DATE: [June 2024]
FOR: [NORDBALE_ECOSAFE]

# SWAT+ model protocol for [Tyrnävänjoki catchment, Finland]

**DATE:** [June 2024]

**AUTHORS:** [Joy Bhattacharjee]

**CITE AS:** [Bhattacharjee, J, 2024. SWAT+ model protocol for *Tyrnävänjoki catchment, Finland*]

# Table of Contents

# 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 basin (Marttila et al., 2013).

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.

In particular, the main objectives are:

- ✓ Setup, calibration, and validation of SWAT+ models in the Tyrnävänjoki River basin
- ✓ Comparison of the SWAT+ model to the existing national model of Finland (VEMALA)
- ✓ Identification of N and P reduction targets and setup scenarios to bring nutrients within safe ecological boundaries under current and future climate conditions

# Code 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 |
| SWAT+ Toolbox (calibration tool) | 0.7.6 | Sensitivity and calibration tool for SWAT+. Installers for the public releases are available here: https://swat.tamu.edu/software/plus/ Source code for the SWAT+ Toolbox is available through github: https://github.com/OpenWaterNetwork/SWATPlus-Toolbox |

| | | |
|---|---|---|
| SWATprepR (model input preparation tool) | 1.0.4 | https://enveurope.springeropen.com/articles/10.1186/s12302-024-00873-1 |
| SWATdoctR (model verification tool) | 0.1.23 | https://git.ufz.de/schuerz/swatdoctr |
| SWATrunR (calibration tool) | 0.9.4 | https://chrisschuerz.github.io/SWATrunR/ |
| SWATtunR (calibration tool) | 0.0.1.9008 | 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, which is a gridded daily climatology dataset of Finland. It includes 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, which is a gridded daily climatology dataset of Finland. It includes key variable, 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, which is a gridded daily climatology dataset of Finland. It includes key variable, Average Daily Relative Humidity (Hum): https://www.nic.funet.fi/index/geodata/ilmatiede/10km_daily_avg_rel_hum/netcdf/ |
| Radiation | Daily (used as daily values for daily simulations) | 10 km x 10 km grid | This dataset is part of FMI ClimGrid, which is a gridded daily climatology dataset of Finland. It includes key 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 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)<br>Open Land Map (OLM) datasets | 25 m × 25 m<br>250 m | https://hakku.gtk.fi/en/locations/search<br>https://www.wateritech.com/data |
| Lakes | Lake-theme | Vector (shapefile) | https://www.syke.fi/en-US/Open_information/Spatial_datasets/Downloadable_spatial_dataset |
| River | 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 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 |

## Additional Discharge data at Tyrnävänjoki station

As there is no monitoring station available at the furthest downstream Tyrnävä outlet, the Acoustic Doppler Current Profiler (ADCP) has been used to measure the discharge data (more detailed mapping available at ADCP points.

# Model setup

## Delineation

| | |
|---|---|
| Channel threshold: | 1.1 km$^2$ (minimum size of sub-watershed, and thereby a landscape unit (LSU), where a small channel that drains to a main stream is created) |
| Stream threshold: | 11 km$^2$ (minimum size of sub-watershed, where a main stream is created) |
| Upslope/Floodplain LSUs: | This will divide each LandScape Unit (LSU) into an Upslope and a Floodplain LSU, and create individual aquifers per LSU (representing the Upslope and the Floodplain areas, respectively). This may render a more realistic flow path for groundwater to the main stream in each subbasin, but also result in a higher computational burden and parameter complexity. When delineating Upslope and Floodplain LSUs, we used the “Buffer Channel” approach with default settings as mentioned in the SWAT+ model interface: |
| Lakes: | In the modelling project, we included a shapefile with Lakes. The delineation will then tailor LSU boundaries to the shoreline of the lakes. |

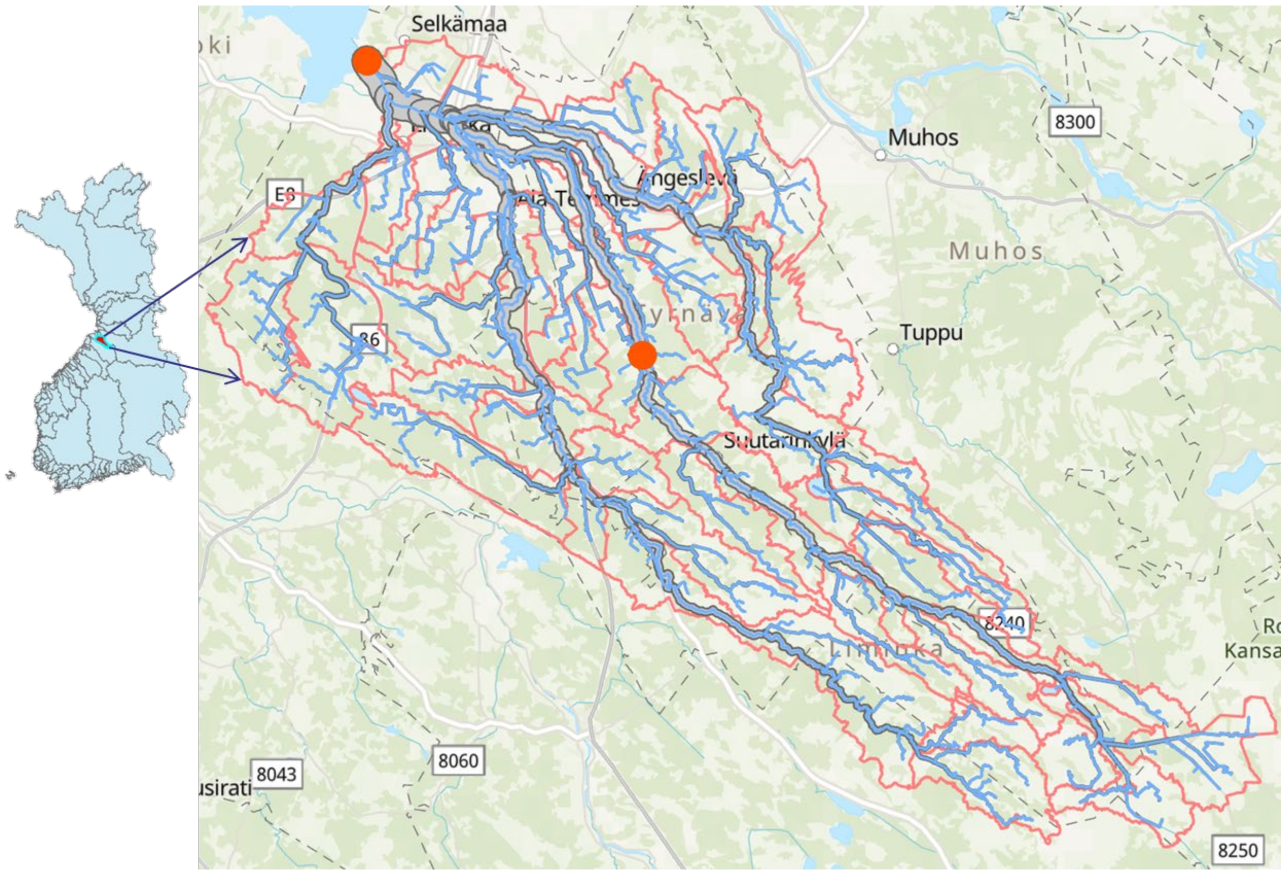


*Figure 1. Watershed, subbasins and streams delineated by SWAT+ with floodplain delineation (areas delineated as floodplains are indicated by light shaded areas). The stream gauge stations at Temmesjoki River and most downstream outlets at Tyrnävä are indicated by red points.*

## HRU creation

| | |
|---|---|
| Land use | Corine (SYKE) raster and lookup table by SYKE. |
| Soil | Texture map from GTK and OLM datasets. Soil database and lookup table by OLM. |
| Slope classes | 3 classes (0-2%, 2-4% and > 4%). |
| HRU filtering | 0% threshold for landuse, soil type and slope class. |

**Final configuration:**

| | | |
|---|---|---|
| # Total watershed area: | 1087.1 $km^2$ | |
| # Subbasins: | 68 | |
| # LSUs: | 1179 | (including both upslope and floodplain LSUs) |
| # HRUs | 32757 | |

## Evaporation method

SWAT+ includes the choice of different evaporation methods including Hargreaves, Penmann/Montieth, Priestly/Taylor or user-defined time series. For this study, the Penman/Monteith method was chosen.

# Calibration and validation

The following procedure has been followed to set up the model in QSWAT+ (Figure 2). The simulation period for the initial model run has been chosen from 2019 to 2021 with a 1-year warm-up period. Next, 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.

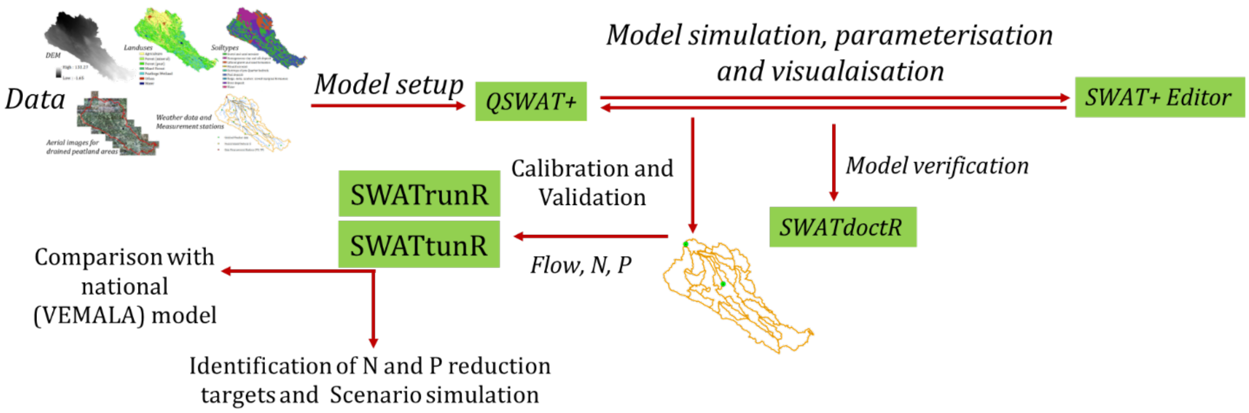


*Figure 2. A flowchart describing the steps of the modelling, calibration, and validation*

Calibration was done for the Temmesjoki River station in the middle of the Tynävänjoki basin. In practice, several iterations were run with approx. 70 model simulations, after which the sample parameter ranges were gradually narrowed to the objective function).

The calibration was performed by the optimization of the Nash-Sutcliffe Efficiency (NSE), which, like the coefficient of determination ($R^2$), is a correlative objective function. Classification of the performance was done by comparing performance against the criteria reviewed by Moriasi et al. (2015).

The following periods were used:

- Model warmup: 1. January 2019 - 31. December 2020 (one year)
- Calibration: 1. January 2020 - 31. December 2021 (one year)
- Validation: 1. January 2021 - 31. December 2022 (two years)

*Table 1 Parameters chosen for calibration.*

| Parameter | Change type | Value min | Value max | Average value |
|---|---|---|---|---|
| snomelt_tmp.hru | absval | -1 | 1 | 0.61 |
| snofall_tmp.hru | absval | -1 | 1 | 0.1 |
| esco.hru | absval | 0.1 | 0.95 | 0.15 |
| epco.hru | absval | 0.2 | 0.9 | 0.65 |
| awc.sol | relchg | -0.2 | 0.4 | 0.38 |
| bd.sol | relchg | -0.25 | 0.6 | 0.59 |
| canmx.hru | relchg | -0.5 | 0.5 | 0.32 |
| cn2.hru | relchg | -0.5 | 0.5 | -0.39 |
| cn3_swf.hru | absval | 0 | 1 | 0.62 |
| ovn.hru | relch | -0.25 | 0.4 | 0.26 |
| surlag.bsn | absval | 0.05 | 6 | 4 |
| lat_time.hru | relchg | -0.15 | 0.15 | 0.1 |
| lat_len.hru | abschg | -30 | 30 | 10 |
| latq_co.hru | absval | 0 | 1 | 0.17 |
| k.sol | relchg | -0.5 | 2 | 0.59 |
| perco.hru | absval | 0 | 1 | 0.25 |
| flo_min.aqu | abschg | -2 | 2 | 1.38 |
| revap_co.aqu | absval | 0.02 | 0.2 | 0.19 |
| revap_min.aqu | abschg | -2 | 2 | 0.16 |
| alpha.aqu | absval | 0.001 | 0.5 | 0.45 |
| chn.rte | absval | 0.02 | 0.1 | 0.08 |

*Table 2 Performance evaluation criteria for recommended statistical performance measures for watershed models by Moriasi et al. (2015).*

| Objective function | Output response | Temporal scale[1] | Performance Evaluation Criteria | | | |
|---|---|---|---|---|---|---|
| | | | **Very Good** | **Good** | **Satisfactory** | **Not Satisfactory** |
| **$R^2$** | Flow | D-M-A | $R^2 > 0.85$ | $0.75 < R^2 \leq 0.85$ | $0.60 < R^2 \leq 0.75$ | $R^2 \leq 0.60$ |
| **NSE** | Flow | D-M-A | NSE > 0.80 | 0.70 < NSE ≤ 0.80 | 0.50 < NSE ≤ 0.70 | NSE ≤ 0.50 |
| **PBIAS (%)** | Flow | D-M-A | PBIAS ≤ ±5 | ±5 ≤ PBIAS < ±10 | ±10 ≤ PBIAS < ±15 | PBIAS ≥ ±15 |

[1] D, M and A denote daily, monthly, and annual temporal scales, respectively.

*Table 3 Performance of SWAT+ model for Tyrnävänjoki basin at the Temmesjoki outlet*

| Objective function | Temmesjoki river calibration | Temmesjoki river validation |
|---|---|---|
| **$R^2$** | 0.83 (good) | 0.71 (satisfactory) |
| **NSE** | 0.78 (good) | 0.71 (good) |

The simulated flow at the Temmesjoki station has been compared with the output of the VEMALA (Finnish national model) model. The simulated flow has shown a lower average compared to the observed flow.

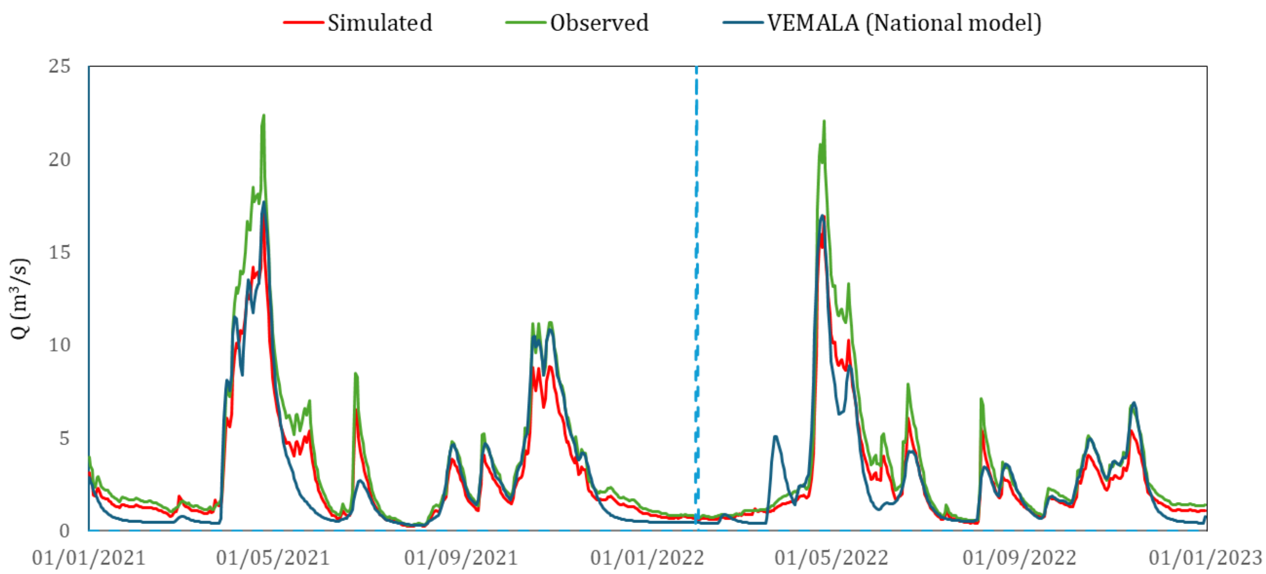


*Figure 3. Observed and simulated discharge for Tyrnävä basin, at "Temmesjoki" station (2021-2022) for the calibrated model. A light blue vertical line separates calibration and validation periods.*

## Next steps

The next step is to focus on the rating curve from the data collected at the Tyrnävänjoki station.

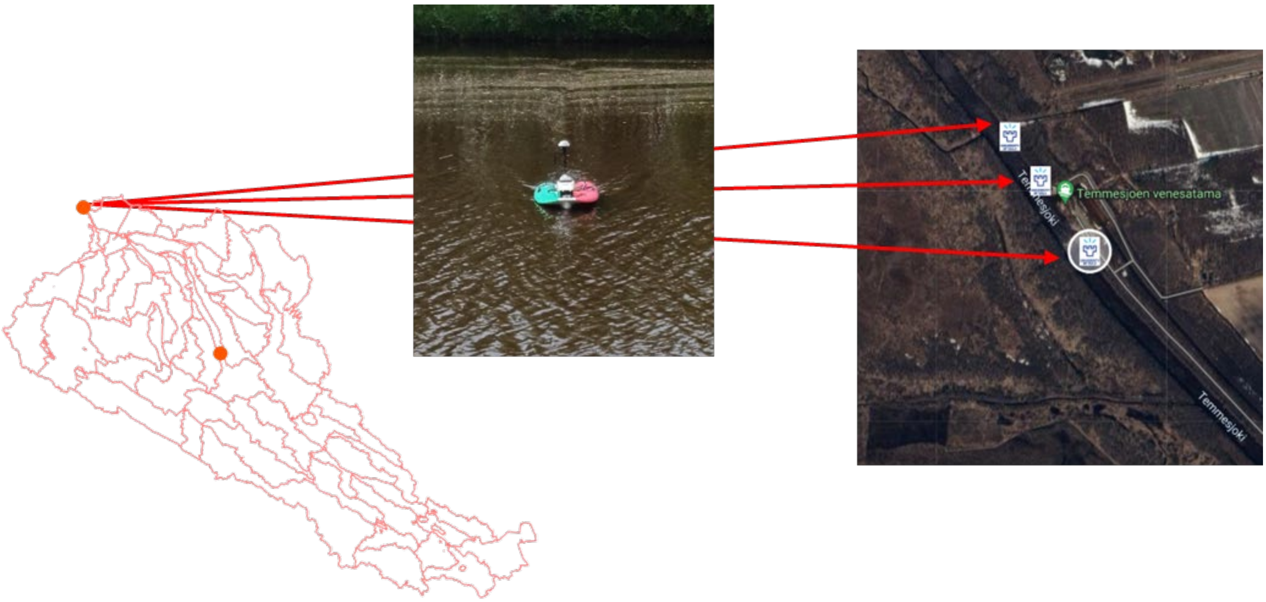


*Figure 4. Locations of ADCP measurement points to measure discharge for the furthest downstream outlet of the Temmesjoki basin*

The following steps will be considered sequentially to fulfil the goals of the study:

- Calibration of flow, N and P at the Tyrnävä outlet by using the rating curve from the collected data
- Comparison with VEMALA for flow, N and P for all the outlets
- Setting up the scenario based on the N and P reduction targets and simulation of the scenarios with the calibrated parameters (Table 2).

*Table 1. Tentative scenarios to reduce N and P target*

| **Transport mitigation measures to reduce N & p target** | Possibility to simulate in SWAT+ | Leaching from the root zone | Surface runoff | Tile flow | Groundwater flow | Stream flow | Flood control | Drought mitigation | Soil health | Methane emissions** | N2O emissions** | Carbon sequestration | Consumption of fossil fuels | Sediment retention | Biodiversity*** | Phosphate emissions from soils |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surface constructed wetlands<br><br>(on fields) | + | | x | | | | 0 | 0 | | 0 | - | 0 | | + | + | + |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Restored wetlands | + | | x | x | x | x | + | + | | - | - | + | | + | + | - |
| Buffer strips with grass | + | x | | | | | 0 | 0 | | 0 | 0 | + | | + | + | 0 |
| Catch Crops | + | | | | | | | | | x | x | | | | | |


## Summary

A SWAT+ model was set up from scratch for the Tyrnävä 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 at the Temmesjoki River station. The simulated flow by the SWAT+ model matched better with the observed data compared to the existing Finish model. The model still needs further improvement for the calibration of flow at the furthest downstream outlet and N and P for both outlets.


## 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