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SWAT+ model protocol for Berze (Latvia)

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Introduction

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. Water quality monitoring activities are carried out at 15 locations on a monthly basis using a grab sampling approach since 2005 thus representing water quality at 15 subbasins with different land use patterns (Figure 1). 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.

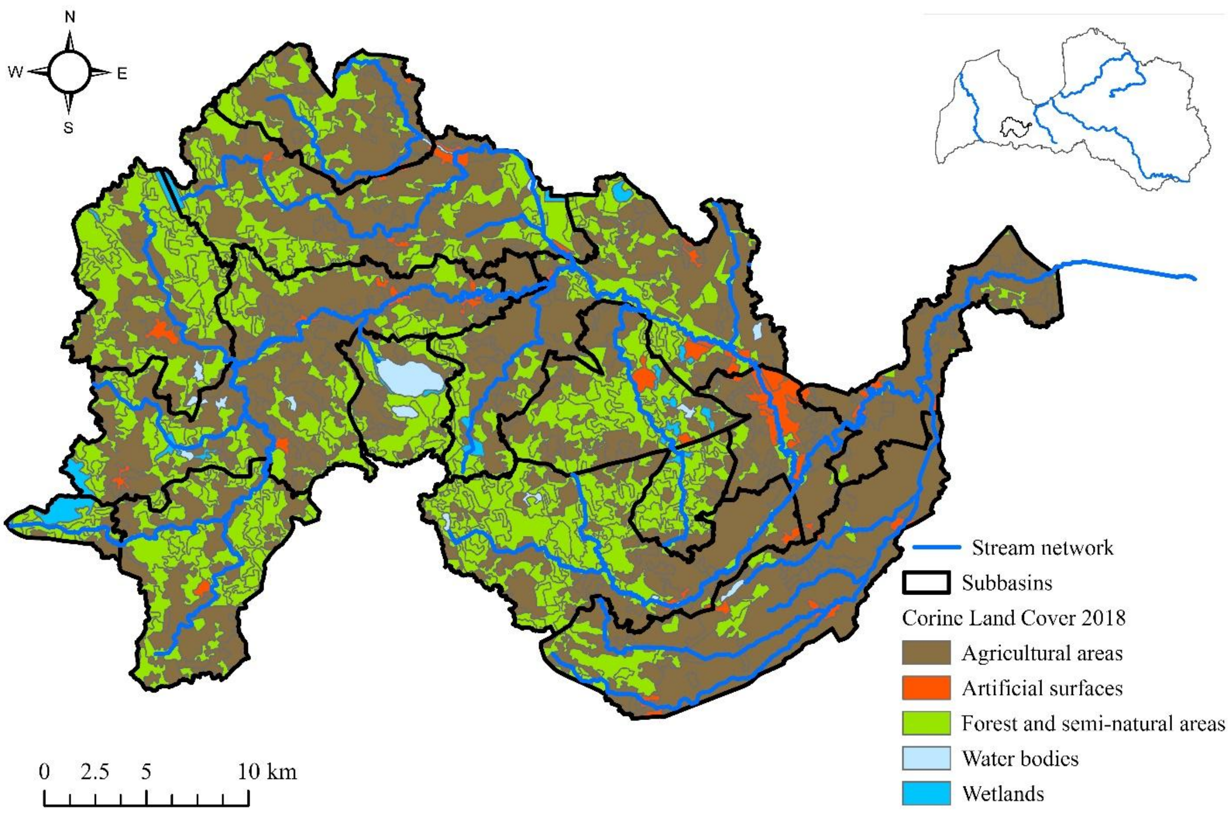


Figure 1. Subbasins, streams and land use of the Berze River catchment.

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)	60.5.2	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)	1x1 km resolution (resampled to 10x10 km)	Data provided by MET Nordic Reanalysis Version 3 and are characterized here: https://github.com/metno/NWPdocs/wiki/MET-Nordic-dataset
Min. and max air temperature	Hourly (resampled to daily)	1x1 km resolution (resampled to 10x10 km)	Data provided by MET Nordic Reanalysis Version 3 and are characterized here: https://github.com/metno/NWPdocs/wiki/MET-Nordic-dataset
Relative humidity	Hourly (resampled to daily)	1x1 km resolution (resampled to 10x10 km)	Data provided by MET Nordic Reanalysis Version 3 and are characterized here: https://github.com/metno/NWPdocs/wiki/MET-Nordic-dataset
Wind speed	Hourly (resampled to daily)	1x1 km resolution (resampled to 10x10 km)	Data provided by MET Nordic Reanalysis Version 3 and are characterized here: https://github.com/metno/NWPdocs/wiki/MET-Nordic-dataset
Radiation	Hourly (resampled to daily)	1x1 km resolution (resampled to 10x10 km)	Data provided by MET Nordic Reanalysis Version 3 and are characterized here: https://github.com/metno/NWPdocs/wiki/MET-Nordic-dataset

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 discharge data used for calibration

Data	Temporal resolution	Spatial resolution	Availability
Stream discharge	Daily	Provided from individual gauge station (Berze-Balozi)	Provided by State Limited Liability Company "Latvian Environment, Geology and Meteorology Centre".

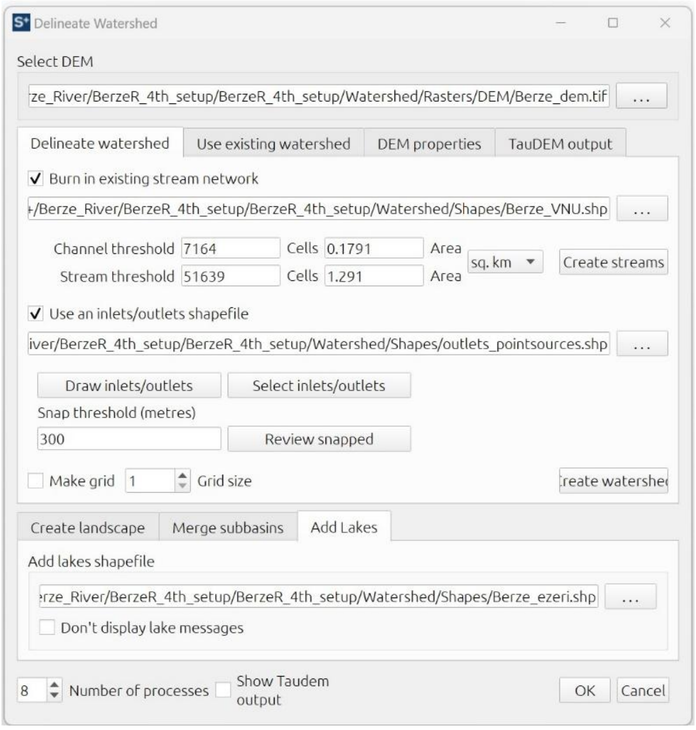
Model setup

Delineation

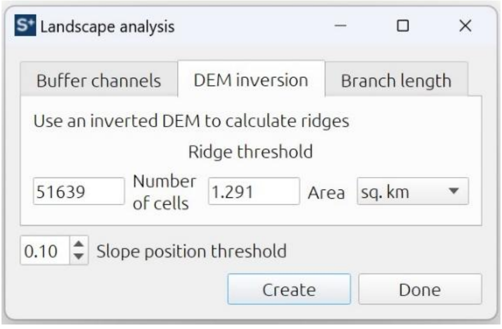
A detailed stream network was employed to refine channel and stream thresholds within the SWAT+ extension in QGIS ensuring a realistic stream network representation. Subsequently, the automatically delineated subbasins were merged to create 15 predefined subbasins representing the contributing areas and locations of water sampling sites, where water monitoring activities have been carried out in a long-term.

Channel threshold: 0.18 km^2 (minimum size of sub-watershed, and thereby a landscape unit (LSU), where a small channel that drains to a main stream is created)

Stream threshold: 1.29 km^2 (minimum size of sub-watershed, where a main stream is created). The existing streams of national significance were burned into the DEM layer to ensure representable generation of stream network:



Upslope/Floodplain LSUs: This is optional. This will divide each LandScape Unit (LSU) into an Upslope and a Floodplain LSU, and create individual aquifers per LSU (representing the Upslope and the Floodplain areas, respectively). This may render a more realistic flow path for groundwater to the main stream in each subbasin, but also result in a higher computational burden and parameter complexity. When delineating Upslope and Floodplain LSUs, we used the "DEM inversion" approach with default settings as indicated here (note this process can take several minutes):



Lakes: This is optional. In the present SWAT+ setup, we included the vector map with 10 lakes and reservoirs, where the largest are Lakes Zebrus and Lake Svete. The delineation will then tailor LSU boundaries to the shoreline of the lakes and reservoirs.

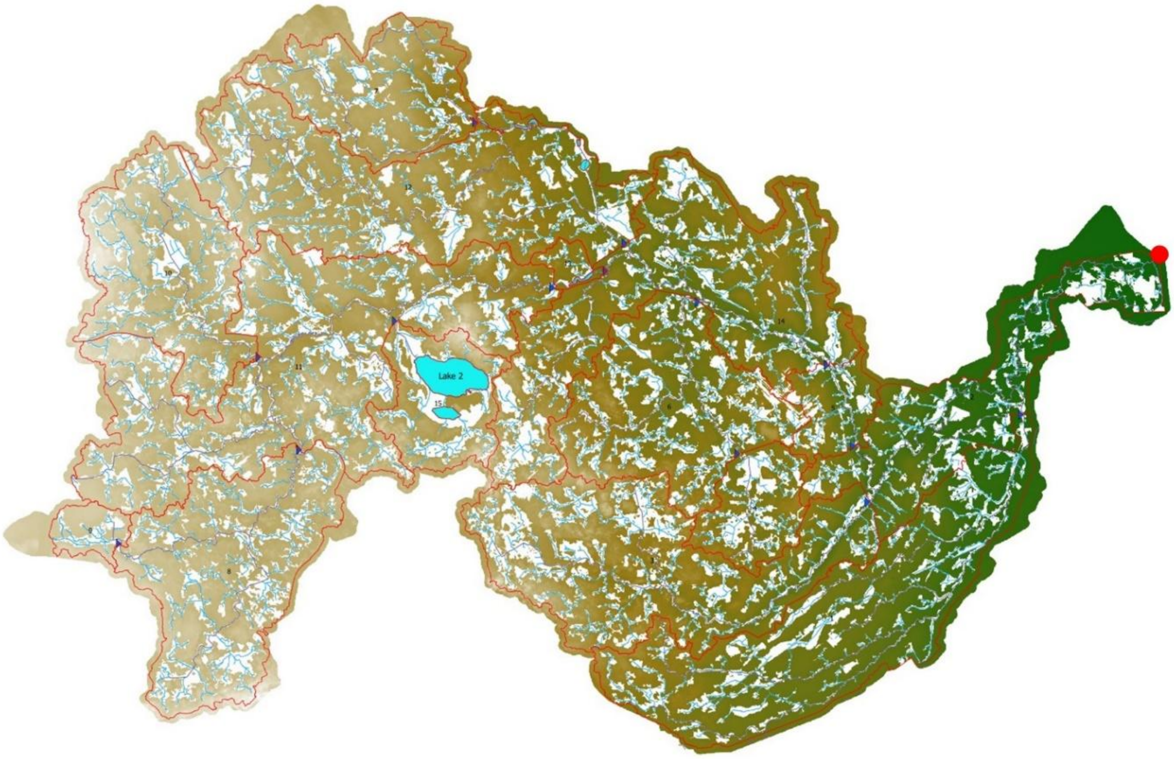


Figure 2. Watershed, subbasins and streams delineated by SWAT+ with floodplain delineation (areas delineated as floodplains are indicated by light shaded areas). The outlets of subbasins are water sampling points and are indicated by blue triangles. The stream gauge station (also a water sampling point) at the Berze River (Berze-Balozi, at outlet of channel # 371) is indicated by red point.

HRU creation

Land use	The CORINE Land Cover inventory from 2018.
Soil	The soil texture map from the national model.
Slope classes	1 class.
HRU filtering	10% threshold for land use, soil type and slope class.

Final configuration:

Total watershed area: 863.4 km^2

Subbasins: 15

LSUs: 76 (excluding floodplain LSUs)

HRUs 724

Channels 2026

Aquifers 16

Reservoirs 10

By utilizing the spatial datasets of Corine Land Cover 2018 and subsurface drainage systems in agricultural fields, which is part of the Digital Drainage Cadastre, the land use was classified into eight categories (Table 1). The arable lands, grasslands, and pastures were further subdivided based on dominant crop types using the "split" function (Tables 2 and 3). The share of dominant crop types was determined from the spatial datasets provided by the Rural Support Service of the Republic of Latvia. The land use codes (SWAT+ codes) were integrated into the plant.plt file and added to the plant database.

Soils were categorized into five classes based on their texture (Table 4). Soil characteristic parameters were assigned and detailed in the "usersoil.csv" file.

***Table 1**. Land use of the Berze catchment as defined in the SWAT+ model*

Land use	Area km^2	Area %	SWAT+ code
Forests	340.9	39.2	FRST
Arable_tile drained	304.6	35.0	agrAreTile
Arable_non tile drained	128.0	14.7	agrNoTile
Graslands and Pastures_tile drained	5.6	0.6	pastAreTile
Graslands and Pastures_non tile drained	45.6	5.2	pastNoTile
Urban	24.5	2.8	UCOM
Wetlands	12.1	1.4	WETN
Water	8.6	1.0	WATR
Total	869.9	100.0	-

***Table 2**. Share of agricultural crops in the Berze catchment as defined in the SWAT+ model*

Crop Type	Area, km^2	Area, %	SWAT_CODE
Spring wheat	29	7	swht (or swhttile)
Winter wheat	227	52	wwht (or wwhttile)
Spring barley	37	9	barl (or barltile)
Winter rape	83	19	wcanol (or wcanoltile)
Broad beans and Peas	23	5	beanb (or beanbtile)
Fallow	11	3	bsvg (or bsvgtile)

Corn	23	5	corn (or corntile)
Total	433	100	-

***Table 3**. Share of pastures and permanent grasslands in the Berze catchment as defined in the SWAT+ model*

Crop Type	Area, km^2	Area, %	SWAT_CODE
Pastures	24	47	past (or pasttile)
Permanent grasslands	27	53	gras (or grastile)
Total	51	100	-

***Table 4**. Soil types in the Berze catchment as defined in the SWAT+ model*

Soil texture	SOIL_ID	SNAM	Area, km2	Area, %
Sand	1	s	152.6	17.5
Loamy sand	2	ms	190.4	21.9
Sandy loam	3	sm	467.8	53.8
Clay	4	m	18.8	2.2
Organic	5	k	40.3	4.6
	Total area		869.9	100.0

The SWAT+ Editor was utilized for further model setup to define agricultural land management practices such as soil cultivation, fertilizer application, and harvest. Additionally, the information on 21 wastewater treatment plants was incorporated into the setup linking the wastewater treatment plants with the stream network and specifying characteristics of discharge and nutrient loading. The total annual load from the wastewater treatment plants accounts for 17,817 kg of nitrogen and 3,236 kg of phosphorus, with a total daily water discharge of 2,908 m^3.

Evaporation method

SWAT+ includes the choice of different evaporation methods including Hargreaves, Penman/Monteith, Priestly/Taylor or user defined time series. A study by Samadi (2017) suggested that Priestly/Taylor may provide best performance when simulating extreme events. Trolle and Nielsen (2020) found that Penmann/Montieth generally resulted in a better performance for the Vejle pilot area. Within the present study tests were performed at the initial stage. The results indicated that Penmann/Monteith outperforms other methods for the Berze catchment, therefore, this method was chosen in the present SWAT+ setup for this case study.

Water abstractions

Not included in the SWAT+ setup for the Berze catchment.

Inputs of external groundwater from areas outside topographical watershed

Not included in the SWAT+ setup for the Berze catchment.

Calibration and validation

The model calibration process has commenced for the Berze catchment. Currently, our focus was orientated towards average long-term crop yields, components of water balance, and daily discharge at the outlet of the Berze River.

The calibration procedure was performed manually.

The calibration was performed by optimization of the coefficient of determination (R^2) and the Nash-Sutcliffe Efficiency (NSE), which, like the R^2, is a correlative objective function. Percent bias, which is a residual objective function, was also evaluated. Classification of the performance was done by comparing performance against the criteria reviewed by Moriasi et al. (2015). The following time periods were used:

- Model warmup: 1. January 2013 - 31. December 2014 (two years)
- Calibration: 1. January 2015 - 31. December 2020 (six years)
- Validation: 1. January 2021 - 31. December 2022 (two years)

***Table 5**. Parameters selected for calibration*

Parameter	Change type	average
Aquifer parameters		
alpha_bf	Replace	0.002
revap	Replace	0.33
Flo_min	Replace	2.35
Revap_min	Replace	2.35
Basin parameters		
Surq_lag	Replace	0.23
Hydrology parameters for forests		
can_max	Replace	9
esco	Replace	0.60
epco	Replace	0.55
perco	Replace	0.86
Latq_co	Replace	1.5
Soil parameters for sandy loam		
awc	Replace	0.205* (0.235)
soil_k	Replace	65* (25)
bd	Replace	1.45* (1.55)
Soil parameters for sand		
awc	Replace	0.13* (0.130**)
soil_k	Replace	370* (300**)
bd	Replace	1.70* (1.60**)
Soil parameters for loamy sand		

awc	Replace	0.145* (0.145**)
soil_k	Replace	100* (100**)
bd	Replace	1.50* (1.60**)
Soil parameters for clay		
awc	Replace	0.26* (0.26**)
soil_k	Replace	30* (10**)
bd	Replace	1.20* (1.30**)
Soil parameters for organic		
awc	Replace	0.5* (0.01**)
soil_k	Replace	258* (50**)
bd	Replace	0.8* (1.10**)
Snow parameters for arable lands		
fall_tmp	Replace	1.4
melt_tmp	Replace	-1.2
melt_max	Replace	4.50
melt_min	Replace	2.1
tmp_lag	Replace	0.19
Snow parameters for forests		
fall_tmp	Replace	1.40
melt_tmp	Replace	-1.20
melt_max	Replace	5
melt_min	Replace	1.9
tmp_lag	Replace	0.26
Tile drain parameters		
dp	Replace	1150
t_fc	Replace	85
lag	Replace	95
drain	Replace	15

*top soil layer
** bottom soil layer

Table 6*. 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[2]	D-M-A	$R^2 > 0.85$	$0.75 < R^2 \leq 0.85$	$0.60 < R^2 \leq 0.75$	$R^2 \leq 0.60$
	Sediment/P	M	$R^2 > 0.80$	$0.65 < R^2 \leq 0.80$	$0.40 < R^2 \leq 0.65$	$R^2 \leq 0.40$
	N	M	$R^2 > 0.70$	$0.60 < R^2 \leq 0.70$	$0.30 < R^2 \leq 0.60$	$R^2 \leq 0.30$
NSE	Flow	D-M-A	NSE > 0.80	0.70 < NSE ≤ 0.80	0.50 < NSE ≤ 0.70	NSE ≤ 0.50
	Sediment	M	NSE > 0.80	0.70 < NSE ≤ 0.80	0.45 < NSE ≤ 0.70	NSE ≤ 0.45
	N/P	M	NSE > 0.65	0.50 < NSE ≤ 0.65	0.35 < NSE ≤ 0.50	NSE ≤ 0.35
PBIAS (%)	Flow	D-M-A	PBIAS ≤ ±5	±5 ≤ PBIAS < ±10	±10 ≤ PBIAS < ±15	PBIAS ≥ ±15
	Sediment	D-M-A	PBIAS ≤ ±10	±10 ≤ PBIAS < ±15	±15 ≤ PBIAS < ±20	PBIAS ≥ ±20
	N/P	D-M-A	PBIAS ≤ ±15	±15 ≤ PBIAS < ±20	±20 ≤ PBIAS < ±20	PBIAS ≥ ±30

[2] Includes stream flow, surface runoff, base flow, and tile flow, as appropriate, for watershed models.

Table 7. Performance of SWAT+ model for the Berze River daily discharge

Objective function	Berze River calibration[1] from 2015 until 2020	Berze River validation[1] from 2021 until 2022
R^2	0.81 (Good)	0.75 (Good)
NSE	0.81 (Very good)	0.78 (Good)
PBIAS (%)	-0.28 (Very good)	-2.07 (Very good)

[1] Classification according to Moriasi et al. (2015) noted in parenthesis.

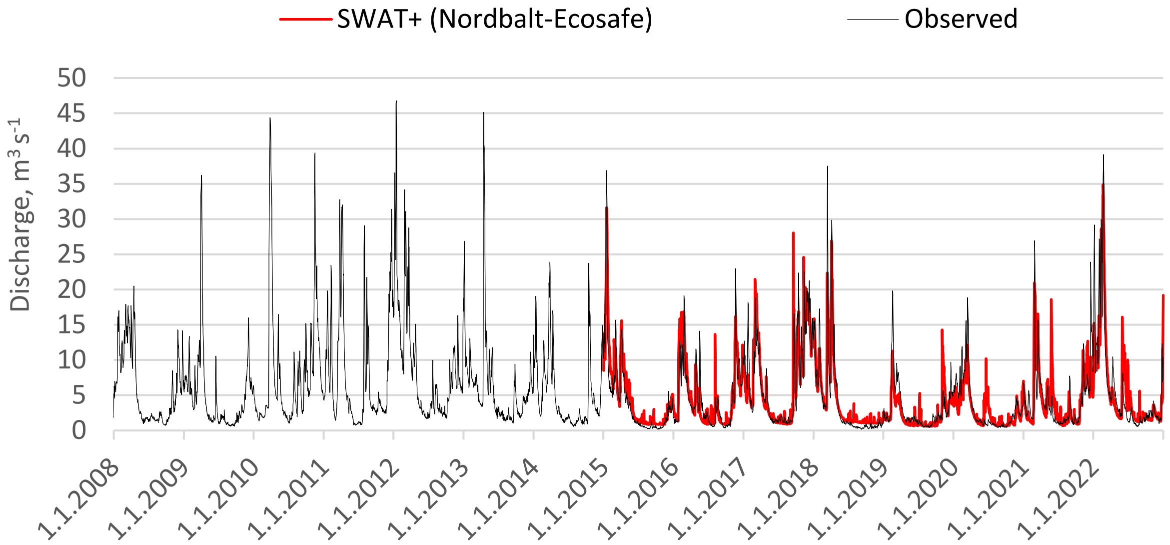


Figure 3. Observed and simulated discharge at the outlet of the Berze River catchment, where the data represents observed discharge at the Berze-Balozi gauge station (2008-2022) and calibrated / validated model (2015-2022).

Summary

A SWAT+ model was set up from scratch for the Berze catchment. The data used in in the presented SWAT+ project are all available at national level, and therefore the SWAT+ approach used in this project can be applied all across Latvia. The SWAT+ model was calibrated on a daily time step, and produced generally satisfactory results for discharge at the outlet of the Berze catchment. Also, the results of simulated crop yields and representation of water balance components are satisfactory.

References

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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.

Samadi, S.Z. 2017. Assessing the sensitivity of SWAT physical parameters to potential evapotranspiration estimation methods over a coastal plain watershed in the southeastern United States. Hydrology Research, 48.2: 395-415.

Trolle, D., Nielsen, A. 2020. SWAT+ model protocol for Vejle pilot. Report by WaterITech prepared for DMI, December 2020, 12p.