VEMALA TOC project report

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1. Summary

During the project new version of the VEMALA TOC model was developed, and it simulates TOC processes in the soils in more process based manner. TOC leaching depends on the C storage, soil moisture, temperature and runoff conditions. VEMALA TOC model was developed, calibrated and tested for monitoring points form SYKE small watershed observations. During next step VEMALA TOC model was applied to all Finnish watersheds within operational version of VEMALA, and three model parameters calibrated for each calibration area. VEMALA TOC model results are available in VEMALA user interface the same way as for other substances. However, checking of the model results still needs to be done in nearest future. Future development ideas of the VEMALA TOC model has been identified during this project and is given at the of the report.

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 structure of the model and process description is given in Appendix 1.

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.

There are 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. 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, C in litter fall (kg ha^{-1} yr^{-1}).

Model has several parameters which are manually calibrated for each land use class. Calibration is done based on two approaches: 1) comparison of observed and simulated TOC concentrations in the streams, from small watershed observations and also from National monitoring points, 2) comparison of simulated annual TOC loading from different land use classes with values published in literature. The problem is that there is not much literature available on TOC leaching from agricultural soils, from mineral forest soils, and also the difference of loading from managed and natural peatlands is not well reported. Only **two** catchment parameters are calibrated by automatic calibration for each calibration area separately.

The project focus was on development of the TOC model for land areas, TOC retention in lakes were simulated with improved VEMALA v1 approach by using **one** calibrated combined C evasion, sedimentation coefficient.

3. Testing of the model in small watersheds, specific loading for different land use classes

During development stage model was tested for 16 small watersheds, which have regular TOC observations. These watersheds have different land use characteristics, so they can be used to calibrate the specific loading from agricultural, forest on mineral and peat soils. There are no better observations available to estimate specific loading from these different land use classes. The following principle was used in model testing and estimation of parameters – the goal was to get simulated concentrations close to observed in catchments with different land use classes. Mean observed TOC concentration for 16 catchments was 18.7 and simulated 16.9 mg/l (Table 1), which is satisfactory result, there is more variation in different catchments.

For these 16 catchments model produced following specific loading ranges: agriculture on clay 45-50 kg ha^{-1} yr^{-1}, agriculture on coarse soils 10-33 kg ha^{-1} yr^{-1}, forest on mineral soils 28-60 kg ha^{-1} yr^{-1}, forest on drained peat 70-173 kg ha^{-1} yr^{-1}, forest on natural peatlands 67-173 kg ha^{-1} yr^{-1} (Table 2).

The variation of specific loading is determined by several characteristics of the catchments – south-north gradient, distribution of runoff between different pathways (surface runoff, subsurface runoff and base flow). Especially in peat soils there are higher TOC concentration in lower peat layer, therefore the runoff pathway really matters.

Table 1. Simulated and observed TOC concentration for small watersheds

Cathcment	Tunnus	Obs conc, mg/l	Sim conc, mg/l	Spec load, kg/ha/yr	Catchm area, km2	Pelto-%	Ojittetu suo%	Ojimaton suo%	Kangasm etsä-%	TOC load, kg/yr
Savijoki	28.009U0098	12.3	9.8	33	16.4	37	2	1	60	54.0
Katajaluoma	35.156U0072	25.7	29.2	100	14.3	3	34	4	59	142.9
Pahkapuro	49.073U0017	21.2	19.0	65	22.2	2	31	16	52	145.1
Kesselinpuro	04.353U0048	29.7	18.5	64	18.7	2	34	2	61	119.5
Hauklammenoja	21.041U0009	10.9	9.2	29	1.7	3	5	0	92	5.0
Hietapuro	04.963U0042	6.6	9.3	36	5.0	0	1	44	55	18.0
Kohisevanpuro	14.774U0022	22.5	19.7	70	11.7	2	21	4	73	82.1
Korpijoki	04.565U0006	24.0	24.7	83	127.5	12	34	3	51	1058.8
Liuhapuro	04.465U0020	29.9	28.0	119	9.7	0	42	12	46	115.2
Mustospuro	14.687U0010	23.6	24.1	81	4.3	0	6	31	62	34.9
Paunulanpuro	35.741U0027	17.3	12.0	37	1.5	1	9	1	89	5.6
Rudbäcken	22.001U0006	14.5	12.2	42	5.4	10	3	2	83	22.7
Ylijoki	64.037U0015	15.0	17.4	77	77.7	1	27	15	44	600.3
Haapajyrä	42.021U0036	15.4	13.9	50	1.5	69	6	0	31	7.3
Ruunapuro	14.355U0005	21.0	11.2	32	6.5	21	10	2	67	21.0
Löytäneenoja	35.121U0030	9.0	11.8	32	3.1	82	0	0	16	10.1
Mean		18.7	16.9	59.6						

Table 2. Simulated specific loading (kg ha^{-1} yr^{-1}) from different land use classes for small watersheds

	Savijoki	Katajaluoma	Pahkapuro	Kesselinpuro	Hauklammenoja	Kohisevanpuro	Korpijoki	Liuhapuro	Mustospuro	Paunulanpuro	Rudbäcken	Ylijoki	Haapajyrä	Ruunapuro	Lyötänenoja	Range	Mean
Uoma	28.009U0098	35.156U0072	49.073U0017	04.353U0048	21.041U0009	14.774U0022	04.565U0006	04.465U0020	14.687U0010	35.741U0027	22.001U0006	64.037U0015	42.021U0036	14.355U0005	35.121U0030		
agriculture, clay	46				50								45			45-50	47
agriculture, coarse		27	18	25		23	33			10	24	23		16	33	10	22
Forest, ditched peat	83	172	108	114	70	146	150	173	136	85	115	118	128	84		70-173	120
Natural peat	83	170	108	111	67	144	148	173	137	85	116	116		82		67-173	118
Forest, mineral	28	60	31	37	29	46	46	57	49	32	40	33	36	29	35	28-60	39
Mean spec loading	33	100	65	64	29	70	83	119	81	37	42	77	50	32	32		

4. Results in the user interface

The model results are available in the VEMALA user interface in the similar way as for other substances, under V5 TOC and V5 CODMN. CODMN observations are used as 'surrogate' observations for TOC in calibration of the model, because TOC observations are very scares, and there is a clear linear relationship between TOC and CODMN observations in Finnish rivers and lakes.

- V5 TOC (keskeneräinen)
- V5 DOC (keskeneräinen)
- V5 CODMN (keskeneräinen)
- V5 CODCR (keskeneräinen)

a. Simulated results for watersheds

For all river basins for river observation points there are following results available – daily simulated concentrations and loads, annual loads for each observation point. For river basins there are also source apportionment of the loads for 5 above mentioned land use classes. TOC specific loading can be calculated for different river basins, which characterizes the difference in peat and mineral soil relationship.

For Aurajoki river basin (Aura 54 ohikulku va6401 point) mean simulated TOC concentration is 14.05 mg/l, observed 14.87 mg/l. Total TOC loading from Aurajoki basin is 3270 t yr^{-1}, specific loading is 38 kg ha^{-1} yr^{-1}. Source apportionment of TOC loading is following – 34% from agriculture on clay fields, 2.5% form agriculture on coarse fields, 38% form forests on mineral soils, 5% from drained peat forests, 2% from natural peatlands.

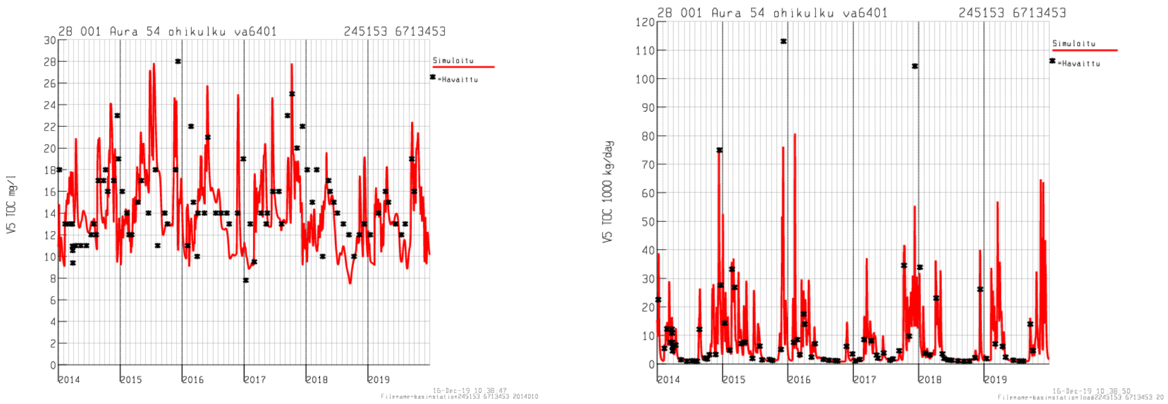

Figure 1. Daily simulated and observed concentration (a) and load (b) for the Aurajoki river

Modelling of large catchments with lake chains (like Kymijoki, Kokemäenjoki, Vuoksi, etc.) has always been more challenging than river catchments due to the regulation effect of lakes to the hydrograph as well as water quality. There are less observation points characterizing loading from the land areas, therefore model calibration is more challenging. However, VEMALA TOC model has been calibrated in two stages: first, two catchments parameters have been calibrated, 2) lake parameter has been calibrated with fixed catchment parameters.

There are TOC concentration and TOC mass balance for lakes (inflow loading, outflow loading, net retention of C) available in user interface in addition to the inflowing river point results in the user interface. Net retention of C in lakes includes two components C loss to the air and C sedimentation. C sedimentation is usually much smaler the C loss to the air, but in VEMALA v1 version one combined term is used. The lake simulation in the model was tested in Päijänne catchment (Kymijoki). TOC concentration is quite well simulated in Päijänne (Figure 2), including increasing trend of TOC concentrations during latest years. Simulated C loss is 10-18 t km^{-2} yr^{-1} with higher values in subcatchments with large lakes like Keitele and Päijänne, due to the high residence time in these lakes.

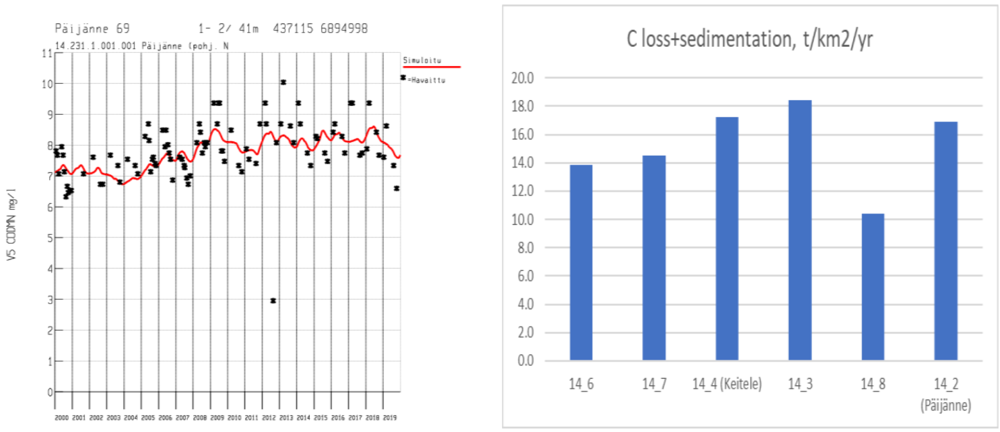

Figure 2. a) Simulated TOC and observed CODMN concentration in Päijänne lake, b) simulated C loss to the air and sedimentation (t km^{-2} yr^{-1}) in Päijänne subcatchments.

b. Maps of the specific loading

There are maps of TOC specific loading (total, from agriculture and from forest and peatlands) for all Finnish watersheds available in VEMALA user interface. The maps clearly show the areas with higher TOC loading, which are usually peat rich areas.

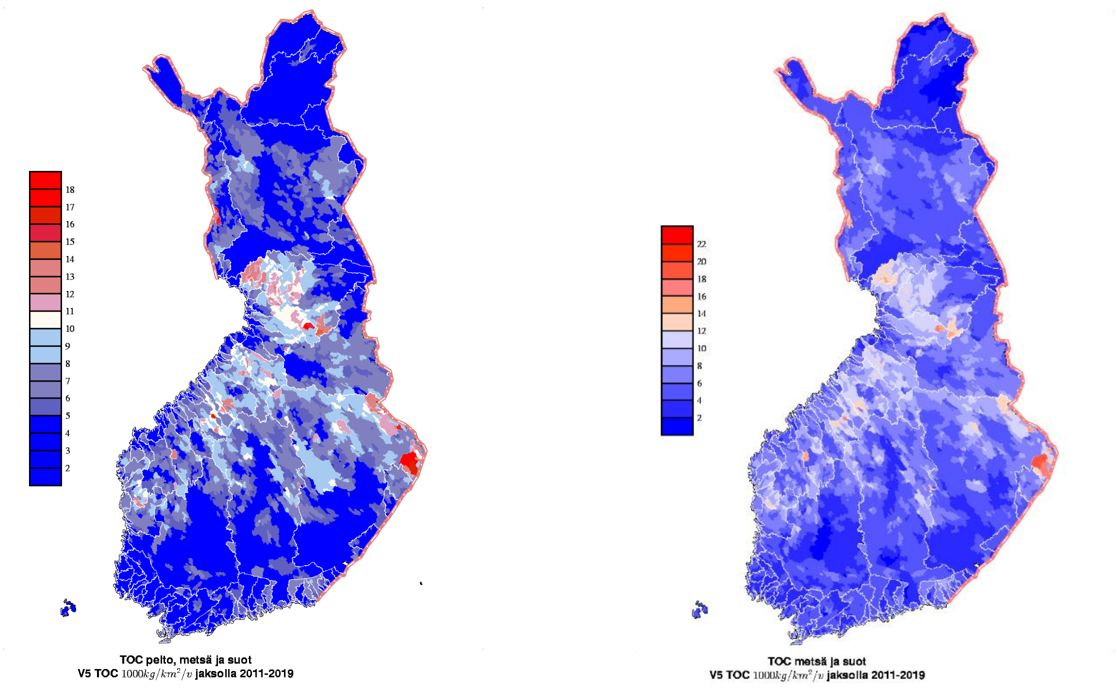

Figure 3. Map of a) total TOC specific loading and b) TOC specific loading from forest and peatlands for Finnish watersheds (t km^{-2} yr^{-1}) for period 2011-2019

5. Development needs in project continuation

During the development of the VEMALA TOC model several future development needs of the VEMALA model has been detected: 1) there is a need to develop the hydrological model in VEMALA. Juho Jakkila's new physical WSFS hydrological model should be implemented into VEMALA. Hydrological model should contain soil texture (clay, coarse, peat soils) in the model, and simulate hydrology (surface runoff, infiltration, water holding capacity, base flow etc.) depending on the soil texture. 2) There is a need to implement into the new VEMALA TOC model more detailed spatial information of C content in the soils and litter fall to cover the whole Finland. C content in peat soils should be obtained from GTK (Jukka Turunen's group). C content and litter fall on mineral forested soils from Multisource National Forest Inventory data (MNFI). C content in agricultural soils can be related to 'multavuus aste' and it is available in VEMALA system, but the data needs to be processed. 3) The difference of TOC leaching between ditched and unditched peatlands should be improved based on Metsävesi and other project results. 4) C processes in lakes (C mineralization, C evasion etc.) should be improved in the next VEMALA TOC development stage.

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.

Appendix 1. VEMALA TOC model process description

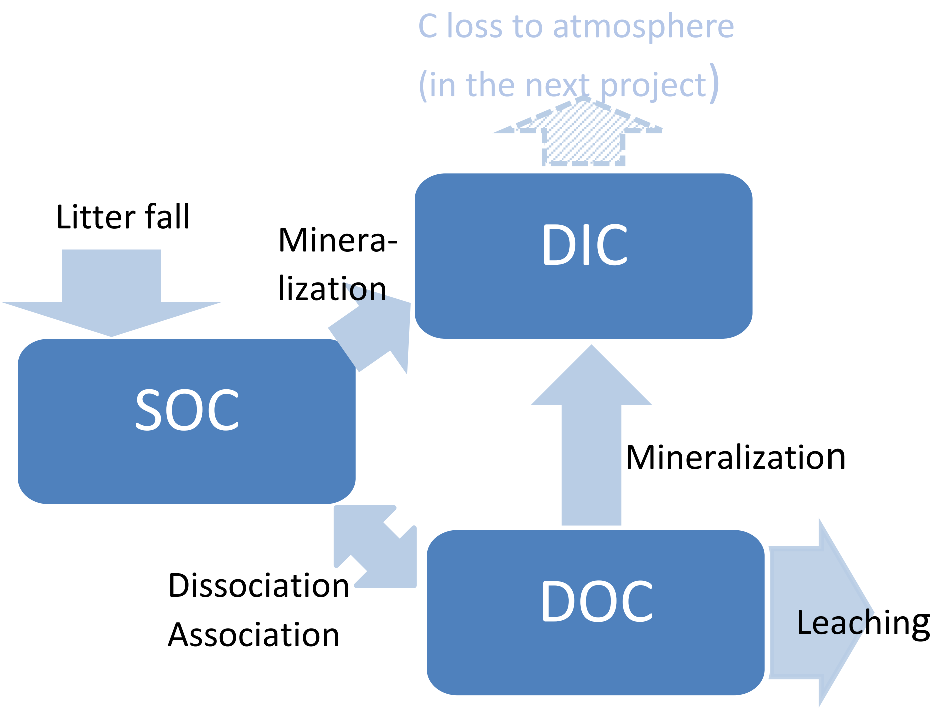

Figure 1. Scheme of C processes and fluxes in VEMALA TOC model