Deliverable 3.5, 27.5.2021

D3.5 Report on the effect of climate change and actions in forestry and agriculture on the water quality in Koitajoki and Puruvesi

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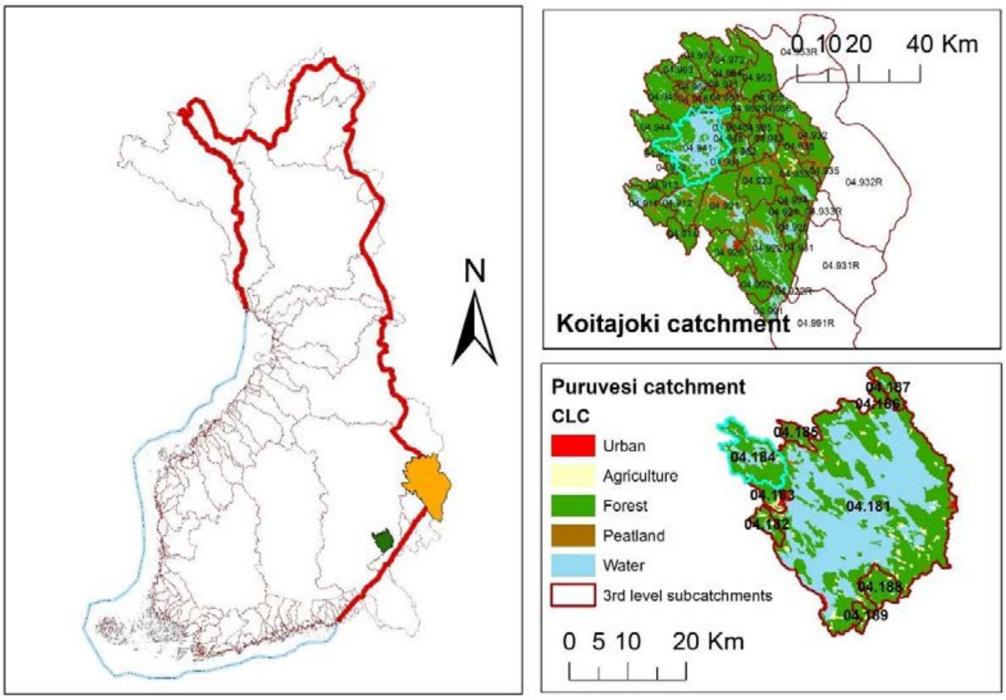

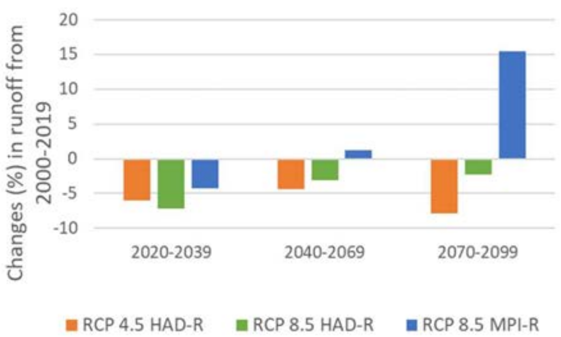

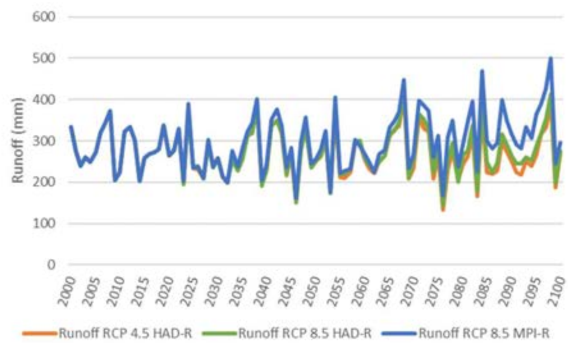

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Content

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1. Intro

Within the Freshabit project we aim at developing tools to better predict the state of the freshwater ecosystem at the end of the century. In this study, we test the coupling of the forest field scale nutrient loading model (NutSpaFHy) to the national scale nutrient loading model (VEMALA v1) in two pilot areas (Koitajoki and Puruvesi catchments). The aim is to model the impact of various forestry scenarios on the total phosphorus loading to the freshwater ecosystem. Within this project, we used various climate change (3 scenarios), forest logging (5 scenarios) and agricultural mitigation (2 scenarios) scenarios to predict the future state of the freshwater within Puruvesi and Koitajoki river basins. The aim is to better understand the main contributors to changes in future water quality toward the end of the century.

2. Methods

2.1. Study areas

Lake Puruvesi catchment (1017 km^2) and Koitajoki catchment (6631km^2) are located in the eastern part of Finland (Figure 1a). Lake Puruvesi covers 41% of the catchment area (416 km^2), forests (533km^2) cover over half of the catchment while agriculture covers only 4% (38km^2) (Figure 1c and Figure 2a). Lake Puruvesi is oligotrophic, clear and a low humic lake with excellent water quality. On the other hand, water in the Koitajoki catchment covers only 8% (534km^2) including Lake Koitere (2.5% and 164km^2), forests cover 91% (6064km^2) and agriculture 0.5% (32km^2) of the catchment area (Figure 1b and Figure 2b). Lake Koitere is a large humic lake with a good ecological quality.

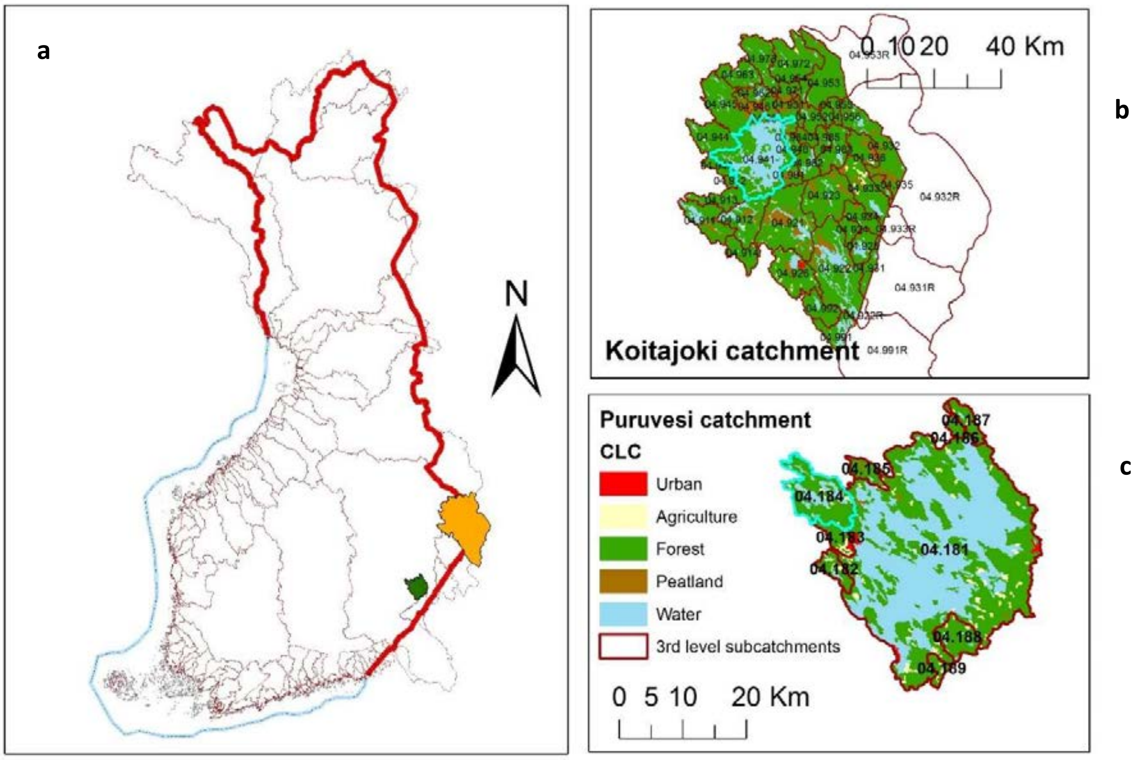

Figure 1: Map of a- Puruvesi (green) and Koitajoki (orange) catchments location in Finland and land use and 3[rd] level subcatchment boundaries (red lines) and number with number including R located in Russia in b- Koitajoki with Koitere lake catchment (04.941) highlighted in light blue and c-Puruvesi catchments with Kuonanjoki subcatchment (04.184) highlighted in light blue.

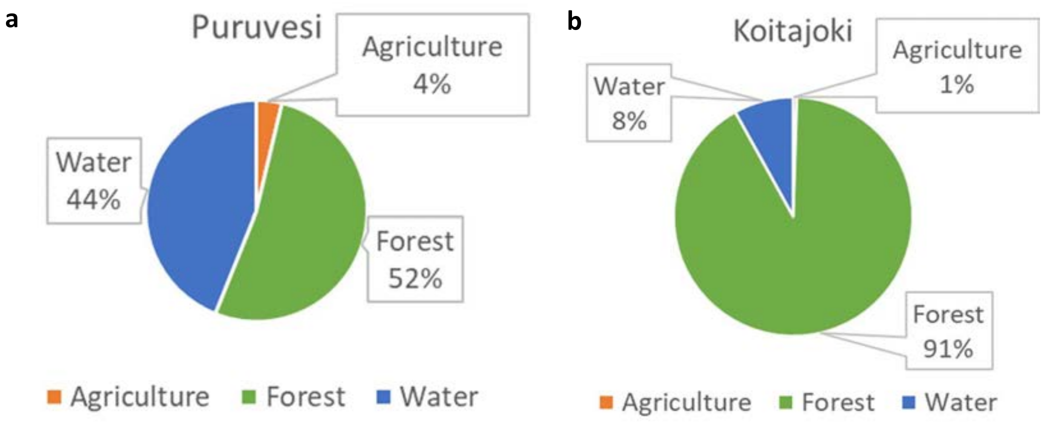

Figure 2: Land use (%) of the total area for a- Puruvesi catchment (04.181) and b-Koitajoki catchment (04.9)

2.2. NutSpaFHy - Puruvesi

2.2.1. NutSpaFHy model

NutSpaFHy (Laurén et al. under preparation) calculates nutrient load (total nitrogen, total phosphorus) from forested areas. The grid-based catchment-scale distributed NutSpaFHy includes three modules: 1) a simplified and computationally efficient hydrological model SpaFHy (Launiainen et al. 2019) at daily scale, 2) a nutrient balance module where N and P uptake by trees and ground vegetation, release and storage are quantified grid by grid at monthly scale, and 3) an export loading module that includes an exponential delay function which is built upon the hydrological simulation of flow velocity, distance to water bodies and nutrient balance quantification.

Nutrients are calculated with mass balance equations and as pools considering the water fluxes through the root zone into groundwater and the return flow from soil to surface runoff and the transport of nutrients empirically as a function of the distance to the outlet (i.e. to the point that collects the water from the catchment before entering to the next catchment or lake) and the model considers also the subsequent utilization of nutrients along the export path by fitting logarithmic equations based on data by Heikkinen et al. (2018). NutSpaFHy prioritizes the largest nutrient fluxes connected to organic matter decomposition and considers also the atmospheric deposition omitting minor processes. The processes that are difficult to parameterize are pooled into calibrated/estimated parameters (e.g. microbial immobilization).

The nutrient balance module considers uptake by forest (calculated based on yield ‘Motti’ simulations by Hynynen et al. 2002) and ground vegetation (biomass computed by models of Muukkonen and Mäkipää 2006, and litterfall by Mälkönen 1974), atmospheric deposition, nutrient immobilization (parameters) and nutrient release in heterotrophic soil respiration (Pumpanen et al. 2003 for mineral soils, Ojanen et al.2010, for peat soils) and calculation of the subsequent changes in storage at each grid cell. In the calculation of soil respiration for mineral soils, soil temperature is derived from mean air temperature and moisture restriction is considered based on SpaFHy output of liquid water content in the root zone, soil porosity and parameters by Skopp et al. (1990). Nutrient release is calculated based on CO_2 efflux from soil, converted to elemental C, nutrient content in mineral soil organic matter parameterized by Tamminen (1991) and the fraction of the released nutrient that is immobilized into microbial biomass. This fraction is calibrated against measured catchments distributed across Finland and it includes also other factors that are not included in the model. These (parameters for N for mineral and peat soil respectively) are the only calibrated parameters and catchment features can be used to explain their variation sufficiently ($R^2 > 0.61$ for N in peat soils, $R^2 > 0.3$ for N in mineral soils). Parameters for P immobilization for mineral and peat soils are here based on averages calculated from the calibrated parameters in Laurén et al. (under preparation).

When a clear-cut occurs, the volume, height, leaf-area and ground vegetation biomass data for the grid cells under clear-cut are modified. The nutrient uptake of ground vegetation nutrient is downscaled during the first 5 years after a clear-cut so that the disturbance linearly decreases from 0.34 to 0 to consider the effect of forest operations in decreasing the ground vegetation biomass production. Nutrient load results are calculated omitting the first year as the model sets up the hydrology to stable level prior to analysis period.

2.2.2. Input data for NutSpaFHy

The input data for the model includes catchment boundaries (SYKE, 4th level subdivision with largest catchments divided to several sub-areas to enable model runs, Figure 3), meteorological drivers and spatial data from forest inventories (forest inventory data, FID, Finnish Forest Centre, 2020 and Multi-source National forest inventory data, MS-NFI, Mäkisara et al. 2016), soil (GSF, 2015), digital elevation model (DEM, NLS 2020) and its derivatives i.e. slope and TWI (Salmivaara et al. 2017), spatial data on peatlands and bare rock areas, roads and water elements (NLS, 2020) and clear-cut scenarios for no additional clear-cuts, business-as-usual (BAU) and all potential clear-cuts (Finnish Forest Centre, 2020).

Besides data on tree species, age and volume and site properties, FID also contains information of forest compartments, which have reached economical regeneration maturity and thus are potentially subject of clear-cut in the near future if so decided by the landowner. FID is based on data collected by air-borne laser scanning (LiDAR) and soil and tree variables measured in the field from the sample plots and data is updated by simulating yearly tree growth considering realized harvesting operations (Finnish Forest Centre, 2021). Because FID contains only forests owned by private landowners, the forests by other landowners were extracted from the MS-NFI, that is based on satellite images, field inventory and other digital maps. The data is in 16x16m grid resolution. The input features from FID were rasterized to 16x16m grid and MS-NFI cell value was used only when FID raster value had no-data.

Three sources for data on meteorological drivers were utilized: current climate is represented by period 2006-2016 from gridded weather observations data by Finnish Meteorological Institute (FMI) in 10 km resolution including mean daily temperature and precipitation, global radiation, temperature sum of growing season (mean temperature over 5 degrees), and relative humidity for the study area (Aalto et al. 2016). The two other sources include the general circulation models MPI-ESM (representing medium equilibrium climate sensitivity) and HadGEM2 (representing high equilibrium climate sensitivity) that were forced by the RCP8.5 emission scenario (van Vuuren et al. 2011), downscaled by regional model RCA4, and bias corrected by comparing control simulation period of year 1971-2000 to observations from same period (e.g. Veijalainen et al. 2012, Gudmundsson et al. 2012).

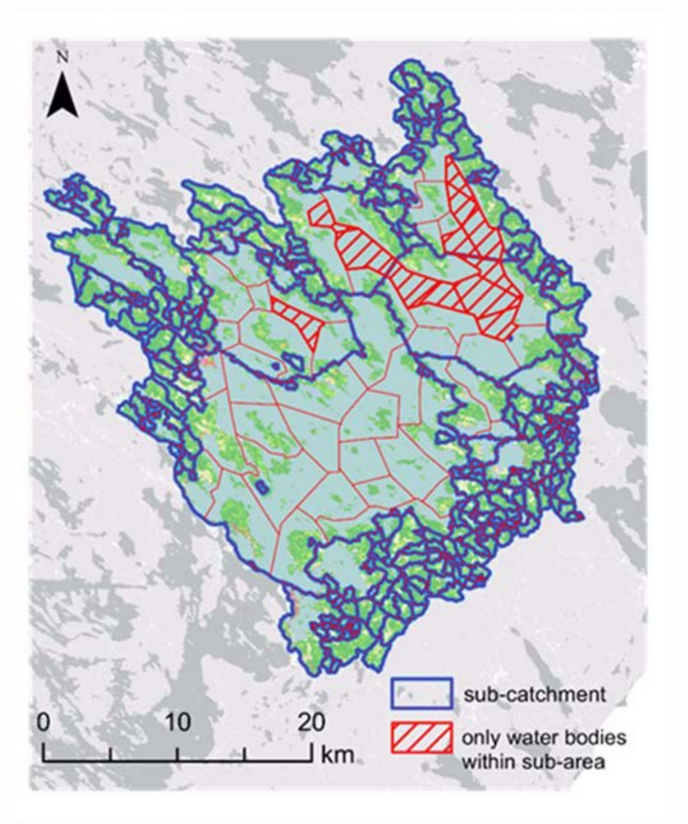

Figure 3 Catchments and sub-areas used as inputs for NutSpaFHy model.

There are altogether 355 sub-catchments within the catchment area of the Lake Puruvesi. Five catchments (04_181A001_001, 04_181A001_010, 04_181A001_012, 04_181A001_013, and 04_181A001_016) were divided to smaller parts to enable smooth run of the NutSpaFHy model. Within these areas there are sub-areas that include only water areas and were left out from the NutSpaFHy model runs resulting in 400 sub-catchments for which model runs were performed.

2.2.3. Logging scenarios – Puruvesi

To quantify the effect of forest use in various future climate scenarios, five different logging scenarios were produced based on forest inventory data (FID) available from privately owned lands. The basic unit is forest compartment, which represents homogenous area, where soil type, tree species, development class lead to uniform type and timing of next harvesting operation. The selection of the harvested areas for each scenario was done amongst those forest compartments, which had reached economical regeneration maturity. To estimate the effect of harvesting in different climates, at first, the scenario with no new clear-cut was calculated. Because Puruvesi catchment has a long history of quite intensive commercial forestry, forest areas in the regions forms a mosaic of numerous small homogenous forest compartments in the different development class depending on the time gone from the last clear-cut.

This means that no clear-cut scenario includes also recent historical clear-cuts done before 1.2.2020, which was the date data was written from forest inventory data system. Clear-cuts occurring on same day in March of the second year of modelling period.

The business as usual (BAU) scenario was formed based on ten years historical period. Yearly average clear-cut area was calculated based on FID from the Puruvesi area separately for peatlands and mineral soils.

BAU+30 scenario was formed similarly by selecting randomly mature forest compartments until target area was reached but increasing clear-cut target area by 30% compared to BAU. BAU+30 scenario represents the future, where timber demand increases from the historical level to the level set as target level in regional forest program set to South-Savo and this increased activity in commercial forests is manifested by increased clear-cut area.

The continuation scenario represents the future where area continuous cover forestry is practiced in much larger scale than during past and present day. This means that considerable portion of the forests stands reached economical regeneration phase in FID are not clear-cut but instead thinned. In this scenario it is assumed that wood demand and pressure to acquire timber remains in the same level than in BAU scenario. To make BAU and continuous cover scenario comparable, total timber yield (saw and pulpwood volume) of the forest compartments selected for clear-cut in BAU was summed and set as harvesting target to continuous cover scenario. Then mature forest compartments estimated suitable for continuous cover harvesting were selected and their timber yield summed. Because timber yield from suitable compartments was less than target set based on BAU, selection was supplemented selecting randomly more mature forest compartments for clear-cut until target timber yield was reached. It was assumed that all mature forest compartment in FID were suitable for continuous cover forestry harvesting if their soil fertility class was at least semi-mesic and they located in peatland areas. Because the goal of the continuous cover forestry harvesting in mature even aged forest is to enhance growth conditions of naturally born seedlings, simulated first continuous cover harvesting was intensive. Half of the total wood volume was removed, although minimum remaining wood volume was set to 100 m^3 ha^{-1} to maintain canopy closure. Because timber yield per harvesting operation is less in continuous cover forestry harvesting than in clear-cut, harvested area was larger than in BAU. But because nutrient uptake of the remaining trees is considerable and ground vegetation's nutrient uptake is not disturbed by the soil preparation continuous cover forestry is considered generally good alternative to evade increased nutrient leaching after clear-cut. In peatland, remaining tree stock also usually maintains sufficient evapotranspiration (e.g. Leppä et. al., 2020), which lessens the need to maintain drainage ditch network to regulate water table level to maintain tree growth. Refraining from ditch network maintenance gives ample opportunity to evade increased suspended solids leaching associated usually to clear-cuts.

The all clear-cut scenario functions as a comparison for the BAU, BAU+30 and continuation scenarios to outline the theoretical maximum effect of clear-cut's in different climate scenarios. In this scenario, all forest compartments reached economical regeneration phase in FID-data were treated with the clear-cut at the same time. In reality, only a certain portion of the mature stands are clear-cut yearly (BAU & BAU+30).

2.3. VEMALA

2.3.1 VEMALA model

VEMALA is an operational, national-scale nutrient loading model for Finnish watersheds. It simulates hydrology, nutrient processes, leaching and transport on land, rivers, and lakes. The model simulates nutrient gross load, retention, and net load from Finnish watersheds to the Baltic Sea (Huttunen et al. 2016). A field scale nutrient loading model ICECREAM (Knisel, 1993; Tattari et al., 2001) is used for simulation of agricultural loading from each field, and the daily loading results are summed together for each VEMALA spatial unit. In this application of the model, only the forest terrestrial loading, used in the operational VEMALA version (VEMALA v1), is replaced with the NutSpaFHy results as input for the total phosphorus (TP) loading from forests. The NutSpaFHy results were treated to provide annual TP loading (kg/ha) under various scenarios for each 3rd level subcatchment in Puruvesi basin. The NutSpaFHy results covered three time periods (2006-2016; 2040-2050; 2070-2080) and were averaged for each period. The average TP loading for each 3rd level subcatchment was interpolated in between each period to run VEMALA model over a continuous period 1960-2100. VEMALA was then run for each climate change and forest and agricultural loading scenario for the Puruvesi catchment. NutSpaFHy results are provided only for RCP8.5 MPI-ESM and RCP 8.5 HADGEM2 over each of the three periods and were linked to the climate scenarios RCP 8.5 MPI-R and RCP 8.5 Had-R respectively in VEMALA. However, an additional scenario was built using the forest loading under present conditions for each logging scenario over the period 2006-2016 combined with the climate change scenario RCP4.5 Had-R to represent a more moderate emission outcome. Agricultural measures simulated in the agricultural mitigation scenario include advanced fertilization and winter vegetation coverage, catch crops and sludge placement. This scenario represents a very efficient farming scenario with farming practices being very effective considering fertilization. Fields are kept in very good conditions and produce good yields. The application of the agricultural scenarios is independent of the forests scenarios and is analysed as a percentage of loading change compared to the business as usual scenario using only the climate change scenarios Had-R RCP 4.5 and Had-R RCP 8.5.

The Koitajoki catchment did not benefit from the logging scenarios and NutSpaFHy runs. Thus, average of TP loading (kg/ha) for the whole Puruvesi catchment were used in Koitajoki for each period and forest logging scenario. In order to compare the impact of forest management versus agricultural mitigation measures implementation, VEMALA was run using the BAU scenario for forests and forestry and the agricultural mitigation measures as well as climate change.

2.3.1. Climate scenarios

Climate change scenarios implemented into the hydrological model within VEMALA are using the delta change method for temperature and precipitation (Table 1). The applied climate scenarios are based on the regional climate model (RCM), data driven by different global climate models (GCMs) and constrained by RCPs. We chose two RCPs, RCP 4.5 (moderate emission and concentrations) and RCP 8.5 (high emissions and concentrations) to cover a wide range of possible outcomes over the current century. In addition to different RCPs, we used data from two GCM-RCM combinations (two GCMs and one RCM: Had-R and MPI-R).

According to the VEMALA model simulation, the runoff will change in the climate scenarios in a wide range from -5% to +17% by period 2070-2099 for Koitajoki river catchment (Figure 2a) and from -8% to +15% in Puruvesi catchment (Figure 3a). The runoff changes are the results of rainfall (Table 1) and evapotranspiration changes in the future. The climate change (CC) scenarios compared in this study are representing a drier scenario (Had-R RCP 4.5 and RCP 8.5) with a wetter scenario (MPI-R RCP 8.5). There is a decrease in runoff by 2 to 8% in scenario Had-R RCP 4.5, which represents the driest scenario in both Koitajoki and Puruvesi, while the highest increase in runoff (+15%-+17%) is in MPI-R RCP 8.5 scenario at the end of the century. In the wettest scenario, the runoff is increased as a result of increased precipitation (+26% over the period 2071-2100, Table 1) and moderate increase in evapotranspiration. Changes in the evapotranspiration are influencing runoff changes in the scenarios to a large extent, which in turn depends on the temperature increase during the vegetation season, and also soil moisture content in the soil. MPI-R RCP 8.5 scenario has exceptionally high winter precipitation (+29% over the period 2071-2100, Table 1) which leads to high runoff from October till March (Huttunen et al., submitted). In all scenarios, there is an important seasonal shift of runoff from spring to winter due to a shorter snow cover period (Huttunen et al., submitted) (Table 1). Late autumn and winter runoff increase is influencing nutrient loading the most due to the bare soil conditions of the agricultural fields at this time of the year.

Table 1: Change in precipitation (P, %) and temperature (T, ^{o}C) for the periods 2021-2050, 2041-2070, 2071-2100 for annual, and seasonal (winter and summer) under the scenarios Had-R RCP 4.5, Had-R RCP 8.5 and MPI-R RCP 8.5 for the Puruvesi catchment.

		2021-2050		2041-2070		2071-2100	
		Temperature change (^{o}C)	Precipitation change (%)	Temperature change (^{o}C)	Precipitation change (%)	Temperature change (^{o}C)	Precipitation change (%)
Had-R RCP4.5	annual	1.8	7.0	2.6	9.9	2.9	7.3
	winter	2.2	7.8	3.4	12.6	3.6	9.6
	summer	1.2	11.7	1.8	15.5	1.9	3.3
Had-R RCP8.5	annual	1.5	5.5	3.0	13.0	4.7	15.3
	winter	1.5	3.1	3.4	11.2	5.3	21.0
	summer	1.3	6.9	2.3	17.7	3.7	10.4
MPI-R RCP8.5	annual	1.5	8.5	2.2	10.7	3.9	26.4
	winter	1.6	-1.4	2.3	3.8	4.8	28.7
	summer	1.0	13.2	1.5	12.2	2.6	19.6

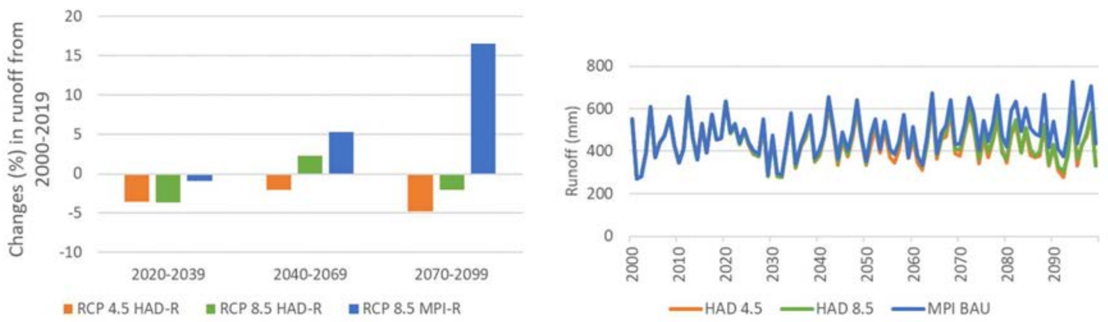

Figure 4: a- Variation of average changes (%) in runoff from Koitajoki catchment in dry scenario (Had-R RCP 4.5 and 8.5) and wet scenario (MPI-R RCP 8.5) for periods 2020-2039, 2040-2069, 2070-2099 compared to period 2000-2019. b- Annual average runoff (mm/year) in Koitajoki catchment in dry scenarios (Had-R RCP 4.5 and 8.5) and wet scenario (MPI-R RCP 8.5) for periods 2000-2099.

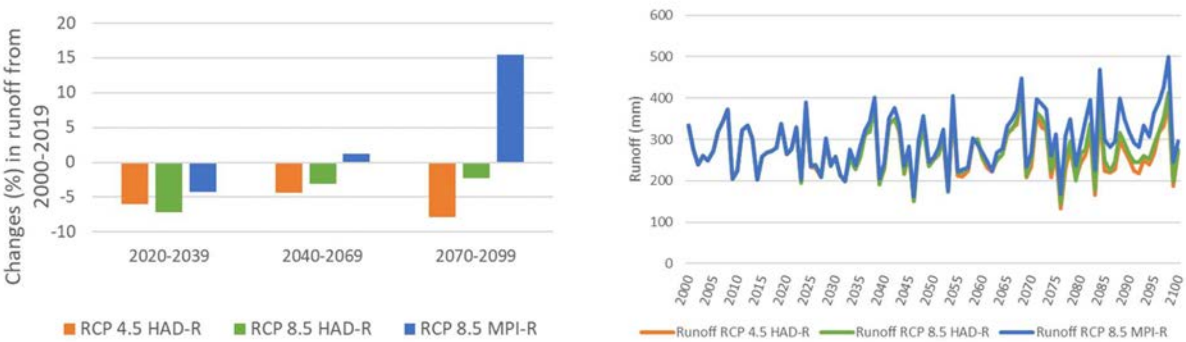

Figure 5: a- Variation of average changes in runoff from Puruvesi catchment in dry scenario (Had-R RCP 4.5 and 8.5) and wet scenario (MPI-R RCP 8.5) for periods 2020-2039, 2040-2069, 2070-2099 compared to period 2000-2019. b- Annual average runoff (mm/year) in Puruvesi catchment in dry scenarios (Had-R RCP 4.5 and 8.5) and wet scenario (MPI-R RCP 8.5) for period 2000-2099.

3. Results

3.1. Source apportionment

VEMALA simulation of the gross TP loading in Koitajoki and Puruvesi catchments over the period 2012-2019 shows that although forest is the main land use type in both catchments, forest and forestry loading is the main source of TP loading (85%) in Koitajoki, while in Puruvesi forest and forestry loading (40%) is less than the sum of agriculture and deposition on water bodies (55%). Agriculture produces 1/4 of the TP loading in Puruvesi with deposition representing 1/3 of the loading. In Koitajoki, agriculture is the source of only 8% of the TP loading and deposition only 5% (Table 2). Kuonanjoki (04.184), a subcatchment of Puruvesi is representative of the whole Puruvesi catchment with similar repartition of the TP loading sources, except for the deposition that is halved (13%) and the forest loading that is increased to 54%.

Table 2: Gross total phosphorus loading from Koitajoki, Puruvesi and Kuonanjoki catchments (kg/year and %) simulated by VEMALA over the period 2012-2019 from various sources.

	Koitajoki		Puruvesi		Kuonanjoki	
Sources	**TP loading (kg/year)**	**% of TP loading**	**TP loading (kg/year)**	**% of TP loading**	**TP loading (kg/year)**	**% of TP loading**
Agriculture	5141	8	2925	25	260	29
Forest and Forestry	51744	85	4670	40	476	54
scattered settlements	391	1	442	4	27	3
Cottages	127	0	120	1	6	1
Urban	17	0	15	0	1	0
Deposition	3190	5	3360	30	114	13
Point sources	197	1	2	0	0	0
Total	60807	100	11530	100	883	100

3.2. Puruvesi 04.181

The TP forest loading from the NutSpaFHy/VEMALA model for the Kuonanjoki catchment (3rd level subcatchment- 04.184) (Figure 6) shows the NutSpaFHy TP loading results used as input data for the forest loading in VEMALA. The RCP 4.5 Had-R scenario uses the present loading scenarios in the future, while RCP 8.5 Had-R and RCP 8.5 MPI-R influence drastically the TP loading from forested areas with increase up to 63% in the MPI-ESM scenario and 50% for the HADGEM2 scenario over the period 2080-2100 for the BAU logging scenario (Figure 7). On the contrary, the logging scenarios within each climate change scenario present a very small variation between them except for the all clear-cut scenario with an increase of the loading compared to the BAU scenario of 12%. Finally, the agricultural mitigation scenario shows no impact on the forest/forestry loading as all the mitigation measures are applied to agricultural fields, not represented in Figure 7.

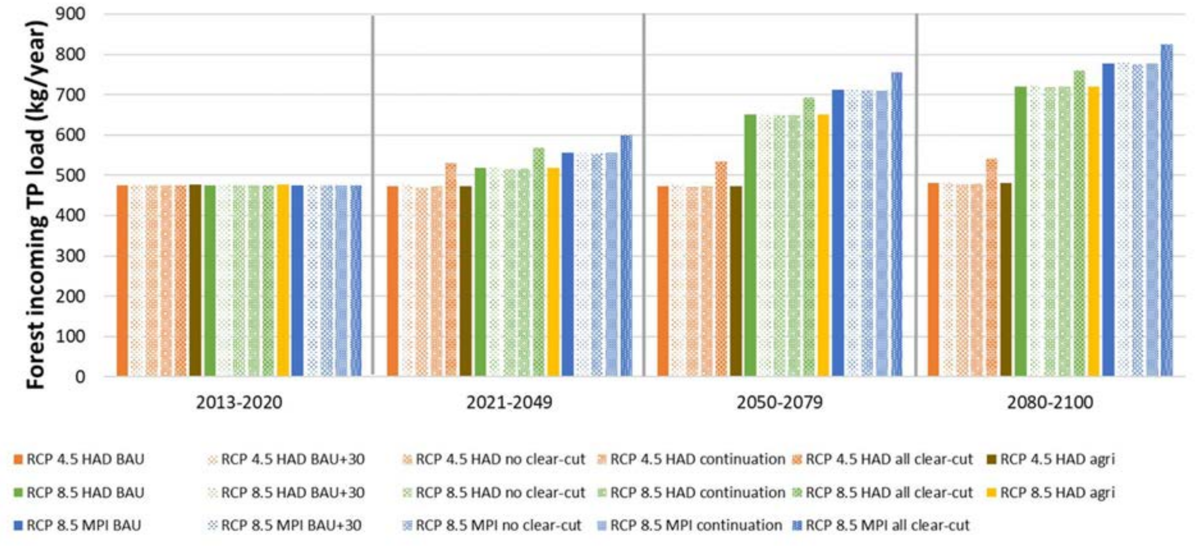

Figure 6: Average TP forest loading (kg/year) from Kuonanjoki catchment (04.184) as calculated by NutSpaFHy/VEMALA over the period 2012-2019, 2020-2049, 2050-2079, 2080-2100 for each forest logging and climate change scenario combination.

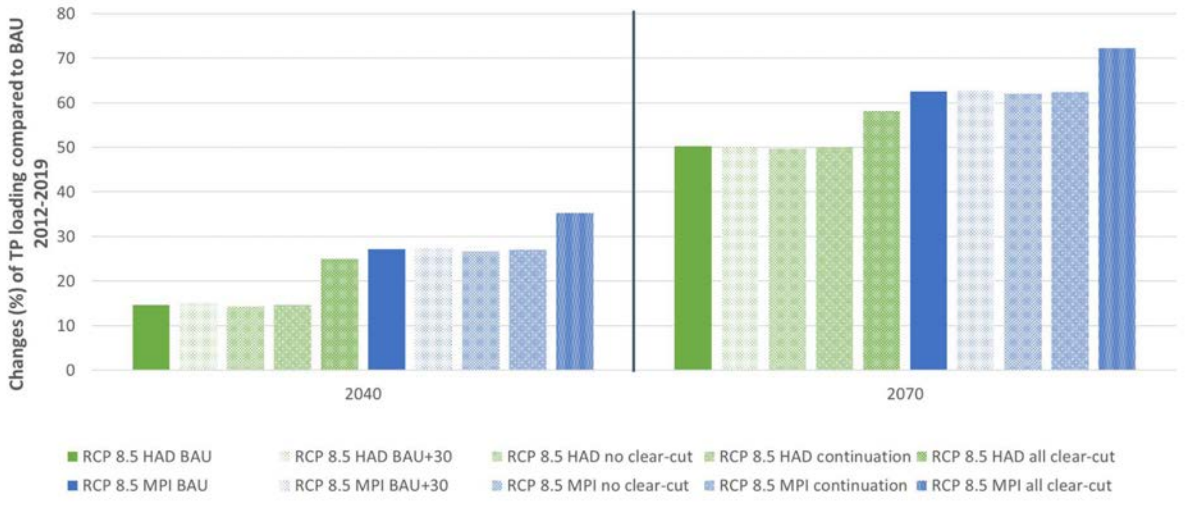

Figure 7: Annual average TP loading changes (%) from Kuonanjoki catchment (04.184) as calculated by NutSpaFHy for 2040 and 2070 for both climate change scenarios.

Figure 8 shows the 30-year average net TP loading from Kuonanjoki catchment (04.184) to the Puruvesi lake in each forest logging and CC scenarios from the VEMALA model. These results include the retention within the river/lake network. Figure 9 shows the net TP loading changes (%) from Kuonanjoki catchment over the period 2020-2049, 2050-2079, 2080-2100 compared to the period 2012-2019 for each forest logging and CC scenario combination. The predicted change in TP loading for the period 2080-2100 will vary from around -5--1% in RCP 4.5 Had-R to +26-30% in RCP 8.5 MPI-R with a middle of the road climate scenario at +14-17% in RCP 8.5 Had-R. The climate scenarios are clearly leading the TP loading change at the end of the century. The agricultural mitigation scenarios within each CC scenario show a small decrease of TP loading compared to the business as usual scenario (run in the other logging scenarios, -5- -4%, Figure 9) towards the end of the century. The increase in the net TP loading at the outlet of Kuonanjoki is about halved compare to the forestry loading change for each scenario. This is due to both the TP loading from other sources and the retention (Figure 10). The highest retention is simulated in the high emissions but dry scenario RCP 8.5 Had-R (30%) at the end of the century against 26-27% in the other scenarios. Although the retention is a calibrated parameter it depends mostly on the concentration in Kuonanjärvi lake. Indeed, the highest retention in RCP 8.5 Had-R is linked to the highest TP concentration in Kuonanjärvi lake (Figure 11) at the end of the century, compared to the other CC and logging scenarios.

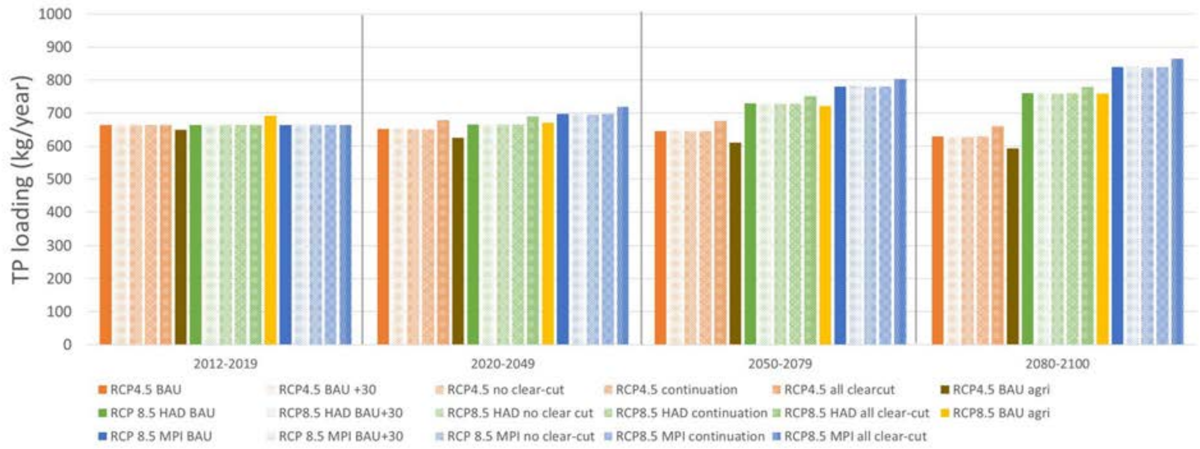

Figure 8: Annual average net TP loading (kg/year) from Kuonanjoki catchment (04.184) over the period 2012-2019, 2020-2049, 2050-2079, 2080-2100 for each forest logging and climate change scenario combination.

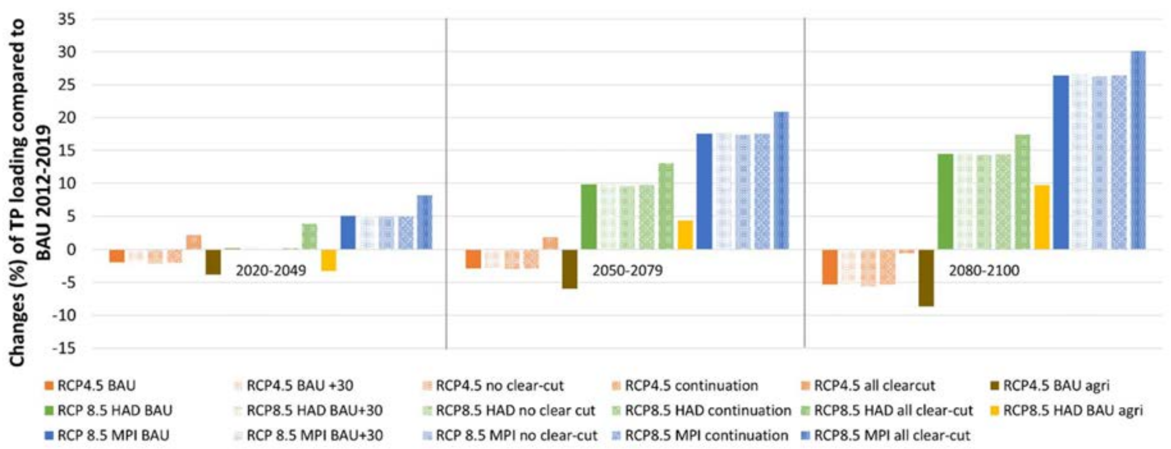

Figure 9: Annual average net TP loading changes (%) from Kuonanjoki catchment (04.184) over the

period 2020-2049, 2050-2079, 2080-2100 compared to the period 2012-2019 for each forest logging and climate change scenario combination.

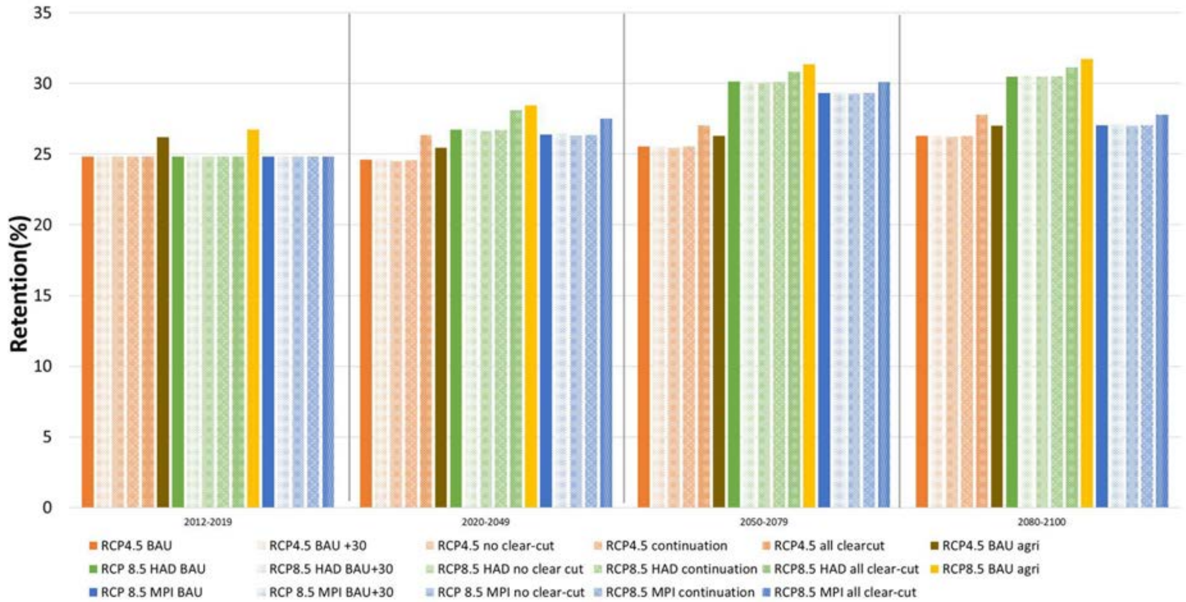

Figure 10: Average retention (%) in the Kuonanjoki catchment (04.184).

Figure 11 and 12 show the impact of the various forest management scenarios combined with the CC scenarios on the TP concentrations in lake Kuonanjärvi and Puruvesi respectively. Although TP concentration in Kuonanjärvi lake (about 40µg/L) is well correlated to the retention within Kuonanjoki catchment, it differs from the larger lake Puruvesi (about 8µg/L) downstream (Figure 12). Indeed, in lake Puruvesi the high emissions scenarios (RCP 8.5 HAD-R and RCP 8.5 MPI-R) are the two scenarios presenting higher concentrations. The difference within the 2 lakes can partially be explained by the importance of deposition as a source of TP loading to the lake Puruvesi (1/3) and the role of retention that is correlated to the % of lake area over the catchment area within VEMALA. Therefore, the higher emission scenarios have the most impact on the lake Puruvesi TP concentrations. Although, the impact of the various scenarios is limited on the water quality, with TP concentrations staying below 8µg/L. If the TP concentrations were to remain below 10µg/L, the ecological state of the Puruvesi lake would remain excellent for a large slightly humic lake regarding TP concentrations. As for Kuonanjärvi, that is classified as a shallow humic lake with a poor ecological water quality, it would probably also remain poor in the future. According to the ecological classification for TP concentration only, Kuonanjärvi should be classified as having moderate water quality (40-65µg/L) under present and future scenarios. However, there are clearly other indicators lowering the ecological state of the lake.

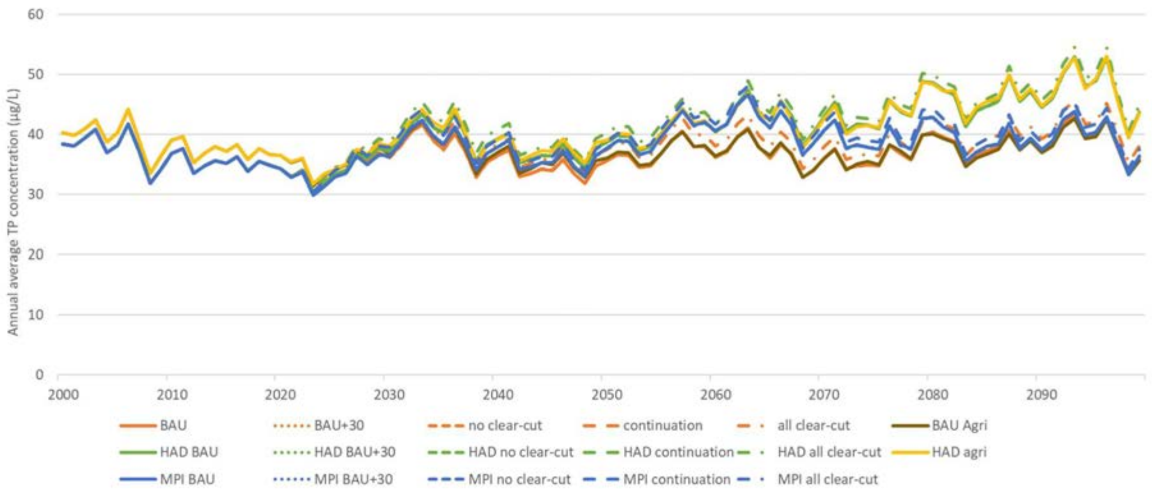

Figure 11: Annual average total phosphorus concentration (µg/L) over the period 2000-2100 in Kuonanjärvi lake

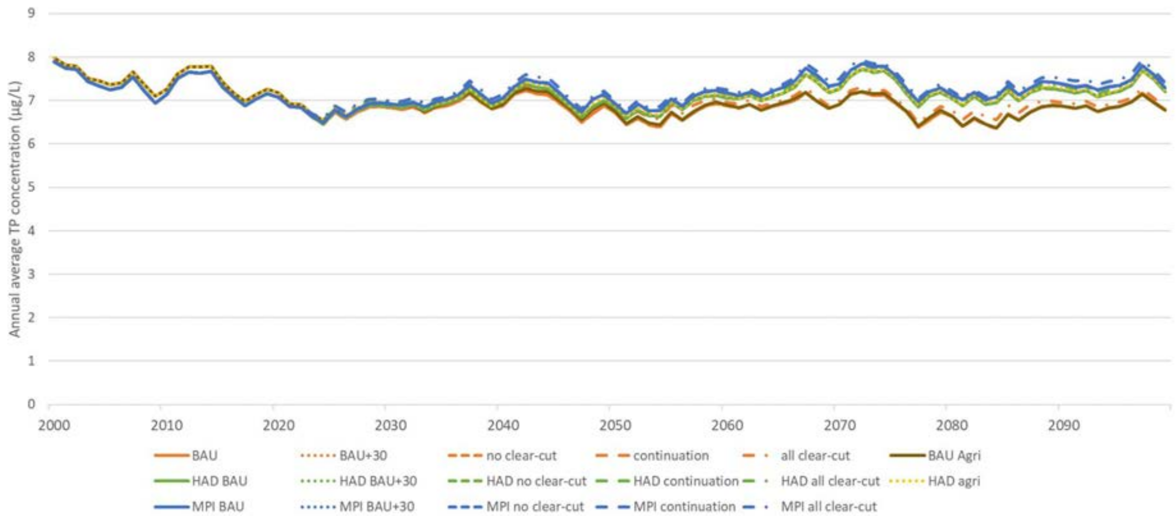

Figure 12: Annual average total phosphorus concentration (µg/L) over the period 2000-2100 in Puruvesi lake

3.3. Koitajoki- Koitajoki 04.9 lylykoski 04.921 to lake system downstream (Koitere lake)

Figure 13 shows the 30-year average TP loading from Koitajoki catchment (04.912) in each forest logging and climate change scenarios. Figure 14 shows the TP loading change changes (%) from Koitajoki catchment over the period 2020-2049, 2050-2079, 2080-2100 compared to the period 2012-2019 for each forest logging and climate change scenario combination. The predicted change in TP loading for the period 2080-2100 will vary from around -4-+4% in RCP 4.5 Had-R to +45-51% in RCP 8.5 MPI-R with a middle of the road climate scenario at +26-30% in RCP 8.5 Had-R. The climate scenarios are also in Koitajoki the most important variable of TP loading change at the end of the century. Indeed, the variation within each CC scenario for each logging scenario is between +4-8% with the clearest impact being the all clear-cut scenario compared to the BAU scenario. The agricultural mitigation scenarios showed no additional impact of the net TP loading from Koitajoki catchment. The TP loading results show that in Koitajoki the impact of forest/forestry loading in the future is even more important than in Puruvesi catchment. In Koitajoki catchment, the highest source of TP loading is forest/forestry (85%). Indeed, the TP loading is increasing drastically towards the end of the century in both high emissions scenarios. The importance of the forest/forestry loading is also presented in the increase of the TP concentration (about 10 to about 12 µg/L) by about 20% under both high emission scenarios in Koitere lake towards the end of the century (Figure 15). The lake is classified as having a good ecological status, however for large humic lakes, if we look at the TP concentration indicator only, the lake should be classified as excellent (TP concentration<15µg/L). The future high emission scenarios are increasing the TP concentration closer to this limit and it could well be that the lake is classified as good in the future according only to TP concentrations.

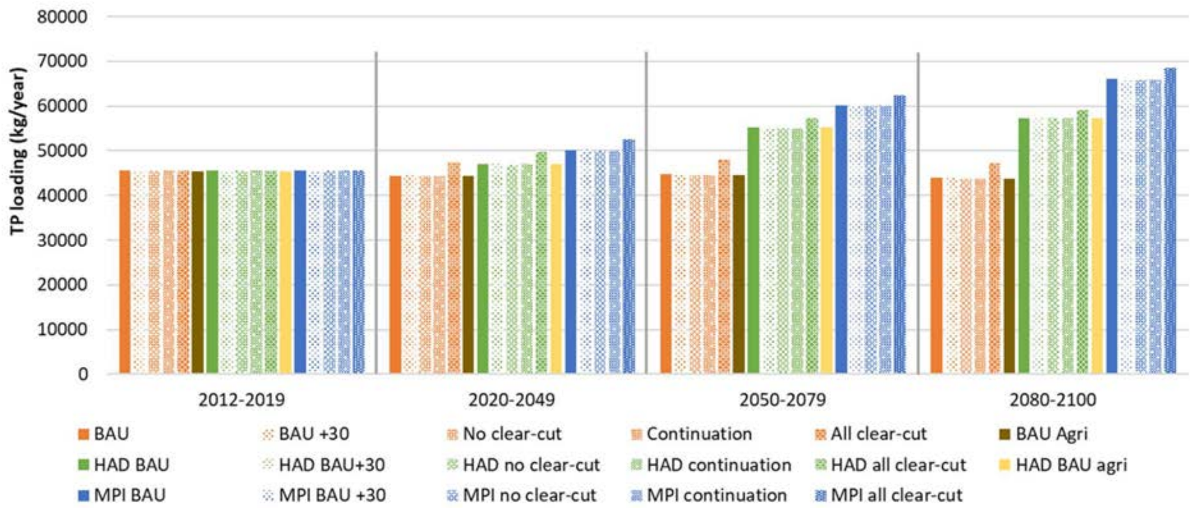

Figure 13: Annual average TP loading (kg/year) from Koitajoki catchment (04.9) over the period 2012-2019, 2020-2049, 2050-2079, 2080-2100 for each forest logging and climate change scenario combination.

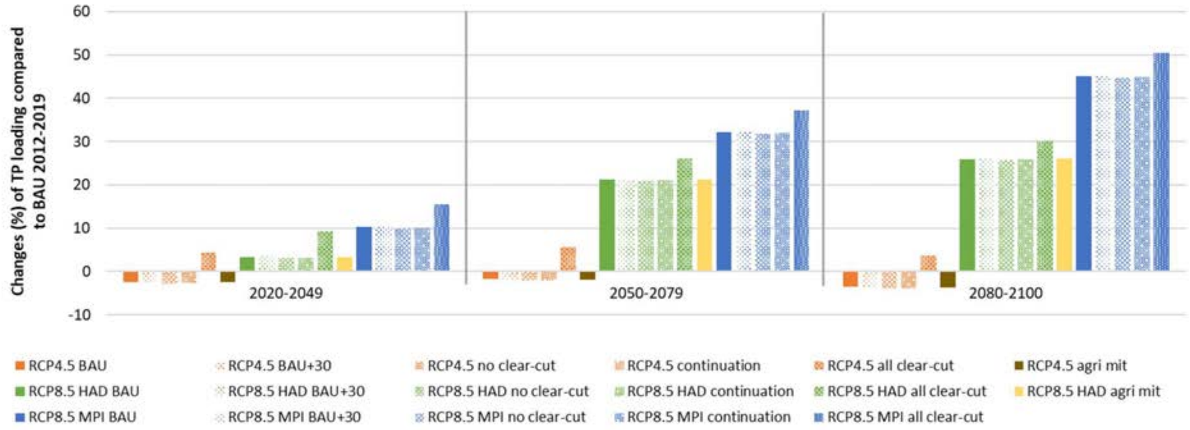

Figure 14: Annual average TP loading changes (%) from Koitajoki catchment (04.912) over the period 2020-2049, 2050-2079, 2080-2100 compared to the period 2012-2019 for each forest logging and climate change scenario combination.

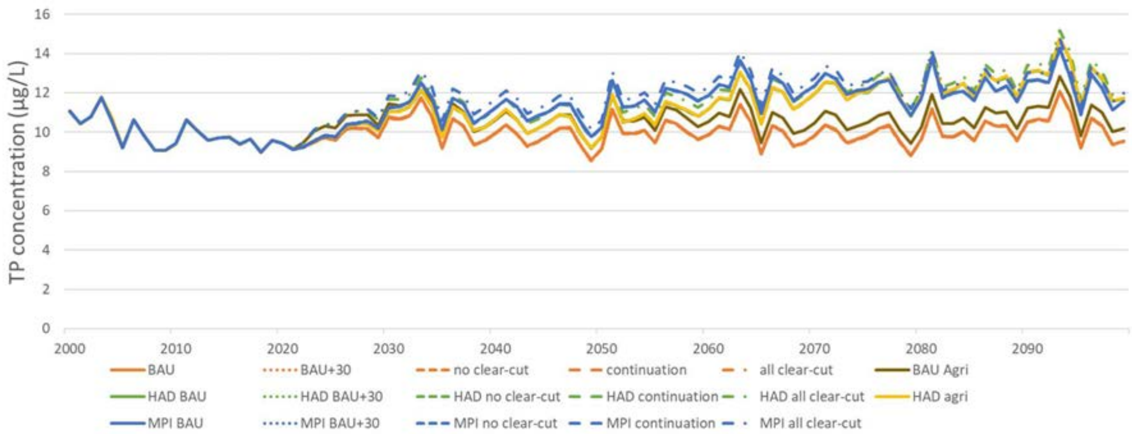

Figure 15: Annual average total phosphorus concentration (µg/L) over the period 2000-2100 in Koitere lake (04.941)

4. Conclusion

In this study, we looked at the impact of various forestry management scenarios and agricultural mitigation scenarios coupled with climate change scenarios on the water quality in Koitajoki and Puruvesi catchments. For this purpose, we coupled the plot scale forest loading model NutSpaFHy with the nutrient loading model (VEMALA). The coupling of the models showed the importance of the increase of TP loading in high emission climate change scenarios (+14-+51%, over the period 2080-2100; Table 3) within highly forested catchments in Eastern Finland. The impact of the high increase in TP loading to the river network was relative when it came to the increase in the TP concentrations (about

+20%) in large lakes in the future (Koitere and Puruvesi). Within each climate change scenario, the forestry management scenarios were not significantly affecting the TP loading except for the utopic all clear-cut scenario that increased the TP forest/forestry loading by 10% compared to the BAU scenario. On the other hand, the changes in TP loading should be mostly dependent on climate change and runoff as an indicator. However, the runoff changes in CC scenario RCP 8.5 Had-R are decreasing or stable (-6--1%) compared to the present period (Table 3). This can be explained by higher variation in annual runoff peaks linked to a higher shift in seasonal runoff towards the autumn-winter period leading to higher TP loading (Huttunen et al., submitted). Moreover, the initial NutSpaFHy simulations for future climate simulated on average too cool summers and too mild winters in the study area, overestimated precipitation and produced too high relative humidity but global radiation was produced reasonably well. This could explain the high increase in forest TP loading simulated by NutSpaFHy.

More work is needed to link the NutSpaFHy results better to the VEMALA model as in this work, we could only use the NutSpaFHY results at the 3rd level subcatchment while the results were produced at the 4th level subcatchment. This is sufficient for analysis of loading changes for Koitajoki, Puruvesi and Kuonanjärvi, but loading scenarios for smaller water bodies would require detailed spatial coupling of the models. Moreover, NutSpaFHY model inputs direct daily output from the weather models while in VEMALA the climate change scenario is implemented by using delta-change method. Therefore, the daily simulation of hydrology is different between the models and the monthly forest/forestry loading had to be averaged over the 10-year period available for 2006-2016, 2040-2050 and 2070-2080, in order to be applied over the whole 2000-2100 period in VEMALA. Therefore, the intra-annual TP forest loading variation produced by the NutSpaFHy model could not be presented with VEMALA.

Table 3: Change in precipitation (%), runoff (%), forest TP loading (%), net TP loading in Kuonanjoki catchment (%) and net TP loading in Koitajoki catchment (%) for the periods 2021-2050 and 2071-2100 compared to 2012-2019 under the scenarios Had-R RCP 4.5, Had-R RCP 8.5 and MPI-R RCP 8.5 and the logging scenarios (BAU, BAU+30, no clear-cut, continuation and all clear-cut) as well as the agricultural scenario (agricultural mitigation measures)

	Precipitation changes (%)		Runoff changes (%)		Forest loading (%)		Net loading Kuonanjoki changes (%)		Net loading Koitajoki changes (%)	
Period	**2021-2050**	**2071-2100**	**2021-2050**	**2071-2100**	**2021-2049**	**2080-2100**	**2020-2049**	**2080-2100**	**2020-2049**	**2080-2100**
RCP4.5 BAU	7	7.3	-5	-7	-1	1	-2	-5	-2	-4
RCP4.5 BAU +30	7	7.3	-5	-7	0	1	-2	-5	-2	-3
RCP4.5 no clear-cut	7	7.3	-5	-7	-1	0	-2	-6	-3	-4
RCP4.5 continuation	7	7.3	-5	-7	-1	1	-2	-5	-3	-4
RCP4.5 all clearcut	7	7.3	-5	-7	11	14	2	-1	4	4
RCP4.5 BAU agri	7	7.3	-5	-7	-1	1	1	-5	-3	-4
RCP 8.5 HAD BAU	5.5	15.3	-6	-1	9	51	0	14	3	26
RCP8.5 HAD BAU+30	5.5	15.3	-6	-1	9	52	0	15	3	26
RCP8.5 HAD no clear cut	5.5	15.3	-6	-1	8	51	0	14	3	26
RCP8.5 HAD continuation	5.5	15.3	-6	-1	9	51	0	14	3	26
RCP8.5 HAD all clear-cut	5.5	15.3	-6	-1	19	59	4	17	9	30
RCP8.5 BAU agri	5.5	15.3	-6	-1	9	51	3	17	3	26
RCP 8.5 MPI BAU	8.5	26.4	-7	19	17	63	5	26	10	45
RCP 8.5 MPI BAU+30	8.5	26.4	-7	19	17	64	5	27	10	45
RCP 8.5 MPI no clear-cut	8.5	26.4	-7	19	16	63	5	26	10	45
RCP8.5 MPI continuation	8.5	26.4	-7	19	17	63	5	26	10	45
RCP8.5 MPI all clear-cut	8.5	26.4	-7	19	26	73	8	30	15	51

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