VEMALA TOC II project report

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1. Summary

During VEMALA TOC II project, VEMALA TOC model was developed further by including one more land use class – fields on peat soils. The accuracy of spatial variability of the TOC simulated loading has been improved by including better representation of carbon content in mineral agricultural fields (field scale data of organic matter content) and in mineral forest soils (multi-source national forest inventory (MFNI) data). The implementation of physically based hydrological model into VEMALA has been started and tested in one river basin. The differentiation of the hydrological processes on peat and mineral soils would considerably improve TOC loading simulations, therefore hydrological model improvement should be continued during next year. The plan of the adding CO_2 emissions from water-air surface has been created, and implementation of this process description into the model should be done during the next year. The improved results and maps have been added to the VEMALA user interface and is available for user usage.

2. Description of the model

VEMALA TOC model development was based on VEMALA-N model (Huttunen et al., 2016) and INCA-C model (Futter et al., 2007).

The model is based on improved VEMALA hydrological model, which simulates runoff formation and transport of TOC load with three flow pathways – surface runoff, subsurface runoff and baseflow. The hydrological and C model has two layers – subsurface soil layer 0-20 cm deep where the subsurface flow is formed, and lower soil layer 20-100 cm deep, from which baseflow is formed. Surface runoff brings the TOC from very top of the soil. C is leached with 3 runoff components – especially important this division is to describe the TOC leaching from peat soils, where highest concentrations in the streams are observed during low flow periods, which means that there is higher DOC concentration in lower soil layer and it is leached with baseflow.

Originally there were 5 land use classes in the model: agriculture on clay soils, agriculture on coarse soils, forests on mineral soils, forests on managed peat soils, natural peatlands. Now one more land use class – fields on peat soils has been added. The basis for choosing these classes is considerable differences in TOC leaching. On agricultural clay soils macropore flow is increasing the DOC leaching form soils. On coarse soils DOC leaching is lower, because water infiltrating into the soil matrix and much less DOC is leached with micropore flow, because it is bound to mineral soil particles. For forests 3 classes are chosen, because of clear TOC leaching difference from mineral and peat soils.

C in soil is described with three storages – solid organic carbon (SOC), dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC). The main processes described in the model are mineralization of organic carbon (OC), dissociation of OC and production of DOC, association of DOC back into SOC. Model simulates

C balance in SOC and DOC storage every day depending on C fluxes. Input data into the model are C content in 1 m deep soil layer and C in litter fall (kg ha^{-1} yr^{-1}).

3. Fields on peat soils

First step was – to estimate agricultural peat soil area. There is detailed agricultural soil description in VEMALA system based on two sources: 1) around 40% of field parcels has the measured soil texture provided by Viljavuuspalvelu oy, 2) for other field parcels soil texture is estimated based on Finnish soil database. From these data sets we have estimated agricultural peat soil area for each channel (uoma) in Finland and used in VEMALA TOC model. Next step was to find TOC loading observation data for peat field and estimate the model parameters for this class. We are very thankful to research scientist Merja Myllys from LUKE, Jokioinen who provided COD measurement data from MTT Karjala Tohmajärvi research station peat field for the period 1984-1991. Based on COD concentration (mg l^{-1}) and runoff volume (l ha^{-1}) measurement data the annual COD loading from peat field was variating from 74 to 346 kg ha^{-1} depending on hydrological conditions. Mean annual COD loading was 236 kg ha^{-1}. We have used empirical equation (1) (Kortelainen, 1993) to relate TOC and COD loads. According to the equation, estimated TOC load from peat field was 161 kg ha^{-1}.

$$TOC\_obs = CODMN\_obs * 0.675 + 1.94 \quad (1)$$

Simulated specific loading from forests on ditched peat lands is around 150-170 kg ha^{-1}, therefore the same parameters (SOC mineralization, disassociation, DOC association) can be used also for agriculture on peat soils. Very few small test catchments with TOC observations have agricultural peat soils, except Korpijoki catchment in Iisalmi waterway (04_565, 127.5 km^2). Model was tested in Korpijoki catchment (Figure 1). The simulation improved after including peat fields in the model. The mean observed TOC concentration is 24.4 mg l^{-1}, and simulated 24.2 mg l^{-1}. Then model was applied to all Finnish watersheds. Table 1 shows the increase in the simulated TOC loads in Pohjanmaa river basins after adding agricultural peat soils to the model.

Table 1. Simulated TOC loading with and without peat fields in the model, peat field area in some Pohjanmaa rivers and Korpijoki (Iisalmi waterway)

	Korpijoki, 04_565	Maalahdenjoki, 40	Laihinajoki, 41	Kyrönjoki, 42	Lapuanjoki, 44	Purmojoki, 46	Ähtävänjoki, 47	Kruunupyynjoki, 48	Perhonjoki, 49	Kälviänjoki, 50	Kalajoki, 53
Peat field area, % of total field area	25	59	27	15	18	25	17	40	32	34	23
Model with peat fields	1042	4008	3045	28727	27813	5048	10418	6291	20376	2254	39073
Model without peat fields	928	3375	2651	26549	26289	4571	9951	5943	19008	2052	36771
Increase, %	12	19	15	8	6	10	5	6	7	10	6

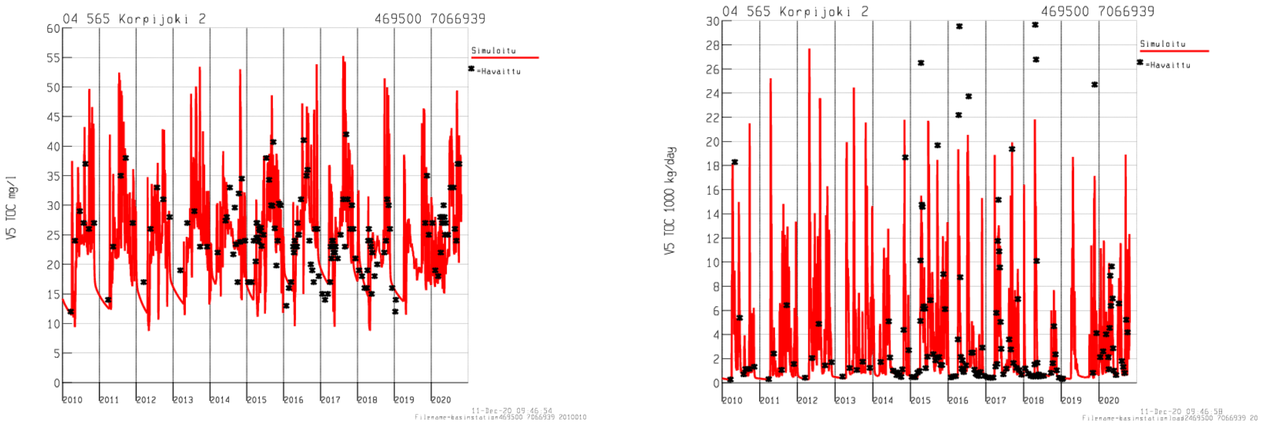


Figure 1. a) TOC concentration and b) load in Korpijoki (04_565, 127.5 km^2). Mean observed concentration 24.4 mg l^{-1}, simulated 24.2 mg l^{-1}.

4. C content in mineral soils

4.1. C content in mineral agricultural soils

C content both in the agricultural and forest soils is an input to the model, and therefore it is important to improve the accuracy and spatial variability of the values. The C content calculation is based on field parcel data from Viljavuuspalvelu oy which contains soil organic matter (SOM) class (vm - vähämultainen, m – multainen, rm – runsasmultainen, erm – erittäin runsasmultainen, mm – multamaa, Tm – turvemaa). Only 5 first classes are for mineral soil and was used in creating C content for mineral soils. Only 40% of fields have observations, so the mean C content for 3rd level subcatchment for clay or for coarse soils was extrapolated based only on 40% of observed data. The methodology was following: 1) the mean SOM content in % for the top soil for each class was obtained from LUKE report (Lemola et al., 2018), 2) the area of agricultural clay soils and coarse soils for each 3rd level subcatchment was estimated, 3) the mean SOM content for clay and coarse soils separately was estimated, and then weighted mean SOM content for 3rd level catchment was estimated, equation (2), 4) SOM content 1000 kg ha^{-1} is calculated by using bulk density of the mineral soils and SOM content, 4) it is assumed that SOM content in the 0-1 m deep soil (1000 kg ha^{-1}) is decreasing exponentially with the layer depth.

$$SOM_{catchm} = (SOM_{clay} \times A_{clay} + SOM_{coarse} \times A_{coarse})/(A_{clay} + A_{coarse}) \qquad (2)$$

Table 2 shows the mean SOM_{catchm} and mean TOC concentration for Aurajoki, Vantaanjoki and Lyötäneenoja (35_121, area 3 km^2, 82% agriculture, mostly coarse soils). There is a trend that TOC concentration is increasing with increasing SOM content. It is also reported by Manninen et al., 2018. Simulation of initial value of SOM in mineral agricultural soils is applied to the all watersheds in Finland and is shown in the Figure 2.

Table 2. Mean SOM_{catchm} and mean TOC concentration for Aurajoki, Vantaanjoki and Lyötäneenoja (35_121, area 3 km^2, 82% agriculture, mostly coarse soils).

	SOM_{catchm}, Mg ha^{-1}	SOM_{clay}, Mg ha^{-1}	SOM_{coarse}, Mg ha^{-1}	obs TOC conc, mg l^{-1}	sim TOC conc, mg l^{-1}
Aurajoki	174	177	155	15	14.6
Vantaanjoki	168	170	130	12.9	14.7
Lyötäneenoja, 35_121	149	144	152	9.1	12.4

4.2. C content in mineral forest soils

The MNFI data is implemented into VEMALA system now, and forest soil fertility classes are aggregated for each 4th level subcatcment (uoma) with the purpose of estimation of the initial C content in mineral forest soils. There are 8 forest fertility classes in MNFI - 1 = lehto, letto ja vastaavat, 2 = lehtomaiset kankaat ja ruohoiset suot ja vastaavat, 3 = tuoreet kankaat ja suursaraiset, mustikkaiset suot ja vastaavat, 4 = kuivahkot kankaat ja piensaraiset, puolukkaiset ja vastaavat, 5 = kuivat kankaat ja tupasvillaiset, isovarpuiset ja vastaavat, 6 = karukkokankaat ja rahkaiset ja vastaavat, 7 = kalliomaat, hietikot, vesijättömaat, 8 = lakimetsät ja tunturit. The C content in 0-1 m layer in different fertility classes is estimated according to regression equations relating C content and effective temperature sum for each fertility class (Liski and Westman, 1997). Based on the MNFI data most fertile mineral forest soils are in Southern, South-Western catchments, Kokemäenjoki, Kymijoki and Vuoksi catchments (Figure 2b). Including more accurate C content in forest soils improved also TOC loading, concentration simulation. Especially improvement is visible in Lapland's river mineral soil dominated basins, where C contents is low and therefore also TOC loading is low (see Table 3).

Table 3. Difference of TOC loading from mineral forest depending on C content in the soil in two different test catchments

	Catchm area, km^2	Obs TOC conc, mg l^{-1}	Sim TOC conc, mg l^{-1}	Sim mineral forest TOC loading, kg ha^{-1}
Laanioja, 71.456U0012	14.28	1.34	8.68	
Laanioja new model, 71.456U0012	14.28	1.34	5.71	16.7
Hauklammenoja, 21.041U0009	1.7	11.09	10.4	29.3

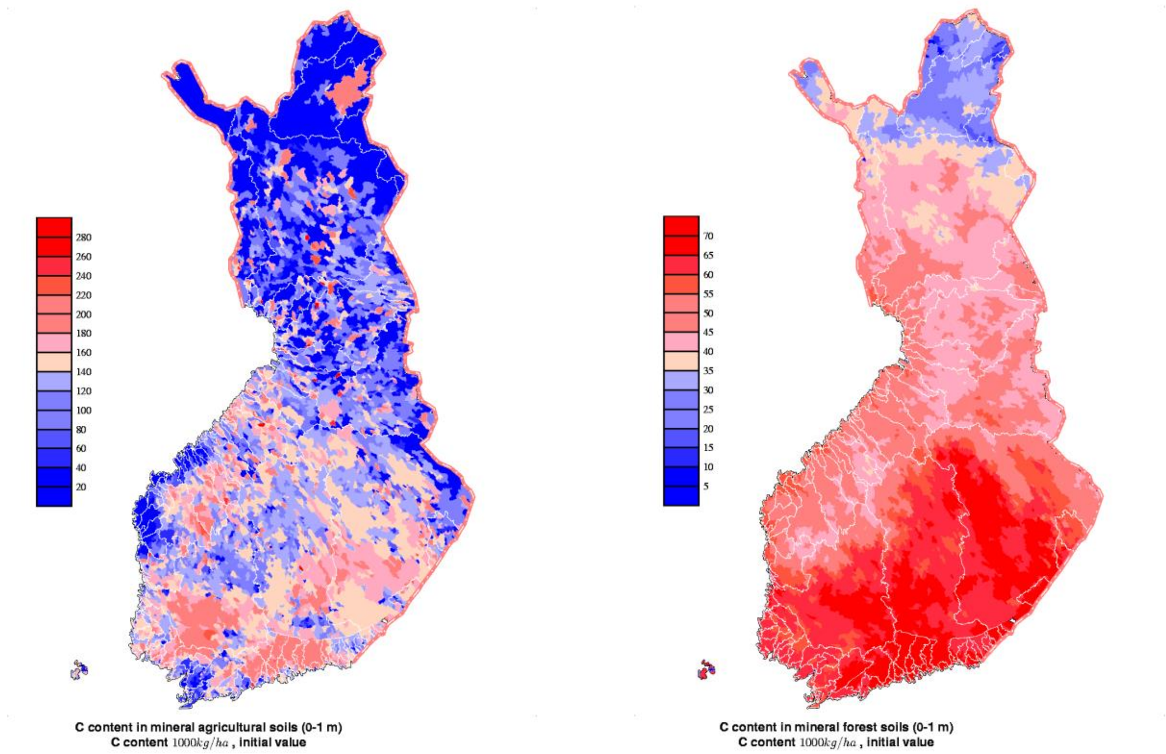


Figure 2. Initial value of C content in a) mineral agricultutal soils (0-1 m) based on SOM class (multavuus) data, b) mineral forest soils (0-1 m) based on MNFI data.

5. Hydrological model development

In co-operation with KLIVA project (Vesitasapaino, ekosysteemipalvelut ja metallien kuljetus muuttuvassa ilmastossa) we have developed VEMALA hydrological model further. In the new model, hydrological processes are simulated separately for each soil texture (clay, moraine, coarse, silt, peat, rock), therefore also the spatial distribution of each soil texture class for 4th level subcatchment is added to the VEMALA. Data is based on Finnish Soil database. The model description is Juho Jakkila's physical hydrological model description implemented into WSFS system. The new model is implemented only to Laihianjoki catchment, and only very first test version is available. However, model gives promising results in terms of discharge simulation (Figure 3.b.) and it is also able to simulate different runoff amounts for different soil textures (Figure 3.a.). Model also simulates different soil moisture content, different runoff amounts through surface runoff, subsurface runoff and base flow. All above mentioned variables influence the TOC leaching processes to a great extent. Future work involves the implementation of the new hydrological model into VEMALA TOC model. More physically based hydrological model will considerably reduce the calibration need and related uncertainty in VEMALA hydrological model.

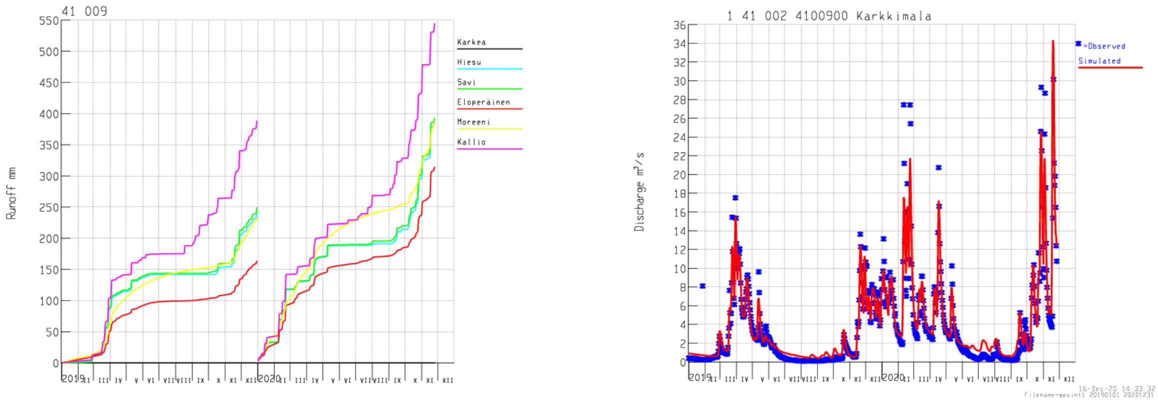


Figure 3. New physically based VEMALA hydrological model test results for Laihianjoki catchment – a) runoff amounts from different soil textures, b) discharge simulation.

6. Results and maps in user interface

VEMALA TOC model results for all Finnish watersheds are available in VEMALA user interface under links 'V5 TOC' and 'V5 TOC CODMN'.

- V5 TOC (keskeneräinen)
- V5 TOC CODMN (keskeneräinen)

Additional results what have been added during 2020 are TOC loading from fields on peat soils and area of fields on peat soils for each lake and each uoma. Similar TOC loading source apportionment is given also for each 3rd level subcatchment.

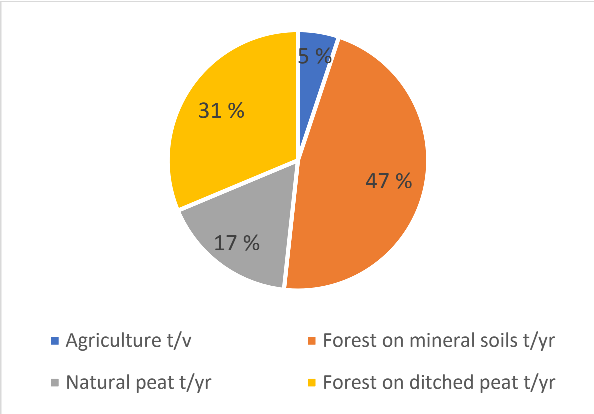
V5 TOC

1 1 1 2 1 3 1 4 2 1 2 2 2 3 2 4 3 1 3

V5 TOC Uomasta 04.565U0006 lähtevä kuorma 1000 kg/vuosi	Nykytila 2012-2019
Agriculture on clay soils	18,12
Agriculture on coarse soils	17,98
metsätalous hakkuut	0,00
metsätalous kunnostusojitus	0,00
metsätalous lannoitus	0,00
Forest on ditched peat	596,34
Forest on mineral soils	297,40
vakituinen haja-asutus	0,00
loma-asunnot	0,00
Natural peat	45,68
Agriculture on peat soils	66,87
pistekuorma	0,00
Summa	1042,39

There now 6 maps available for TOC results – 1) Specific TOC loading from agricultural fields (1000 kg km^{-2} a^{-1}), 2) TOC loading from agricultural fields on peat soils (1000 kg km^{-2} a^{-1}), 3) TOC loading from forests on mineral and peat soils, bogs (1000 kg km^{-2} a^{-1}), 4) total TOC loading (1000 kg km^{-2} a^{-1}), 5) Initial value of C content (1000 kg ha^{-1}) in mineral agricultutal soils (0-1 m) based on SOM class (multavuus) data, 6) in mineral forest soils (0-1 m) based on MNFI data.

There are also the summary tables of TOC loading source apportionment, TOC gross, net loading and retention available in user interface, and summary shown in Figure 4. The biggest source of TOC loading is forest on mineral soils (47%), because that is the largest land use area for Finnish watersheds. Next source is forests on ditched peat soils (31%). TOC loading from peat soils is around 2.5 to 3 times higher than from mineral soils. The highest mean simulated TOC specific loading for test basins is from forest on ditched peat soils 120 kg ha^{-1}, from forest on mineral soils 39 kg ha^{-1}, from agriculture on mineral soils 22-47 kg ha^{-1}. According to the present model version (v1 for lake simulation) 630 t yr^{-1} 33% of TOC loading is retained in the lakes (sedimented or lost to the air). However, lake model needs to be developed during the future projects to include more process based C cycle in the lakes.



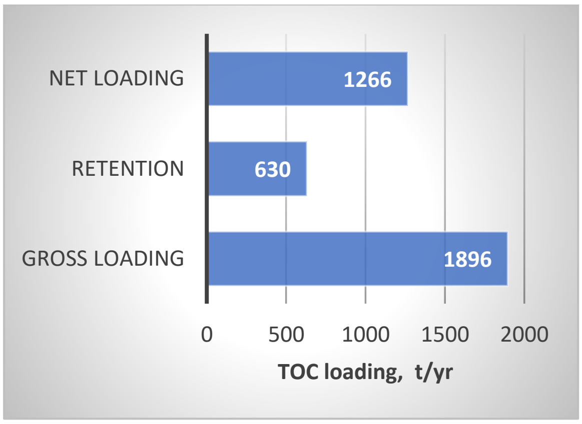


Figure 4. a) Source apportionment of total TOC loading, b) TOC gross, net loading and retention for river basins draining into the Baltic Sea.

7. Development needs

During the project several important improvements have been started, but they need to be continued during the continuation project:

- The implementation of physically based hydrological model into VEMALA has been started during 2020. The differentiation of the hydrological processes on peat and mineral soils would considerably improve TOC loading simulations, therefore hydrological model improvement should be continued during next year.
- The addition of the process description of CO_2 emissions from both water-air surface from lakes and from terrestrial areas should be done during the next year. Especially the knowledge of CO_2 losses from lakes is needed for C budget accounting on national scale.
- C content in peat soils should be improved based on GTK turvetilinpito data.
- Continuation of MFNI data implementation in VEMALA TOC model should be done, by taking into use tree biomass data for litter fall estimation.

References

Futter, M., Butterfield, D., Cosby, B., Dillon, P., Wade, A., 2007. Modeling the mechanisms that control in-stream dissolved organic carbon dynamics in upland and forested catchments. Water Resources Research 43(2). DOI 10.1029/2006WR004960

Huttunen, I., Huttunen, M., Piirainen, V., Korppoo, M., Lepistö, A., Räike, A., Tattari, S. & Vehviläinen, B. 2016. A national scale nutrient loading model for Finnish watersheds – VEMALA**.** Environmental Modeling & Assessment, 21(1), 83-109. DOI: 10.1007/s10666-015-9470-6.

Kortelainen, P. 1993. Content of Total Organic Carbon in Finnish Lakes and Its Relationship to Catchment Characteristics. Canadian Journal of Fisheries and Aquatic Sciences**.** Vol. 50, pp 1477-1483.

Lemola, R., Uusitalo, R., Hyväluoma, J., Sarvi, M., Turtola, E. 2018. Suomen peltojen maalajit, multavuus ja fosforipitoisuus. Vuodet 1996–2000 ja 2005–2009. Luonnonvarakeskus (Luke), Helsinki, 209 p.

LISKI, J., WESTMAN, J. Carbon storage in forest soil of Finland. 1. Effect of thermoclimate. *Biogeochemistry* **36,** 239–260 (1997). https://doi.org/10.1023/A:1005711024022

Manninen , N J , Soinne , H S , Lemola , R , Hoikkala , L K & Turtola , E, 2018 , Effects of agricultural land use on dissolved organic carbon and nitrogen in surface runoff and subsurface drainage , Science of the Total Environment , vol. 618 , pp. 1519-1528 . https://doi.org/10.1016/j.scitotenv.2017.09.319