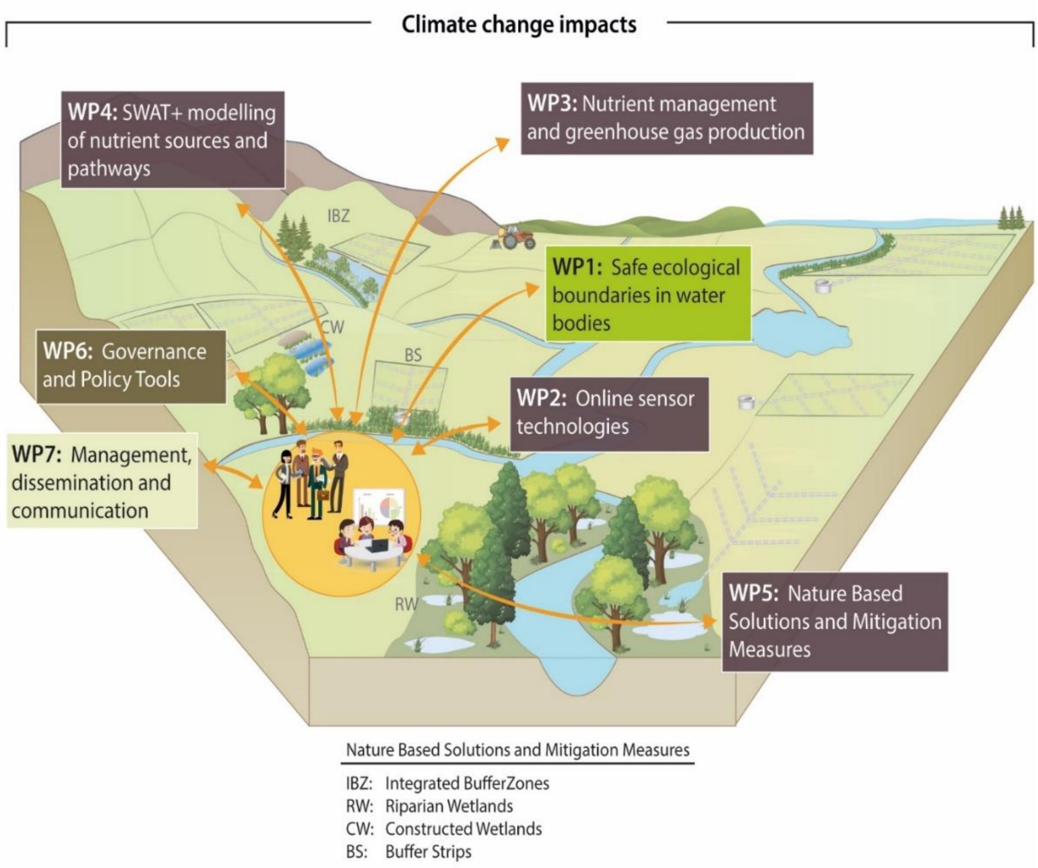

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Beneficiaries: All partners in NORDBALT-ECOSAFE

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Contents

Introduction

The calibrated and validated SWAT+ models for the six river basins are shared on the Online Networking Platform (https://projects.au.dk/nordbalt-ecosafe/wp4 .

This deliverable describes comparison of SWAT+ model with national/regional hydrological models as well as graphs and maps of the most relevant outputs documenting the model performance and comparison. Case and demonstration study-specific model descriptions and inputs are in the report as appendices.

DATE: December 2024
FOR: NORDBALT-ECOSAFE

Appendix 1: Results and comparison of the SWAT+ with the national model VEMALA for Tyrnävänjoki catchment, Finland

DATE:	December 2024
AUTHORS:	Joy Bhattacharjee and Hannu Marttila
CITE AS:	Bhattacharjee and Marttila 2024. Results and comparison of the SWAT+ with the national model VEMALA 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 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.

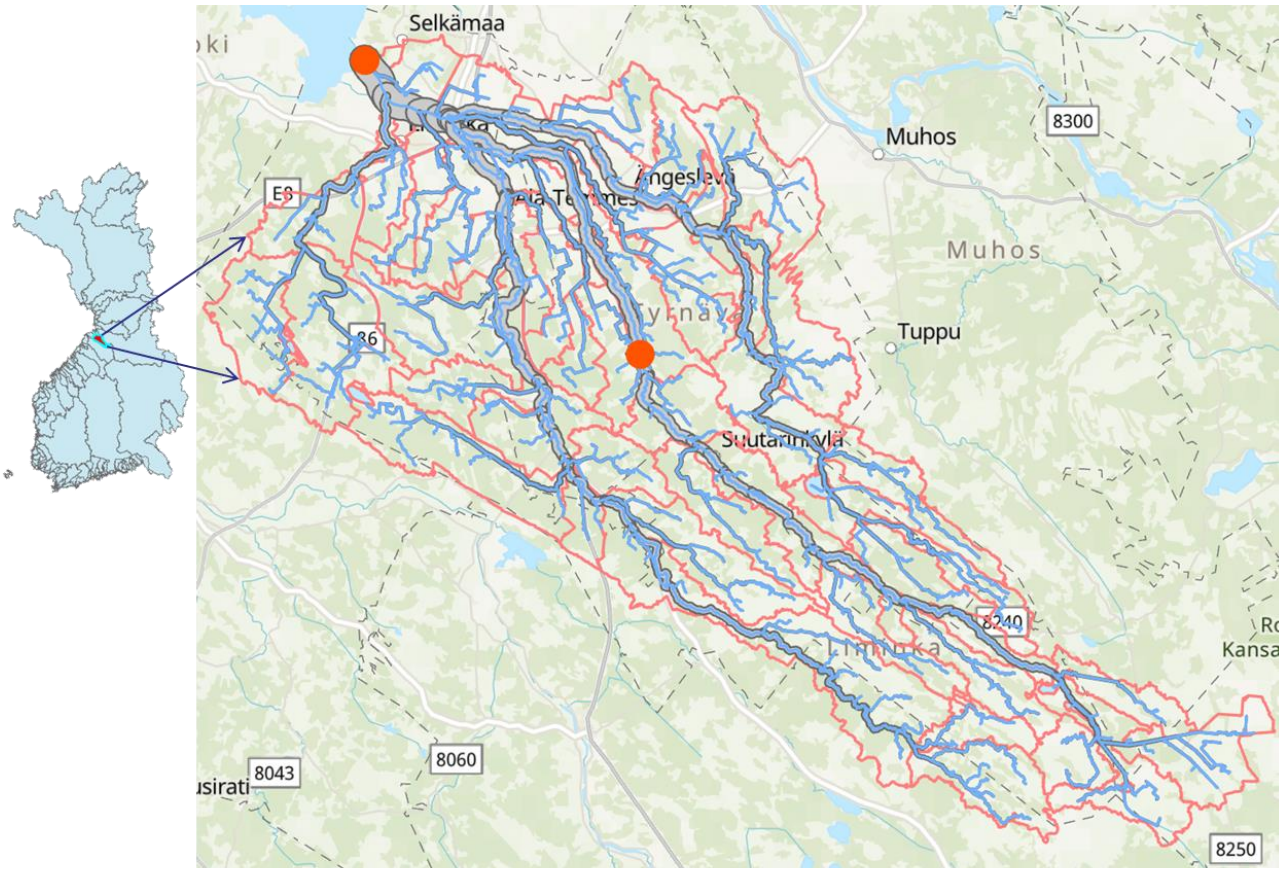

Figure 1. Watershed, subbasins and streams delineated by SWAT+ with floodplain delineation (areas delineated as light-shaded areas indicate floodplains). The stream gauge stations at Temmesjoki River and most downstream outlets at Tyrnävä are indicated by red points.

This report involves the model setup, calibration, and validation of the SWAT+ model in the region for simulating hydrological and nutrient dynamics. Additionally, the SWAT+ model is compared against the existing Finnish national model, VEMALA, to evaluate its relative performance and accuracy.

Model Setup

The following procedure has been applied to set up the model in QSWAT+ (Figure 2). 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.

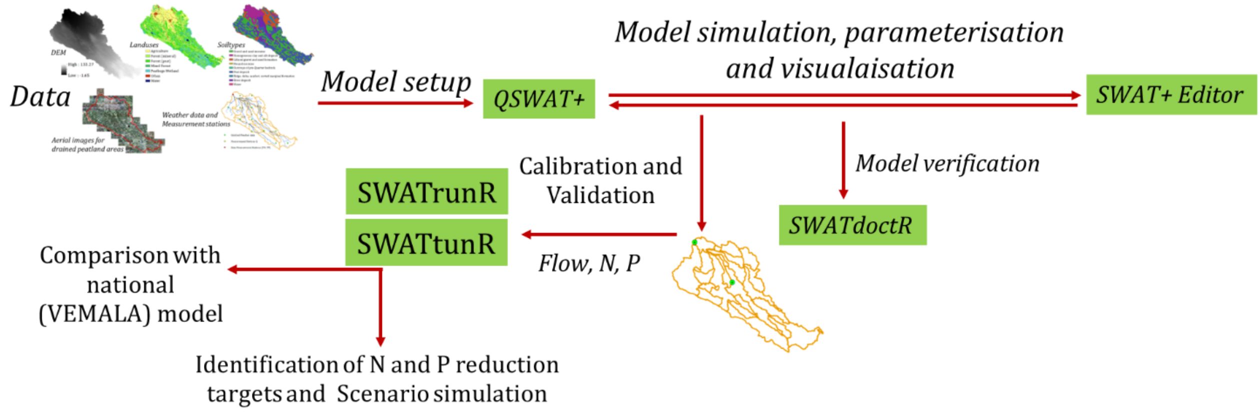

Figure 2. A flowchart describing the steps of the modelling, calibration, and validation

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
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 a 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 a 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 a 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 a 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) 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
River	River-theme	Vector (shapefile)	https://www.syke.fi/en-US/Open_information/Spatial_datasets/Downloadable_spatial_dataset

Stream 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

Description of the national model

The Vemala model is an operational, national-scale nutrient loading model designed for Finnish watersheds (Huttunen et al., 2016). It's a critical tool for simulating nutrient processes, leaching, and transport across terrestrial areas, rivers, and lakes. The model comprehensively assesses nutrient gross loads, retention, and net loads from Finnish watersheds, ultimately quantifying nutrient delivery to the Baltic Sea.

The Vemala model includes two primary sub-models:

- WSFS Hydrological Model
- Vemala Water Quality Model

These sub-models are integrated within the Watershed Simulation and Forecasting System (WSFS) developed by the Finnish Environment Institute (Syke). A few model versions have been developed in the last few years, transitioning the basic functionality into a more process-based nutrient-loading framework. From the simulated output of hydrological and water quality processes, Vemala provides a detailed assessment of nutrient loading and informs water resource management in Finland.

Calibration and validation

The following variables have been considered for calibration and validation purposes.

- Total Nitrogen (TN)
- Suspended sediment (SS)
- Total Phosphorus (TP)

For Modelling:

- Model warmup: 01/01/2012-31/12/2014
- Calibration: 01/01/2015-31/12/2020
- Validation: 01/01/2021-31/12/2022

Table 1 Parameters chosen for N calibration.

Parameter	Change type	Value min	Value max	Average value
n_updis.bsn	absval	0	100	94.25
nperco.bsn	relchg	0	1	0.142
sdnco.bsn	relchg	0	1	0.465
cmn.bsn	relchg	0.001	0.003	0.002
rsdco.bsn	absval	0.02	0.1	0.032
hlife_n.aqu	absval	0	365	174
no3_init.aqu	absval	0	30	1.84
lat_orgn.hru	absval	0	200	4.3
erorgn.hru	absval	0	5	0.985
cdn.bsn	absval	0	3	2.655

Table 2 Parameters chosen for SS calibration.

Parameter	Change type	Value min	Value max	Average value
cov.rte	absval	-0.001	10	0.26
ch_clay.rte	absval	0	100	97.605
bedldcoef.rte	absval	0	1	0.2385
prf.bsn	absval	0	2	0.005
lat_sed.hru	absval	0	5000	2890.2
spexp.bsn	absval	1	1.5	1.125
usle_p.hru	relchg	0	1	0.917
adj_pkr.bsn	absval	0.5	2	1.79

Table 3 Parameters chosen for P calibration.

Parameter	Change type	Value min	Value max	Average value
p_updis.bsn	absval	0	100	94.9
pperco.bsn	absval	10	17.5	10.225
phoskd.bsn	absval	100	200	197
psp.bsn	absval	0.01	0.7	0.018
erorgp.hru	absval	0	5	3.04
usle_k.sol	absval	0	0.65	0.625
lat_orgp.hru	absval	0	200	1.5

Table 4 Performance of SWAT+ model (N, SS and P)

Objective function	Calibration				Validation			
	Flow	N	SS	P	Flow	N	SS	P
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

Results

Flow:

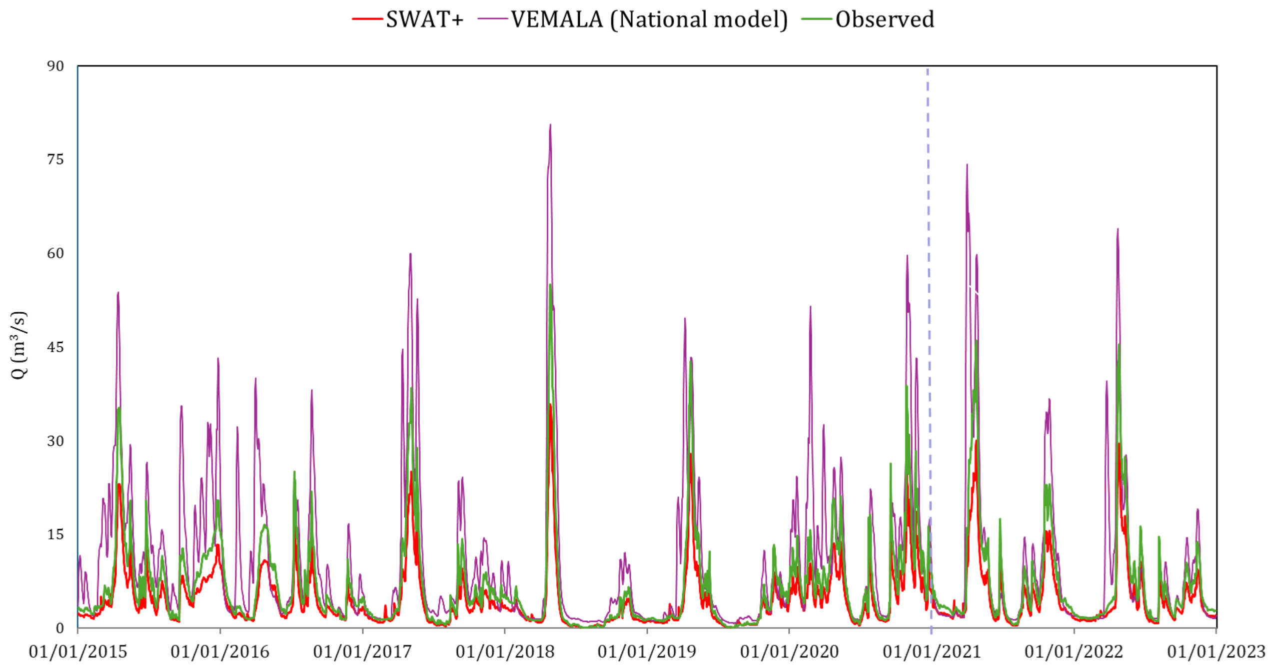

Figure 3. Observed and calibrated discharge along with the data from the national model. A light blue vertical line separates calibration and validation periods.

Total N

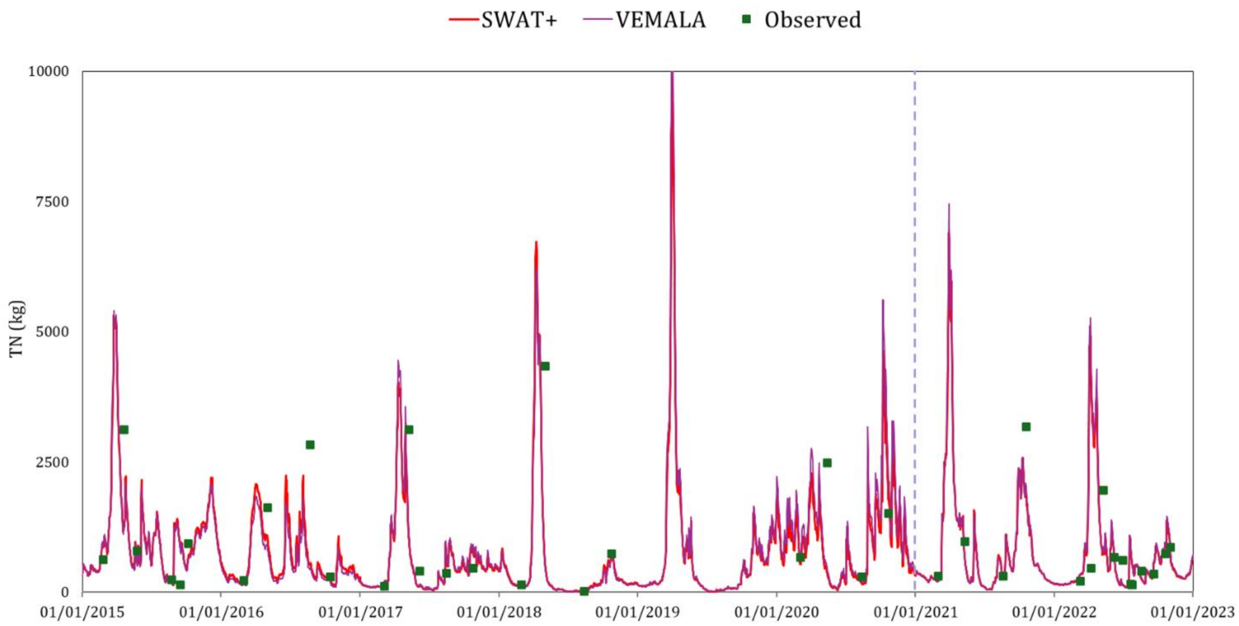

Figure 4. Observed and calibrated total N along with the data from the national model. A light blue vertical line separates calibration and validation periods.

SS

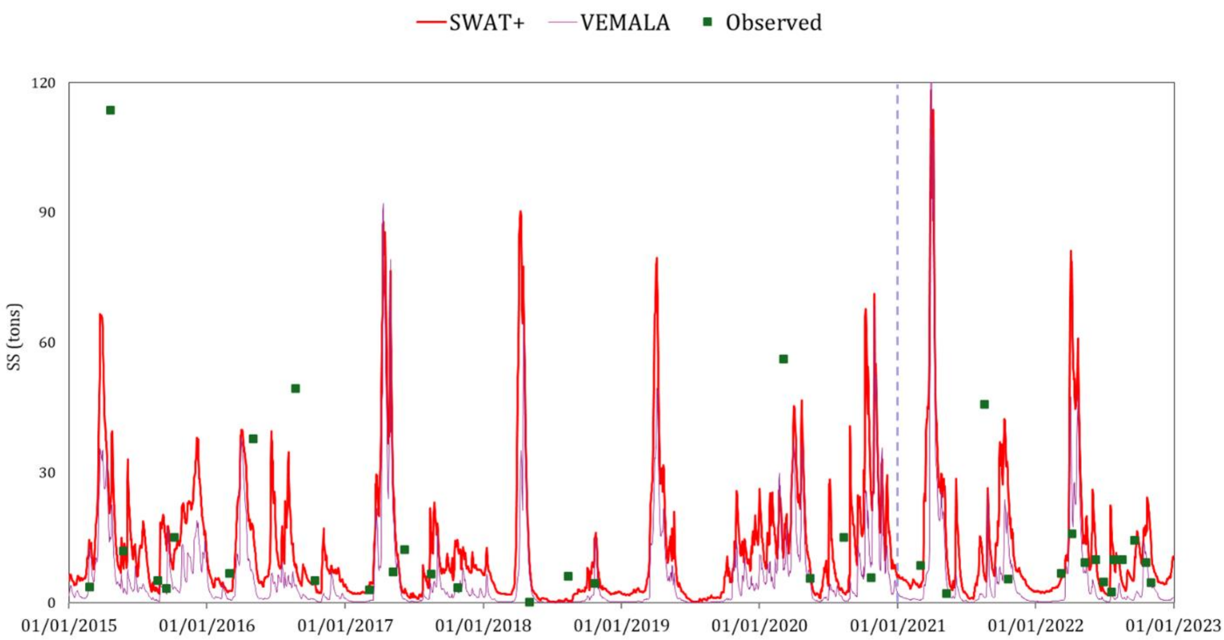

Figure 5. Observed and calibrated SS along with the data from the national model. A light blue vertical line separates the calibration and validation periods

Total P

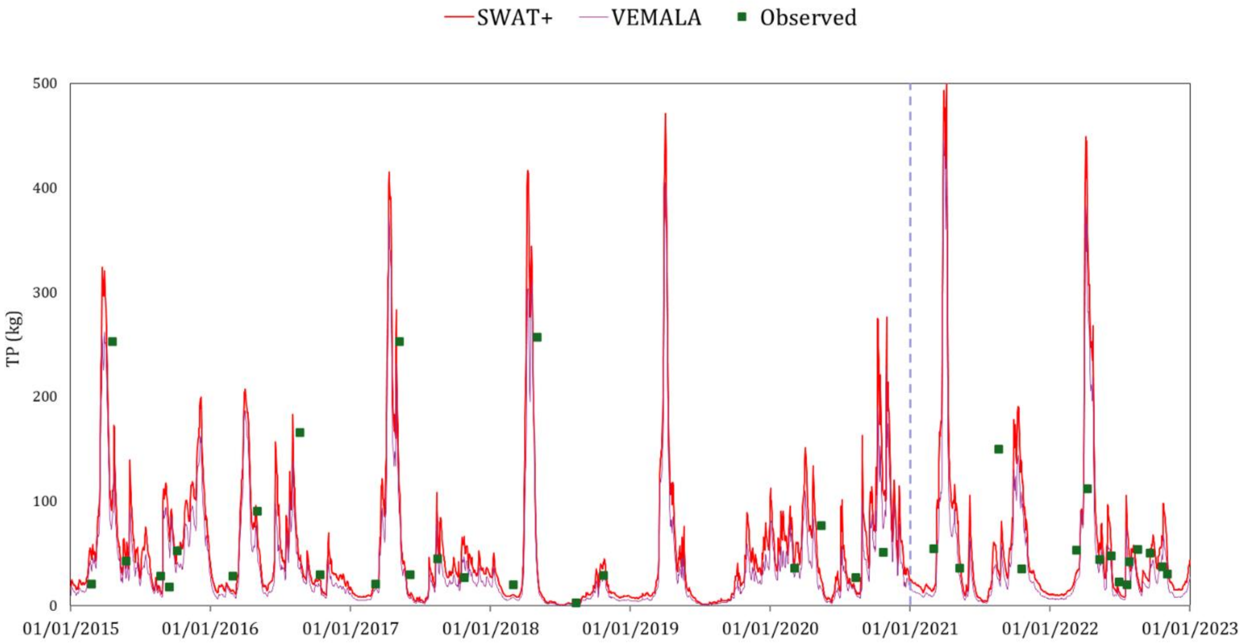

Figure 6. Observed and calibrated total P along with the data from the national model. A light blue vertical line separates the calibration and validation periods

Summary

A SWAT+ model was set up from scratch for the catchment. 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 and nutrient loads at the outlet.

The simulated flow by the SWAT+ model matched better with the observed data compared to the existing Finish model. Calibration results for total nitrogen are in good agreement with both observed data and the outputs of the national model. However, calibration results for SS and total P require further assessment. These results, as presented in this report, are still under assessment to have more accurate and reliable calibration.

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

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 and Assessment*, *21*(1), 83–109. https://doi.org/10.1007/s10666-015-9470-6

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

DATE: December 2024
FOR: NORDBALT-ECOSAFE

Appendix 2: Results and comparison of SWAT+ with the national model DK-QNP for the Odense Fjord Catchment, Denmark

DATE: December 18, 2024

AUTHORS: Katrin Bieger, Brian Kronvang

CITE AS: Bieger, K. and Kronvang, B. 2024. Results and comparison of SWAT+ with the national model DK-QNP for the Odense Fjord Catchment, Denmark. 11 pp.

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Introduction

The 1061-km^2 Odense Fjord Catchment is located on the Island of Funen in Denmark. The Odense River drains into the Odense Fjord. The geomorphology of the catchment is characterized by younger clayey moraines from the Weichsel glaciation. It is dominated by agricultural land use (68% of the area). Approximately 80% of the agricultural land are tile-drained. Urban areas (City of Odense) and forests cover 16% and 10% of the catchment area, respectively. The average annual precipitation is 825 mm and the mean temperature is 8.4°C.

Due to nutrient inputs from the intensive agriculture in the Odense Fjord Catchment, many of the freshwater bodies do not meet the criteria for good ecological status defined by the European Water Framework Directive and the ecological status of Odense Fjord is classified as moderate/bad.

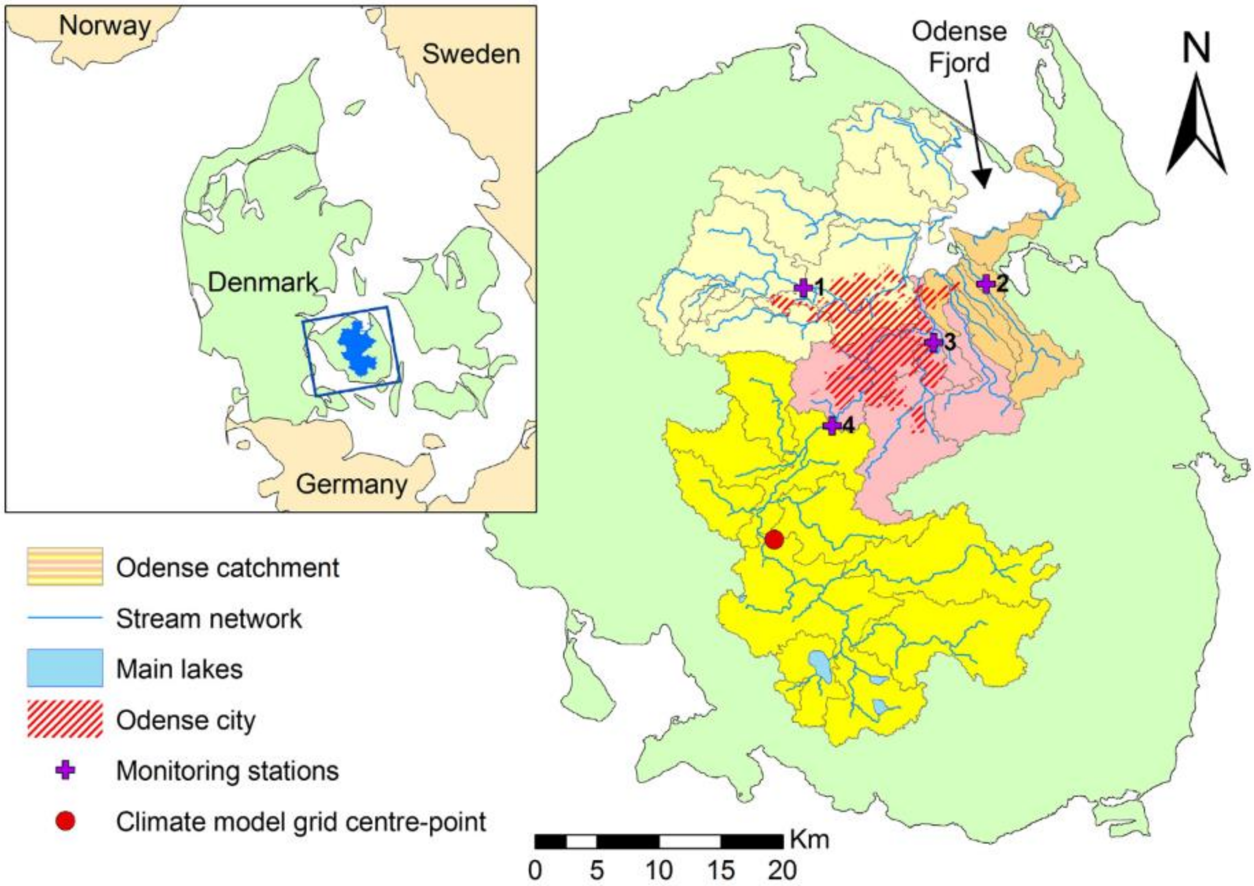

Figure 1. Location of the Odense Fjord Catchment in Denmark and overview of the stream network, large lakes, and monitoring stations (from Molina-Navarro et al., 2018)

Code/software versions used

Code	Version number	Availability
QGIS	3.22.16	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
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)	2.4.1	Code and official installer releases are available here: https://bitbucket.org/ChrisWGeorge/qswatplus3/downloads
SWAT+ Editor (interface)	2.3.1	Code and official installer releases are available here: https://bitbucket.org/swatplus/swatplus.editor/downloads/
SWATdoctR (model setup verification)	1.0	R package for SWAT+ model calibration and model diagnostics. https://git.ufz.de/schuerz/swatdoctr
SWATrunR (calibration tool)	0.1.3	R-package developed for hard calibration of the SWAT+ model. https://chrisschuerz.github.io/SWATrunR/

Weather input data used

Data	Temporal resolution	Spatial resolution	Availability
Precipitation	Daily	10km grid	Provided by the Danish Meteorological Institute.
Min. and max. air temperature	Daily	Stations	Provided by the Danish Meteorological Institute.
Relative humidity	Daily	Stations	Provided by the Danish Meteorological Institute.
Wind speed	Daily	20km grid	Provided by the Danish Meteorological Institute.
Solar radiation	Daily	20km grid	Provided by the Danish Meteorological Institute.

GIS input data used

Data	Map	Resolution	Availability
DEM	National DEM	32m raster	Based on resampling of a 1,6 m LidarDEM (KMS, 2010).
Landuse	Land Use Map + Field Map	10m raster	Created by combining the general land use map from the Danish Area Information System (Nielsen et al. 2000) and the 2020 Field Map downloaded from MiljøGIS (https://miljoegis.mim.dk/cbkort?profile=lbst).
Soil	National Topsoil Texture Map	250m raster	Derived from approximately 45,000 soil samples, which were interpolated using ordinary kriging (Greve et al., 2007).

Lakes	DK Lakes	Vector (shapefile)	Downloaded from MiljøGIS, edited to only include lakes with a surface area > 5 ha.
Rivers	DK Rivers	Vector (shapefile)	Downloaded from MiljøGIS

Stream discharge and nutrient data used for calibration

Data	**Temporal resolution**	**Spatial resolution**	**Availability**
Stream discharge	Daily	4 stations	Downloaded from odaforalle.au.dk.
Nitrogen loads	Daily, calculated from appr. bi-weekly data	4 stations	Provided internally at Aarhus University.
Phosphorus loads	Daily, calculated from appr. bi-weekly data	4 stations	Provided internally at Aarhus University.

Description of the national model

In Denmark, the model DK-QNP is used for calculating monthly runoff and monthly total nitrogen (TN) and total phosphorus (TP) loadings for ca. 3200 small hydrological units (HU) named ID15 (ca. 15 km2), covering the entire land area of Denmark (Windolf et al. 2011).

In short, the monthly net TN load from each HU is calculated by subtracting the N retention in surface waters (streams, lakes and wetlands) within the HU from the inputs of TN from point sources and diffuse sources (agriculture and natural losses). Total N inputs considered include monthly diffuse TN loads from the HUs, which are estimated based on DK-N empirical model simulations of monthly discharge-weighted concentrations that are multiplied by modelled monthly runoff derived from a national MIKE-model setup. Monthly TN emissions from point sources where data are collected from Danish municipalities by the Danish EPA are then added to diffuse losses within each HU. Finally, N retention in surface waters is subtracted from the N-load within each HU on a monthly basis. The model estimated monthly net TN loads from each HU and the resulting TN concentrations are validated in catchments where observed TN concentrations and loads are available from the national monitoring programme (NOVANA). A regional bias correction factor is developed for each region based on the differences between modelled and observed diffuse TN-loads and the bias correction factors are applied when estimation TN loadings for ungauged areas in Denmark (Thodsen et al., 2023). The DK-QNP model is used to estimate discharge and nutrient loads for ungauged areas in Denmark only. For all gauged areas (65% of the Danish land area), observed data is used.

Calibration and validation

Hard calibration of daily discharge was performed using the R tool SWATrunR at four gauges: Odense Å at Kratholm, Stavis Å, Lindved Å, and Geels Å. Daily total nitrogen loads were calibrated manually at the same gauges. The following time periods were used for model calibration and validation:

- Model warm-up: 1/1/2008 – 31/12/2010
- Calibration: 1/1/2011 – 31/12/2016
- Validation: 1/1/2017 – 31/12/2022

An acceptable calibration of total phosphorus loads has not been accomplished yet. Possible reasons for this are currently being analyzed with the support of the SWAT+ model development team. Detailed information about the model setup and calibration can be found in Bieger & Kronvang (2024).

Table 1. Parameters used for discharge and total nitrogen calibration, their units, 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 relative value), minimum and maximum value, and final value after calibration.

Parameter	Description	Unit	Change type	Min value	Max value	Final value
surq_lag	Surface runoff lag coefficient	none	absval	0.05	5	0.32
esco	Soil evaporation compensation factor	none	absval	0.1	0.5	0.25
epco	Plant uptake compensation factor	none	absval	0.1	0.5	0.48
ov_mann	Overland roughness (Manning's n	none	abschg	-0.3	0.3	0.28
cn2	Curve Number for moisture condition II	none	abschg	-15	0	-8.24
cn3_swf	Soil water adjustment factor for CN3	none	abschg	-0.5	0.5	0.15
perco	Percolation coefficient	none	abschg	-0.5	0.5	-0.12
latq_co	Lateral flow coefficient	none	abschg	-0.5	0.5	0.07
lat_ttime	Lateral flow travel time	days	absval	0.5	20	6.92
dp	Depth of drain tube from the soil surface	cm	absval	800	1200	870.5
t_fc	Time to drain soil to field capacity	hours	absval	10	72	57.74
lag	Drain tile lag time	hours	absval	10	100	54.33
drain	Drainage coefficient	mm/day	absval	10	51	33.39
z	Depth of the soil layer	mm	relchg	-0.5	1	0.18
awc	Available water capacity of the soil layer	mm/mm	relchg	-0.1	0.1	-0.09
k	Hydraulic conductivity of the soil layer	mm/hour	relchg	-0.5	1	0.96
alpha	Alpha factor for groundwater recession curve	1/days	absval	0.001	0.9	0.42
sp_yld	Specific yield of the aquifer	m3/m3	absval	0	0.5	0.25
mann	Channel roughness (Manning's n value)	none	relchg	-0.5	0.5	-0.03
n_perc	Nitrate percolation coefficient	none	n/a	n/a	n/a	0.9
nperco_lchtile	Nitrogen concentration coefficient for tile flow and leaching from bottom layer	none	n/a	n/a	n/a	0.8
denit_frac	Denitrification threshold water content	none	n/a	n/a	n/a	1.0
orgn_min	Rate factor for humus mineraliza-tion of active organic nutrients	none	n/a	n/a	n/a	0.0003
hl_no3	Half-life of NO3-N in the aquifer	days	n/a	n/a	n/a	200.0

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

Gauge	**KGE**		**pbias**		**NSE**	
	Cal	**Val**	**Cal**	**Val**	**Cal**	**Val**
Odense Å at Kratholm	0,85	0,90	-12,7	-3,8	0,83	0,87
Stavis Å	0,77	0,74	10,7	15,7	0,73	0,70
Lindved Å	0,79	0,61	-1,3	15,0	0,66	0,65
Geels Å	0,45	0,56	0,1	3,8	0,27	0,62

Table 3. Model evaluation statistics for total nitrogen loads during the calibration (Cal) and validation (Val) periods.

Gauge	**KGE**		**pbias**		**NSE**	
	Cal	**Val**	**Cal**	**Val**	**Cal**	**Val**
Odense Å at Kratholm	0,85	0,90	-12,7	-3,8	0,83	0,87
Stavis Å	0,77	0,74	10,7	15,7	0,73	0,70
Lindved Å	0,79	0,61	-1,3	15,0	0,66	0,65
Geels Å	0,45	0,56	0,1	3,8	0,27	0,62

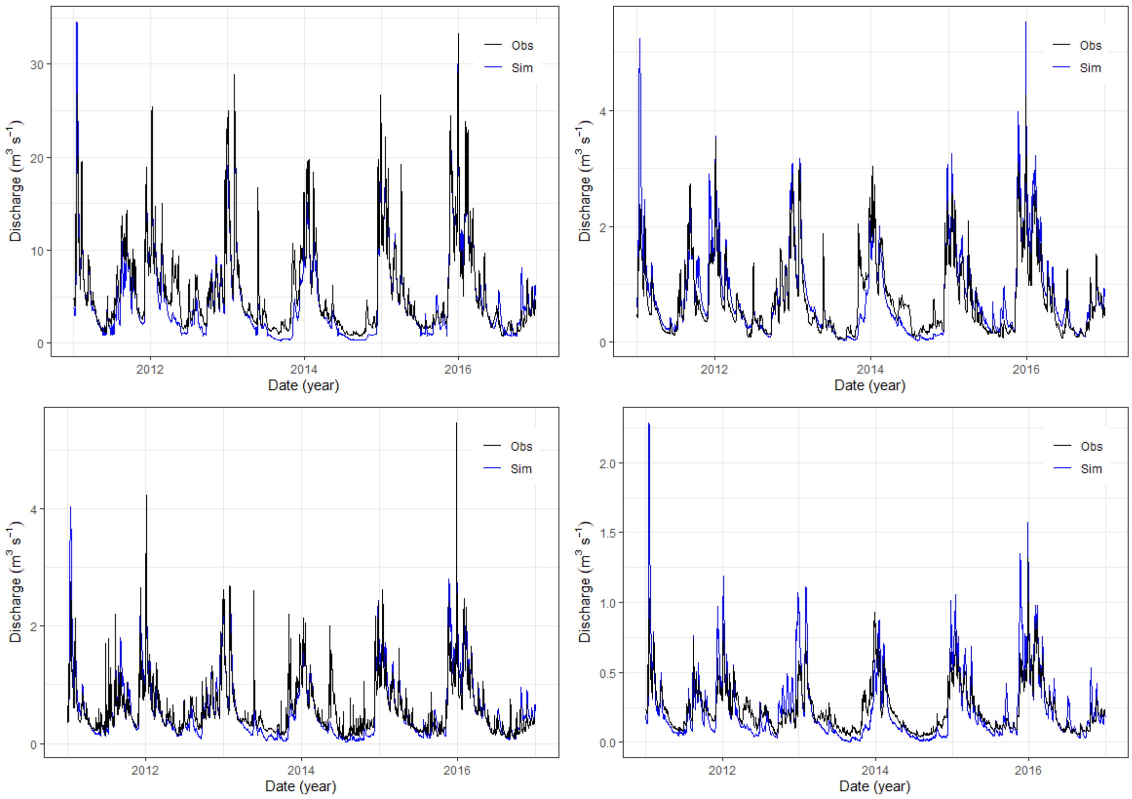

Figure 2. Observed and simulated discharge for Odense Å at Kratholm, Lindved Å, Geels Å and Stavis Å during the calibration period.

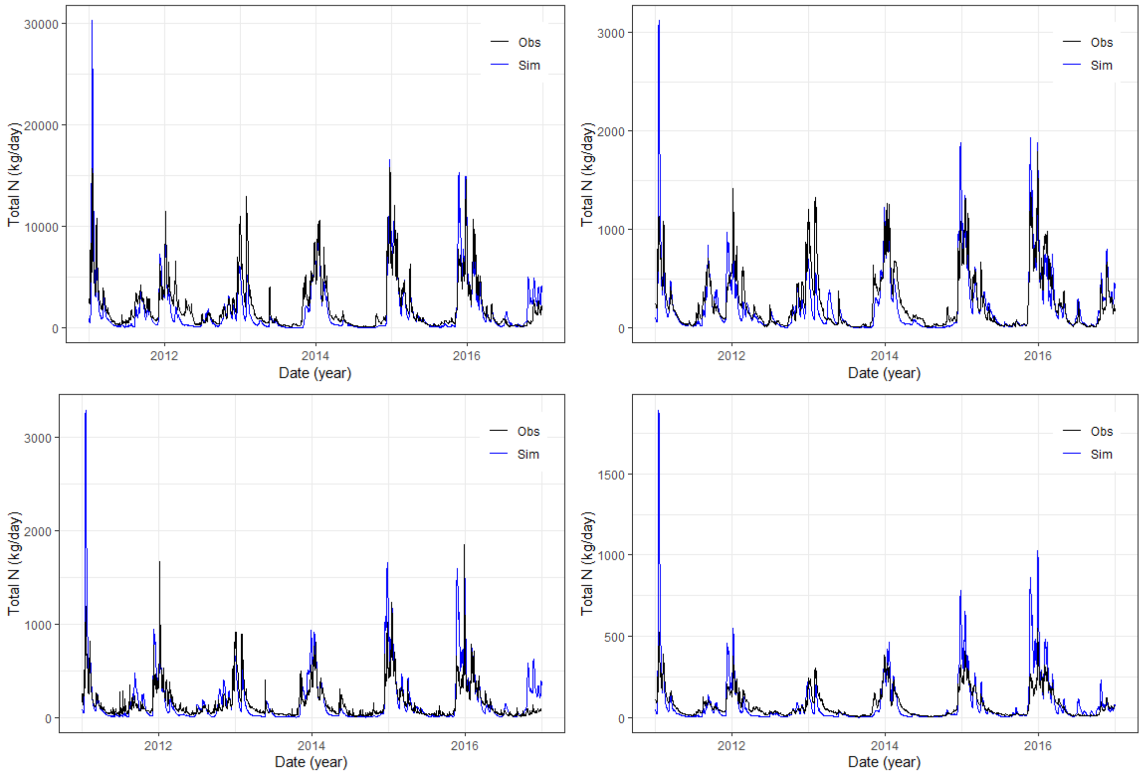

Figure 3. Observed and simulated total nitrogen loads for Odense Å at Kratholm, Lindved Å, Geels Å and Stavis Å during the calibration period.

Results

Figures 4 to 7 show the comparison between the monthly discharge and TN loads to Odense Fjord estimated by SWAT+ and the DK-QNP model. The Coefficient of Determination for discharge is very high (0.95), indicating a very good fit between SWAT+ and the national model (Figure 5). This is confirmed by the time series in Figure 4. SWAT+ generally simulates slightly higher discharge values during high flow periods but lower discharge during baseflow periods.

The differences between the two models are larger for TN loads, but the Coefficient of Determination (0.78) still indicates a good fit (Figure 7). Figure 6 shows that except for the winters 2011/2012 and 2012/2013, SWAT+ estimates higher TN loads than DK-QNP during the winter.

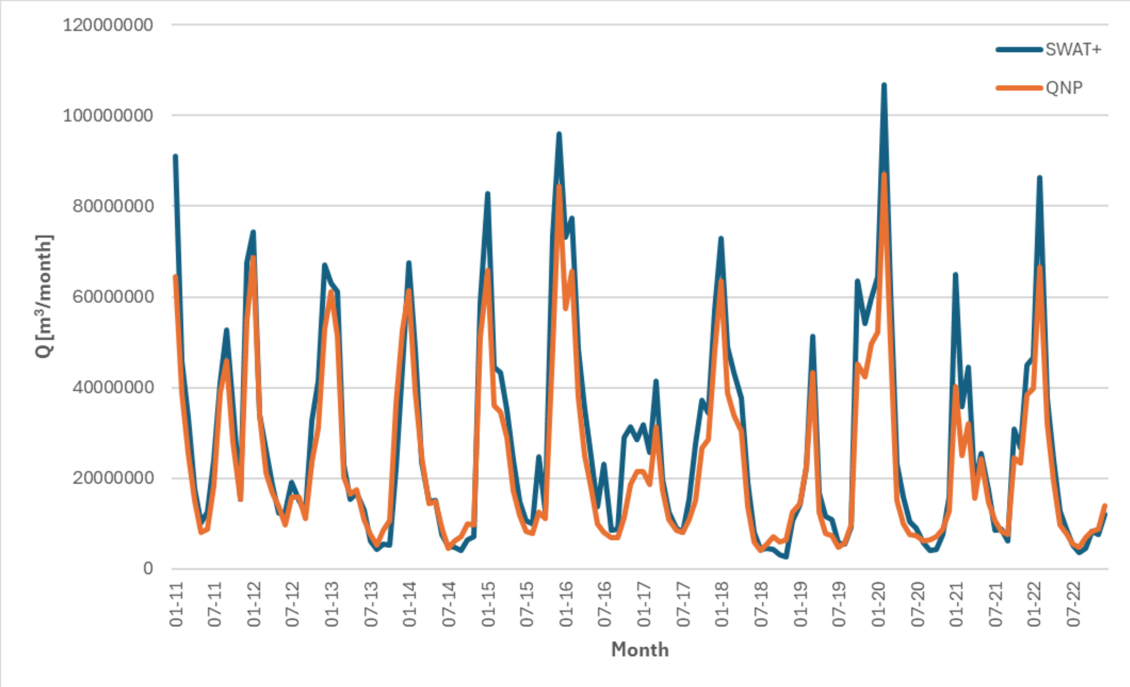

Figure 4: Time series of monthly discharge to Odense Fjord simulated by SWAT+ and the Danish national model DK-QNP for the years 2011-2022.

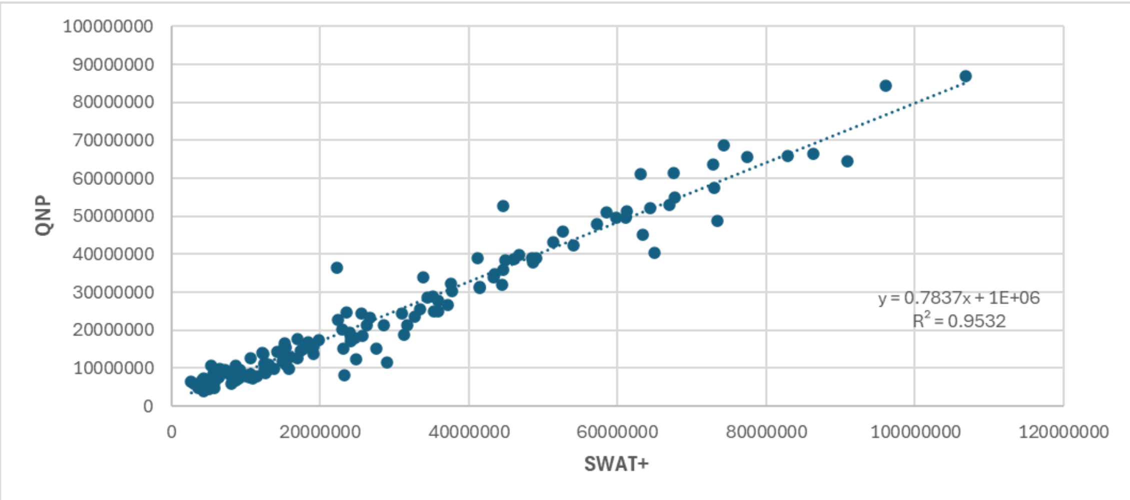

Figure 5: Scatterplot of monthly discharge to Odense Fjord simulated by SWAT+ and the Danish national model DK-QNP for the years 2011-2022.

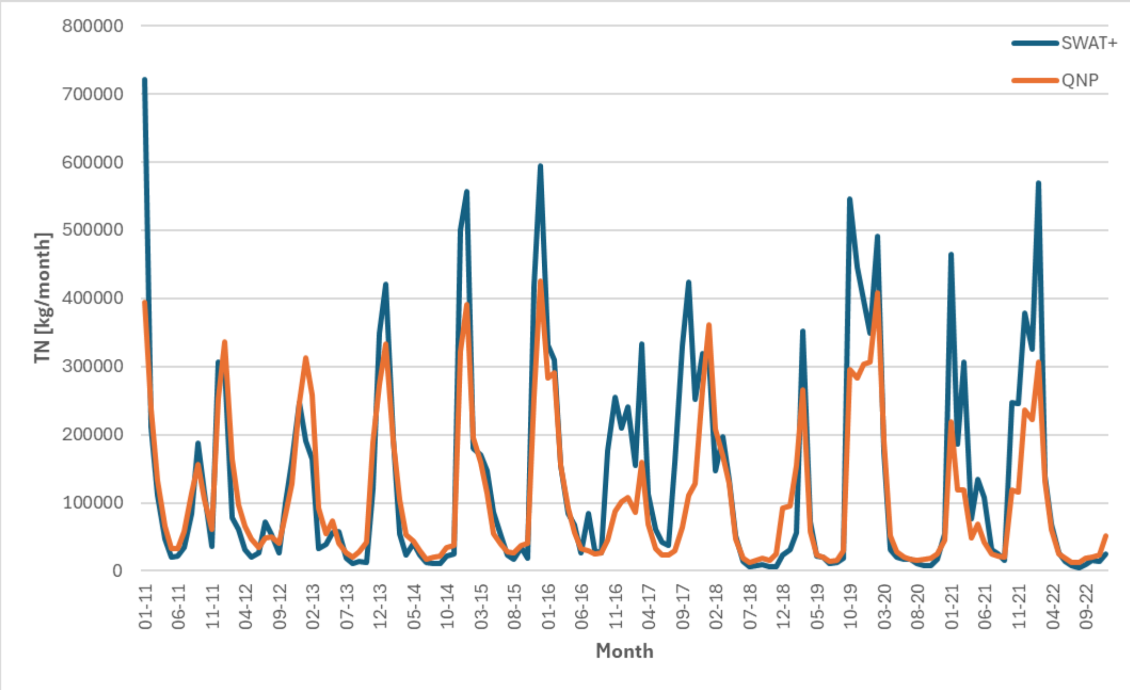

Figure 6: Time series of monthly TN loads to Odense Fjord simulated by SWAT+ and the Danish national model DK-QNP for the years 2011-2022.

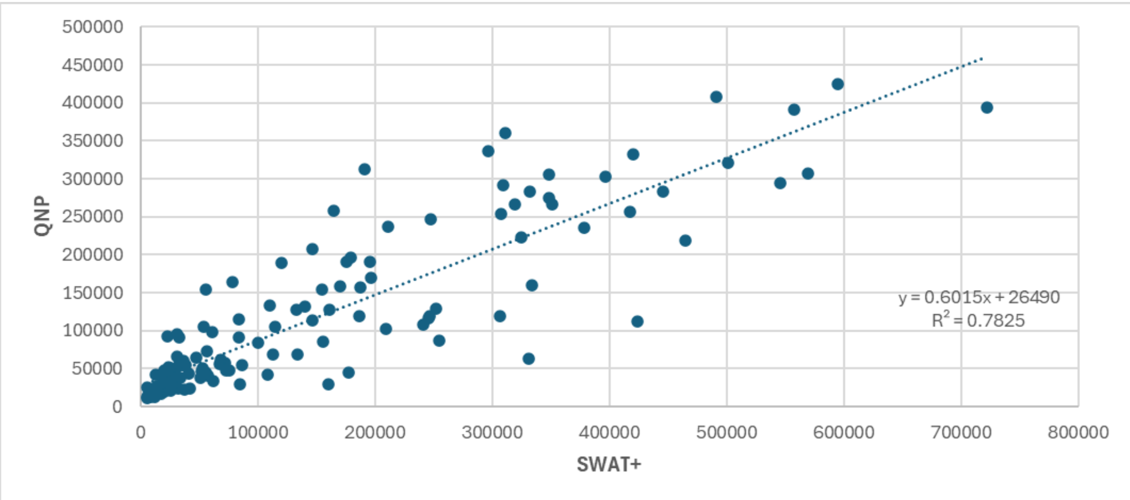

Figure 7: Scatterplot of monthly TN loads to Odense Fjord simulated by SWAT+ and the Danish national model DK-QNP for the years 2011-2022.

Summary

A SWAT+ model was set up for the Odense Fjord Catchment in Denmark. The parameterization was adjusted to reflect the environmental conditions in the catchment as realistically as possible. The calibration resulted in a good simulation of discharge and acceptable model performance for total nitrogen loads. The comparison of monthly discharge and TN loads to Odense Fjord indicates a very good and good fit between SWAT+ and DK-QNP for discharge and TN loads, respectively.

References

Bieger, K, Kronvang, B, 2024. SWAT+ model protocol for Odense Fjord Catchment, Denmark. 14 pp. https://projects.au.dk/nordbalt-ecosafe/wp4/denmark.

Greve MH, Greve MB, Bøcher PK, Balstrøm T, Breuning-Madsen H, Krogh L, 2007. Generating a Danish raster-based topsoil property map combining choropleth maps and point information. Geografisk Tidsskrift/Danish J Geogr. 107:1–12.

KMS, 2010. Danmarks Højdemodel – DHM Terræn [Digital elevation model for Denmark]. Copenhagen: National Survey and Cadastre. 10 pp. In Danish.

Molina-Navarro E, Andersen HE, Nielsen A, Thodsen H, Trolle D, 2018. Quantifying the combined effects of land use and climate changes onstream flow and nutrient loads: A modelling approach in the Odense Fjord catchment (Denmark). Science of the Total Environment 621:253-264.

Nielsen K, Stjernholm M, Olsen BØ, Müller-Wohlfeil D-I, Madsen I-L, Kjeldgaard A, Groom G, Hansen HS, Rolev AM, Hermansen B, et al., 2000. Areal Informations Systemet – AIS [Land use information system –AIS]. National Environmental Research Institute. p. 112. In Danish.

Thodsen, H, Tornbjerg, H, Rolighed, J, Kjær, C, Larsen, SE, Ovesen, NB, Blicher-Mathiesen, G, 2023. Vandløb 2021 - Kemisk vandkvalitet, stoftransport og miljøfarlige forurenende stoffer. NOVANA. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 90 s. - Videnskabelig rapport nr. 527. http://dce2.au.dk/pub/SR527.pdf. In Danish.

Windolf, J, Thodsen, H, Troldborg, L, Larsen, SE, Bøgestrand, J, Ovesen, NB, Kronvang, B, 2011. A distributed modelling system for simulation of monthly runoff and nitrogen sources, loads and sinks for ungauged catchments in Denmark. Journal of Environmental Monitoring 13:2645–2658.

DATE: December 2024
FOR: NORDBALT-ECOSAFE

Appendix 3: Results and comparison of SWAT+ with the existing /national model for the Słupia catchment (Poland)

DATE:	December 2024
AUTHORS:	Mikołaj Piniewski, Svajunas Plunge, Ignacy Kardel, Marek Giełczewski
CITE AS:	Piniewski, M., Plunge, S., Kardel, I., Giełczewski, M. 2024 Results and comparison of SWAT+ with the existing /national model for Słupia catchment (Poland)

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Introduction

The Słupia catchment (Fig. 1) is a coastal river basin in northern Poland covering an area of 1623 km^2. It drains into the southern Baltic Sea through the 138 km long Słupia River. The area's climate is classified as warm-summer humid continental (Dfb), with mean annual precipitation of 850 mm/y. The mean water flow at the catchment outlet from the period 2000-2016 was 17 m^3/s, with a range of 8.4 to 53 m^3/s. The altitude ranges from 0 to 267 m a.s.l., with the highest parts located in the south-east of the basin. Sands and loamy sand are the most typical soil types.

The main environmental challenges are related to: a) nutrient losses from agricultural areas; b) the need to increase water retention and slow down water outflow; and c) flash floods in urban areas (Słupsk) caused by extreme rainfall events. In this project, we focus mainly on the first problem related to nutrients (nitrogen and phosphorus).

This report builds on the previous one (Piniewski et al., 2024), in which the model setup protocol and preliminary discharge calibration results were presented. The model setup was generated using an R-based workflow recently developed within the EU project OPTAIN (Piniewski et al., 2024; Schürz et al., 2022; Plunge et al., 2024a; Plunge et al., 2024b). While the primary purpose of SWAT+ modeling in the Nordbalt-Ecosafe project is to simulate the effectiveness of mitigation measures on water quality, this report focuses on calibration and validation of nutrients, which is a prerequisite for scenario simulations. Comparison with the national model was not made for the Słupia catchment since no national-scale water quality model exists in Poland.

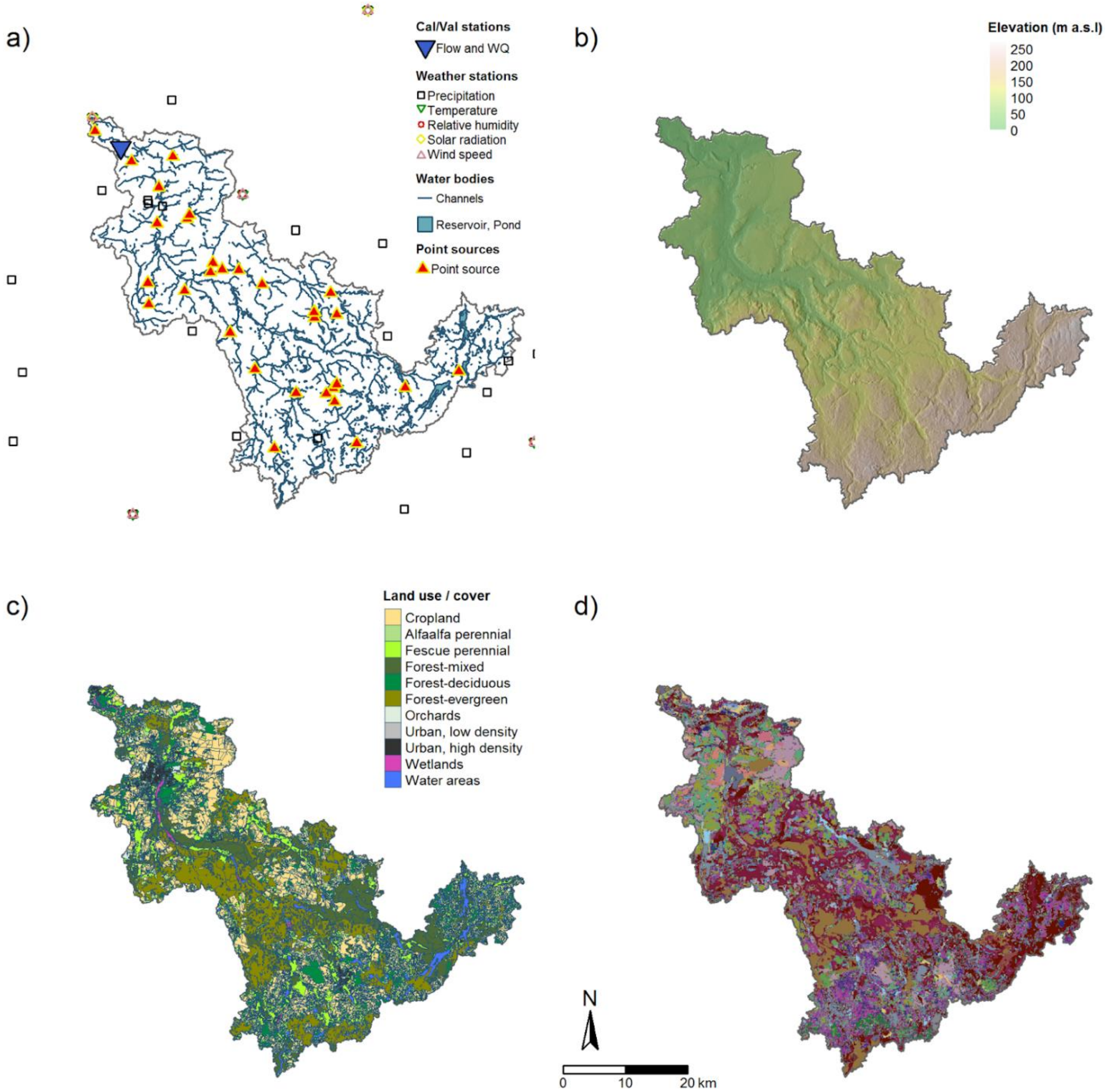

Figure 1. Input maps used for setting up the SWAT+ model for the Słupia catchment: a) weather stations, monitoring points, lakes and point sources; b) Digital Elevation Model; c) Land use; d) Soils (legend not shown).

Code versions used

Code	Version number	Availability
R scripted workflow	1.0	SWAT+ model setup preparation scripted workflow developed in the OPTAIN project (Plunge et al., 2024). See Piniewski et al. (2024) for description of individual components of the scripted workflow.
SWAT+ (core model)	61.0	The SWAT+ fortran code is version controlled through bitbucket. Official code releases are available here: https://bitbucket.org/blacklandgrasslandmodels/modular_swatplus/src/master/ Note: a modified version of the executable was used to account for changes in the

		amount of nitrogen in the falling leaves (pl_leaf_senes). Using the original version led to excessive nitrate losses from forests.
SWATdoctR (model verification tool)	1.0	SWATdoctR is a collection of functions and routines for SWAT model calibration and model diagnostics and was applied for model verification and soft calibration of the hydrological routines. https://git.ufz.de/schuerz/swatdoctr
SWATrunR	0.1.3	R-package developed for executing the SWAT+ model in R (here adapted for 'hard' calibration of discharge and nutrients) https://chrisschuerz.github.io/SWATrunR/
SWATtunR	0.0.2	R-package developed for the SWAT+ model calibration (here used for crop yield calibration) https://biopsichas.github.io/SWATtunR/index.html

Weather input data used

Data	**Temporal resolution**	**Spatial resolution**	**Availability**
Precipitation	Daily	Provided from individual weather stations	Observed daily precipitation data for period 2003-2021 for 29 stations (6 of them with 100% data coverage, and 14 with coverage above 95%; average temporal coverage: 85%) was downloaded from the Institute of Meteorology and Water Management - National Research Institute database available at https://danepubliczne.imgw.pl/en.
Min. and max air temperature	Daily	Provided from individual weather stations	Observed daily min. and max. temperature data for period 2003-2021 for 11 stations (5 of them with 100% data coverage, and 2 with coverage above 85%; average temporal coverage: 85%) was downloaded from the Institute of Meteorology and Water Management - National Research Institute database available at https://danepubliczne.imgw.pl/en.
Relative humidity	Daily	Provided from individual weather stations	Observed daily relative humidity data for period 2003-2021 for 10 stations (5 of them with 100% data coverage, and 2 with coverage above 85%; average temporal coverage: 86%) was downloaded from the Institute of Meteorology and Water Management - National Research Institute database available at https://danepubliczne.imgw.pl/en.
Wind speed	Daily	Provided from individual weather stations	Observed daily wind speed data for period 2003-2021 for 10 stations (5 of them with 100% data coverage, and 2 with coverage above 85%; average temporal coverage: 87%) was downloaded from the Institute of Meteorology and Water Management - National Research Institute database available at https://danepubliczne.imgw.pl/en.
Radiation	Daily	Provided from individual weather stations	Observed daily radiation data for period 2003-2021 for 7 stations (2 of them with 100% data coverage, and 1 with coverage above 95%; average temporal coverage: 68%) was downloaded from the Institute of Meteorology and Water Management - National Research Institute database available at https://danepubliczne.imgw.pl/en.

Note: All weather input data were interpolated for each day to a 5 km grid using the inverse distance weighted method available in the SWATprepR package (Plunge et al., 2024a).

GIS input data used

Data	Map	Resolution	Availability
DEM	NMT PL-KRON86-NH	1 m raster	Official 1 m raster map from LIDAR hosted by the Polish Central Office of Geodesy and Cartography. For SWAT+ purposes, the DEM was resampled to 10 m resolution. The data is available for download from https://geoportal.gov.pl
Landuse	BDOT10k	Vector (shapefile)	Database of Topographic Objects - official land use layer in scale 1:10 000 hosted by the Polish Central Office of Geodesy and Cartography. The data is available for download from https://geoportal.gov.pl
Crops	GSAA	Vector (shapefile)	Polish Geo-spatial Aid Application (GSAA) data collection is managed by the Agency for Restructuring and Modernisation of Agriculture (ARiMR) in scale 1:500 and contains parcel-level data on cultivated crops since 2020. The data is available for download from https://geoportal.arimr.gov.pl (login required).
Soils	IUNG	Vector (shapefile)	Map of soil-agricultural units from the Institute of Soil Science and Plant Cultivation (IUNG) in the scale 1:100 000. Both the map and soil parameters available from the SWAT2012 model setup developed in the BONUS RETURN project (Piniewski et al., 2021).
Lakes (optional)	MPHP10k	Vector (shapefile)	Database of Topographic Objects - official land use layer in scale 1:10 000 hosted by the Polish Central Office of Geodesy and Cartography. The data is available for download from https://geoportal.gov.pl
Rivers (optional)	MPHP10k	Vector (shapefile)	Official layer of rivers reaches (rzeki_r) from the data set Map of the Hydrographic Division of Poland in the scale 1:10 000 hosted by the State Water Holding Polish Waters. Online visual access only via QGIS plugin: Wody Polskie - Baza WMS
Drainage	GeoMelio	Vector (shapefile)	Underground drainage pipes from the official GeoMelio dataset in scale 1:500 hosted by the National Water Management Authority. No online access available.

Discharge and water quality data used for calibration and validation

Data	Temporal resolution	Spatial resolution	Availability
Crop yields	Average annual	Catchment average	Expert-based data provided for major crops included in the model setup by the Pomeranian Agricultural Advisory Centre (branch in Słupsk).
Stream discharge	daily	Provided from individual gauge stations	Observed daily discharge data for period 2003-2021 for 2 gauge stations (Charnowo, Soszyca; each with 100% temporal data coverage) was downloaded from the Institute of Meteorology and Water Management - National Research Institute database available at https://danepubliczne.imgw.pl/en.
Nitrate nitrogen (NO_3-N), phosphate phosphorus (PO_4-P) concentrations	Grab sample (monthly)	Provided from individual gauge stations	Data available from the Chief Inspectorate of Environmental Protection (GIOŚ) for station Charnowo

In addition to the input data listed in above tables, we used expert-based data on agricultural practices in the Słupia catchment that are necessary to parametrize management schedules of all major crops in the SWAT+ model setup. This information was provided by the Pomeranian Agricultural Advisory Centre (branch in Słupsk). Data on point sources (discharges from major wastewater treatment plants) were acquired from the Central Statistical Office, the Słupsk Waterworks and other municipalities in the catchment.

Description of national/existing Model

To the best of our knowledge, Poland does not have a national-scale water quality model that could be used for the comparison of outputs with the SWAT+ model used in the Norbalt-Ecosafe project. Therefore, it was not possible to carry out this task.

Calibration and validation

- Model warmup: 2003-2006
- Calibration: 2007-2013
- Validation: 2014-2021

Table 1 Parameters chosen for simultaneous calibration of discharge, N-NO3, and P-PO$_4$*.*

Parameter	Change type	Value min	Value max	Calibrated value
esco	absval	0.03	0.02	0.08
awc	relchg	-0.18	-0.25	-0.13
cn2	relchg	0.05	0.05	0.16
surlag	absval	0.36	0.35	0.55
bd	relchg	-0.02	-0.05	0.15
k	relchg	-0.33	-0.5	0
tile_lag	absval	286	200	300
tile_drain	absval	5.99	3.5	7
alpha	absval	0.0019	0.0016	0.0026
sp_yld	absval	0.025	0.015	0.035
n_updis	absval	54.4	1	100
nperco	absval	0.10	0	0.15
sdnco	absval	0.98	0.95	1.05
hlife_n	absval	117	60	150
cmn	absval	0.00019	0.00015	0.00035
pperco	absval	15.03	10	17.5
phoskd	absval	129	100	200
psp	absval	0.045	0.045	0.06
p_updis	absval	64	0	100
perco_low*	absval	0.89	0.8	0.9
cn3_swf_low**	absval	0.81	0.8	0.95
perco_mod*	absval	0.96	0.9	0.96
cn3_swf_mod**	absval	0.43	0.4	0.8

perco_high*	absval	0.99	0.96	0.99
cn3_swf_high**	absval	0.13	0.1	0.4

** For HRUs with low, moderate and high leaching potential, respectively*
*** For HRUs with low, moderate and high runoff potential, respectively*

Table 2 Performance of SWAT+ model (NO_3-N and PO_4-P concentrations).

Objective function	Calibration			Validation		
	Discharge	NO_3-N	PO_4-P	Discharge	NO_3-N	PO_4-P
KGE [-]	0.81	0.54	0.0	0.75	0.39	-0.1
PBIAS [%]	0.5	19.6	-29.2	6.6	15.6	-26.9

Results

Crop yields

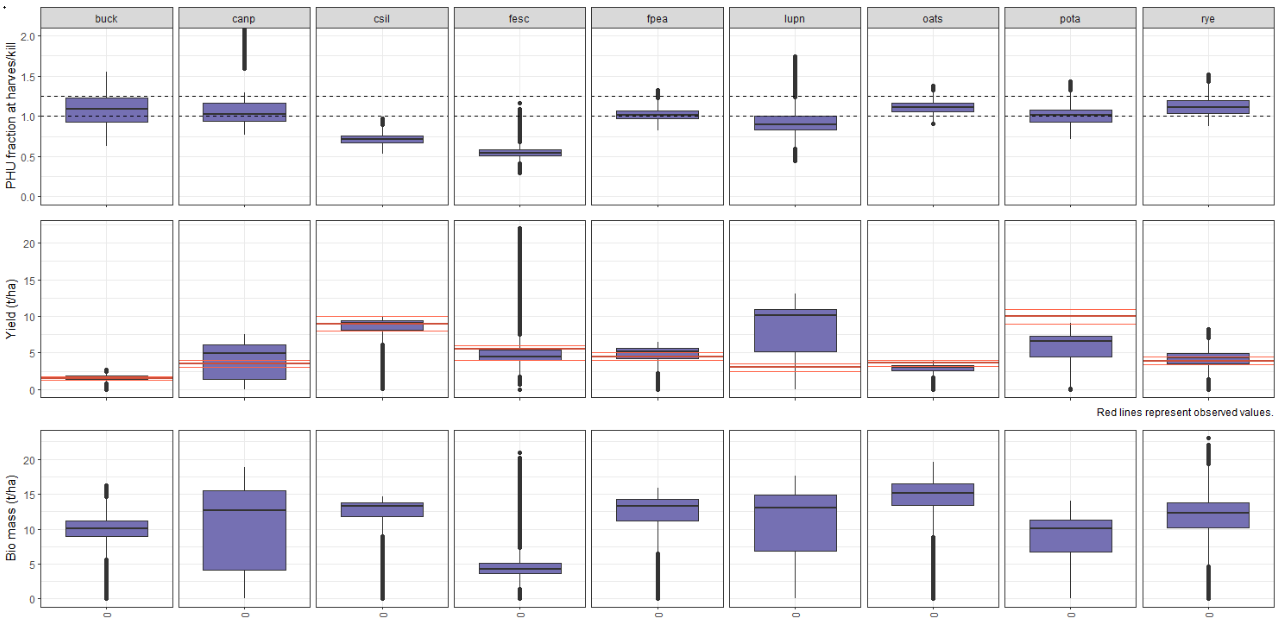

Figure 2 Crop yield calibration results: PHU fraction at harvest/kill (top panel), simulated vs observed crop yield (middle panel) and simulated biomass (bottom panel). Red lines denote observed values (average and min/max).

Flow

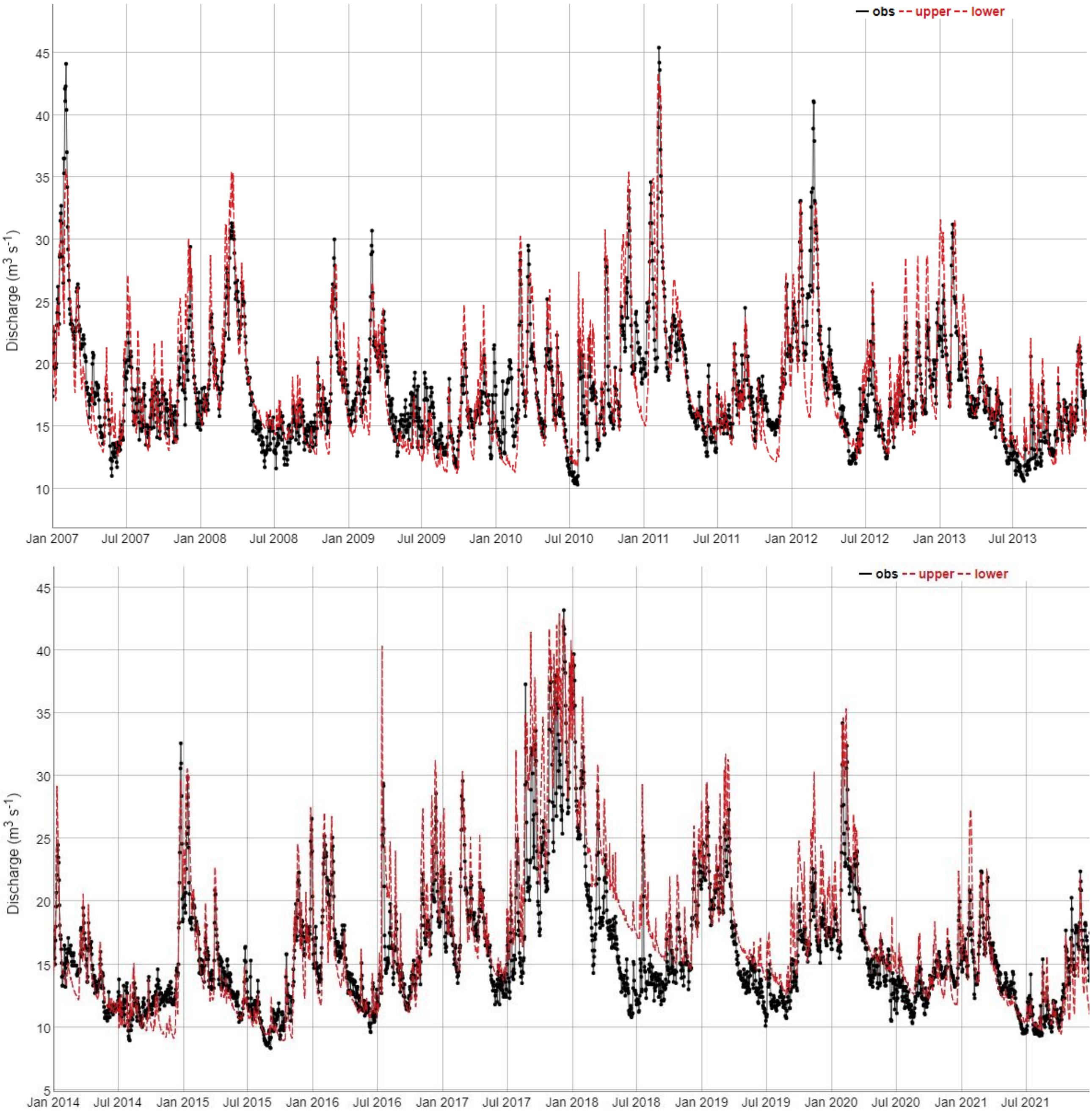

Figure 3. Observed and simulated daily discharge (m^3/s) at the Charnowo gauge station for the calibration period 2007-2013 (upper panel) and the validation period 2014-2021 (lower panel).

NO_3-N (load and concentration)

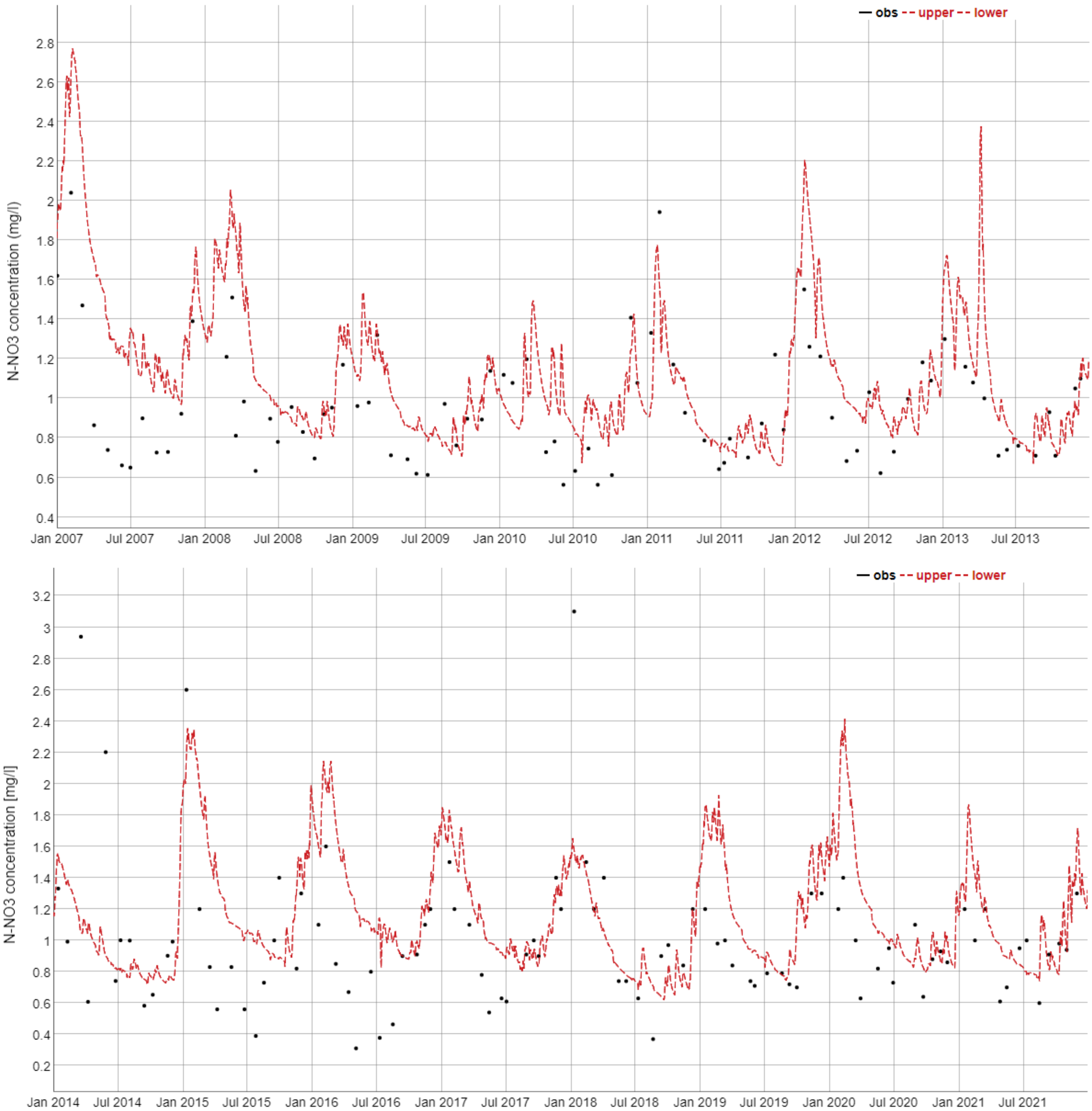

Figure 4. Observed and simulated NO_3-N concentrations at the Charnowo gauge station for the calibration period 2007-2013 (upper panel) and validation period 2014-2021 (lower panel).

P (load and concentration)

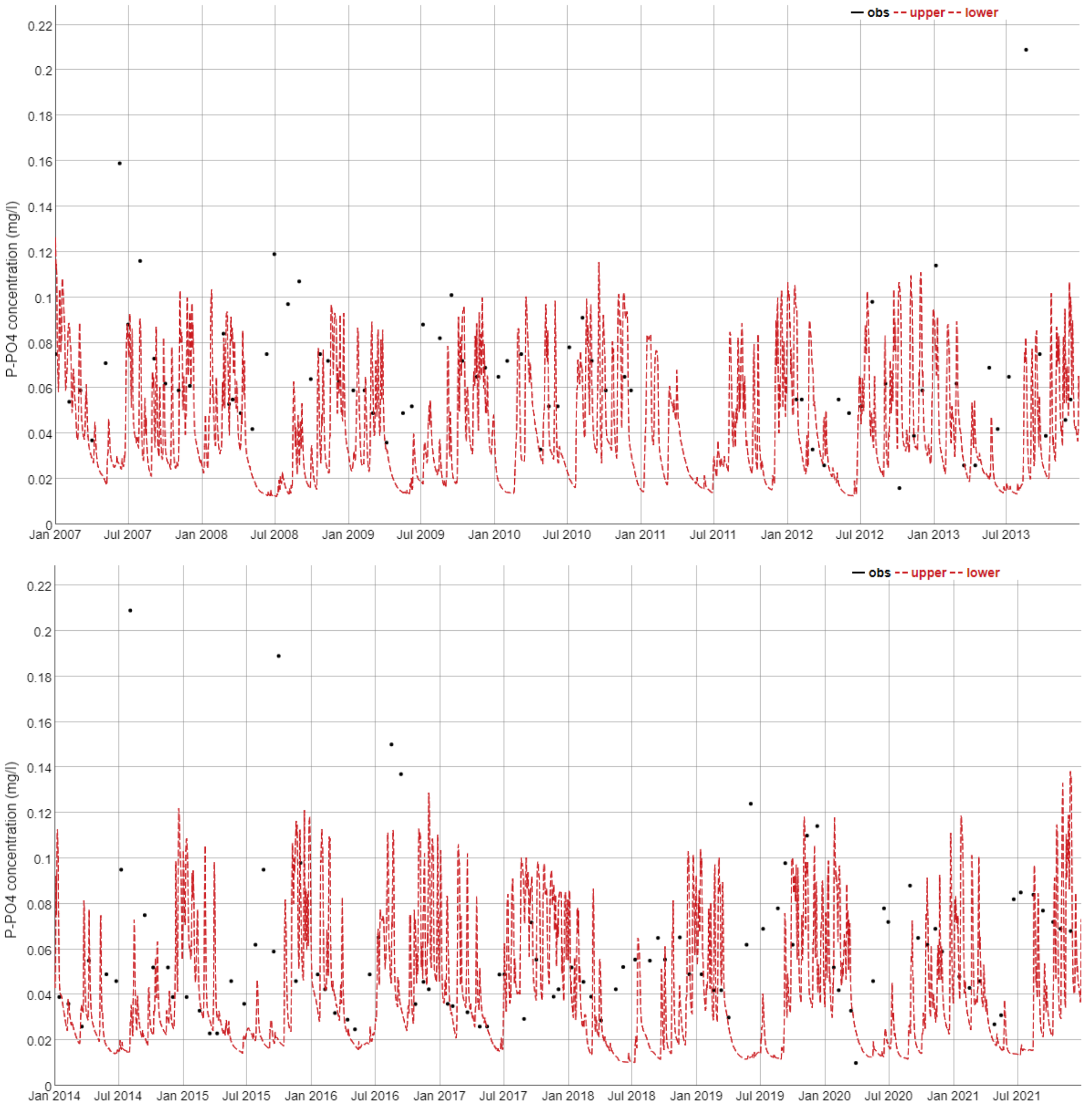

Figure 5. Observed and simulated PO_4-P concentrations at the Charnowo gauge station for the calibration period 2007-2013 (upper panel) and validation period 2014-2021 (lower panel).

Summary

In the first step of the calibration, average annual simulated and observed crop yields were matched using several parameters from the plants database. The results were mostly positive, with the exception of potato and lupin, which occupy rather small areas and, therefore, have a low impact on the results. Crop yield calibration helps fix the evapotranspiration and nutrient uptake before the water and nutrient calibration.

The SWAT+ model performance in simulating discharge can be considered very good. The model captures the flow regime variability, including high and low flow events. Słupia is a groundwater-dominated catchment with a significant number of lakes that moderate its flow regime. This feature is well represented in SWAT+. The errors can be partly attributed to a cascade of hydropower plants located in the middle section of the river that modify the flow regime to some extent, as their operation rules are unknown and not represented in the model.

SWAT+ also performs well in the simulation of nitrate-nitrogen concentration. In this case, the assessment is more challenging due to the much lower frequency of observed data than discharge (one grab sample per month). Nitrate concentrations in Słupia, as in most Polish rivers, have a seasonal distribution with a peak in winter and lowest values in summer. This feature is well represented in SWAT+. The average and the range of simulated and observed concentrations match well. However, there is a small over-estimation, particularly of the lowest concentrations. Model-based daily NO_3-N concentrations do not drop below 0.6 mg/l, while observed values can be lower than this, particularly during the validation period. It should be noted that excellent discharge calibration results, in combination with good nitrate concentration calibration results, lead to a very good match of simulated and observed loads.

The SWAT+ model does not perform as well for soluble phosphorus as nitrate nitrogen. A high underestimation bias, low correlation, and different seasonal dynamics manifest this. Since discharge calibration results were very good, monthly PO4-P loads can still be acceptable. Nevertheless, the unsatisfactory behavior of SWAT+ for phosphorus simulation requires a more in-depth assessment.

References

Piniewski, M., Strauch, M., Plunge, S., Schürz, C., Čerkasova, N., Chiaradia, E. A., Witing, F. 2024 Assessment of NSWRM effectiveness under current and future climate at the catchment scale. Deliverable D4.4 of the EU Horizon 2020 project OPTAIN. Zenodo. https://doi.org/10.5281/zenodo.11233622

Piniewski, M., Plunge, S., Kardel, I., Giełczewski, M. 2024 SWAT+ model protocol for Słupia catchment (Poland). Deliverable 4.1, Nordbalt-Ecosafe.

Plunge, S., Szabó, B., Strauch, M., Čerkasova, N., Schürz, Ch., Piniewski, M. 2024a SWAT + input data preparation in a scripted workflow: SWATprepR. Environ Sci Eur 36, 53 https://doi.org/10.1186/s12302-024-00873-1

Plunge, S., Schürz, Ch., Čerkasova, N., Strauch, M., Piniewski, M. 2024b SWAT+ model setup verification tool: SWATdoctR, Environmental Modelling & Software, Volume 171, 105878, https://doi.org/10.1016/j.envsoft.2023.105878.

Plunge, S., Piniewski, M., Schürz, C., & Strauch, M. (2024). SWAT+ model setup preparation scripted workflow (in R language). Zenodo. https://doi.org/10.5281/zenodo.12564534

Schürz, Ch., Čerkasova, N., Farkas, C., Nemes, A., Plunge, S., Strauch, M., Szabó, B., Piniewski, M. 2022 SWAT+ modeling protocol for the assessment of water and nutrient retention measures in small agricultural catchments. Zenodo. https://doi.org/10.5281/zenodo.7463395

DATE: December 2024
FOR: NORDBALT-ECOSAFE

Appendix 4: Results and comparison of the SWAT+ with the national model TEOTIL for the Hobølelva catchment in Norway

DATE: December, 2024

AUTHORS: Csilla Farkas, Moritz Shore, Mojtaba Shafiei

CITE AS: Farkas Cs., Shore M., Shafiei M. 2024. Results and comparison of the SWAT+ with the national model TEOTIL for the Hobølelva catchment in Norway.pp.11.

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Introduction

1. Catchment characteristics

The Hobølelva catchment, located in S-E Norway covers approximately half of the area of the Vansjø-Hobøl catchment (Fig. 1), which is the pilot area of implementing the WFD in Norway. The catchment area is 333 km^2. The upstream part of the Hobølelva River runs through forests and lakes (main upstream lakes being Lakes Sætertjern, Bindingsvann, Langen, Våg and Mjær). Downstream of Lake Mjær the river changes character as it enters into marine clay deposits. This lower part of the catchment covers about 186 km^2, and the river is here characterised by meanders through agricultural fields. The Kråkstadelva is the main tributary of this 186 km^2 area, which also drains agricultural fields and joins the main river some 12 km downstream of Lake Mjær. Downstream of the confluence, the Hobølelva River runs through two waterfalls; the first is called Høgfoss where there is a mill and a stage gauge, and the second is called Kurefoss, where there is a monitoring station for water quality.

The river drains into Lake Vansjø (25 m a.s.l.) covering an area of 36 km^2 with a mean depth of 7 m. In terms of floods, the Hobølelva River and Lake Vansjø are considered as parts of an interlinked system: when the water discharge in the Hobølelva River increases, the shores of Lake Vansjø often get inundated by flood water. This is mainly due to the narrow outlet of the lake. The outlet is controlled by a dam, but even when all gates of the dam are open, the narrow straits leading down to the dam slows down the water flow and cause inundation of agricultural lands upstream.

According to the monitoring station at Høgfoss, the annual runoff in the Hobølelva River at Høgfoss is 4.5 m^3/s (1977-2002), thus comprising about 40% of the water discharge into Lake Vansjø.

2. Drivers and pressures

In the Hobølelva catchment, as in most of Norway, floods typically occur during spring (snowmelt) and autumn (heavy rains). Floods can, however, also occur during summer (heavy rains) and winter (melting-freezing episodes, as well as rainstorms). The geography and hydrology of this catchment also contribute to the flood risk pressure. When the water discharge in the Hobølelva River increases, the shores of Lake Vansjø often get inundated by flood water.

Extreme storm events cause damages amounting to several million Norwegian kroner each year. In addition to agricultural runoff and soil erosion, the erosion of river banks due to floods results in a marked increase in both suspended sediment and nutrient loads (the marine clay is rich in the phosphorus-rich mineral apatite). In the last few years, clay avalanches have contributed significantly to increased suspended sediments and phosphorus in the river system (Recare Project Report, 2018)

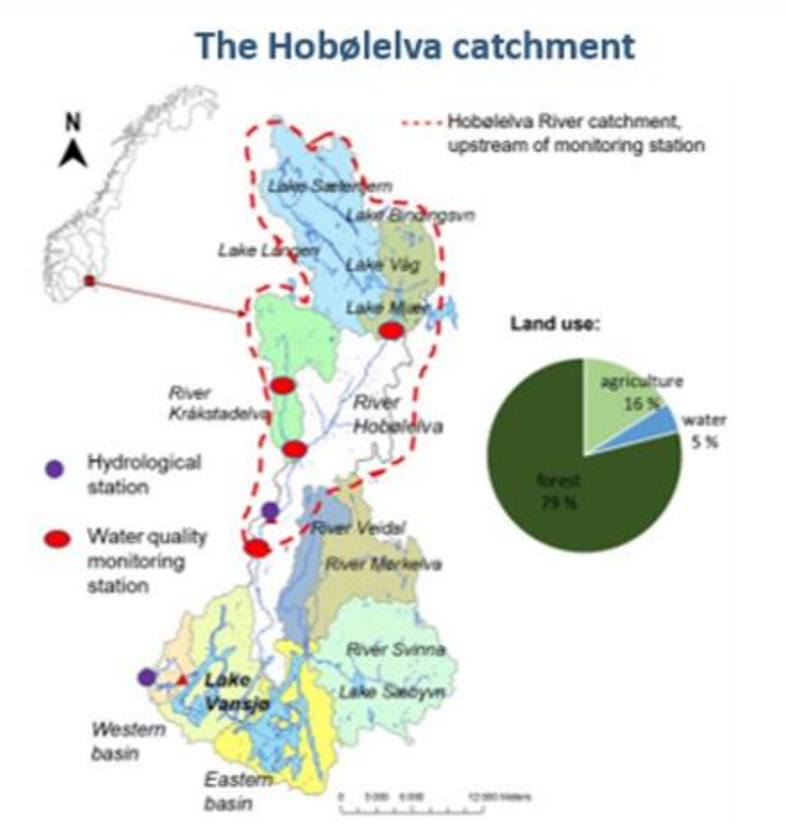

Figure 1. The Hobølelva catchment within the Vansjø-Hobøl river system

3. Model setup

The SWAT+ model was setup for the Hobølelva catchment aiming to evaluate the combined effects of climate and land use changes and nature-based solutions on surface and subsurface runoff, flood occurrence, soil erosion and water quality.

The most important nature-based solutions to be implemented in the model setup are *constructed wetlands* and *avoiding autumn tillage*. Autumn ploughing, leaving the soil surface unprotected during the winter season highly contributes to soil structural degradation and soil erosion. Field-scale experiments within the study region indicate, that soil losses, occurring during the winter period due to freezing-thawing can be reduced approximately four times if shifting from winter crops to summer crops and leaving stubble on the soil surface during the winter period.

Apart of the above-mentioned measures, buffer strips, grassed waterways, sedimentation ponds in the forested areas, grass cover in flood-prone areas and reduced fertilization are also relevant within the study area.

The SWAT+ model was set up using in QGIS v. 3.22.11. The type and the source of the input data are described below. Figure 2 demonstrates the GIS layers processed for setting up the model.

Code versions used

Code	Version number	Availability
QGIS	3.28.15	QGIS used as a basis for running the QSWAT+ plugin. In this project, the latest long-term 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-3.28.15-1.msi
SWAT+ (core model)	61.0.64	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)	2.4.7	Code and official installer releases (including v2.1.8) are available here: https://bitbucket.org/ChrisWGeorge/qswatplus3/downloads/
Miljøtools Handling MetNordic	0.3.2	R-package for downloading the Met Norway re-analyses dataset https://moritzshore.github.io/miljotools/
SWAT+ Editor (interface)	2.3.3	Code and official installer releases (including v2.3.3.) are available here: https://bitbucket.org/swatplus/swatplus.editor/downloads/ Direct link: https://plus.swat.tamu.edu/downloads/2.3/2.3.3/editor/swatplus.editor-2.3.3c-windows.zip
SWAT+ Toolbox (calibration tool)	1.0.5	Sensitivity and calibration tool for SWAT+. Installers for the public releases is available here: https://swat.tamu.edu/media/3u4bhkyo/swatplus-toolbox-v105-installer.zip Source code for the SWAT+ Toolbox is available through github: https://github.com/OpenWaterNetwork/SWATPlus-Toolbox
SWATprepR (model input preparation tool)	1.0.4	R-package for preparing input data for the SWAT+ model. https://biopsichas.github.io/SWATprepR/
SWATdoctR (model verification tool)	1.0	SWATdoctR is a collection of functions and routines for SWAT model calibation and model diagnostics and was applied for model verification and soft calibration of the hydrological routines. https://git.ufz.de/schuerz/swatdoctr
SWATrunR (calibration tool)	0.1.3	R-package developed for hard calibration of the SWAT+ model https://chrisschuerz.github.io/SWATrunR/

Weather input data used

Data	Temporal resolution	Spatial resolution	Availability
Precipitation	daily	1 x 1 km grid	https://moritzshore.github.io/miljotools/articles/metno_reanal.html The MET Nordic dataset of the Norwegian Meteorological Institute consists of post-processed products that (a) describe the current and past weather (analyses), and (b) give our best estimate of the weather in the future (forecasts). The products integrate output from MetCoOp Ensemble Prediction System (MEPS) as well as measurements from various observational sources, including crowdsourced weather stations.
Min. and max air temperature	daily	1 x 1 km grid	
Relative humidity	daily	1 x 1 km grid	
Radiation	daily	1 x 1 km grid	

GIS input data used

Data	Map	Resolution	Availability
DEM	The Norwegian Mapping Authority (karverket.no)	10 m	https://hoydedata.no/
Landuse	Norwegian Institute of Bioeconomy Research (NIBIO)	50 m	AR50 Land cover data, Scale: 1:50000
Soil	NIBIO and the Geological Survey of Norway (NGU)	1 km	Raw vector layer of soil types for agricultural areas (Jordsmonn, NIBIO) and soil forming materials, derived from the geological map of Norway (Løsmasser, NGU) for the forested areas.
Lakes	World Lake Database	Not relevant	https://wldb.ilec.or.jp/
River	Norwegian Water and Energy Directorate (NVE)	Not relevant	Catchment boundaries and stream network https://nedlasting.nve.no/gis/ and https://nevina.nve.no/

Stream data used for calibration

Data	Temporal resolution	Spatial resolution	Availability
Stream discharge	Daily	Provided from individual gauge stations	https://vannmiljo.miljodirektoratet.no/
Suspended sediments (SS), Total nitrogen (TN) and total phosphorus (TP)	Monthly or be-weekly	Provided from individual gauge stations	https://vannmiljo.miljodirektoratet.no/

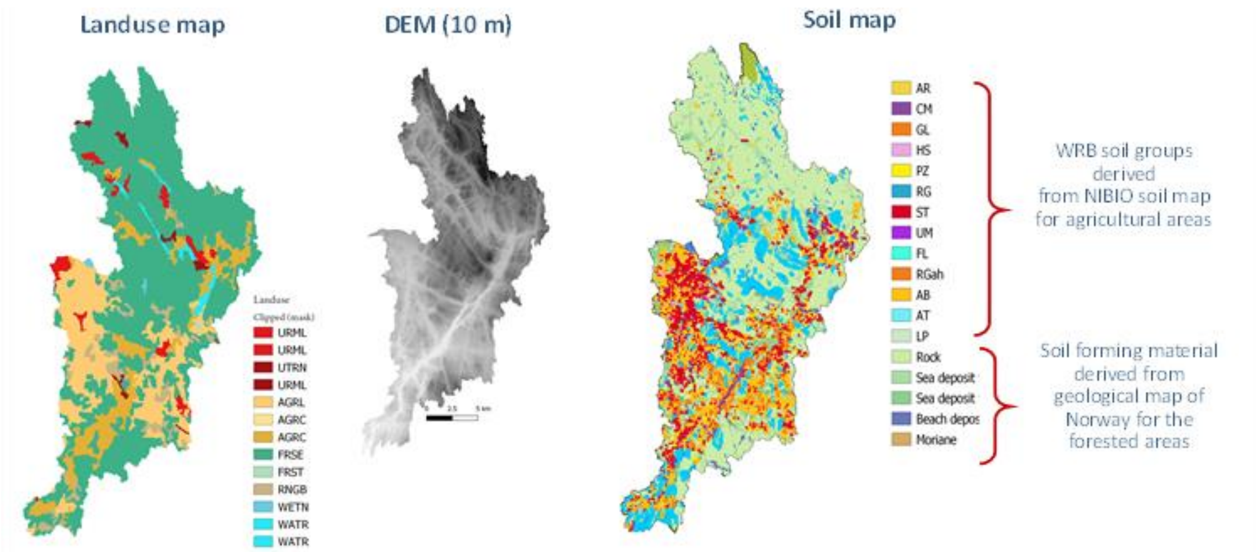

Figure 2. GIS input data used for setting up the SWAT+ project in QGIS for Hobølelva

Description of national model TEOTIL

TEOTIL3 (Sample et al., 2024), developed by NIVA, is a national scale model for calculating source-apportioned nutrient inputs from rivers and direct inputs to the coast of Norway. The model estimates annual (calendar year) water discharge and loads of suspended sediment (SS), total organic carbon (TOC), total phosphorus (TOTP), dissolved total phosphorus (TDP), total particulate phosphorus (TPP), total nitrogen (TOTN), dissolved inorganic nitrogen (DIN) and totalt organic nitrogen (TON). Contributions from the following sources are considered: natural areas like forests, mountains and glaciers, atmospheric deposition, urban areas, small and large wastewater treatment plants, industry, aquaculture and agriculture. The controbutions from agriculture are calculated in a separate model, AGRITIL (Kværnø et al., 2024), developed by NIBIO. The predeccessor models TEOTIL2 and JOVAest, replaced by TEOTIL3 and AGRITIL from 2023, are run on annual basis to provide results for previous year for the annual reporting to OSPAR Commission.

Model calculations are performed at the spatial resolution of NVE's "REGINE" catchment network, and the loads are routed between the catchments according to the catchment hierarchy. Retention of nutrients in lakes is included in the calculations. All input data to the TEOTIL3 and AGRITIL models are from official national databases and maps. The spatial resolution of the data sources vary: Several data sources are available at the (sub-)REGINE scale, other at lower resolution, e.g. municipality level for small wastewater treatment plants, crop distribution and livestock numbers, and county/regional/national scale for yields and mineral fertilizer amounts. The model results should therefore not be presented indiscriminately at REGINE scale, but rather for larger units.

For comparison with the SWAT+ model, the output from SWAT+ needs to be aggregated to the annual time step, as TEOTIL3 provides data for the annual temporal scale only. Currently, results from TEOTIL3 are available for the years 2013-2022, so the comparison of the two models was performed for this period.

Calibration and validation

A short description of the variables that are calibrated and validated

- Model warmup: 2012-2013
- Calibration period: 2014-2017
- Validation period: 2018-2020

Table 1 Parameters chosen for N calibration.

Parameter	Change type	Value min	Value max	Average value
n_updis.bsn	absval	10	80	4.466
nperco.bsn	absval	0.2	1	0.513
sdnco.bsn	absval	0.75	0.9	0.832
hlife_n.aqu	absval	0	200	134.118
no3_init.aqu	absval	0	30	29.000
cmn.bsn	absval	0.001	0.0015	0.001289
rsdco.bsn	absval	0.02	0.15	0.020529

Table 2 Parameters chosen for SS calibration.

Parameter	Change type	Value min	Value max	Average value
cov.rte	absval	0.005	1	0.40117
bedldcoef.rte	absval	0.01	1	0.07838
cherod.rte	absval	0.05	1	0.73545

Table 3 Parameters chosen for P calibration.

Parameter	Change type	Value min	Value max	Average value

Does not make sense without proper sediment calibration

Table 4 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 5 Performance of SWAT+ model (N, SS and P)

Objective function	Calibration			Validation		
	Q	TN	SS	Q	TN	SS
R^2	0.64	0.76	NA	0.32	0.38	NA
NSE	0.53	0.80	NA	0.31	0.38	NA
KGE	0.75	0.83	NA	0.66	0.31	NA
PBIAS	-4.9	-10.8	NA	-4.4	-9.2	NA

Results

Figures 3. and 4. demonstrate the relationship between the different indicators, calculated with the SWAT+ and TEOTIL models for the outlet of the Vansjø watershed. Please, note, that no flow and concentration data were provided from the national model for evaluation.

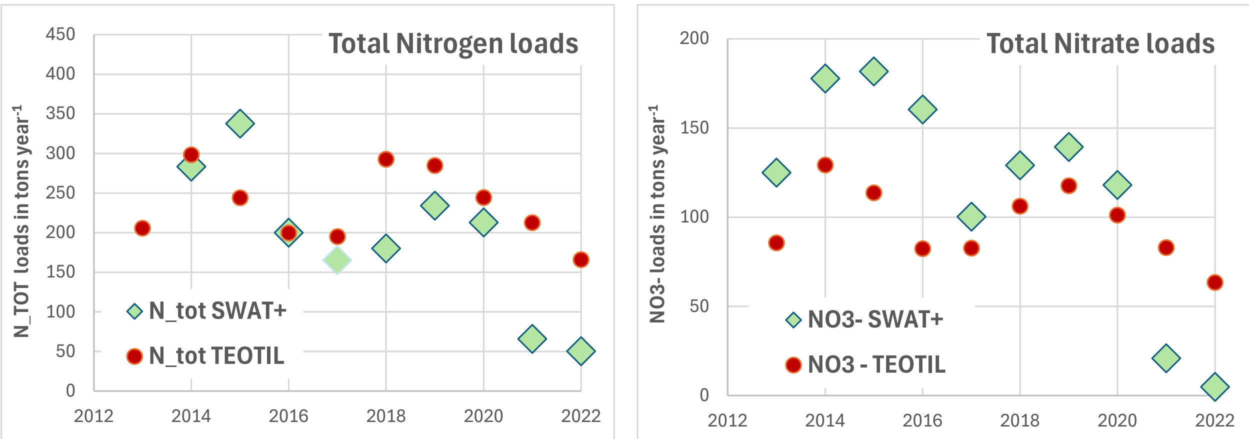

Figure 3. Comparison of yearly total Nitrogen (left) and Nitrate (right) loads simulated with SWAT+ and calculated with the TEOTIL model

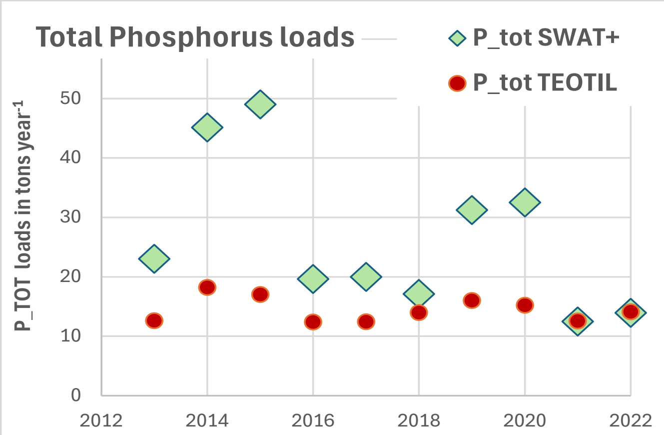

Figure 4. Comparison of yearly total Phosphorus loads simulated with SWAT+ and calculated with the TEOTIL model. Note, that the SWAT+ model calibration for total P is not yet verified.

Table 6. Determination coefficients (R^2) indicating the relationship between four various variables calculated with SWAT+ and TEOTIL models

	NO3-	TN	TP	Sed
R^2	0.60	0.53	0.76	0.60

Note, that the SWAT+ model calibration for total P and sediment loads is not yet verified.

Summary

In this report we describe he progress in setting up and calibrating the SWAT+ hydro-geochemical model for the Hobølelva catchment in Norway. We also present results on the comparison of nitrogen and phosphorus loads, simulated by the SWAT+ model with those, calculated by the Norwegian national model TEOTIL3. As the national model provides data in annual resolution so far for years from 2013 and 2022, the comparison for each variable – total N and P loads and nitrate and sediment loads – was based on 10 values by aggregating the SWAT+ daily output on annual level.

The calibration of the SWAT+ model for discharge and total nitrogen loads was good and satisfactory, respectively. Further efforts are needed to perform model calibration for sediment and phosphorus loads, as the SWAT+ model is relatively new and has not been extensively tested for these components.

When comparing the outputs of the SWAT+ and TEOTIL models we concluded, that the nitrogen and nitrate values are comperable and show, for some years, rather similar dynamics. The comparison of the phosphorus loads should be carefully interpreted as the SWAT+ model has not been successfully calibrated for phosphorus yet.

By analysing the differences between the values, calculated by the two models we will have an opportunity to find the weaknesses and possibly give recommendations on how to improve the calculations withi the national TEOTIL model for ceral production areas of Norway.

References

EEA. 2018. CORINE Land Cover (CLC), © European Union, Copernicus Land Monitoring Service 2018, European Environment Agency (EEA), https://land.copernicus.eu/pan-european/corine-land-cover.

Kværnø, S.H., Fischer, F.K., Bechmann, M. 2024. **AGRITIL** - Nutrient loss model for agriculture: Modelling soil, organic carbon, nitrogen and phosphorus losses from Norwegian agricultural areas to surface water. NIBIO Report, Vol. 10, No. 43.

Moriasi, D.N., Gitau, M.W, Pai, N., and Daggupati, P. 2015. Hydrologic and Water Quality Models: Performance Measures and Evaluation Criteria. Transactions of the ASABE. 58(6): 1763-1785. doi: 10.13031/trans.58.10715.

Sample, J.E., Jackson-Blake, L., Vogelsang, C., Kaste, Ø. 2024. **TEOTIL3**: a model for calculating source-apportioned nutrient inputs from rivers and direct inputs to the coast. NIVA 7996/2024. (in Norwegian)

DATE: December 2024
FOR: NORDBALT ECOSAFE

Appendix 5: Results and comparison of the SWAT+ (Nordbalt-Ecosafe) with the SWAT+ (National model) for the Berze River Catchment, Latvia

DATE: December 2024

AUTHORS: Arturs Veinbergs, Ieva Siksnane, Kaspars Abramenko, Ainis Lagzdins

CITE AS: Veinbergs A., Siksnane I., Abramenko K., Lagzdins A. 2024. Results and comparison of the SWAT+ (Nordbalt-Ecosafe) with the SWAT+ (National model) for the Berze River Catchment, Latvia, 13 p.

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Introduction

Catchment characteristics

The catchment of the Berze River is located in the central part of Latvia. The Berze River is a tributary of the Svete River, which further inflows into the Lielupe River. The length of the river is 117 km, the catchment area is 882.8 km^2, the stream gradient is 1 m/km. The largest tributaries on the left bank are Bikstupe (32 km) and Licupe (14 km), while on the right bank Alave (24 km), Sesava (24 km) and Gardene (17 km). The hydrological regime of the river is affected by the dams constructed to ensure operation of four small hydroelectric power plants. The catchment is located in the Lielupe River basin district, which is designed according to the EU Water Framework Directive, the largest part of the catchment is located within the Nitrate Vulnerable Zones designed according to the EU Nitrates Directive. The catchment area is divided into 15 subbasins, which are different in size and land use patterns (Figure 1). Implementation of targeted water quality monitoring activities provides with necessary data sets to assess the effects of dominant land use on water quality in each of 15 subbasins. For example, the effects of agricultural areas and forested and semi-natural areas can be assessed in the subbasins No. 7, 8, 14 and subbasins No. 1, 4, 11, respectively. Meanwhile, in the subbasins No. 9 and 12 the impact of the city of Dobele on water quality can be determined (Figure 1).

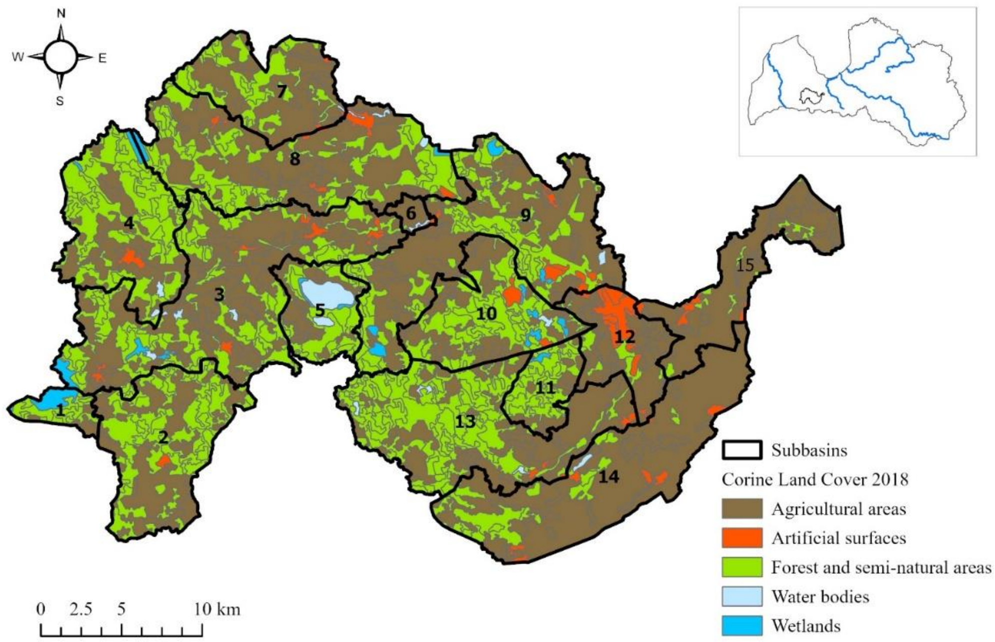

Figure 1. Subbasins and land use of the Berze River catchment.

The upstream part of the Berze River catchment and respective subbasins are situated in the landscape with relatively higher altitudes and steeper slopes, which limits agricultural activities and increase water flow velocity in this part of the Berze River and its main tributaries. In contrast, the downstream part of the catchment is relatively flat and favorable for agricultural activities, therefore, in this part most of the agricultural land is artificially drained with subsurface and surface drainage systems (Figure 2). The section of the Berze River close to the mouth is dammed in the length of approximately 7 km to mitigate flood risks in surrounding areas.

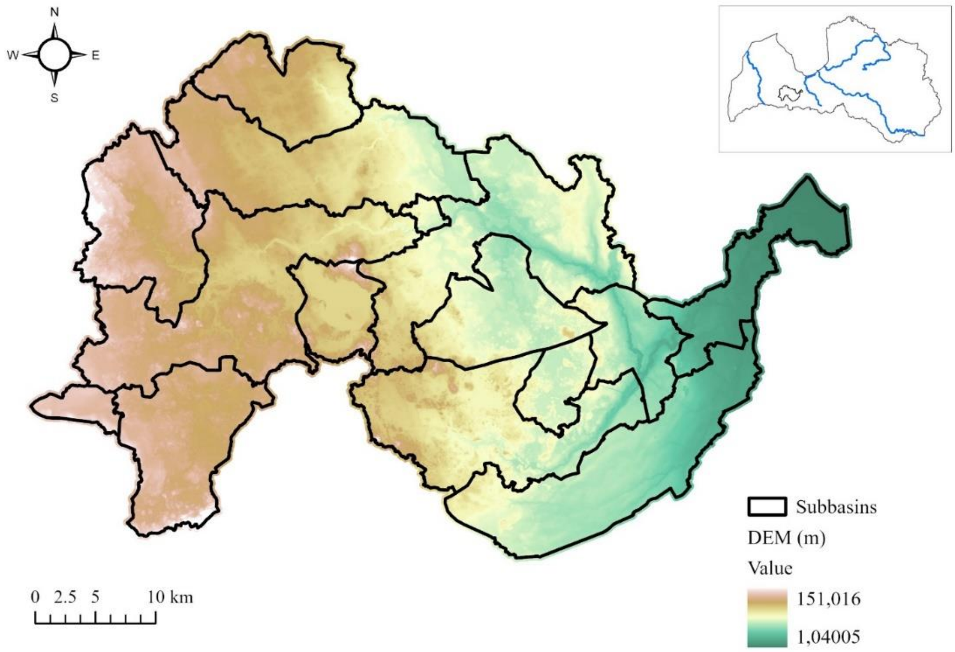

Figure 2. The digital elevation model of the Berze River catchment.

Water quality monitoring activities are carried out at 15 locations on a monthly basis using a grab sampling approach since 2005 (Figure 3). Water samples are analyzed in an accredited laboratory for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), total nitrogen (TN), orthophosphate phosphorus (PO_4-P), and total phosphorus (TP) concentrations. One stream gauging station (Berze-Balozi) is located at the outlet of the Berze River, which provides the data on daily discharge.

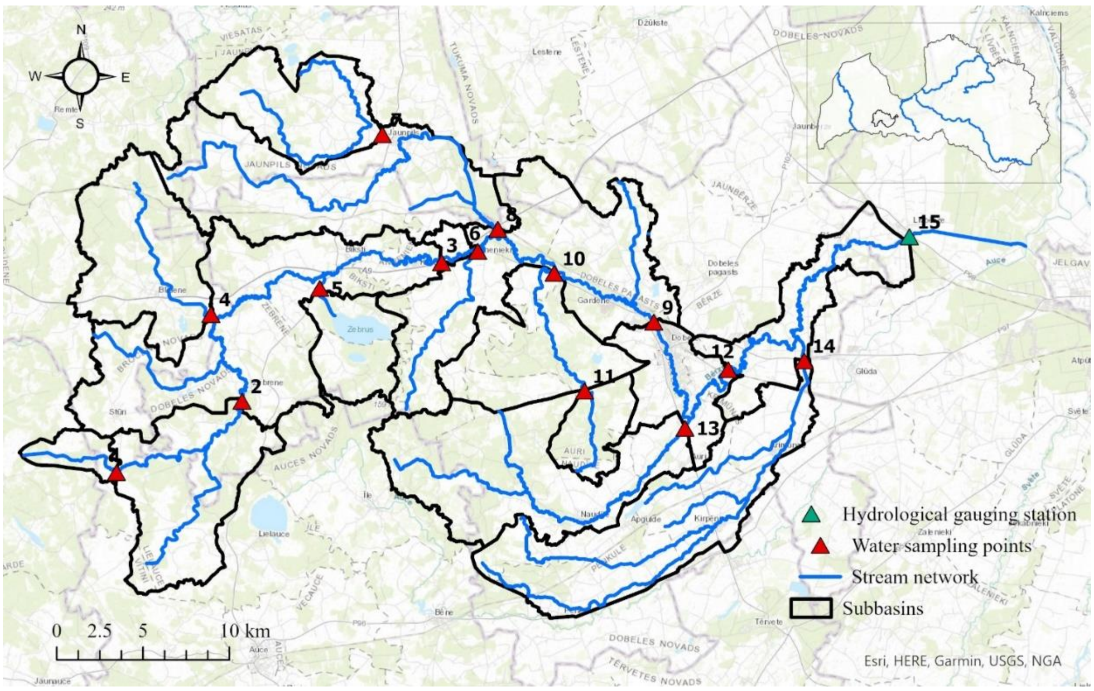

Figure 3. Subbasins, streams, water sampling points and hydrological gauging station of the Berze River catchment.

Pressures

The results of the Agricultural Runoff Monitoring programme representing the time period from 2005 to 2024 show increased average concentrations of total nitrogen in 11 subbasins and ammonium nitrogen in 4 subbasins. In these subbasins average concentrations of total nitrogen and ammonium nitrogen exceed the threshold values determined for good ecological status according the criteria defined to the EU Water Framework Directive (2000/60/EC). The latest Lielupe River Basin Management Plan (2022-2027) reports that the chemical status of water in the waterbody of L109DA Bērze_4, which is the downstream part of the Berze River catchment, is moderate mainly due to high average concentration of total nitrogen (3.85 mg l^{-1}). Overall, in the water body of L109DA Bērze_4 significant pressures have been identified from diffuse sources and hydromorphological alterations. In the middle part of the Berze River catchment the chemical status of water in the waterbody of L111DA Bērze_3 is evaluated as moderate as well mainly due to high average concentration of total nitrogen (3.44 mg l^{-1}).

Model setup

The SWAT+ model was setup for the Berze River catchment in order to simulate discharge and nutrient concentrations and loads as affected by natural factors, e.g., topography, stream network, soils, weather conditions, and anthropogenic factors, e.g., agricultural and forestry activities, drainage systems, wastewater treatment plants. Additionally, SWAT+ model is applied to simulate the effects of field, transport and in-stream mitigation measures aiming to reduce nutrient losses. In Latvia, the most relevant field mitigation measures are catch crops and reduced fertilizer use, buffer strips with grass as a transport mitigation measure, and constructed wetlands as an in-stream mitigation measure.

Code versions used

Code	**Version number**	**Availability**
QGIS	3.28.2	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://download.qgis.org/downloads/QGIS-OSGeo4W-3.28.2-1.msi
SWAT+ (core model)	60.5.7	Official code releases are available here: https://swatplus.gitbook.io/docs/installation
QSWAT+ (interface)	2.4.0	Code and official installer releases are available here: https://swatplus.gitbook.io/docs/installation
SWAT+ Editor (interface)	2.3.0	Code and official installer releases are available here: https://github.com/swat-model/swatplus-editor/releases

Weather input data used

Data	**Temporal resolution**	**Spatial resolution**	**Availability**
Precipitation	Hourly (resampled to daily)	Provided from individual meteorological station located in the Dobele City	Provided by State Limited Liability Company “Latvian Environment, Geology and Meteorology Centre”.

Min. and max air temperature	Hourly (resampled to daily)	Provided from individual meteorological station located in the Dobele City	Provided by State Limited Liability Company “Latvian Environment, Geology and Meteorology Centre”.
Relative humidity	Hourly (resampled to daily)	Provided from individual meteorological station located in the Dobele City	Provided by State Limited Liability Company “Latvian Environment, Geology and Meteorology Centre”.
Wind speed	Hourly (resampled to daily)	Provided from individual meteorological station located in the Dobele City	Provided by State Limited Liability Company “Latvian Environment, Geology and Meteorology Centre”.
Radiation	Hourly (resampled to daily)	Provided from individual meteorological station located in the Dobele City	Provided by State Limited Liability Company “Latvian Environment, Geology and Meteorology Centre”.

GIS input data used

Data	**Map**	**Resolution**	**Availability**
DEM	DEM	5m raster	Raster map from the national model with the resolution of 5x5 m.
Landuse	Corine	Vector (shapefile)	The CORINE Land Cover (CLC) inventory from 2018 was downloaded from https://land.copernicus.eu/en/products/corine-land-cover/clc2018
Landuse	Crops	Vector (shapefile)	The map of agricultural field blocks provided by the Rural Support Service of the Republic of Latvia. The map was applied for determination of the share of crops in agricultural fields.
Landuse	Drainage	Vector (shapefile)	The map of Digital Drainage Cadastre provided by State Limited Liability Company “Real Estates of Ministry of Agriculture”. The map was applied for determination of the share of subsurface drainage systems in agricultural fields.
Soils	Soils	Vector (shapefile)	Vector map from the national model.
Lakes	Lakes	Vector (shapefile)	Vector map provided by the State Limited Liability Company “Latvian Environment, Geology and Meteorology Centre”.
Rivers	Rivers	Vector (shapefile)	The map of Digital Drainage Cadastre provided by State Limited Liability Company “Real Estates of Ministry of Agriculture”. The map was applied to represent the streams of national significance.
Outlets	Outlets	Vector (shapefile)	Manually marked considering the locations of water sampling sites.

Stream data used for calibration

Data	Temporal resolution	Spatial resolution	Availability
Stream discharge	Daily	One gauging station (Berze-Balozi)	Provided by State Limited Liability Company "Latvian Environment, Geology and Meteorology Centre".
Nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), total nitrogen (TN), orthophosphate phosphorus (PO_4-P), total phosphorus (TP)	Monthly	The outlets of 15 subbasins	The Agricultural Runoff Monitoring carried out by Latvia University of Life Sciences and Technologies

Description of national Model

SWAT+ model (National model) is a national scale model that has been developed by the PAIC (Limited liability company "Center of processes´ analysis and research") within the LIFE GoodWater IP project (https://goodwater.lv/en/) and is planned to be applied in the process of elaboration of upcoming River Basin Management Plans in Latvia. The modelling system is based on SWAT+ model, Python 3 programming language, and open access GIS systems, databases and libraries.

The following software has been applied for the modelling system:

- Database: PostgreSQL version 13.1-1 or later with spatial extension PostGIS version 3.0.3 or later for Windows-x64 is required for storing all modelling system.
- Python 3.8.6: WinPython64-3.8.6.0cod.exe portable distribution of the Python programming language for Windows-x64 is used for all the scripts forming the modelling system.
- Geospatial information system QGIS with GDAL libraries for operations with geospatial data is used.
- SWAT+ version rev. 60.5.4 released on 13-Apr-2022.
- SWAT+ Editor v 2.0.1 source code (PAIC, 2022).

SWAT+ model (National model) is capable to simulate discharge, concentrations of nitrate nitrogen, ammonium nitrogen, organic nitrogen, orthophosphate phosphorus, organic phosphorus, suspended sediment, biochemical oxygen demand, dissolved oxygen at multiple spatial and temporal scales. The calibration and validation of the model is performed on a regional scale.

The Berze River catchment is represented in the national model with three water sampling sites, where water samples are collected occasionally on a campaign basis and one gauging station with daily discharge measurements. The modeling time period for the national model is from 2006 to 2018. The modeling results presented in this report are relevant for the outlet of the Berze River catchment. The screenshot of the national model is presented in Figure 4.

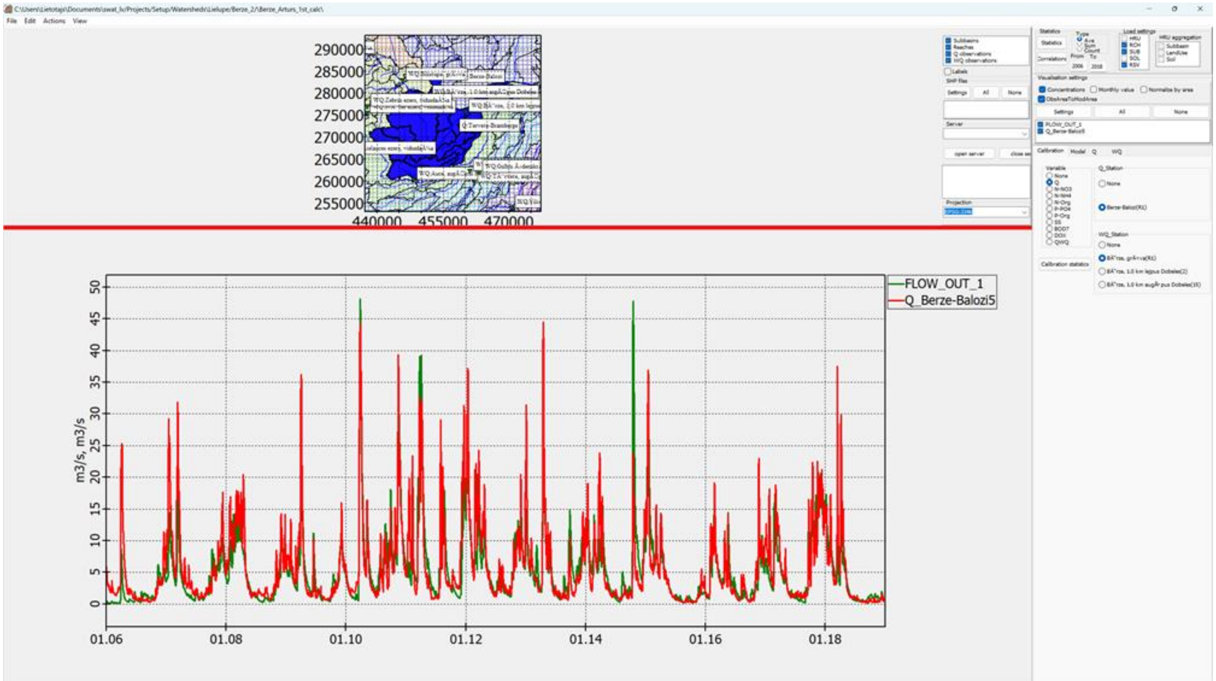

Figure 4. The screenshot of the SWAT+ (National model) – observed and simulated discharge at the outlet of the Berze River catchment.

Calibration and validation

- Model warmup: January 1, 2005 - December 31, 2007 (three years)
- Calibration: January 1, 2010 - December 31, 2018 (nine years)
- Validation: January 1, 2008 - December 31, 2009 (two years) and January 1, 2019 - December 31, 2020 (two years)

Table 1 Parameters chosen for N calibration.

Parameter	Change type	Value min	Value max	Average value
hlno3n	absval	0	60	40
nperco_lchtile.bsn	absval	0.4	0.7	0.7
Nitrate.soil	absval	10	105	80
n_uptake.bsn		15	30	30

Table 2 Parameters chosen for SS calibration.

Parameter	Change type	Value min	Value max	Average value
SS has not yet been calibrated due to lack of observed data				

Table 3 Parameters chosen for P calibration.

Parameter	Change type	Value min	Value max	Average value
Lab_p.soil	absval	1.0	1.7	1.3

expo_co.soil	absval	0.00009	0.00093	0.00093
p_uptake.bsn	absval	15	25	25

Table 4 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 5 Performance of SWAT+ model (Q, NO_3-N, SS and PO_4-P)

Objective function	Calibration				Validation (2008-2009)			
	Q*	NO_3-N**	SS	PO_4-P**	Q*	NO_3-N**	SS	PO_4-P**
R^2	0.68	0.02	NA	0.02	0.75	0.15	NA	0.00
NSE	0.61	-1.23	NA	-16.81	0.67	-0.33	NA	-2.67
PBIAS (%)	9.73	-77.32	NA	52.48	-16.66	-47.86	NA	-51.16

*Daily time step
**Montly time step

Results

Flow

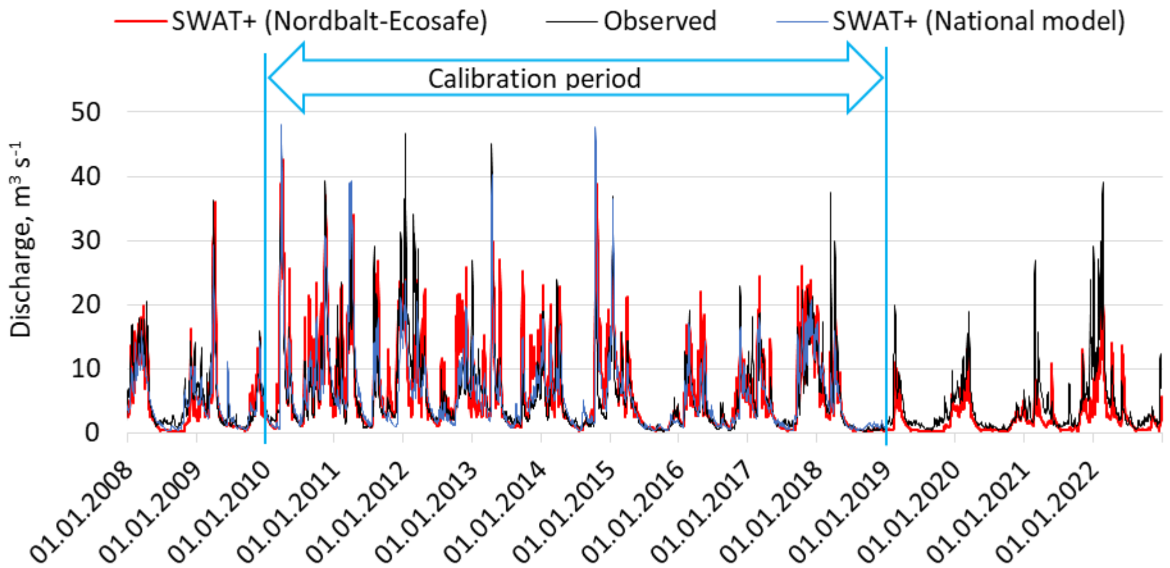

Figure 5. Observed and calibrated discharge along with the data from the national model. A light blue vertical line separates calibration and validation periods.

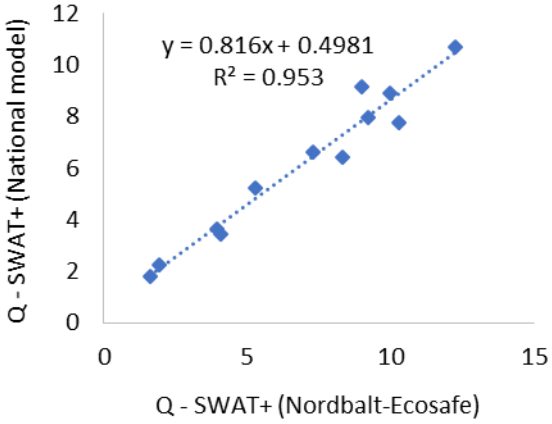

Figure 6. The comparison of simulated discharge: SWAT+ (Nordbalt-Ecosafe) vs. SWAT+ (National model).

N (concentration)

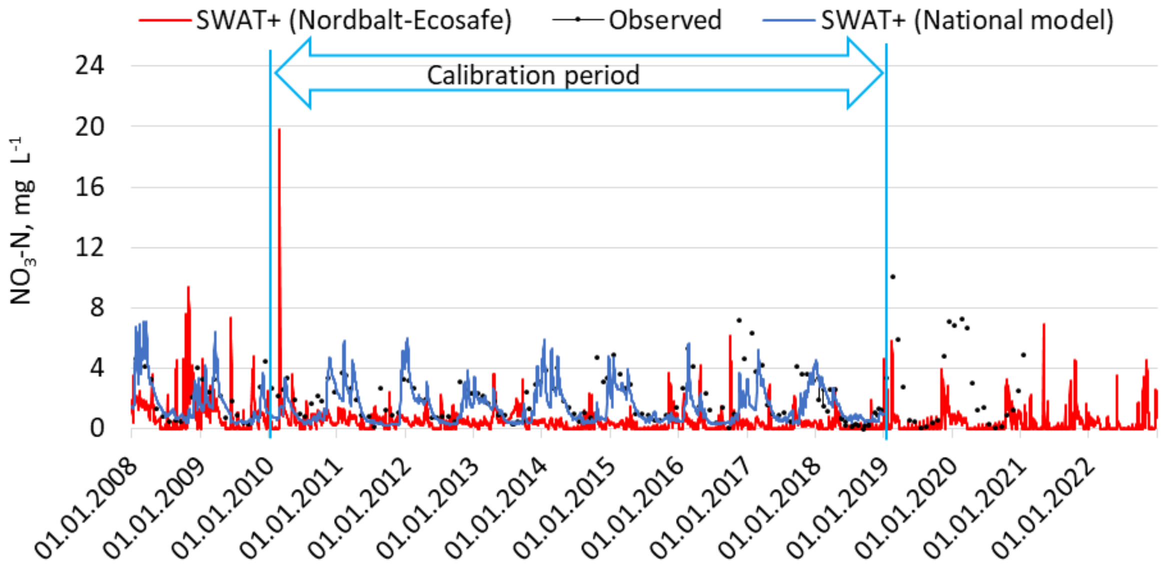

Figure 7. Observed and calibrated NO_3-N along with the data from the national model. A light blue vertical line separates calibration and validation periods.

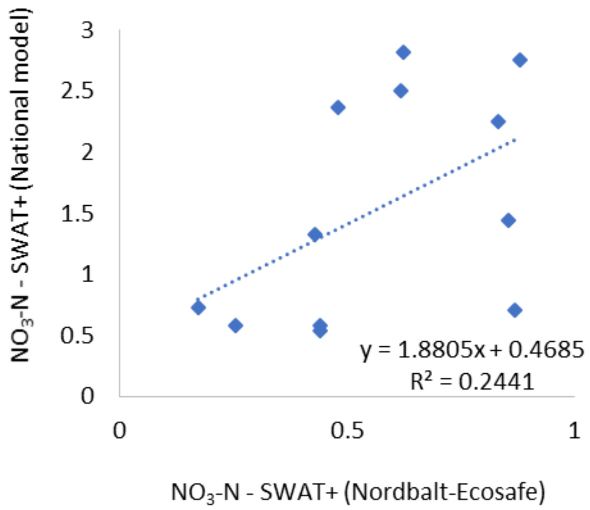

Figure 8. The comparison of simulated NO_3-N concentrations: SWAT+ (Nordbalt-Ecosafe) vs. SWAT+ (National model).

SS (concentration)

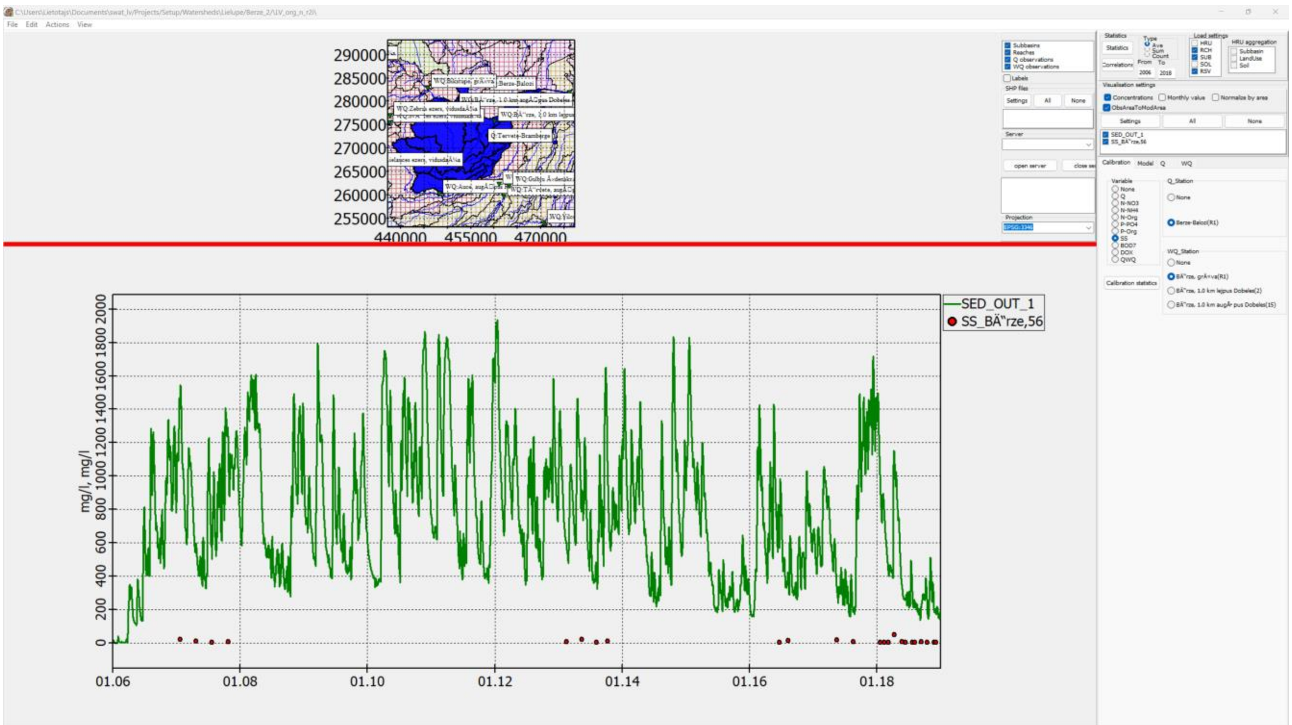

Figure 9. The screenshot of the SWAT+ (National model) – observed and simulated SS at the outlet of the Berze River catchment.

P (concentration)

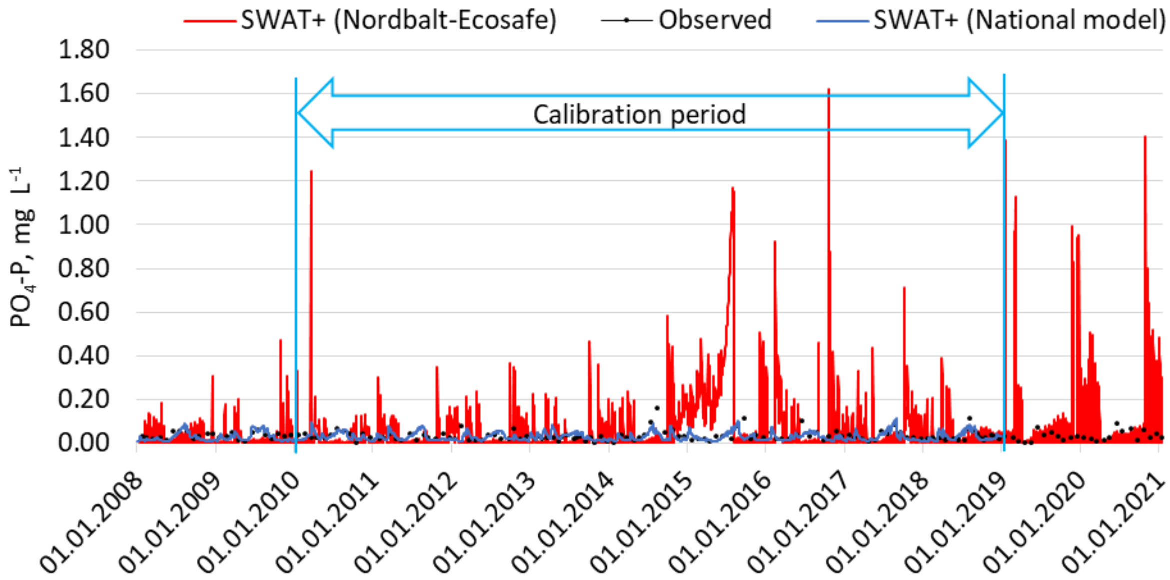

Figure 10. Observed and calibrated PO_4-P along with the data from the national model. A light blue vertical line separates the calibration and validation periods

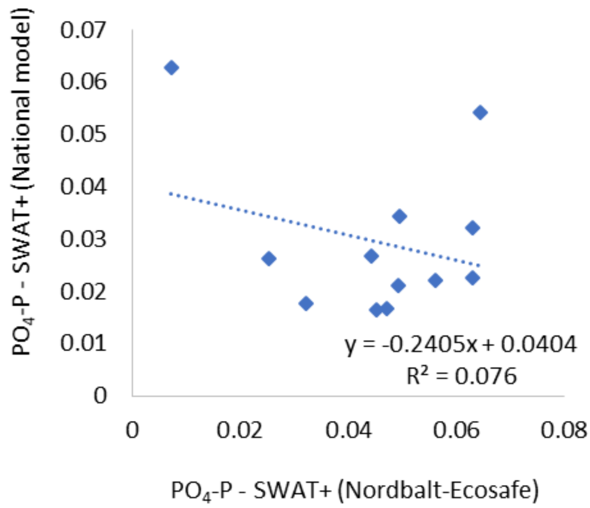

Figure 11. The comparison of simulated PO_4-P concentrations: SWAT+ (Nordbalt-Ecosafe) vs. SWAT+ (National model).

Summary

SWAT+ (Nordbalt-Ecosafe) has more detailed setup including representation of streams, ditches, subsurface drainage systems, agricultural activities (crop distribution and rotation, fertilizer application, yield) rather than SWAT+ (National model), which allows to implement field, transport and in-stream mitigation measures in SWAT+ (Nordbalt-Ecosafe) setup and evalutate their performance in improving water quality.

The calibration and validation of water quality parametrs of interest in SWAT+ (Nordbalt-Ecosafe), e.g. nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), total nitrogen (TN), orthophosphate phosphorus (PO_4-P), and total phosphorus (TP) concentrations and loads, has been done based on the results of water quality monitoring activities carried out on a monthly basis at 15 sites (subbasins), while in SWAT+ (National model) water quality parameters have been calibrated and validated based on the results collected occasionaly on a campaign basis at 3 sites. Both models for calibration and validation purposes applied the same results of observed discharge representing one gauging station located at the outlet of the Berze River catchment. Discharge and water quality parametrs in SWAT+ (National model) has been calibrated on a regional scale using the observed data from a few selected basins and then transferred to other basins on a regional basis, while in SWAT+ (Nordbalt-Ecosafe) calibration of discharge and water quality parametrs has been done on basin and subbasin scale, respecitvely.

Overall, the discharge simulated by both models show good agreement. Of note, the personnel of LBTU have been involved in calibration of discharge simultaneously for both models allowing to tranfer best knowledge and results to improve performance of both models. The results of both models representing nitrogen, phosphorus and suspended sediment concentrations and loads need further assessment and calibration, especially as it comes to phosphorus and suspended sediment.

References

EEA, 2018. CORINE Land Cover (CLC), © European Union, Copernicus Land Monitoring Service 2018, European Environment Agency (EEA), https://land.copernicus.eu/pan-european/corine-land-cover.

Moriasi, D.N., Gitau, M.W, Pai, N., and Daggupati, P, 2015. Hydrologic and Water Quality Models: Performance Measures and Evaluation Criteria. Transactions of the ASABE. 58(6): 1763-1785. doi: 10.13031/trans.58.10715.

PAIC, 2022. CALIBRATED AND VALIDATED MODELLING SYSTEM. LIFE GoodWater IP, Rīga, 47 p.

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Appendix 6: Results and comparison of the SWAT+ with the national model for Örsundaån, Sweden

DATE: December 2024

AUTHORS: Kristina Mårtensson

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Introduction

This model set up is a part of WP4 in the NordBalt-Ecosafe project.

The Swedish case study catchment is called Örsundaån, located in the vicinity of Uppsala with its outlet draining into Lake Alstasjön and later into Lake Mälaren, Sweden's fourth largest lake. The catchment is 736 km^2, with a large proportion of agricultural land (36%). Several of the streams and the main river in the catchment (Örsundaån) have a mean phosphorus (P) concentration of 0.15 mg/L and mean nitrogen (N) concentration of 1.76 mg/L at the outlet (Sandström et al., 2024), where P is the main nutrient contributing to eutrophication problems. There is an active Water Council around the main river consisting of farmers, stakeholders and other people who own land connected to and affecting the water quality in the river. There is also active catchment officers working with the farmers in the area with mitigation measures against nutrient losses. For comparison with the national model one of the subcatcatchments was selected, catchment C6 and subid 7319 in S-HYPE, respectively.

This work was started by Sara Sandström and after her parental leave in May 2024 Kristina Mårtensson is continuing the work.

Code versions used

Code	Version number	Availability
QGIS	3.34. 5	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://download.qgis.org/downloads/QGIS-OSGeo4W-3.34.5-1.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)	2.4.7	Code and official installer releases are available here: https://bitbucket.org/ChrisWGeorge/qswatplus3/downloads/
SWAT+ Editor (interface)	2.3.3	Code and official installer releases are available here: https://bitbucket.org/swatplus/swatplus.editor/downloads/
SWAT+ Toolbox (calibration tool)	1.3.0.0	Sensitivity and calibration tool for SWAT+. Installers for the public releases is available here: https://swat.tamu.edu/software/plus/ Source code for the SWAT+ Toolbox is available through github: https://github.com/OpenWaterNetwork/SWATPlus-Toolbox

Weather input data used

Data	Temporal resolution	Spatial resolution	Availability
Precipitation	Daily	5 stations	Data downloaded through the Swedish Meterological and Hydrological Institute (SMHI). https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer#param=precipitationHourlySum,stations=core
Min. and max air temperature	Daily	5 stations	Data downloaded through the Swedish Meterological and Hydrological Institute (SMHI). https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer#param=airtemperatureInstant,stations=core
Relative humidity	Daily	5 stations	Data downloaded through the Swedish Meterological and Hydrological Institute (SMHI) https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer#param=airHumidity,stations=core
Wind speed	Daily	5 stations	Data downloaded through the Swedish Meterological and Hydrological Institute (SMHI). https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer#param=wind,stations=core
Radiation	Daily	1 station	Data downloaded through the Swedish Meterological and Hydrological Institute (SMHI). https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer#param=globalIrradians,stations=core

GIS input data used

Data	Map	Resolution	Availability
DEM	Lantmäteriet:Höjddata, Grid 2+ 2019 TILES (tif) Elevation data, Grid 2+	2 m, resampled to 10 m	Official 2 m laser scanned map is hosted by the Lantmäteriet (https://www.lantmateriet.se/). The map was resampled to a 10 m resolution. The DEM over Örsundaån was corrected in certain areas to better suit the official catchment boundaries.
Landuse	NMD (National landcover map)	10m raster	The National landcover map (Naturvårdsverket, 2019) was downloaded from https://www.naturvardsverket.se/verktyg-och-tjanster/kartor-och-karttjanster/nationella-marktackedata/

			Some of the landuse classes were joined since the NMD is very detailed.
Soil	Digital soil map	50 m raster	The soil map used was based on the Digital soil map (Söderström & Piikki, 2016) of all arable land and the Swedish Geological Survey (SGU) for all non-arable land (SGU, 2016). https://www.sgu.se/samhallsplanering/planering-och-markanvandning/markanvandning/jordbruk-skog-och-fiske/lerhaltskartan-digital-akermarkskarta/
Lakes	SVAR2012	Vector (shapefile)	Streams and lakes were based on Swedish Hydrological Institutes (SMHI) database SVAR2012. https://www.smhi.se/data/utforskaren-oppna-data The stream network was combined with the ditch network (Lidberg et al., 2021) and then simplified based on ortophotos of the area to identify existing streams and ditches (and thus several were removed), and small non-connected lines were removed. The main outlet was based on a sampling point with water quality data and modelled discharge data. Two additional outlets within the catchment were added based on sampled data and measured discharge.

Stream data used for calibration

Data	**Temporal resolution**	**Spatial resolution**	**Availability**
Stream discharge	Daily calculated to monthly	Main outlet and C6 (subchatchment)	https://www.smhi.se/data/hydrologi/ladda-ner-hydrologiska-observationer/waterdischargeDaily/2248 https://jordbruksvatten.slu.se/default.cfm
Suspended sediments (SS), Total nitrogen (TN) and total phosphorus (TP)	Biweekly calculated to monthly Monthly (varying) (TN, TP)	C6 (subchatchment) Main outlet	https://jordbruksvatten.slu.se/default.cfm https://miljodata.slu.se/MVM/Search

Description of national model

The S-HYPE model was selected as the Swedish national model (Strömqvist et al. 2012).

The Hydrological Predictions for the Environment (HYPE) model is a semi-distributed, physically based catchment model, which simulates water flow and substances on their way from precipitation through different storage compartments and fluxes, in the landscape at the catchment scale, to the sea (Lindström et al., 2010). Its spatial division is related to catchments and sub-catchments, land use or land cover, soil type and elevation. Within a catchment the model will simulate different compartments; soil including shallow groundwater, rivers and lakes. The model application that covers total Sweden is called S-HYPE (Strömqvist et al. 2012), and results at subcatchment resolution is downloaded at Vattenweb (https://vattenwebb.smhi.se/modelarea/). The model calculates evapotranspiration, snow storage and melt, soil moisture, groundwater fluctuations, routing in lakes and streams along the river network from source to sea.

SMHI is continuously developing S-HYPE both in terms of area division, updates of input data and improvements of process descriptions, as well as calibration of the model. The principle in the further development of S-HYPE is that the model is improved gradually, but that at each specific time the best possible estimate is made in time and space of flows of both water and nutrients. Improvements also refer to improvements in the model code, new functions and calculation variables. It is calibrated regionally, i.e. not tuned for individual stations but calibrated stepwise for specific hydrological processes using representative gauges from the full dataset to be robust enough for predictions also in ungauged basins (Arheimer and Lindström, 2013).

The HYPE setup used was s-hype2022_version_2022a_1.0.0 with the HYPE version HYPE_version_5_25_0 and SVAR version SVAR_2022_1_1.

Calibration and validation

Nitrogen (N) was calibrated and validated with Nperco and Cmn (Table 1). Cmn describes the mineralization of organic N and Nperco the concentration of N in surface runoff. Suspended solids (SS) was calibrated and validated withLat_sed, Prf_bsn and Spcon (Table 2). Lat_sed describes sediment concentration in water flow. Prf_bsn describes peak rate adjustment of sediment routing in the main channel. Spcon is a linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing. Phosphorous (P) was calibrated and validated with Psp and P_updis (Table 3). Psp controls phosphourous availablity index and P_updis controls the P uptake.

The model set up was:

- Model warmup: 2010-2012
- Calibration: 2013-2017
- Validation: 2018-2021

Table 1. Parameters chosen for N calibration.

Parameter	Change type	Value min	Value max	Average value
nperco	absval	0	1	0.15
Cmn.bsn	absval			25

Table 2. Parameters chosen for SS calibration.

Parameter	Change type	Value min	Value max	Average value
Lat_sed.hru	absval	0	5000	28
Prf_bsn.bsn	absval	0	2	1.1
Spcon.bsn	absval	0.001	0.010	0.005

Table 3. Parameters chosen for P calibration.

Parameter	Change type	Value min	Value max	Average value
Psp.bsn	absval	0.1	0.7	0.25
P_updis.bsn	absval	20	100	50

Table 4. 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 5 Performance of SWAT+ model (N, SS and P)

Objective function	Calibration			Validation		
	N	SS	P	N	SS	P
R^2	0.26	0.10	0.21	0.37	0.34	0.44
NSE	0	0	-1	-2	0	0
KGE	0.36	0.01	-0.16	-0.32	0.05	0.56

Results

Flow

The observed, calibrated and the national models discharge are shown in Figure 1.

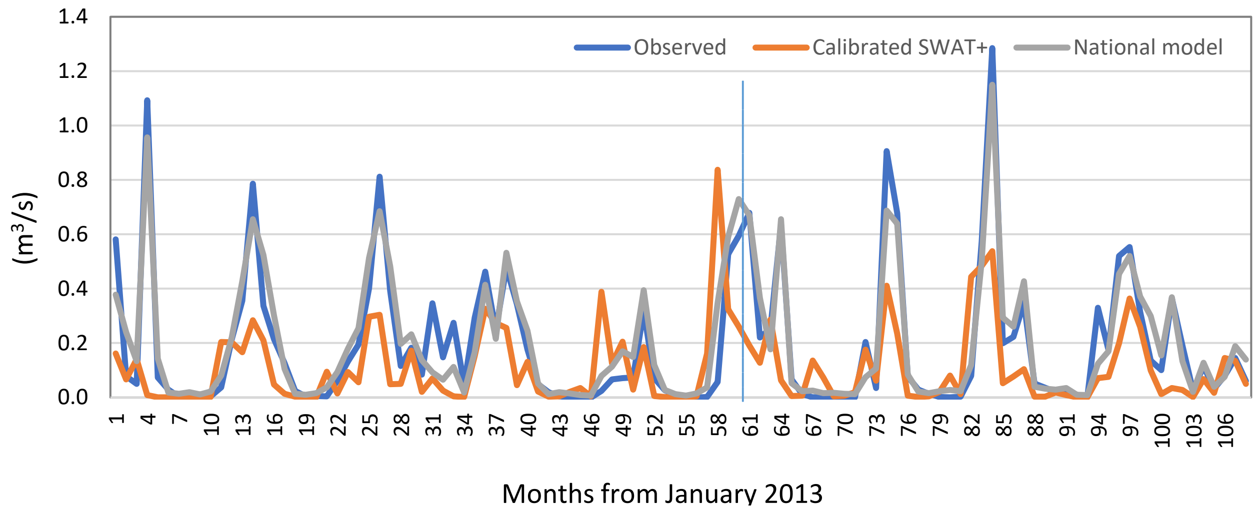


Figure 1. Observed and calibrated discharge along with the data from the national model. A light blue vertical line separates calibration and validation periods.

N (load and concentration)

The observed, calibrated and the national models N load and concentration are shown in Figure 2.

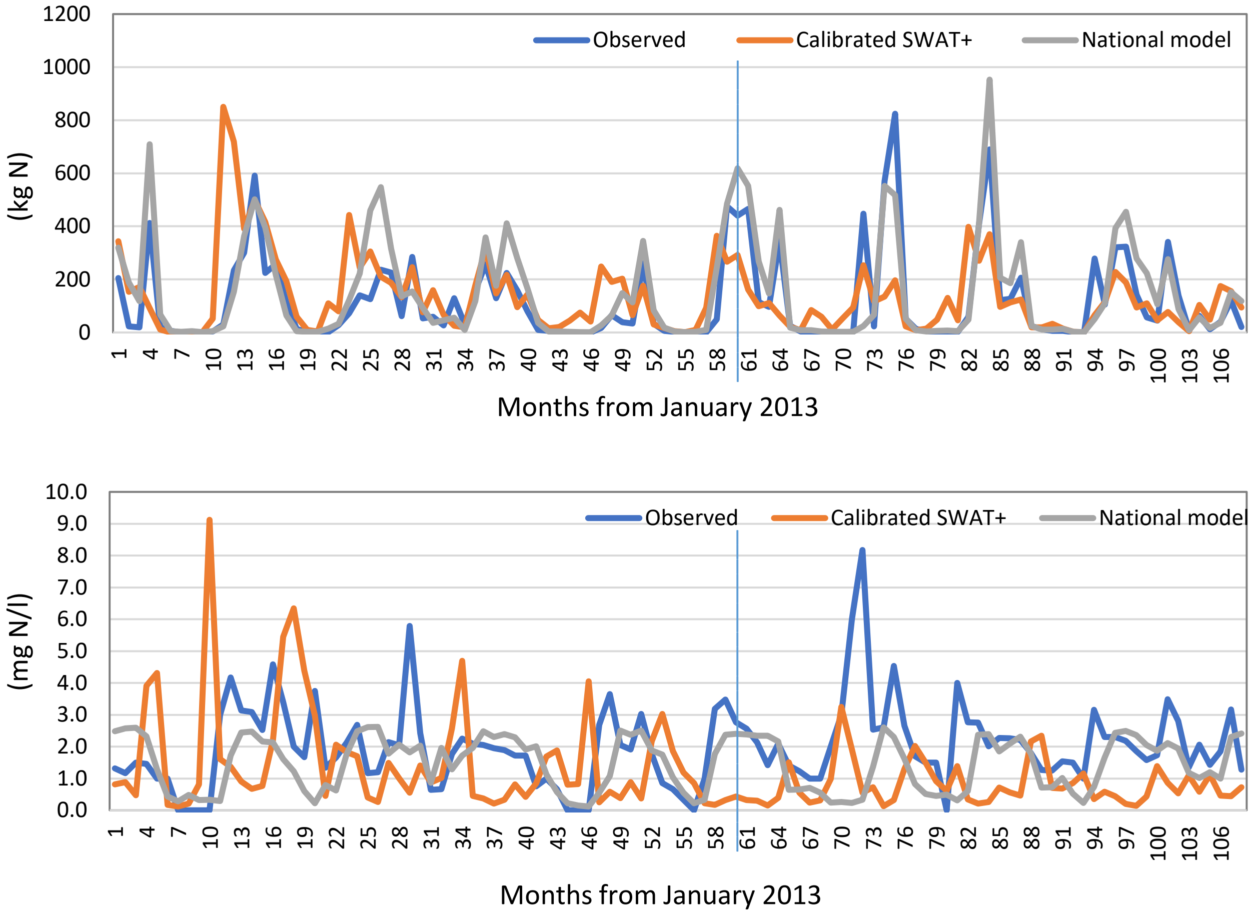
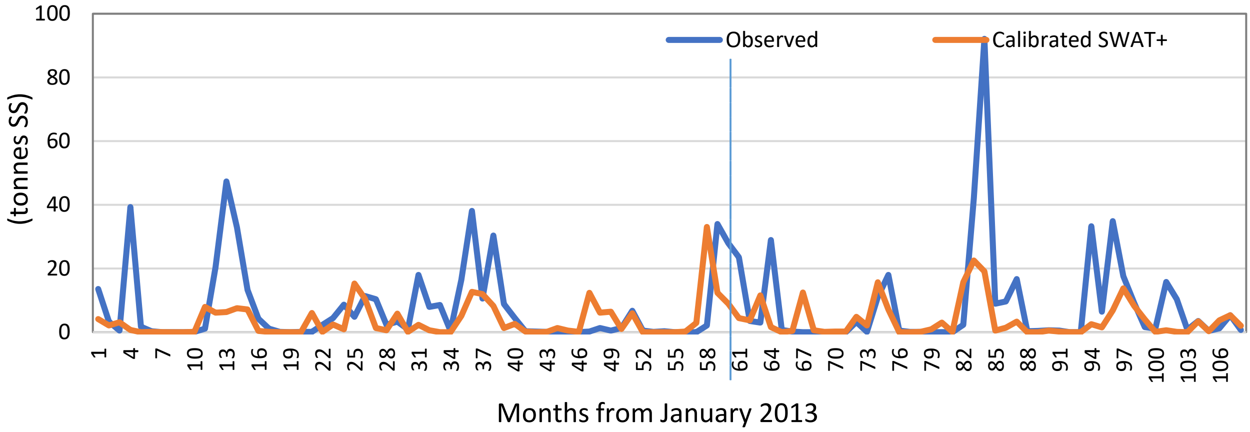


Figure 2. Observed and calibrated total mineral N along with the data from the national model. A light blue vertical line separates calibration and validation periods.

SS (load and concentration)

The observed and calibrated load and concentration of suspended solids (SS) are shown in Figure 3. There is no model calculating SS on the national level in Sweden.



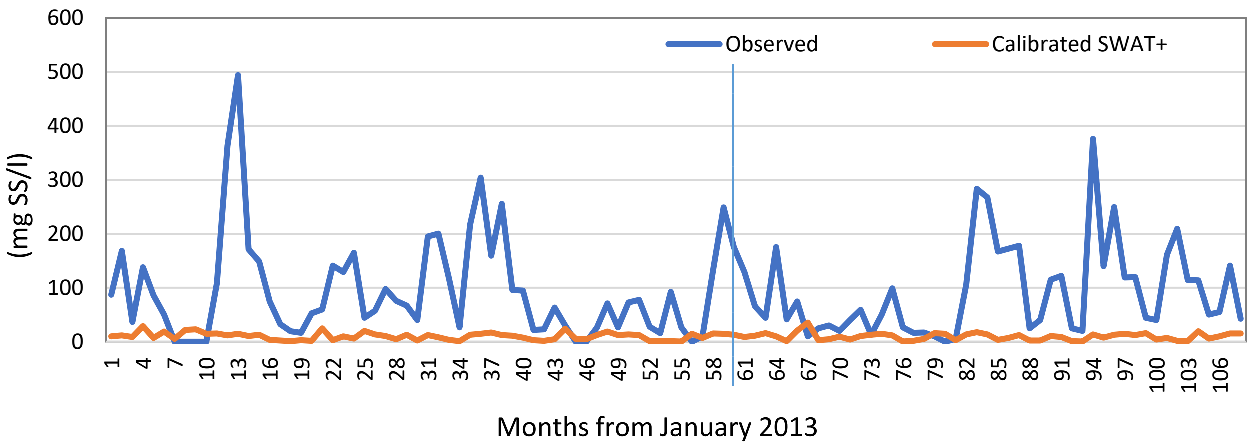


Figure 3. Observed and calibrated SS along with the data from the national model. A light blue vertical line separates the calibration and validation periods

P (load and concentration)

The observed, calibrated and the national models N load and concentration are shown in Figure 4.

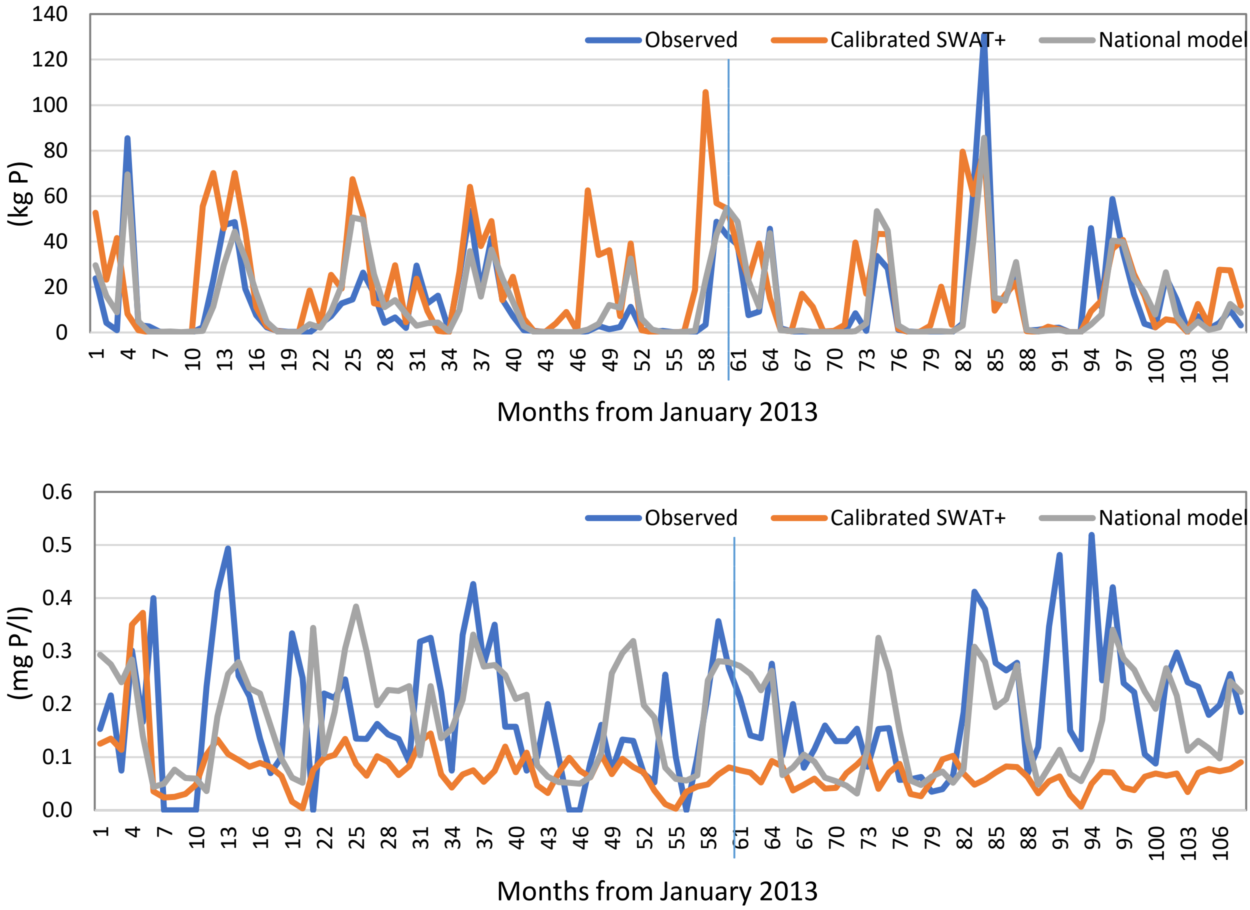


Figure 4. Observed and calibrated total P along with the data from the national model. A light blue vertical line separates the calibration and validation periods

Summary

The SWAT+ calibration of the load of N, P and SS had reasonable results at a visual observation although the statistical performance measure indicated not satisfactory performance. The statistical performance measure indicated not satisfactory performance of the SWAT+ results of the concentration of N, P and SS. The simulated loads of N and P from the national model S-HYPE tended to fit the observed load better than the simulated concentration fitted the observed concentration.

References

Arheimer, B. & Lindström, L. (2013). Implementing the EU Water Framework Directive in Sweden. Chapter 11.20 in: Blöschl, G., Sivapalan, M., Wagener, T., Viglione, A. & Savenije, H. (Eds). Runoff Predictions in Ungauged Basins – Synthesis across Processes, Places and Scales. Cambridge University Press, Cambridge, UK. (p. 465) pp. 353-359.

Lantmäteriet (2014). *Produktbeskrivning: GSD-höjddata, grid 2+ lantmäteriet*. Gävle, Sweden: GSD Geografiska Sverige Data. (In Swedish)

Lidberg, W., Paul, S.S., Westphal, F., Richter, K., Lavesson, N., et al. (2021). Mapping drainage ditches in forested landscapes using deep learning and aerial laser scanning (1.0.0). https://doi.org/10.5281/zenodo.1234 accessed [2022–08-16].

Lindström, G., Pers, C., Rosberg, J., Strömqvist, J. & Arheimer, B. (2010). Development and testing of the HYPE (Hydrological Predictions for the Environment) water quality model for different spatial scales. Hydrology Research 41.3–4, 295-319.

Moriasi, D.N., Gitau, M.W, Pai, N., and Daggupati, P. 2015. Hydrologic and Water Quality Models: Performance Measures and Evaluation Criteria. Transactions of the ASABE. 58(6): 1763-1785. doi: 10.13031/trans.58.10715.

Naturvårdsverket (2019). Nationella marktäckedata 2018. Teknisk rapport. (In Swedish)

Sandström, S., Lannergård, E. E., Futter, M. N., & Djodjic, F. (2024). Water quality in a large complex catchment: Significant effects of land use and soil type but limited ability to detect trends. Journal of Environmental Management, 349, 119500

SGU (2016). *Product: Bedrock 1:50 000 - 1:250 000*. Sweden: Geological Survey of Sweden.

Strömqvist, J., Arheimer, B., Dahné, J., Donnelly, C. & Lindström, G. (2012). Water and nutrient predictions in ungauged basins: set-up and evaluation of a model at the national scale, Hydrological Sciences Journal, 57:2, 229-247.

Söderström, M., and Piikki, K. (2016). “Digital soil map - detailed mapping of soil texture in the topsoil of the arable land,” in *Swedish University of Agricultural Sciences, Department of Soil and Environment* 37, 342