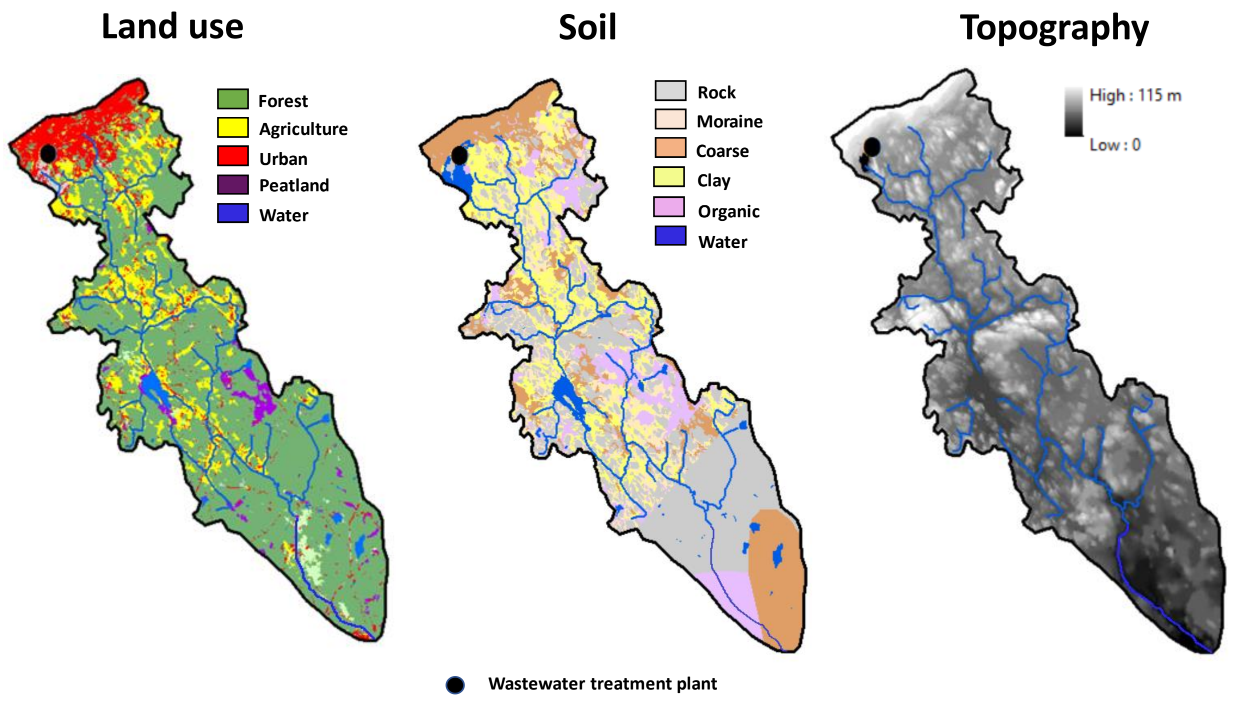


Figure 2. Land use, soil and topography of the Rakkolanjoki catchment.

Sestra (Rajajoki; Siestarjoki)

The Sestra catchment (380.7 km^2) is located in the north-eastern Russia. The Sestra river is 74-km long and it drains into the man-made reservoir – lake Sestroretsky Razliv. The average annual precipitation in the area during the last decade was 648 mm. The land elevation ranges between 10 and 170 m a. s. l. The highest altitudes are in the northern parts of the catchment. Podzols and peat are the dominant soil types. In terms of land use, forest (68 %) is the dominant class. Marshes (11 %) are concentrated in the northern and southern parts (near the Sestroretsk reservoir) of the catchment. The rest of the Sestra catchment area is covered by fields (7 %), meadows (5 %) and urban areas (3 %).

At the measuring station near the Sestra river outlet, the average flow was 5.95 m^3s^{-1} (2019) and it ranges between 1.59 and 24.5 $m^3\ s^{-1}$. At the river outlet there is the wastewater treatment plant belongs to the Sestroretsk municipality. However, within the catchment there is a settlement Beloostrov with 2 295 people, living in properties not connected to the sewer networks and with onsite wastewater treatment

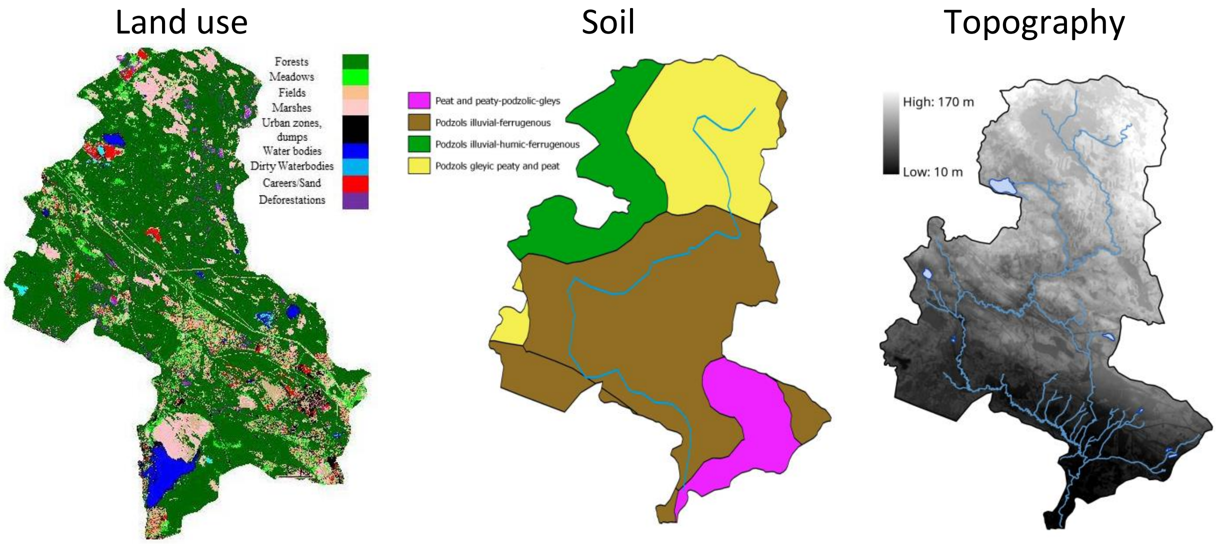


Figure 3. Land use, soil and topography of the Sestra catchment.

Land use change during 2000-2018

Changes in land use in both the Virojoki and Rakkolanjoki catchments have been small over the last 20 years (Table 2). Land used for agriculture has decreased on the Virojoki area by 163 ha (=3%), while there has been a slight increase (11 ha that is 0.3%) in the

Rakkolanjoki River basin. The build-up area in both catchments has increased, in Virojoki 133 ha (=10 %) and in Rakkolanjoki 109 ha (=5.5%). Growth and decrease typically occur

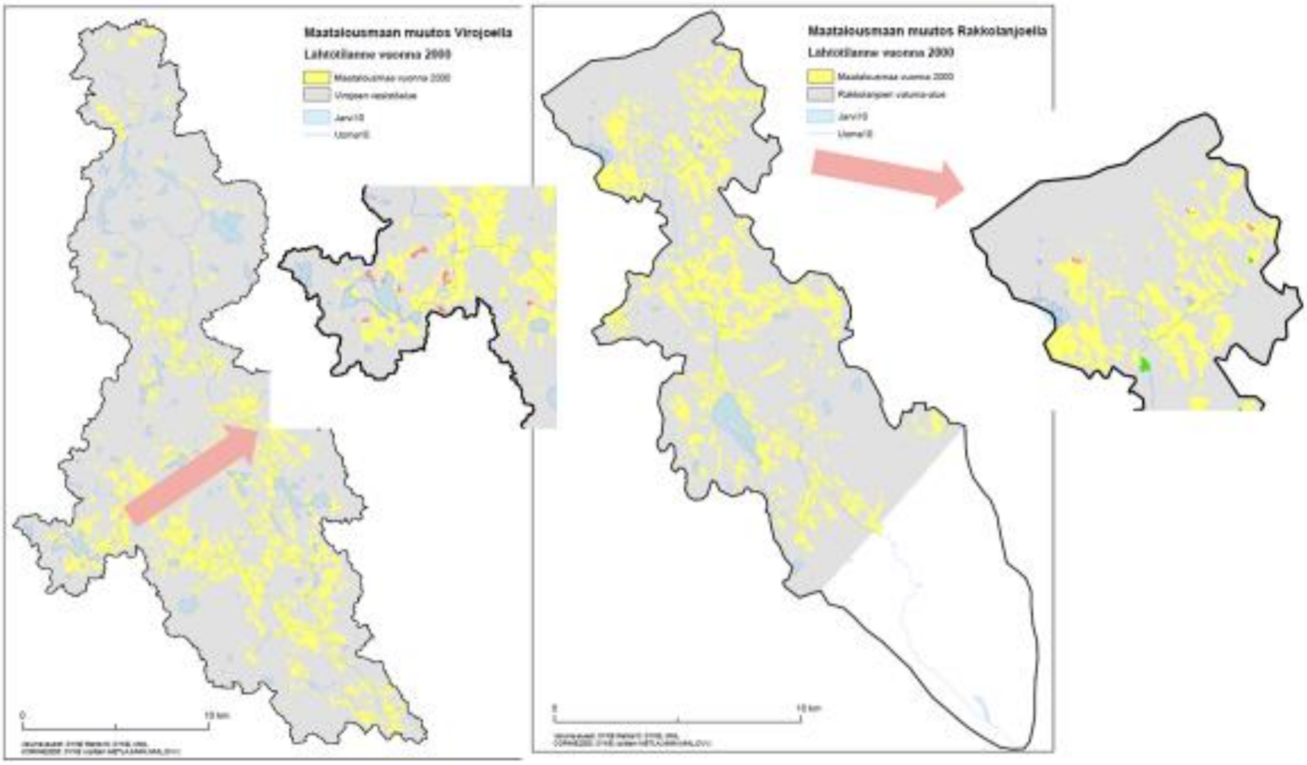


Figure 4. Agricultural area (yellow) of the Virojoki and Rakkolanjoki catchments in 2000. The small figure shows, by way of example, a change - an increase in green and a decrease in red.

in individual areas (see Figs. 4–5), unless it is, for example, a larger construction project for a new resettlement area. Based on these results, it is not possible to predict the direction or magnitude of the changes in the future. However, it is assumed that the changes will be rather percentages than tens of percents per two decades.

Table 2. Change in agricultural and build-up areas during 2000–2006, 2006–2012 and 2012-2018 in the Virojoki and Rakkolanjoki catchments in Finland.

Period	Virojoki		Rakkolanjoki		Virojoki		Rakkolanjoki	
	increase in agri area (ha)	decrease in agri area (ha)	increase in agri area (ha)	decrease in agri area (ha)	increase in build-up area (ha)	decrease in build-up area (ha)	increase in build-up area (ha)	decrease in build-up area (ha)
2000-2006	+12	-75	+64	-17	+24	-	+63	-1
2006-2012	+4	-92	+6	-62	+16	-	+50	-25

2012-2018	+9	-21	+26	-6	+93	-	+22	-
Σ	**+25**	**-188**	**+96**	**-85**	**+133**	**-**	**+135**	**-26**

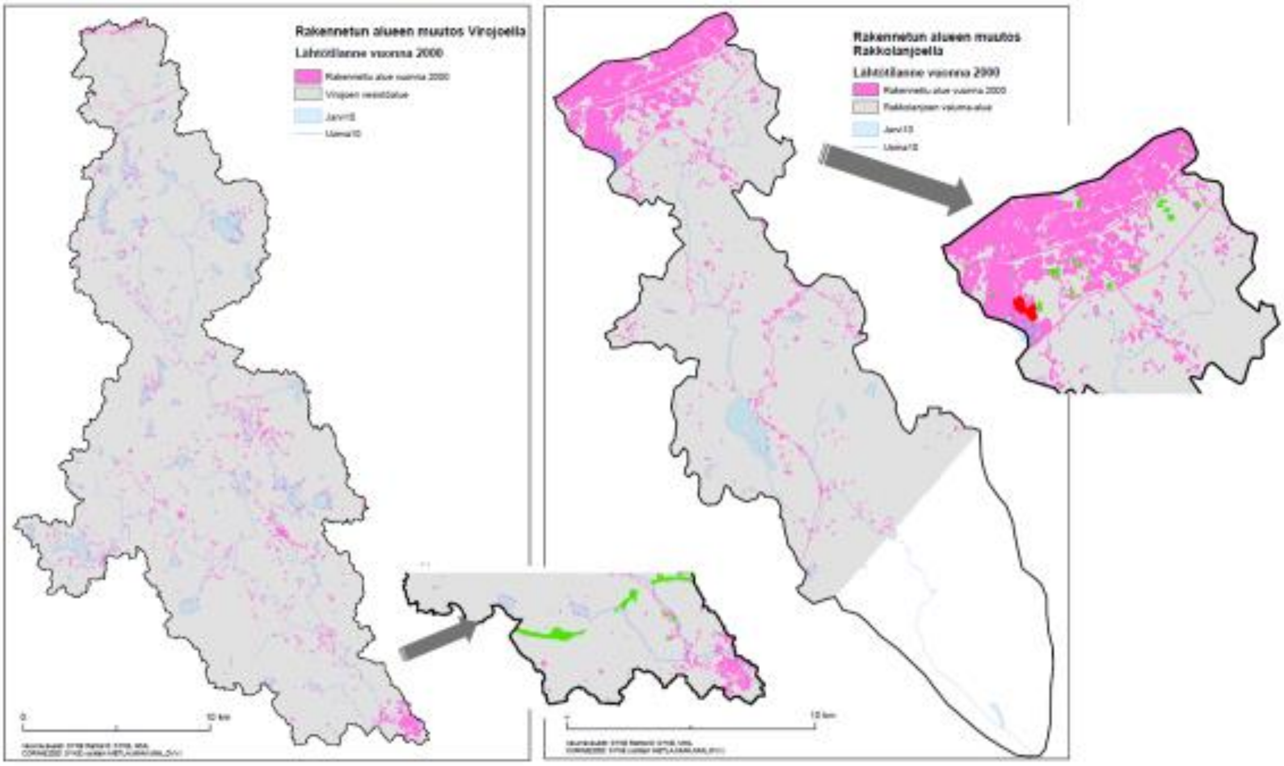


Figure 5. Build-up area (lilac) of the Virojoki and Rakkolanjoki catchments in 2000. The small figure shows, by way of example, a change - an increase in green and a decrease in red.

Calculation of runoff and nutrient load under present conditions

Short description of the ILRAS models

The runoff model - ILHM (Institute of Limnology Hydrological Model) was developed at the Institute of Limnology RAS (Kondratyev & Shmakova, 2005, 2019; Kondratyev, 2007) and is designed for calculations of hydrographs of snowmelt and rainfall runoff from the catchment area, as well as water levels in the waterbody. The model has a conceptual framework and it describes the processes of snow accumulation and snowmelt, evaporation and soil moisture in the aeration zone, runoff formation, as well as runoff within a homogeneous catchment, the characteristics of which are assumed to be constant for the entire area.

The model functions both with a monthly time step and with an annual time step. During the simulation, the catchment is represented as a homogeneous simulated storage accumulating incoming water and then gradually allowing it to flow away. The values of the basic parameters of the hydrological model, determining the shape of the runoff hydrograph, are determined depending on the ratio of the water area to the overall area of the catchment.

The model also takes into account the depth of the water body receiving runoff from the catchment, evaporation from water surface and water outflow (Fig. 6). The model has been verified in a number of facilities located in the north-western region of Russia (river catchments Tigoda, Lizhma, Syanga, Olonka, Sunnah, Shuya, Ojat, Sjas, Vuoksa, Svir, Velikaya and Neva) (Kondratyev & Shmakova, 2005, 2019; Kondratyev et al., 2008) and Finland (river catchments Mustajoki and Harajoki) (Kondratyev et al., 2003).

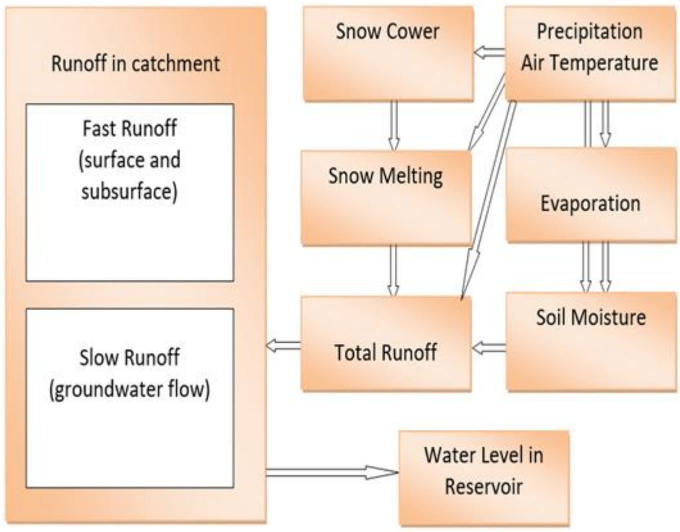


Fig. 6. Schematic picture of the hydrological model ILHM.

The model of nutrient loading – ILLM (Institute of Limnology Load Model) was developed on the basis of existing modeling of runoff and removal of nutrients from the catchment areas and nutrient inputs into the water bodies (Kondratyev, 2007; Kondratyev & Shmakova, 2019; Kondratyev et al., 2011, 2021). The recommendations of HELCOM for assessing the load on water bodies of the Baltic Sea were also built into the model [HELCOM, 2005]. The model is designed to solve problems associated with the quantification of nutrient load formed by point and nonpoint sources of pollution, and to forecast of its changes under the influence of possible anthropogenic and climatic changes. The model incorporates the existing capabilities of data input from the state monitoring system of water bodies, as well as of materials of state statistical reporting on wastewater discharges and agricultural activities in catchment areas.

The model also allows the calculation of the removal of nutrients from the catchment with the influence of hydrological factors and retention by the catchment. The final result of the model is an evaluation of the nutrient load and its components on the water body from the catchment (Fig. 7).

The ILRAS nutrient loading model has been verified at a number of sites located in the Northwest region of Russia in the catchment areas of the rivers Velikaya, Luga, Mga, Izhora and Slavyanca (Kondratyev et al., 2011). According to the Balthazar II (2012, component 2.2) *"…the ILLM model can be used to calculate the nutrient load on Baltic Sea from non-monitored and partly-monitored areas in Russian part of catchment area"*. In conclusions on the project RusNIP II Implementation of the Baltic Sea Action Plan (BSAP) in Russian Federation (RusNIP II, 2015) is said that *"The ILLM model is most suitable for use in relatively large catchments".*

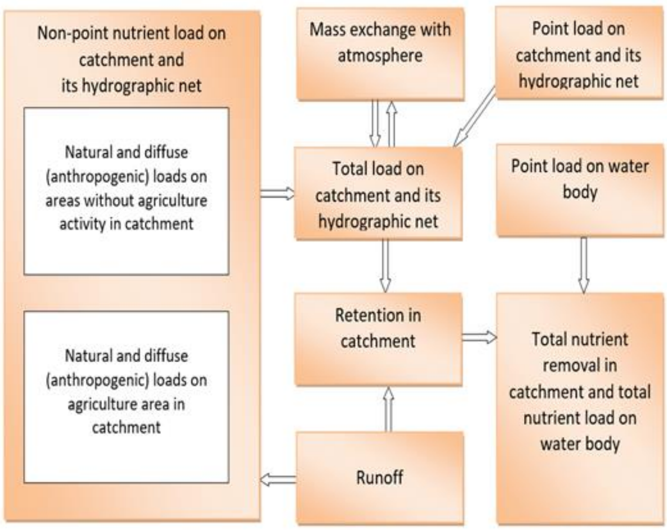


Fig. 7. Schematic picture of the load model ILLM.

VEMALA model

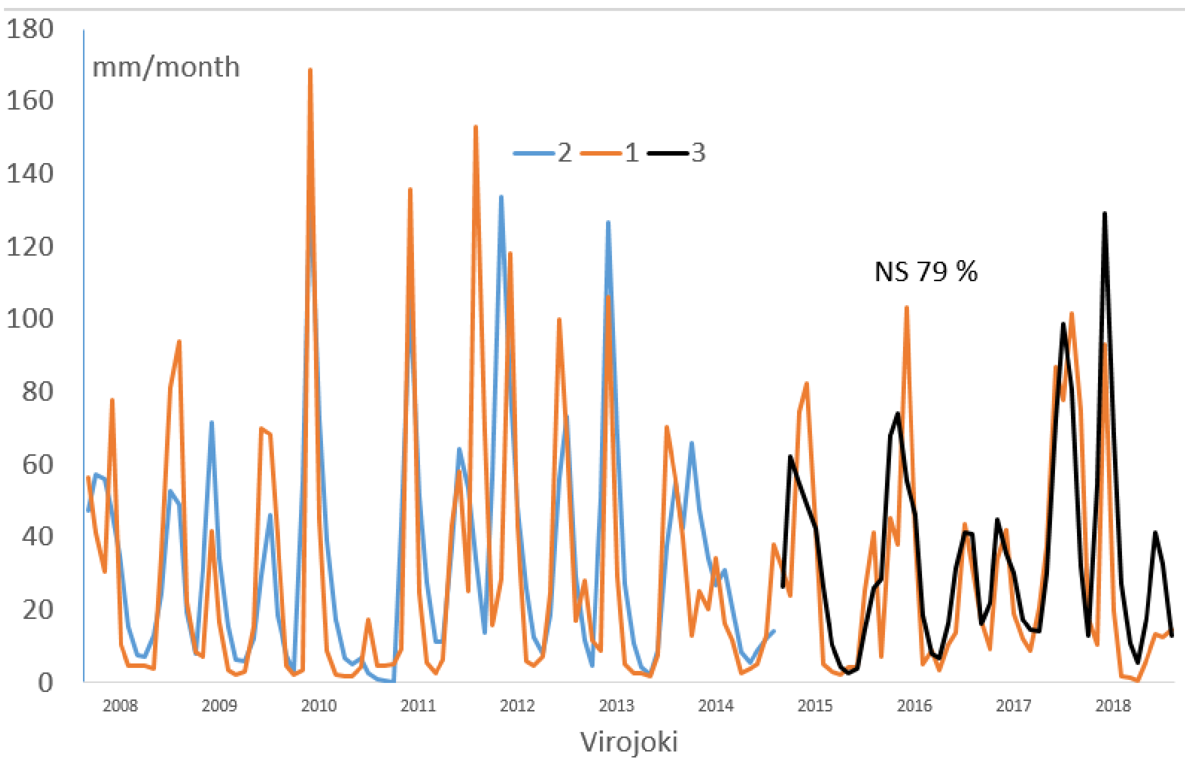
The VEMALA model is an operational, national scale nutrient loading model for Finnish watersheds (Huttunen et al., 2016). It simulates nutrient processes, leaching and transport on land and in rivers and lakes. The model simulates nutrient gross load, retention and net load from Finnish watersheds to the Baltic Sea. It includes two main sub-models, the WSFS hydrological model (Vehviläinen, 1994) and the VEMALA water quality model (Huttunen et al., 2016). The model was developed through the years and two versions are operational today simulating different nutrients and their processes. Successive versions of the model have been developed leading to a more process-based nutrient loading model. The model has been used to assess the climate change effects on flooding and adaptation to agriculture (e.g., Huttunen et al., 2015).

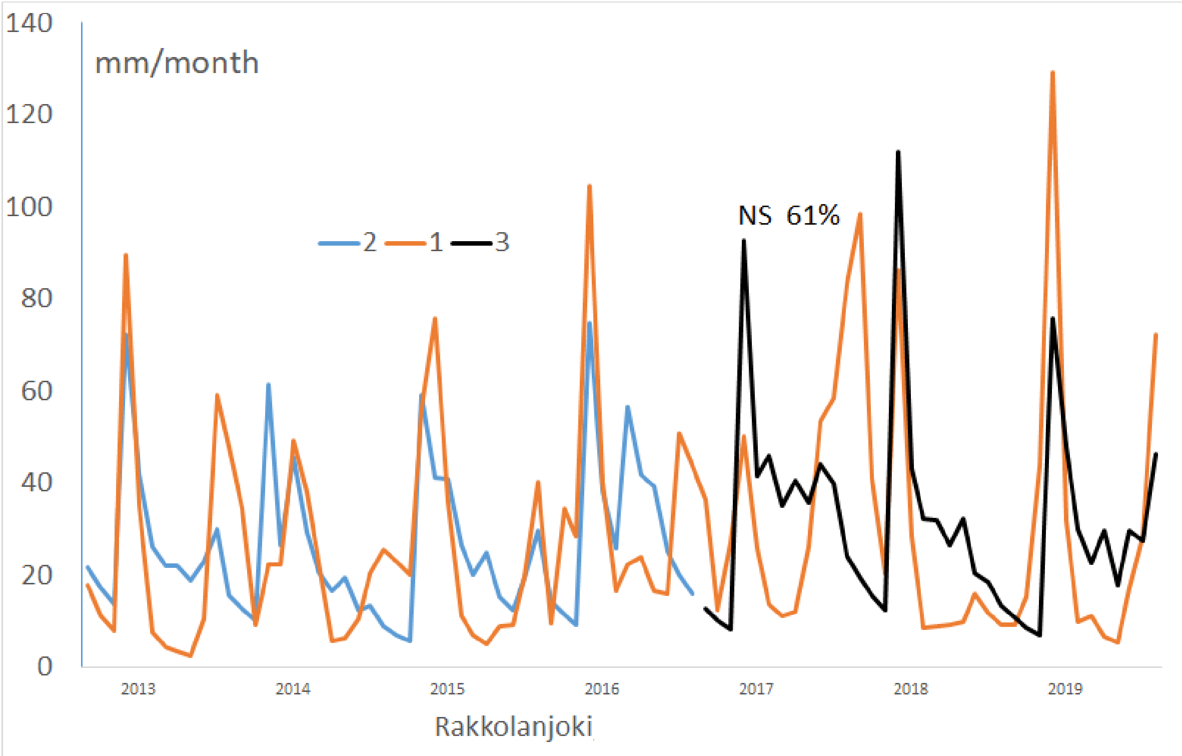
ILRAS model's calibration and testing

Model's calibration and testing was carried out using discharge observations and the grab sampling concentration data of total nitrogen and total phosphorus. For the Virojoki and Sestra rivers the calculations were done at the river outlets. There was not sufficient data for calibration at the outlet of the Rakkolanjoki River, therefore the calculations were carried out just for the Lyzhaika, because for this point we have the necessary long series of observations.

We used not only the data obtained during the implementation of this project, but also results of previous monitoring. The setting of meteorological parameters (average monthly values of precipitation and air temperature) was carried out on the base of data from the Vyborg meteorological station.

The runoff model was calibrated based on observations 2013–2016 for Rakkolanjoki (Luzhaika) and 2008–2014 for Virojoki and Sestra. The following calculation up to 2020 (up to 2019) was testing. A comparison of the measured and calculated runoff hydrographs from the pilot catchments is shown in Fig. 8.





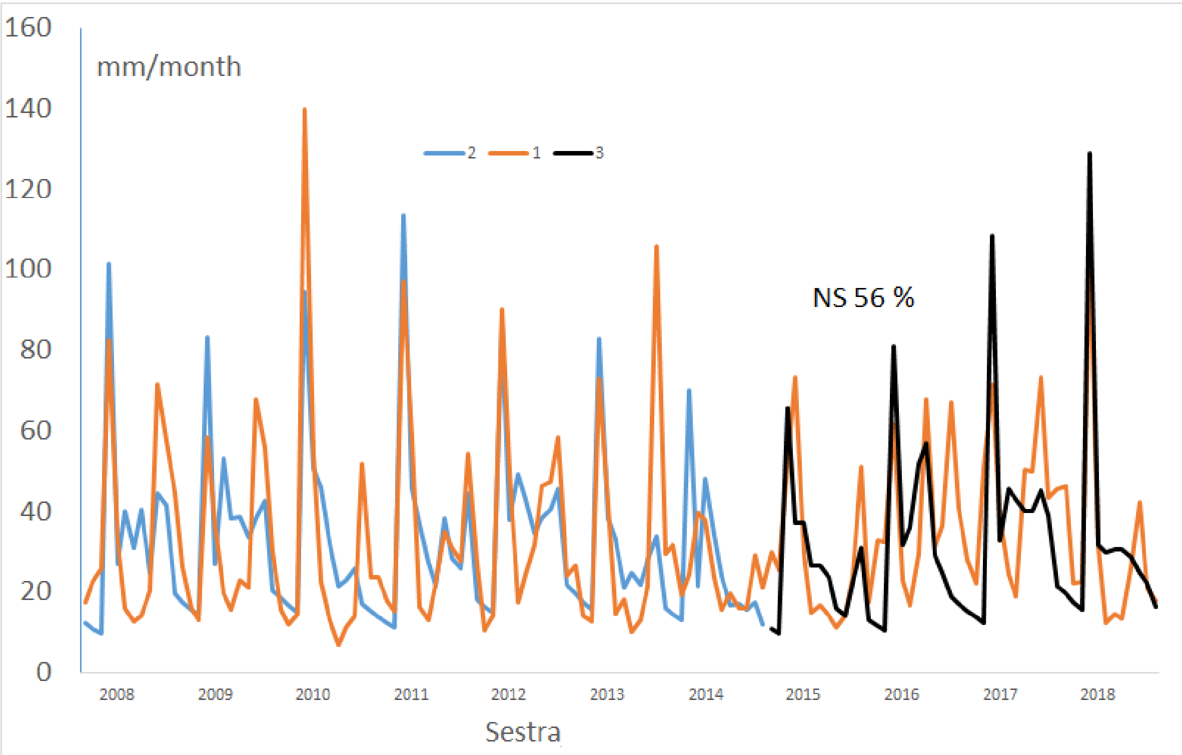


Fig. 8. Comparison of the measured (orange line) and calculated monthly runoff hydrographs from the pilot catchments Virojoki, Sestra and Rakkolanjoki. Calibration period (blue line) and testing period (black line) are shown separately. NS is the Nash-Sutcliffe criterion for testing period.

The ILHM model was calibrated by optimizing the Nash-Sutcliffe (NS) criterion. The calibration parameters include the coefficient characterizing a ratio of fast and slow components of runoff and the coefficient characterizing intensity of the rise/fall of runoff hydrograph. NS value was calculated for the testing period of the model. The obtained results (Fig. 8) show that the measured and calculated values of water discharge in the studied rivers are satisfactory correspond to each other. NS criterion is best in the Virojoki basin.

The ILLM model was calibrated based on conditions of correspondence of the calculated values of total nitrogen and total phosphorus removal to the average value calculated on the base of the observational data for period 2019–2020 (Table 3).

Table 3. The average total phosphorus and nitrogen load from studied catchments. which were used for model calibration. Runoff was estimated to be 375 mm/year for all catchments.

Catchment	TP load t/year (2019-20209)	kg/ha	TN load t/year (2019-2020)	kg/ha
Virojoki	6.9	0.19	150	4.2
Sestra	6.0	0.16	200	5.2
Rakkolanjoki (Luzhaika)	8.0	0.37	170	7.9

The calibration parameter of ILLM model is included in the formula of calculation nutrient retention by the catchment and its hydrographic network (Kondratiev, Shmakova, 2019). The calculations of N and P removal for the whole catchment of Rakkolanjoki (outlet) were performed with the same parameters obtained for the Luzhaika site.

The largest point source of nutrient load in the studied catchments is a wastewater treatment plant of Lappeenranta city located in the upper part of the catchment of the Rakkolanjoki River (3.3 tP/year, 201.2 tN/year). A significant contribution to the nutrient load in the studied area is due to the scattered settlements who have no access to a centralized wastewater treatment plant. There are about 2 295 inhabitants in the catchment of the Sestra River, 3 227 inhabitants in lower part of the Rakkolanjoki catchment and 1 133 inhabitants in the Virojoki catchment. Nutrient load calculation for scattered settlements was made based on HELCOM recommendations (0.9 kg P and 4.4 kg N per person per year). The contribution to the load by Russian *agricultural enterprises* was 0.91

tP/year, 14.03tN/year for the catchment area of the Sestra River and 1.93 tP/year, 29.38 tN/year for the lower part the Rakkolanjoki catchment area. Atmospheric deposition was assumed to be 5 kg P/(km^2 $year^{-1}$) and 770 kg N/(km^2 $year^{-1}$)

The values of parameters characterizing diffuse removal of nitrogen and phosphorus from the different types of land uses were taken in accordance with the results of previous studies carried out on small tributaries of the Gulf of Finland during the implementation of the project "Year of the Gulf of Finland - 2014" (Kondratyev et al., 2019).

Building up the scenarios and estimation of future nutrient loads

Climate scenarios

The climate scenarios were calculated using the Institute Pierre-Simon Laplace climate model (IPSL-CM5A, 2010 – until now). It is the last version of the IPSL model and is based on a physical atmosphere-land-ocean-sea ice model, and it also includes a representation of the carbon cycle, the stratospheric chemistry and the tropospheric chemistry with aerosols. The IPSL-CM5A model participates in the World Climate Research Program Coupled Model Intercomparison Project Phase 5 (WCRP CMIP5). The model allows to provide input meteorological data for both ILLM and QSWAT models. In total, four different scenarios of human socio-economic activity were recommended, expressed as a Representative Concentration Pathway (RCP), namely RCP2.6, RCP4.5, RCP6.0, and RCP8.5. The numbers here indicate the additional amount of radiation energy ($W/m^2/s^{-1}$) that will be accumulated by the atmosphere as a result of greenhouse gas emissions. In our study, we chose only two scenarios - the best and the worst in terms of environmental impacts, specified as RCP2.6 and RCP8.5 respectively. Data on the selected scenarios are available in the Archives of the European Center for Medium-Range Weather Forecasts [https://cds.climate.copernicus.eu/cdsapp#!/search?type=dataset&keywords=((%20%22Temporal%20coverage:%20Future%22%20))].

Meteorological inputs for ILHM model with a time step of 1 year are presented in Figures 9 and 10**.** The linear trends illustrate a possible decrease for precipitation values and a minimum increase for air temperature in the Vyborg Bay area for the perspective till year 2100 under the implementation of the RCP 2.6

scenario. The RCP 8.5 scenario assumes a significant increase for both precipitation and air temperature in the study region.

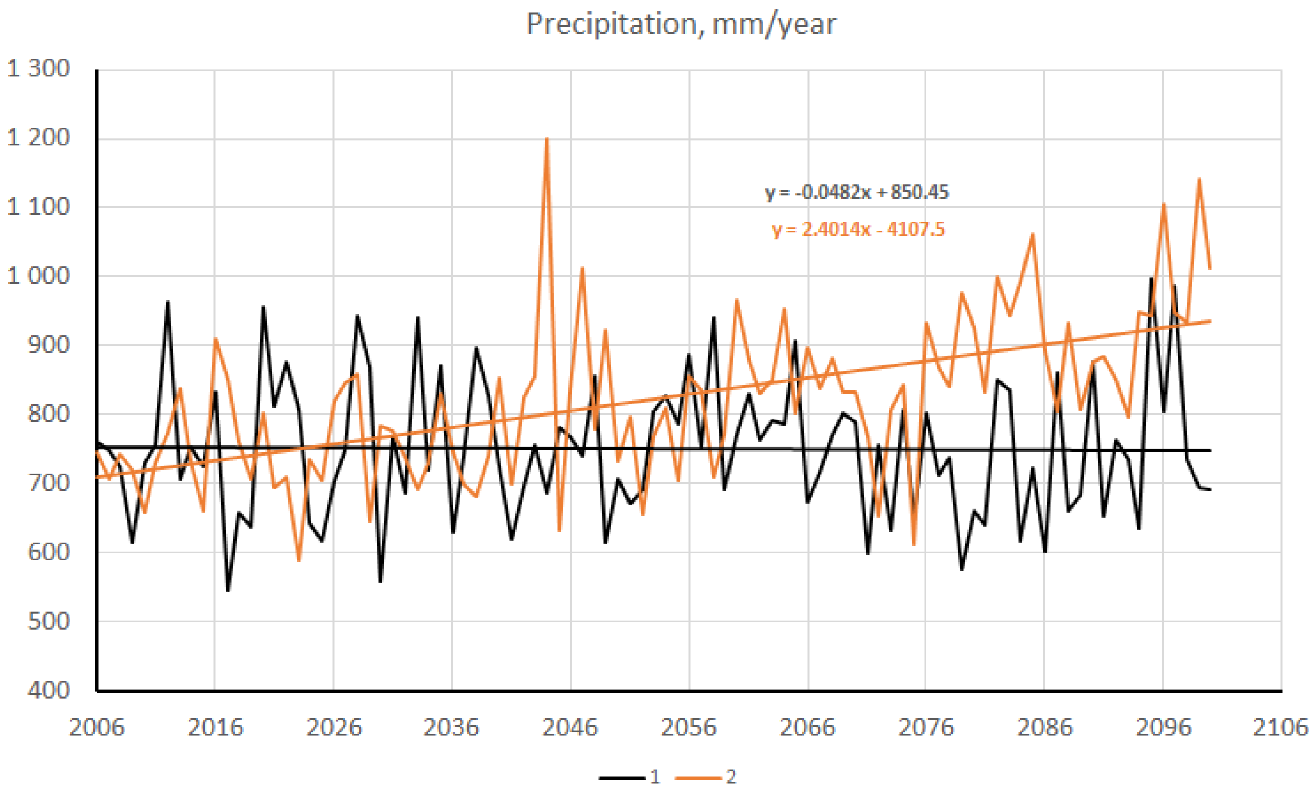


Fig. 9. Possible changes of annual precipitation in the Vyborg Bay region for the perspective to year 2100 according to the scenarios RCP 2.6 (1=black line) and RCP 8.5 (2=orange line).

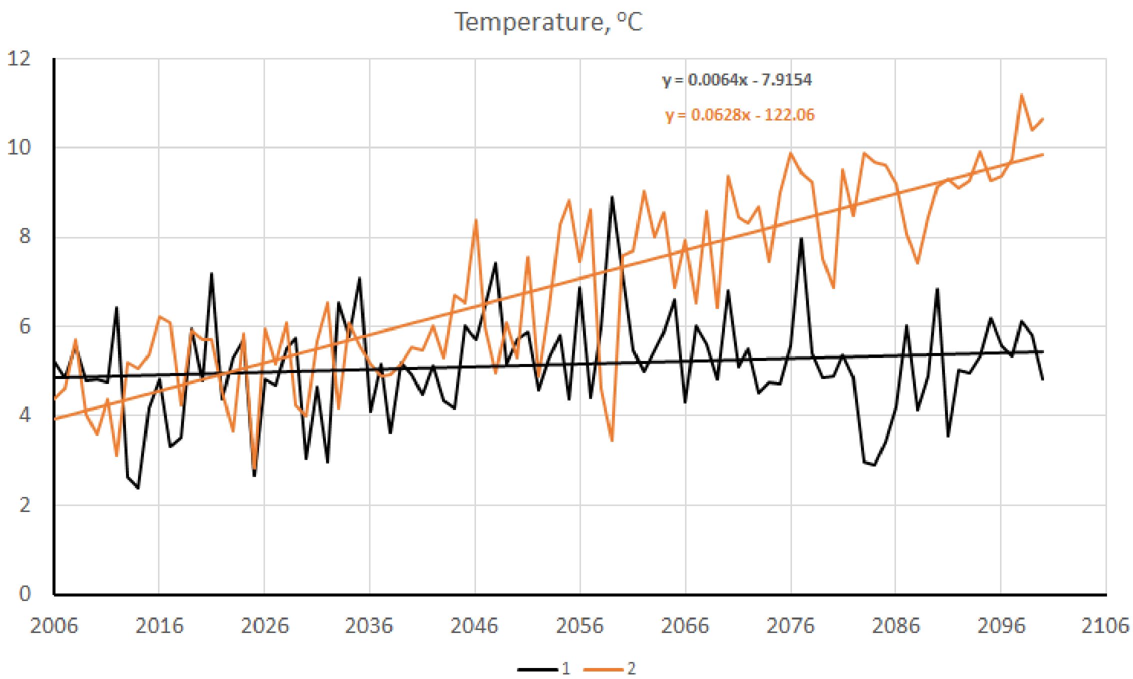


Fig. 10. Possible changes of annual air temperature in the Vyborg Bay region for the perspective till year 2100 according to the scenarios RCP 2.6 (1= black line) and RCP 8.5(2= orange line).

The annual evaporation and runoff scenarios for the Sestra, the Rakkolanjoki and the Virojoki catchments are shown in Figures 11–16. Since the physico-geographical conditions of the studied catchments are similar and the same climatic scenarios were used in all calculations, there are no big differences in the forecast estimations. The RCP 2.6 scenario, which assumes a significant reduction in greenhouse gas emissions into the atmosphere, leads to a small (3–6% compared to the period 2006–2015) decrease in runoff at the end of the 21st century. The implementation of the unfavorable scenario RCP 8.5 leads to increase in precipitation and air temperature in the region and will cause increase in runoff up to 25% in relation to the reference period.

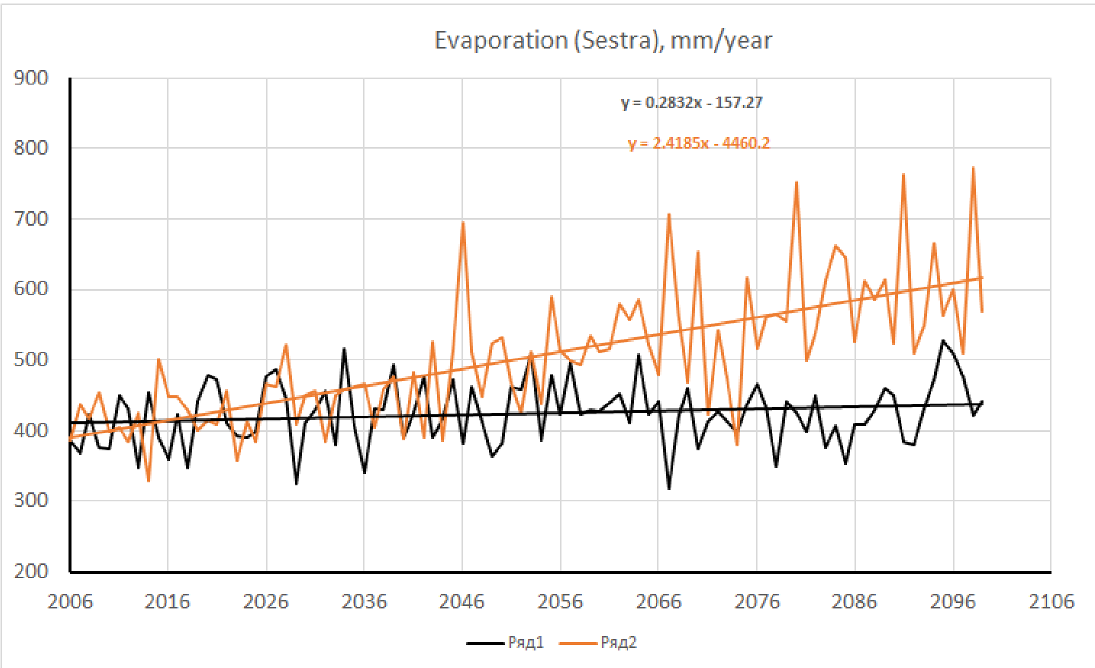


Fig. 11. Possible change in annual evaporation for the Sestra river (mm/year) for the perspective to year 2100 according to the scenarios RCP 2.6 (1) and RCP 8.5 (2)

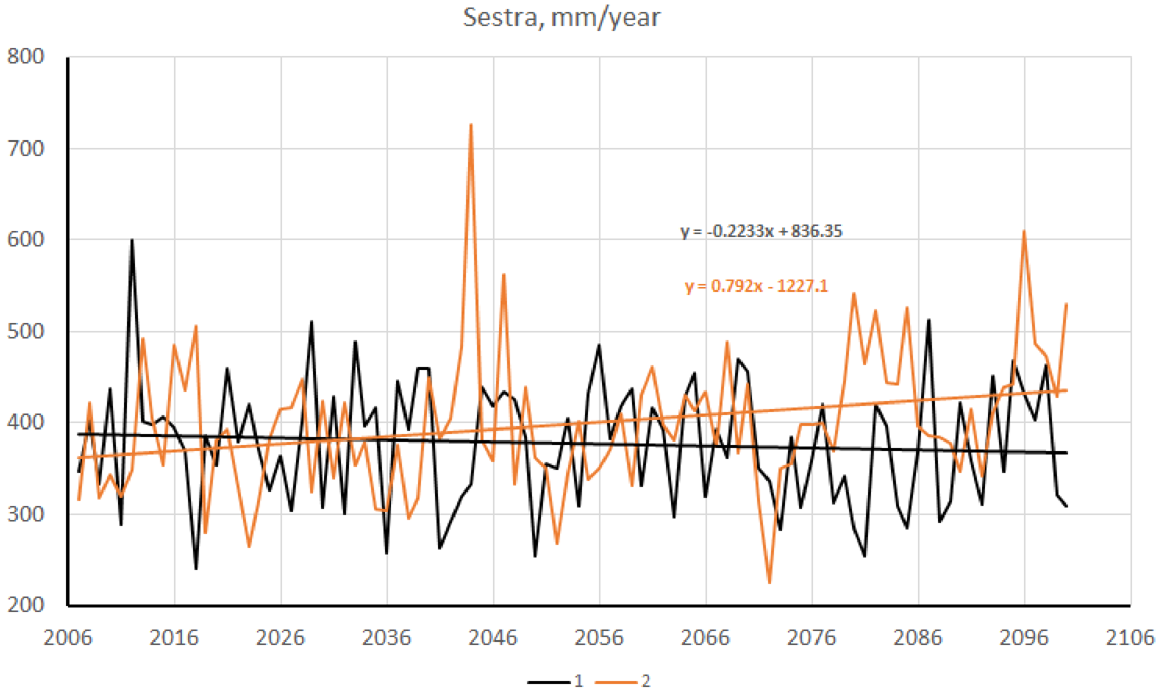


Fig. 12. Possible changes in annual runoff for the Sestra river (mm/year) for the perspective to year 2100 according to the scenarios RCP 2.6 (1) and RCP 8.5 (2).

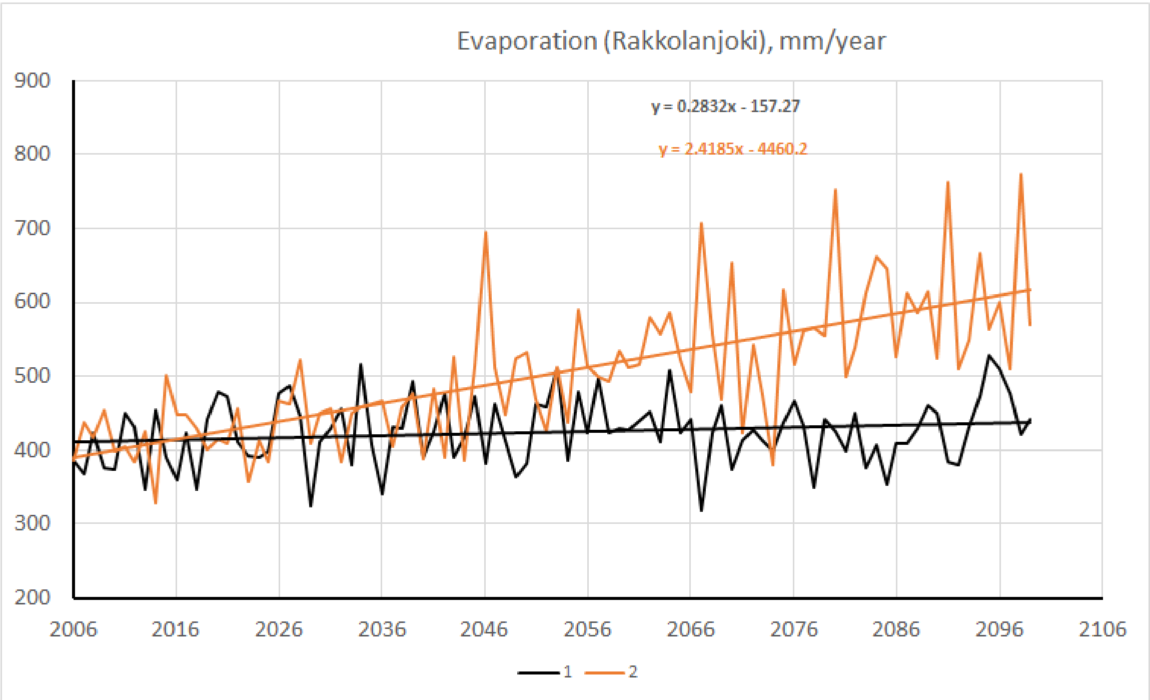


Fig. 13. Possible changes in annual evaporation for the Rakkolanjoki river (mm/year) for the perspective to year 2100 according to the scenarios RCP 2.6 (1) and RCP 8.5 (2).

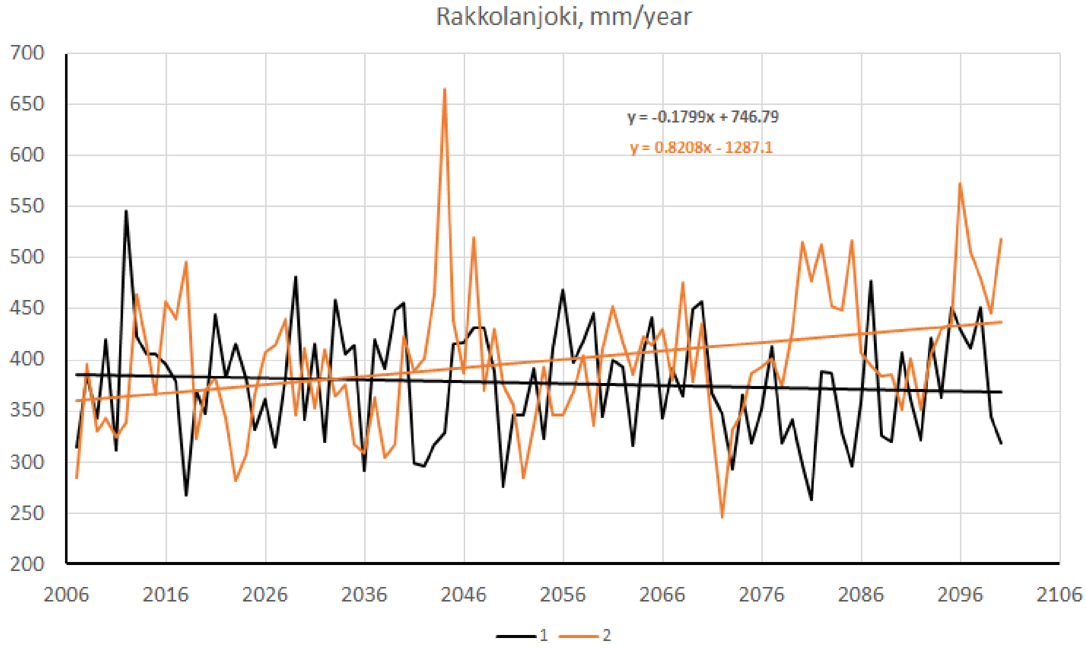


Fig. 14. Possible changes in annual runoff for the Rakkolanjoki river (mm/year) for the perspective to year 2100 according to the scenarios RCP 2.6 (1) and RCP 8.5 (2).

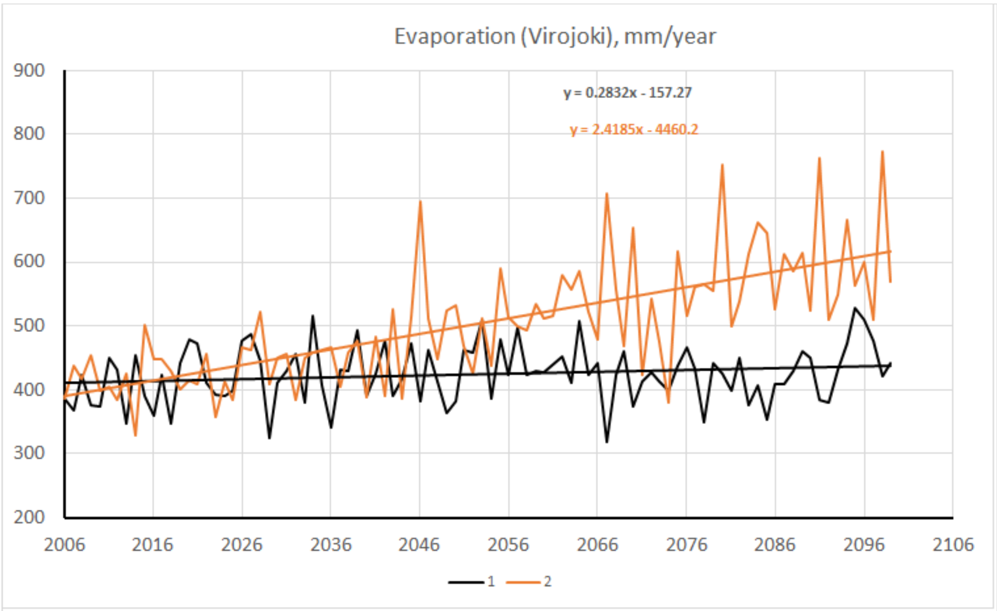
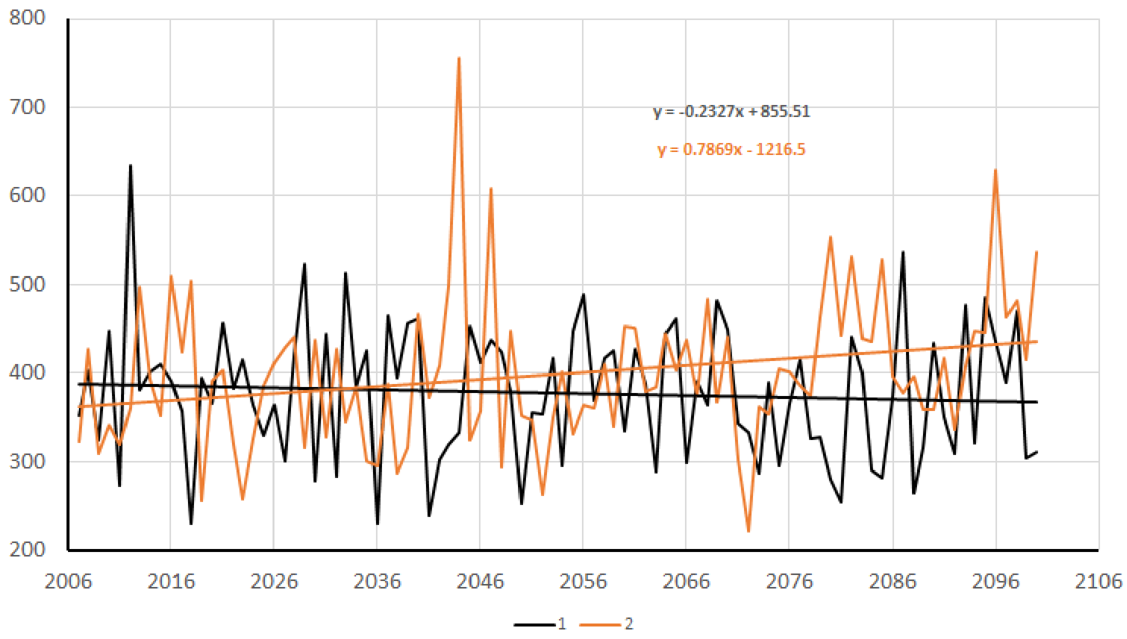


Fig. 15. Possible changes in annual evaporation for the Virojoki river (mm/year) for the perspective to year 2100 according to the scenarios RCP 2.6 (1) and RCP 8.5 (2).



1 – RCP2.6, 2 – RCP8.5

Fig. 16. Possible changes in annual runoff for the Virojoki river (mm/year) for the perspective to year 2100 according to the scenarios RCP 2.6 (1) and RCP 8.5 (2).

The results of calculations of possible changes in the nitrogen and phosphorus annual removal from the catchments and the modules of removal per unit area (load and specific load) caused by influence of the climatic factor are presented in Tables 4 and 5. The calculated changes in N and P removal depend both on climate changes (through runoff) and on the characteristics of nutrient load on the catchment. It should be noted that all the input parameters of the model (except for the runoff) used during calculations, remained correspondent to the modern conditions.

The favorable RCP 2.6 scenario may lead to a decrease in nitrogen and phosphorus removal to 7 and 5%, respectively to the end of the 21st century in relation to the period 2006–2015. Implementation of the unfavorable scenario RCP 8.5 will cause an increase in runoff up to 46% for phosphorus and 48% for nitrogen in relation to the reference period. The maximum values of specific load are typical for the Rakkolanjoki (Luzhaika site) catchment - 0.4 kgP/ha per year and 12.4 kgN/a per year. It can be explained by the discharge from relatively large sewage treatment plants in Lappeenranta**.** The minimum nutrient load on the Virojoki catchment area due to high forest coverage and the insignificance of point sources determines the minimum specific nitrogen and phosphorus load values.

Table 4. Total nitrogen (TN) and total phosphorus (TP) load assessment for 2006–2015 and 2091–2100 using RCP2.6 and RCP8.5 scenarios.

	RCP2.6			RCP8.5		
	2006-2015	2091-2100	%	2006-2015	2091-2100	%
Sestra						
Runoff (mm/year)	402	386	-4.0	368	458	24.5
TP Load (t/year)	7.7	7.2	-7.0	6.6	9.6	45.5
TN Load (t/year)	171	159	-7.0	144	212	47.9
Rakkolanjoki (Luzhaika)						
Runoff (mm/year)	400	387	-3.3	362	455	25.7
TP Load (t/year)	6.5	6.21	-3.7	5.7	7.4	29.4
TN Load (t/year)	213	206	-3.3	191	242	26.7
Rakkolanjoki (outlet)						
Runoff (mm/year)	403	385	-4.5	369	458	24.1
TP Load (t/year)	18.1	17.2	-5.2	16.3	20.9	28.1
TN Load (t/year)	474	450	-5.1	429	541	26.1
Virojoki						
Runoff (mm/year)	403	379	-6.0	375	458	22.1
TP Load (t/year)	8.5	8.1	-5.2	8.0	9.5	19.0
TN Load (t/year)	181	173	-4.4	171	201	17.5

Table 5. TN and TP specific load assessment for 2006-2015 and 2091-2100 using RCP2.6 and RCP8.5 scenarios.

	RCP 2.6		RCP 8.5	
	2006-2015	2091-2100	2006-2015	2091-2100
Sestra				
Runoff (mm/year)	402	386	368	458
TP Specific load (kg/ha year)	0.21	0.20	0.18	0.26
TN Specific load (kg/ha year)	4.65	4.32	3.92	5.77
Rakkolanjoki (Luzhaika)				
Runoff (mm/year)	400	387	362	455
TP Specific load (kg/ha year)	0.33	0.32	0.29	0.38
TN Specific load (kg/ha year)	10.94	10.58	9.81	12.43
Rakkolanjoki (outlet)				
Runoff (mm/year)	403	385	369	458
TP Specific load (kg/ha year)	0.29	0.28	0.26	0.34
TN Specific load (kg/ha year)	7.63	7.24	6.91	8.71
Virojoki				
Runoff (mm/year)	403	379	375	458

TP Specific load (kg/ha year)	0.24	0.23	0.22	0.27
TN Specific load (kg/ha year)	5.06	4.83	4.78	5.61

The used RCP 8.5 climatic scenario is extreme, and therefore and it may not be realized. Most likely the real changes of greenhouse gas emissions into the atmosphere are smaller than RCP 8.5 forecasts. Therefore, by the end of the 21st century, we hardly expect significant changes in the hydrological regime of the studied rivers caused by climatic influences.

Climate scenarios based on VEMALA model

The future nutrient loads were also calculated with the VEMALA model (Huttunen et al. 2016) using the same climate scenarios (RCP 2.6 and RCP 8.5) as the ILLM model and assuming that no new water protection measures were done. The VEMALA calculations were made for the larger Hounijoki river basin, whose tributary the Rakkolanjoki river is. During the reference period (2006–2015) the average TN load was 437 t/year. Using the RCP 2.6 meteorological data as input for the period 2010-2100 the average TN load was clearly lower (374 t/year) than during the reference period. During the last decade 2091-2100 the average load was 350 t/year. With RCP 8.5 data the TN load increased (398 t/year 2010-2100, 414 t/year 2091–2100) a bit compared to RCP 2.6, but unlike the ILLM scenario result it was still lower than the average load during the reference period (Fig. 17).

During the reference period (2006–2015) the average TP load was 11.9 t/year. The average TP load was lower (11 t/year) using the RCP 2.6 meteorological data as input for the period 2010-2100 (10.1 t/year for 2091–2100). With RCP 8.5 data the TN load increased (11,93 t/year 2010–2100, 12.6 t/year 2091–2100) a bit compared to RCP 2.6, especially during the last decade 2091–2100 (Fig. 18).

The two models give a different view of the future. Both the models predict a reduction in nutrient load up to 2091-2100 with RPC 2.6 data. The load reduction calculated with the VEMALA model is 20% for nitrogen and 15% for phosphorus, while the load reduction for both nutrients is only 5% with the ILLM model. ILLM model predicts quite large increase in nutrient loading (26–28%) while VEMALA model gives 6% increase for TP, and -5% decrease for TN (see Table 6).

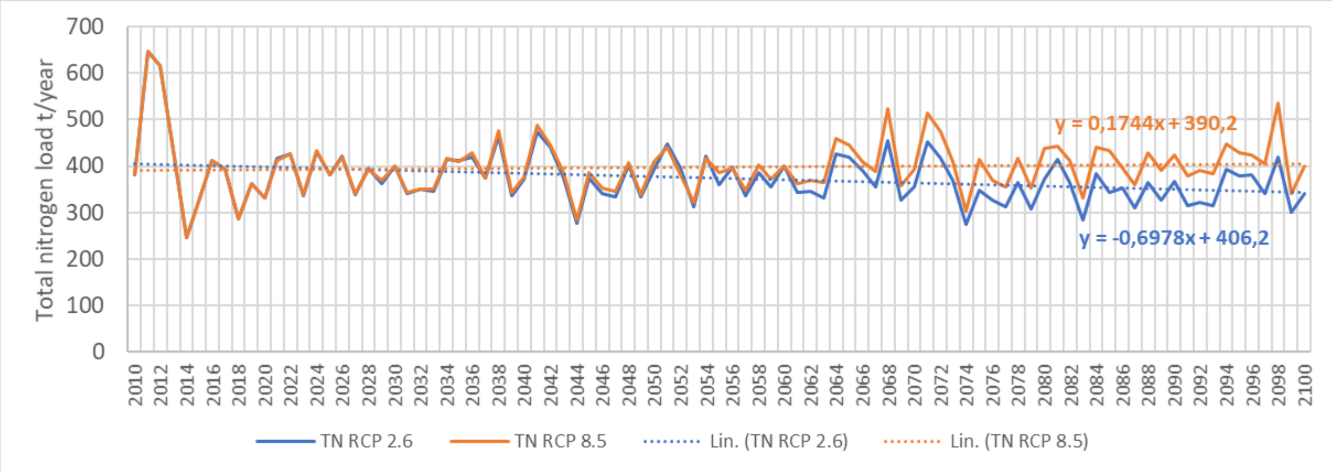


Fig. 17. The future TN load calculated using RCP 2.6 and RCP 8.5 meteorological data with the VEMALA model for the Hounijoki River basin.

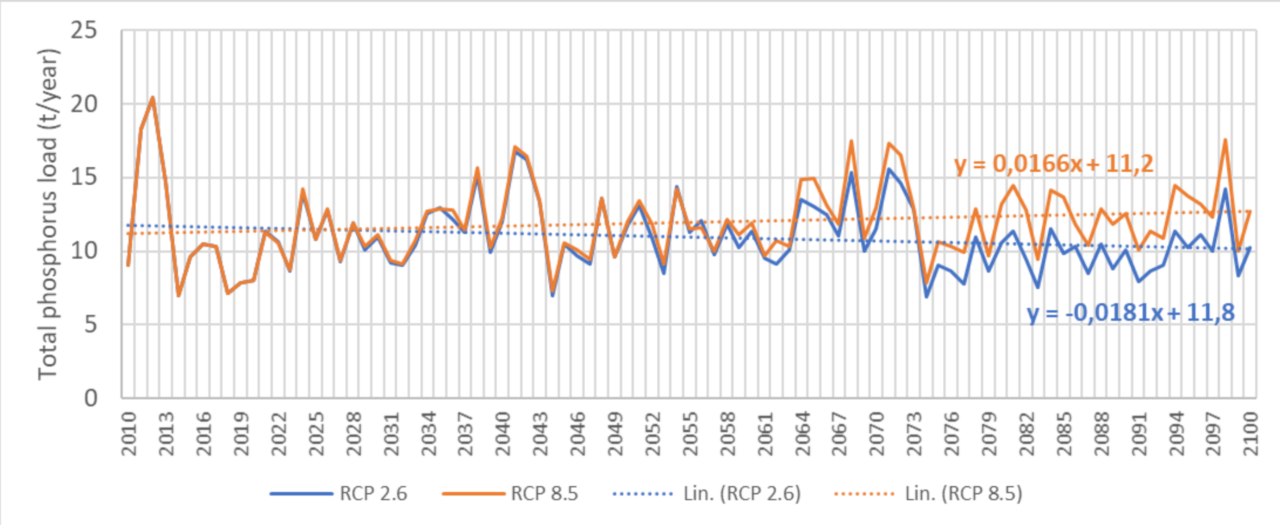


Fig. 18. The future TP load calculated using RCP 2.6 and RCP 8.5 meteorological data with the VEMALA model for the Hounijoki River basin.

Table 6. Comparison of results from two different models using RCP 2.6. and RCP 8.5 climate scenarios.

	ILLM Rakkolanjoki	VEMALA Hounijoki	ILLM Rakkolanjoki	VEMALA Hounijoki
	Change ref → RCP 2.6		Change ref → RCP 8.5	
TN	-5.1%	-19.9%	+26.1%	-5.3%
TP	-5.2%	-15.1%	+28.1%	+5.9%

Land use changes

Besides climate changes and corresponding changes in runoff it is possible that nutrient removal from the catchments is affected by anthropogenic changes in land use, as well as the modernization / closing of point sources of wastewater discharge (e.g., industrial, agricultural, municipal). Possible scenarios of the point loading are nowadays based on state plans for the development of the territory. At this moment, there are no plans to organize any large enterprises in the studied catchments (in Russian side). Therefore, in this project we don’t make scenarios for changes in point loading, except in the Rakkolanjoki, where QSWAT model is used to estimate the effects of improving the efficiency of the wastewater treatment plant in the Lappeenranta city.

However, the daily life of populations leads to gradual changes in the land use. Typically, it means increase of urbanized and agricultural areas. In the project, we studied how much the nutrient load increases when the arable land is taken into use or the area is built. The land use scenario results are shown in Figs. 19–22. Calculations were carried out for the areas of possible changes (both increase and decrease) of agricultural and urbanized territories within the studied catchments.

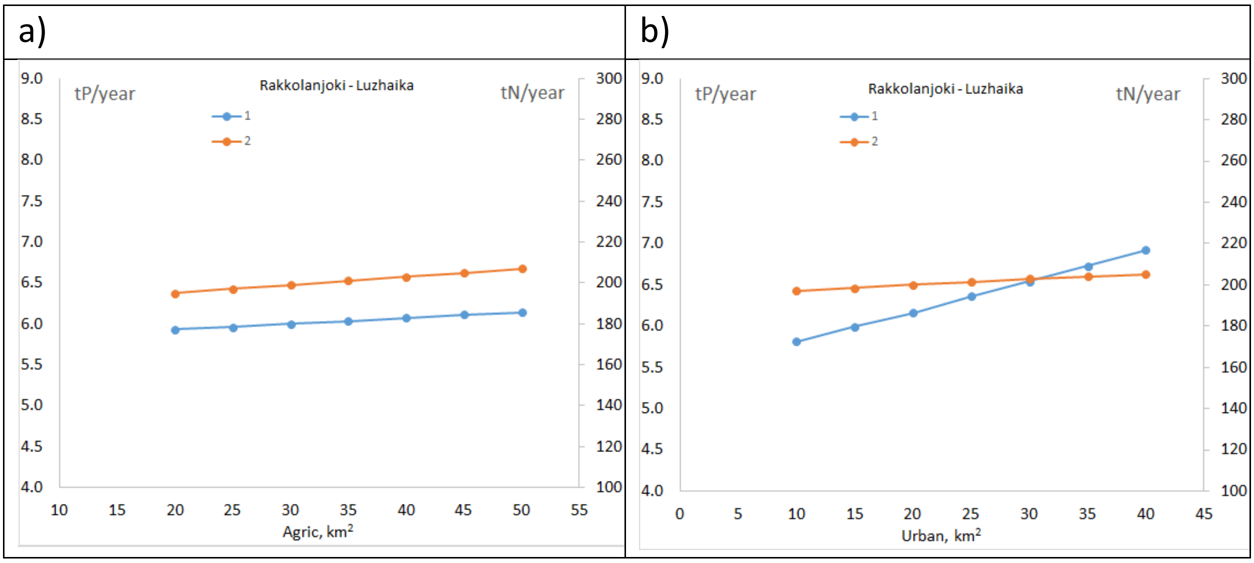


Fig. 19. The total annual phosphorus (1=blue line) and the total annual nitrogen (2=orange line) load depending on the amount of agricultural land (figure a) and urban land (figure b) in the Rakkolanjoki (Luzhaika site) catchment.

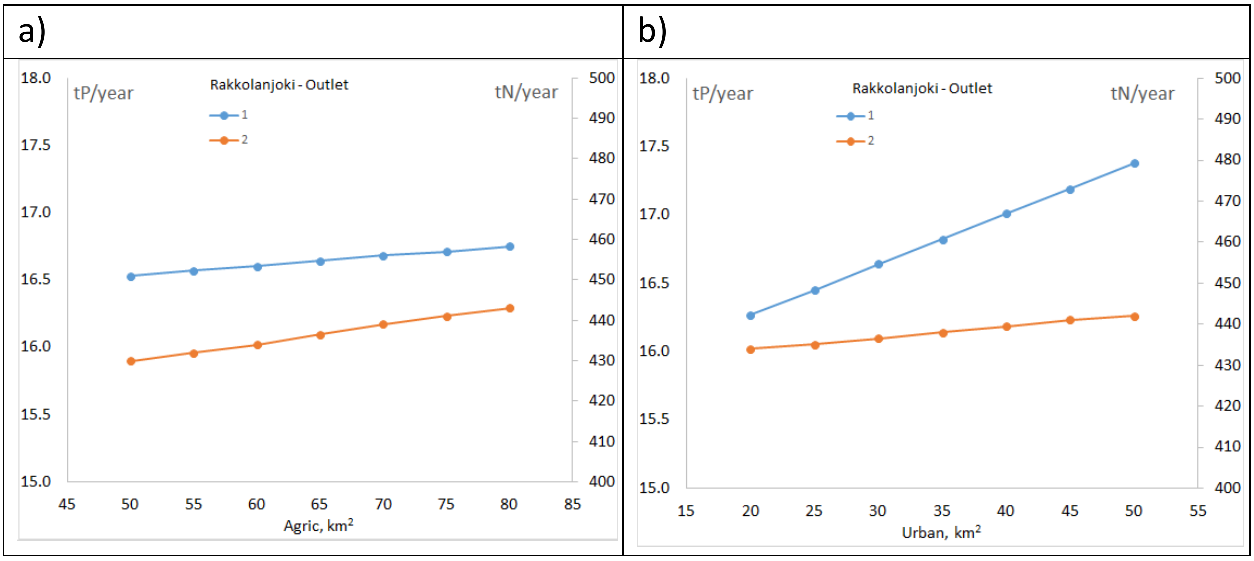


Fig. 20. The total annual phosphorus (1=blue line) and the total annual nitrogen (2=orange line) load depending on the amount of agricultural land (figure a) and urban land (figure b) in the Rakkolanjoki (outlet) catchment

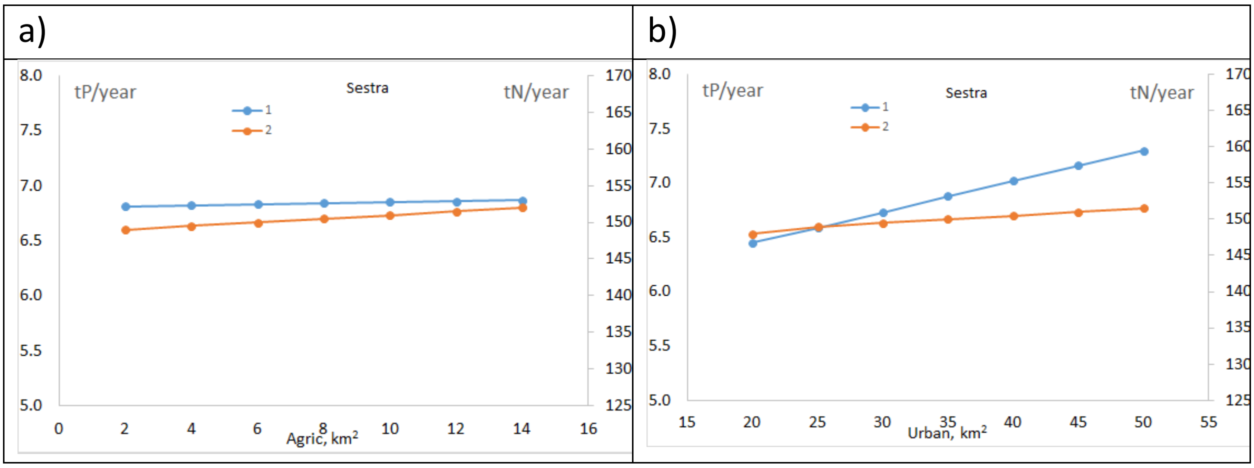


Fig. 21. The total annual phosphorus (1=blue line) and the total annual nitrogen (2=orange line) load depending on the amount of agricultural land (figure a) and urban land (figure b) in the Sestra catchment

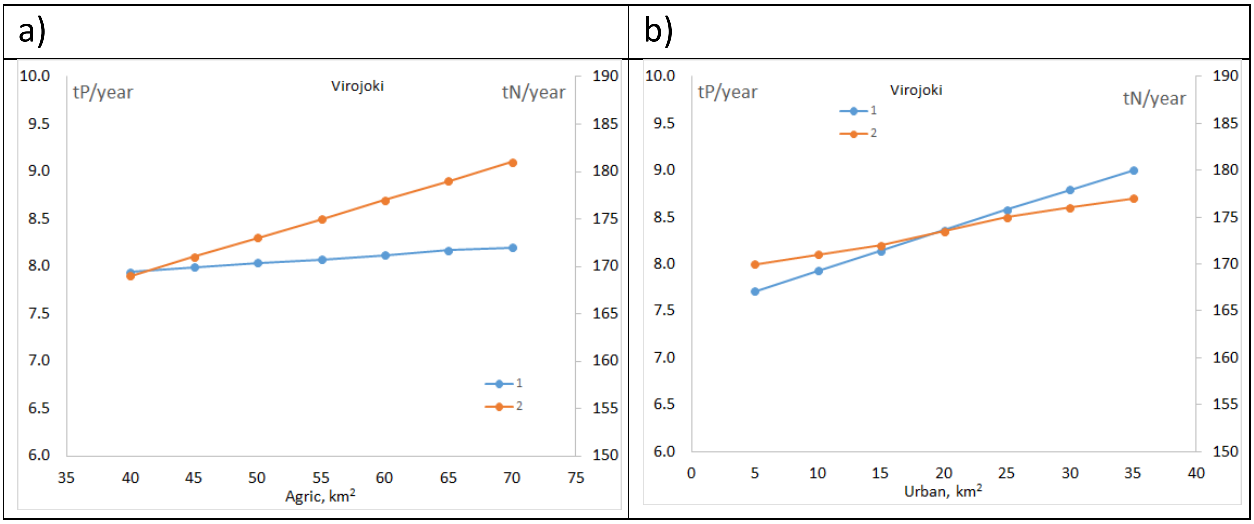


Fig. 22. The total annual phosphorus (1=blue line) and the total annual nitrogen (2=orange line) load depending on the amount of agricultural land (figure a) and urban land (figure b) in Virojoki catchment.

In Table 7, the increase in nutrient load is shown if the share of agricultural or build-up area increases 1 km^2. Building a square kilometer increases the phosphorus load by about 5–6 times more than putting the same size area into agricultural use. In terms of nitrogen, taking the same area as agricultural land is a little more burdensome than building the area.

Table 7. Increase in nutrient load (kg/year) if the share of agricultural or built-up area increases by 1 km^2.

	Virojoki	Rakkolanjoki (Luzhaika)	Rakkolanjoki (outlet)	Sestra
P agri, kg/year	8	6	8	6
P urban, kg/year	38	38	38	29
N agri, kg/year	700	600	400	800
N urban, kg/year	500	300	300	600

Conlusions and discussion

Changes in land use in both the Virojoki and Rakkolanjoki catchments have been small over the last 20 years. Agricultural land has decreased on the Virojoki by 3%, while there has been a slight increase 0.3% in the Rakkolanjoki River basin. The build-up area in both catchments has increased, in Virojoki 10% and in

Rakkolanjoki 5.5%, respectively. Growth and decrease typically occur in individual, isolated areas. However, based on these results, it is not possible to predict the direction or magnitude of the changes in the future. Over the last twenty years, however the changes have been rather small. Still, even small changes have an effect, because in general the reduction obtained by water protection methods (e.g., agricultural measures) is also small and in this case even a small change in land use can cancel out this positive effect at the catchment scale.

The RCP 2.6 and RCP 8.5 climate scenarios were used as meteorological inputs for the ILHM and VEMALA models with a time step of 1 month and 1 day, respectively. The modelled linear trends illustrate a possible decrease for precipitation values and a minimum increase for air temperature in the Vyborg Bay area for the perspective until year 2100 under the implementation of the RCP 2.6 scenario. The RCP 8.5 scenario assumes a significant increase for both precipitation and air temperature in the study region. The RCP 8.5 climatic scenario is extreme, and therefore it may not be realized. Most likely the real changes of greenhouse gas emissions into the atmosphere are smaller than RCP 8.5 forecasts. Therefore, by the end of the 21st century, we hardly expect significant changes in the hydrological regime of the studied rivers caused by climatic influences.

Analyzing the ILLM model scenario results, it can be concluded that increase in both agricultural and urbanized areas leads to gradual increase in nitrogen and phosphorus removal. In all studied catchments the main land use type is forest. The catchment area of the Rakkolanjoki River (Luzhaika site) is characterized by the maximum agricultural area (13% of the total catchment area). The maximum value of urbanized areas (9% of the total area) occurs in the Sestra catchment. According to ILLM model building a square kilometer increases the phosphorus load by about 5–6 times more than putting the same size area into agricultural use. In terms of nitrogen, taking the same area as agricultural land is a little more burdensome than building the area.

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