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SWAT+ model protocol for [Tyrnävänjoki catchment, Finland]

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Introduction

The study area is in the Temmesjoki River basin in northern Finland. The river Temmesjoki is in the commuting area of the city of Oulu in the municipalities of Liminka and Tyrnävä. The drainage area is 1087 km^2 (Figure 1). Most of the inhabitants live in the municipality centres of Liminka and Tyrnävä, while the remaining population lives in scattered settlements mainly along the river network (Hallin-Pihlatie et al., 2013).

The river Temmesjoki discharges to Liminganlahti Bay, which is an internationally significant bird and nature conservation area. The basin has a highly cultivated drainage area. It covers 18.29% of agricultural land, which is mainly situated in the lower parts of the basin. Forest and bog areas (78.5%) dominate the upper parts of the river basin. The basin contains 35.3% peat deposits, whereas it has homogenous clay and soil deposits of around 11.8%. The mean annual temperature is 2.4°C, and precipitation is 477 mm/yr. The proportion of lakes is 0.5% in the Temmesjoki catchment (Marttila et al., 2013).

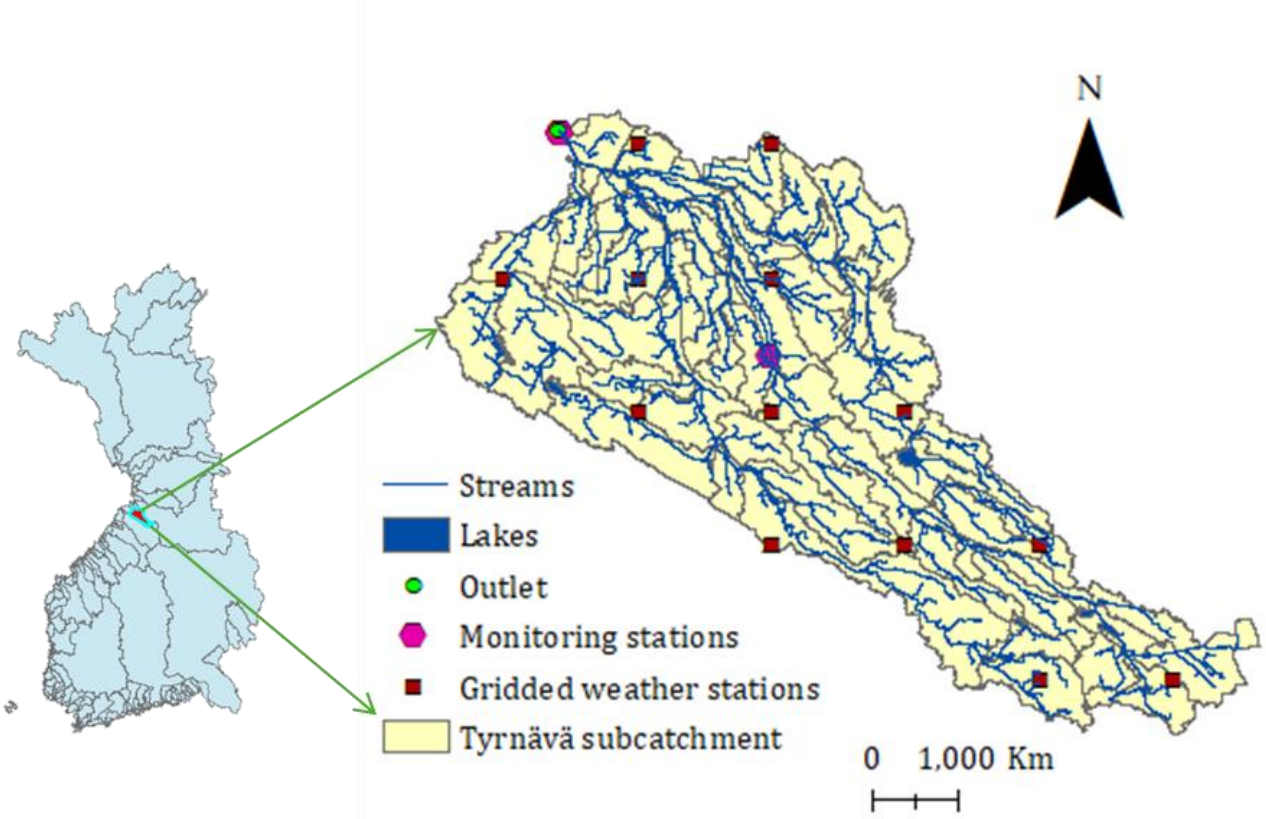

Figure 1. Tyrnävä subcatchment in Finland and the stream network, lakes, and monitoring stations

The river Temmesjoki has two tributaries: River Tyrnävänjoki and River Angeslevänjoki, which have a poor ecological status. The concentrations of nutrients and suspended solids are very high, and the ecological status of the main river channel is poor. Thus, the objectives of the current study are to apply the SWAT+ model in the Temmesjoki (Tyrnävänjoki) river basin and to understand the status of Nitrogen (N) and Phosphorus (P) and nutrient sources, pathways, and to reduce nutrient emissions efficiently.

Code/software versions used

Code	Version number	Availability
QGIS	3.34.7	QGIS used as a basis for running the QSWAT+ plugin. In this project, the latest stable release was used, which is the version that QSWAT+ aims to be compatible with. This can be downloaded from: https://qgis.org/downloads/QGIS-OSGeo4W-3.34.7-1.msi
SWAT+ (core model)	60.5.7	The SWAT+ Fortran code is version-controlled through bitbucket. Official code releases are available here: https://bitbucket.org/blacklandgrasslandmodels/modular_swatplus/src/master/
QSWAT+ (interface)	2.5.1	Code and official installer releases are available here: https://bitbucket.org/ChrisWGeorge/qswatplus3/downloads/QSWATPlus3_12install2.5.1.exe
SWAT+ Editor (interface)	2.3.4	Code and official installer releases (including v2.3.) are available here: https://bitbucket.org/swatplus/swatplus.editor/downloads/ Direct link: https://bitbucket.org/swatplus/swatplus.editor/downloads/swatplus.editor-installer-2.3.4.exe
SWATdoctR (model verification tool)	0.1.23	R package for SWAT+ model calibration and model diagnostics. https://git.ufz.de/schuerz/swatdoctr
SWATrunR (calibration tool)	0.9.4	R-package developed for hard calibration of the SWAT+ model. https://chrisschuerz.github.io/SWATrunR/
SWATtunR (calibration tool)	0.0.1.9008	R-package developed for hard calibration of the SWAT+ model. https://biopsichas.github.io/SWATtunR/index.html

Weather input data used

Data	Temporal resolution	Spatial resolution	Availability
Precipitation	Daily (used as daily values for daily simulations)	10 km x 10 km grid	This dataset is part of FMI ClimGrid, a gridded daily climatology dataset for Finland. It includes the key variable, Daily Precipitation Sum (RRday): https://www.nic.funet.fi/index/geodata/ilmatiede/10km_daily_precipitation/netcdf/
Min. and max air temperature	Daily (used as daily values for daily simulations)	10 km x 10 km grid	This dataset is part of FMI ClimGrid, a gridded daily climatology dataset for Finland. It includes key variables, Daily Maximum Temperature (Tmax) and Daily Minimum Temperature (Tmin): https://www.nic.funet.fi/index/geodata/ilmatiede/10km_daily_maximum_temperature/netcdf/
Relative humidity	Daily (used as daily values for daily simulations)	10 km x 10 km grid	This dataset is part of FMI ClimGrid, a gridded daily climatology dataset for Finland. It includes the key variable, Average Daily Relative Humidity (Hum): https://www.nic.funet.fi/index/geodata/ilmatiede/10km_daily_avg_rel_hum/netcdf/
Radiation	Daily	10 km x 10 km grid	This dataset is part of FMI ClimGrid, a gridded daily climatology dataset for Finland. It includes the key

	(used as daily values for daily simulations)		variable, Daily Global Radiation (kJ/m**2) (GlobRad): https://www.nic.funet.fi/index/geodata/ilmatiede/10km_daily_radiation/netcdf/

GIS input data used

Data	Map	Resolution	Availability
DEM	FMI (https://etsin.fairdata.fi/dataset/f87f7910-9fbc-4001-8798-994deb5b01af/maps)	2 m x 2 m	All metadata for this dataset is available from the Etsin metadata service with permanent ID: http://urn.fi/urn:nbn:fi:csc-kata00001000000000000187 http://www.nic.funet.fi/index/geodata/mml/dem2m/2008_latest/
Landuse	Corine, updated by the Finnish Environment Institute (SYKE) https://ckan.ymparisto.fi/dataset/%7B0B4B2FAC-ADF1-43A1-A829-70F02BF0C0E5%7D	20 m x 20 m	The CORINE Land Cover (CLC) inventory from 2018. Raster and SWAT+ lookup table has been prepared from https://www.syke.fi/en-US/Open_information/Spatial_datasets/Downloadable_spatial_dataset
Soil	Geological Survey of Finland (GTK) Open Land Map (OLM) datasets	25 m × 25 m 250 m	https://hakku.gtk.fi/en/locations/search https://www.wateritech.com/data
Lakes	Lake-theme	Vector (shapefile)	https://www.syke.fi/en-US/Open_information/Spatial_datasets/Downloadable_spatial_dataset
Rivers	River-theme	Vector (shapefile)	https://www.syke.fi/en-US/Open_information/Spatial_datasets/Downloadable_spatial_dataset

Stream discharge data used for calibration

Data	Temporal resolution	Spatial resolution	Availability
Stream discharge	daily	Individual gauge station	Observed daily discharge data was downloaded from https://wwwp2.ymparisto.fi/scripts/oiva.asp; https://www.syke.fi/fi-FI/Avoin_tieto/Ymparistotietojarjestelmat for Temmesjoki station in the lower part of the catchment
Suspended sediments (SS), Total nitrogen (TN) and total phosphorus (TP)	15-20 samples per year	Individual gauge station	Observed concentration data were downloaded from https://wwwp2.ymparisto.fi/scripts/oiva.asp; https://www.syke.fi/fi-FI/Avoin_tieto/Ymparistotietojarjestelmat for Temmesjoki station in the lower part of the catchment

Model setup

Delineation

Channel threshold: 1.1 km^2

Stream threshold: 1.1 km^2

Lakes: Lake shapefiles from the source to the model

Next, the Landscape units, DEM, stream network and lakes were manually edited in QGIS and added later in the QSWAT+ interface as predefined catchment. Some lakes were excluded as they were not located on the stream network.

HRU creation

Land use	Customized land use map from Corine (SYKE) raster and Finnish Environment Institute (SYKE).
Soil	Texture map from GTK and OLM datasets. Soil database and lookup table by OLM.
Slope classes	3 classes (0-3%, and > 3%).
HRU filtering	5% threshold for landuse, soil type and slope class.

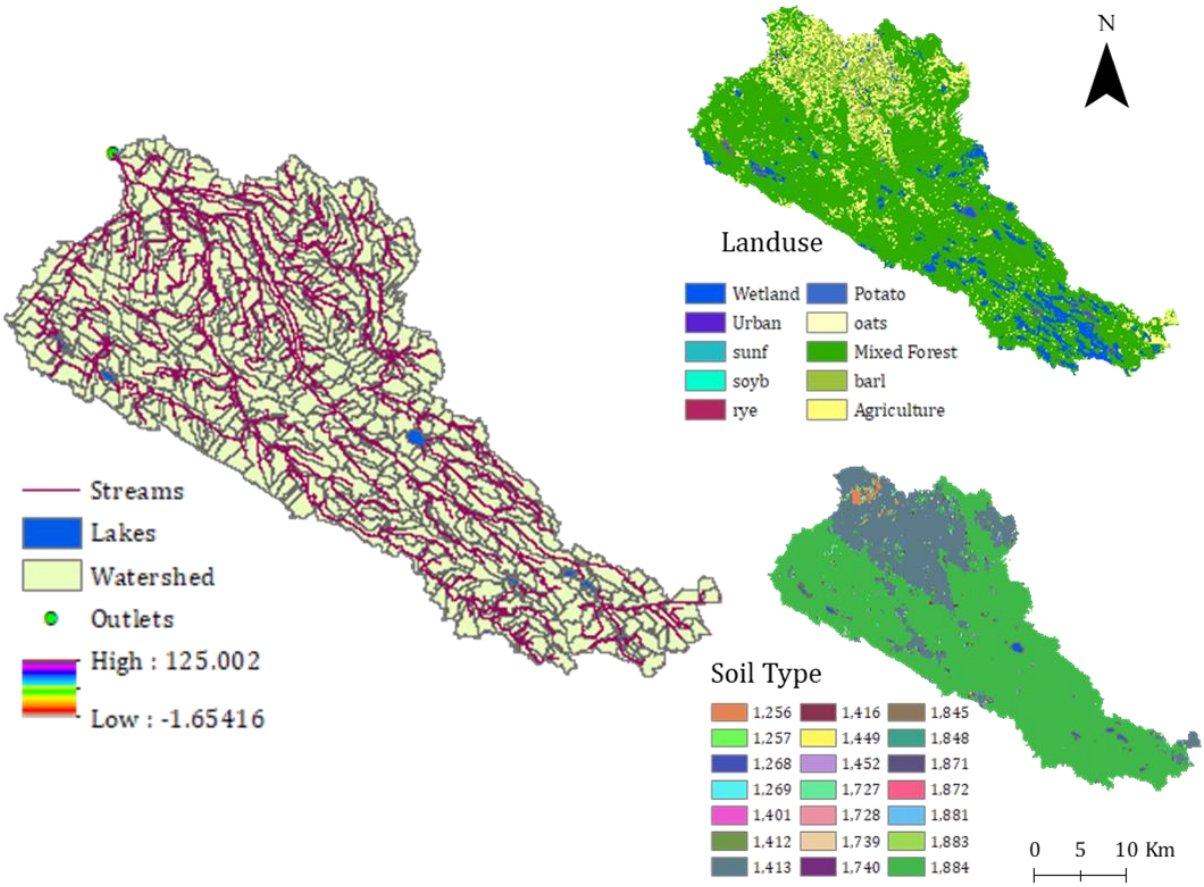

Figure 2. Watershed, subbasins and streams delineated by SWAT+ and the Landuse. Detailed properties of different soil types are provided in the model input files. Specific crop rotations are in the SWAT+ input file management.sch

Final configuration

# Total watershed area:	1087.1 km^2	
# Subbasins:	68	
# Channels	605	
# LSUs:	605	(including both upslope and floodplain LSUs)

# HRUs	3967
# Lakes	17

Evaporation method

Penman/Monteith

Additional changes

- The values of three parameters that control the runoff and leaching potential of the HRUs (perco, cn3_swf, latq_co) were edited based on the suggestion from the SWATtunR developers.
- Management schedules were implemented to define agricultural management operations (Mainly sowing, harvest) for the different crop rotations.

Calibration and validation

The following procedure has been followed to set up the model in QSWAT+ (Figure 3). The simulation period for the initial model run has been chosen from 2012 to 2022 with a 3-year warm-up period. Next, the SWAT+ editor and SWATdoctR have been used to verify the model input and output. Finally, SWATrunR and SWATtunR have been used for soft and hard calibration purposes.

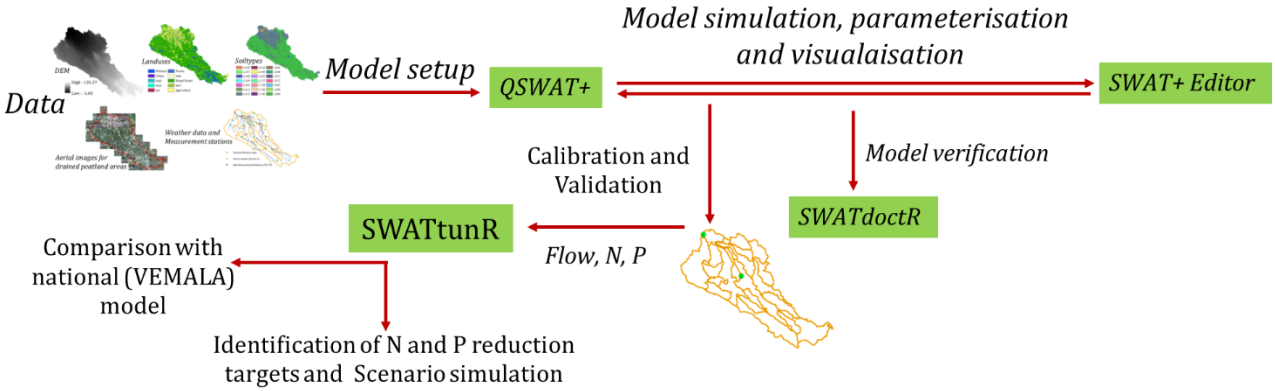

Figure 3. A flowchart describing the steps of the modelling, calibration, and validation

Calibration was done for the Temmesjoki River station at the most downstream of the Tyrnävänjoki basin. In practice, several iterations were run with 500 model simulations, after which the sample parameter ranges were gradually narrowed to the objective function. The calibration and validation were performed by evaluation of the Nash-Sutcliffe Efficiency (NSE), Kling-Gupta efficiency (KGE) and coefficient of determination (R^2).

The following periods were used:

- Model warmup: 1. January 2012 - 31. December 2014
- Calibration: 1. January 2015 - 31. December 2020
- Validation: 1. January 2021 - 31. December 2022

Table 1. Parameters chosen for calibration, change type (absval = initial value is replaced, abschg = initial value is changed by adding or subtracting an absolute value, relchg = initial value is increased or decreased by a percentage value), minimum and maximum value, and final value after calibration.

Parameter	Change type	Value min	Value max	Final value
Discharge				
snomelt_tmp	absval	-2	-0.1	-1
snofall_tmp	absval	1	4	3
esco	absval	0.69	0.75	0.72
epco	absval	0.55	0.6	0.575
awc	relchg	-1.1	0.2	-0.45
canmx	relchg	0.2	1.2	0.7
cn2	relchg	-15	15	0
cn3_swf	absval	1.2	1.5	1.35
ovn	relchg	-2	5	1.5
surlag	absval	0	0.1	0.05
lat_len	abschg	28	30	29
latq_co	absval	0.1	0.4	0.25
bd	relchg	-0.25	0.25	0
k	relchg	-5	-1	-3
perco	absval	0.3	0.4	0.35
flo_min	abschg	0.05	0.15	0.1
revap_co	absval	0.07	0.09	0.08
revap_min	abschg	0	0.5	0.25
alpha	absval	0.26	0.4	0.33
bf_max	absval	2.2	4	3.1
chn	absval	0.08	0.1	0.09
Suspended sediment (SS)				
cov	absval	0.25	0.27	0.26
slope_len	absval	130	132	131
chs	relchg	-0.65	-0.63	-0.64
cherod	absval	0.095	0.1	0.0975
prf	absval	0.0044	0.0046	0.0045
lat_sed	absval	2890.1	2890.3	2890.2
usle_p	relchg	0.91	0.924	0.917
Total Nitrogen (TN)				
n_updis	absval	88.5	100	94.25
nperco	relchg	0.13925	0.144	0.141625
sdnco	relchg	0.45	0.48	0.465
cmn	relchg	0.0015	0.0025	0.002
rsdco	absval	0.0286	0.0345	0.03155
hlife_n	absval	165	183	174
no3_init.	absval	1.8	1.88	1.84

lat_orgn	absval	3.6	5	4.3
cdn	absval	2.56	2.75	2.655
orgn	absval	4.76	5	4.88
nh3	absval	0.99	1	0.995
no2	absval	0.01	0.5	0.255
Total Phosphorus (TP)				
p_updis	absval	89.8	100	94.9
pperco	absval	10.22	10.23	10.225
phoskd	absval	196	198	197
psp	absval	0.018175	0.0182	0.0181875
erorgp	absval	3	3.08	3.04
usle_k	absval	0.64	0.65	0.645
lat_orgp	absval	0.5	2.5	1.5

Table 2. Model evaluation statistics for daily discharge, TN, SS and TP during the calibration (Cal) and validation (Val) periods.

Objective function	Calibration				Validation			
	Flow	TN	SS	TP	Flow	TN	SS	TP
R^2	0.94	0.67	0.26	0.27	0.93	0.57	0.23	0.24
NSE	0.78	0.51	0.14	0.16	0.77	0.42	0.12	0.15
KGE	0.53	0.49	0.11	0.09	0.52	0.43	0.09	0.07

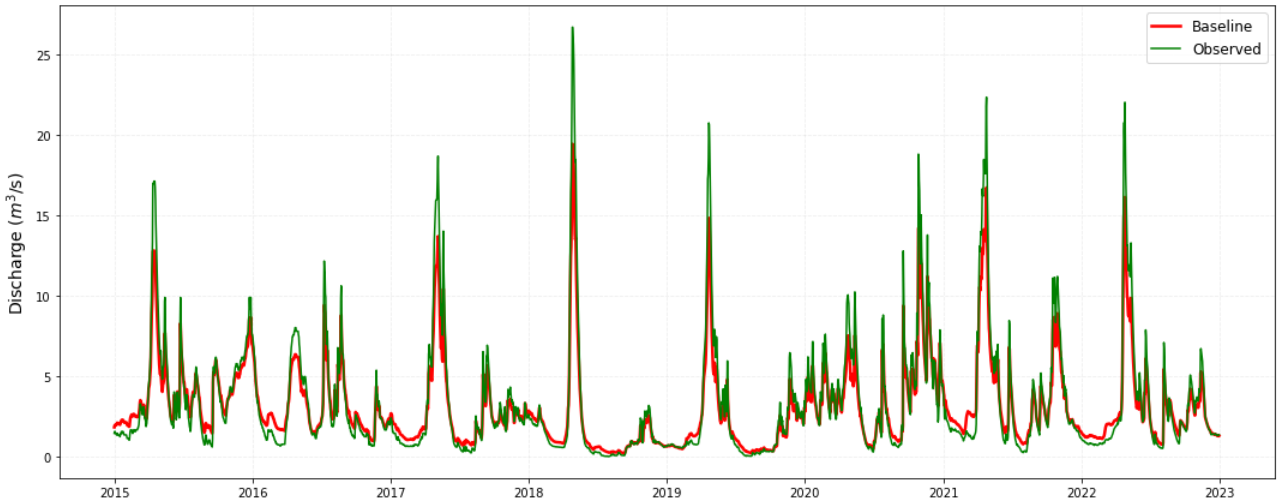

Figure 4. Observed and simulated discharge for Tyrnävä basin, at "Temmesjoki" station (2015-2020) for the calibration and 2021-2022 for the validation.

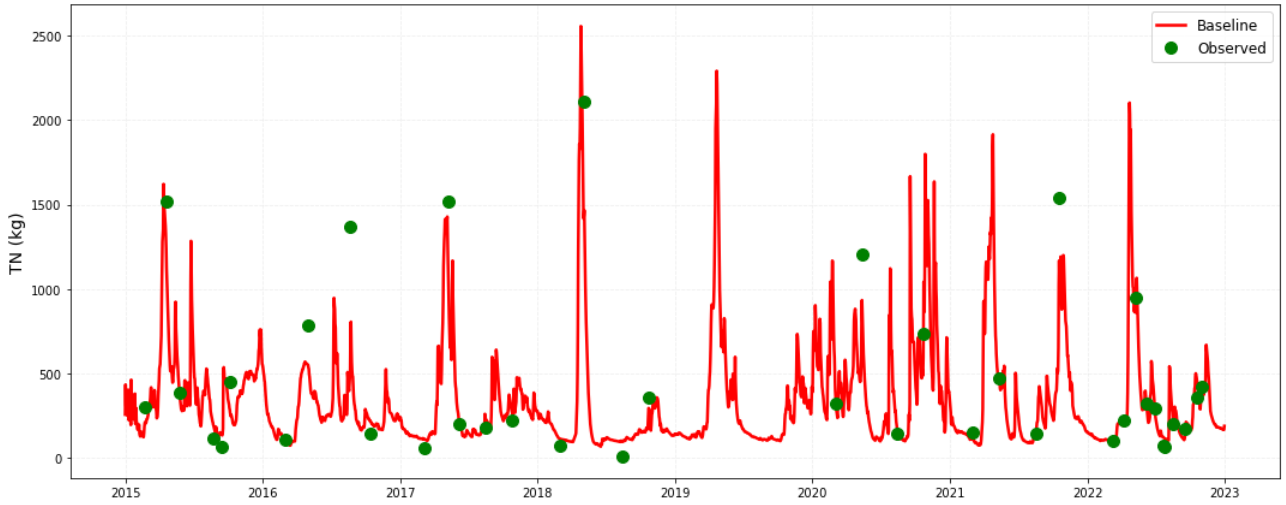

Figure 5. Observed and simulated TN for Tyrnävä basin, at "Temmesjoki" station (2015-2020) for the calibration and 2021-2022 for the validation.

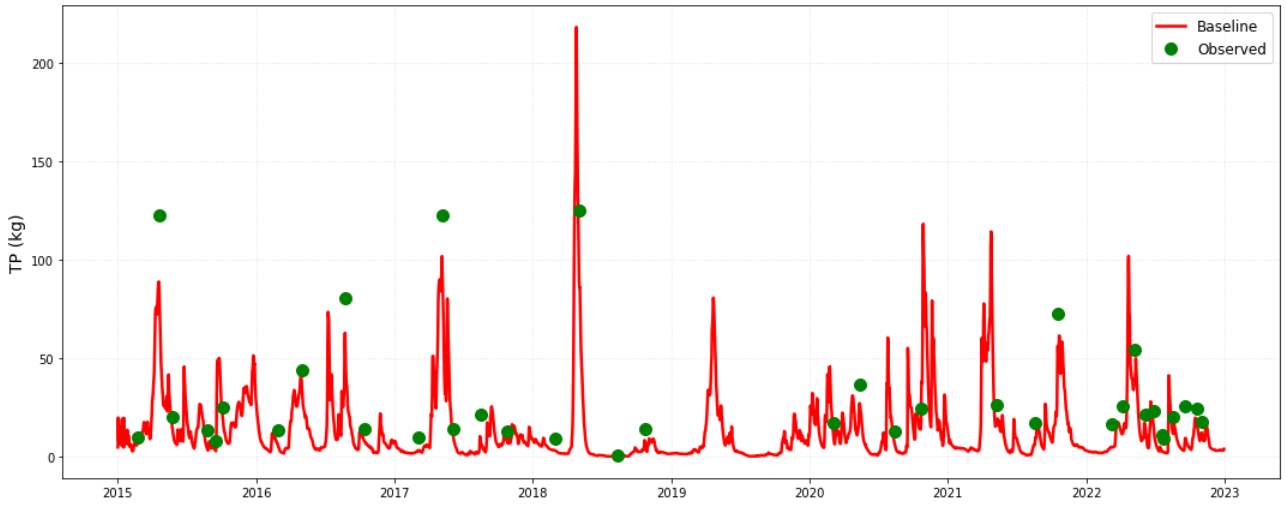

Figure 6. Observed and simulated TP for Tyrnävä basin, at "Temmesjoki" station (2015-2020) for the calibration and 2021-2022 for the validation. A light blue vertical line separates calibration and validation periods.

Summary

A SWAT+ model was set up for the Tyrnävänjoki river basin. Data used in this project are all available at the national level. The SWAT+ model was calibrated on a daily time step and produced results for river discharge, TN and TP load at the Temmesjoki River station. The calibration process of TN and TP can be improved further if there is more data availability of the total phosphorus and total nitrogen concentration in the river basin.

References

Hallin-Pihlatie, L., Rintala, J., & Hansen, H. S. (2013). Integration of climate change and land-use scenarios in nutrient leaching assessment. *International Journal of Climate Change Strategies and Management*, *5*(3), 285–303. https://doi.org/10.1108/IJCCSM-04-2011-0016

Marttila, H., Saarinen, T., Celebi, A., & Kløve, B. (2013). Transport of particle-associated elements in two agriculture-dominated boreal river systems. *Science of the Total Environment*, *461–462*, 693–705. https://doi.org/10.1016/j.scitotenv.2013.05.073