

DATE: 2025-06-12

FOR: NordBalt-Ecosafe

# SWAT+ model protocol for Örsundaån (Sweden)

**DATE:** 2025-06-12

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**CITE AS:** Sandström, S., Mårtensson, K. and Kyllmar, K. 2025. SWAT+ model protocol for Örsundaån (Sweden), 13 p.

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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 Mälaren, Sweden's fourth largest lake providing drinking water for millions of people in Stockholm, Sweden's capital. The catchment is 736 km<sup>2</sup>, with a large proportion of agricultural land (36%). Several of the streams and the main river in the catchment (Örsundaån) have eutrophication issues and 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 that 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.

## 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: <a href="https://download.qgis.org/downloads/QGIS-OSGeo4W-3.34.5-1.msi">https://download.qgis.org/downloads/QGIS-OSGeo4W-3.34.5-1.msi</a>
SWAT+ (core model)	60.5.7	The SWAT+ fortran code is version controlled through bitbucket. Official code releases are available here: <a href="https://bitbucket.org/blacklandgrasslandmodels/modular_swatplus/src/master/">https://bitbucket.org/blacklandgrasslandmodels/modular_swatplus/src/master/</a>
QSWAT+ (interface)	2.4.7	Code and official installer releases are available here: <a href="https://bitbucket.org/ChrisWGeorge/qswatplus3/downloads/">https://bitbucket.org/ChrisWGeorge/qswatplus3/downloads/</a>
SWAT+ Editor (interface)	2.3.3	Code and official installer releases are available here: <a href="https://bitbucket.org/swatplus/swatplus.editor/downloads/">https://bitbucket.org/swatplus/swatplus.editor/downloads/</a>
SWAT+ Toolbox (calibration tool)	1.3.0.0	Sensitivity and calibration tool for SWAT+. Installers for the public releases is available here: <a href="https://swat.tamu.edu/software/plus/">https://swat.tamu.edu/software/plus/</a>  Source code for the SWAT+ Toolbox is available through github: <a href="https://github.com/OpenWaterNetwork/SWATPlus-Toolbox">https://github.com/OpenWaterNetwork/SWATPlus-Toolbox</a>
SWATrunR	R 4.4.	R package to run and calibrate SWAT+. Documentation available here: <a href="https://chrisschuerz.github.io/SWATrunR/articles/SWATrunR.html">https://chrisschuerz.github.io/SWATrunR/articles/SWATrunR.html</a>

## Weather input data used

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

## GIS input data used

Data	Map	Resolution	Availability
DEM	Lantmäteriet:Höjd data, 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 ( <a href="https://www.lantmateriet.se/">https://www.lantmateriet.se/</a> ). 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 <a href="https://www.naturvardsverket.se/verktyg-och-tjanster/kartor-och-karttjanster/nationella-marktackedata/">https://www.naturvardsverket.se/verktyg-och-tjanster/kartor-och-karttjanster/nationella-marktackedata/</a> . 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). <a href="https://www.sgu.se/samhallsplanering/planering-och-markanvandning/markanvandning/jordbruk-skog-och-fiske/lerhaltskartan-digital-akermarkskarta/">https://www.sgu.se/samhallsplanering/planering-och-markanvandning/markanvandning/jordbruk-skog-och-fiske/lerhaltskartan-digital-akermarkskarta/</a>
Lakes and streams	SVAR2012	Vector (shapefile)	Streams and lakes were based on Swedish Hydrological Institutes (SMHI) database SVAR2012. <a href="https://www.smhi.se/data/utforskaren-oppna-data">https://www.smhi.se/data/utforskaren-oppna-data</a> 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 discharge data used for calibration

Data	Temporal resolution	Spatial resolution	Availability
Stream discharge	daily	Provided from individual gauge stations and modelled discharge	Observed discharge data was downloaded from <a href="https://jordbruksvatten.slu.se/vaxtnaring_start.cfm">https://jordbruksvatten.slu.se/vaxtnaring_start.cfm</a> for one of the subcatchment. Modelled discharge from SMHI <a href="https://www.smhi.se/data/hydrologi/vattenwebb">https://www.smhi.se/data/hydrologi/vattenwebb</a>

## Model setup

### Delineation

Channel threshold: 100 ha

Stream threshold: 100 ha

Upslope/Floodplain LSUs: A floodplain map was created and used with the buffer channels approach.

Lakes: Shape file with lakes was included.

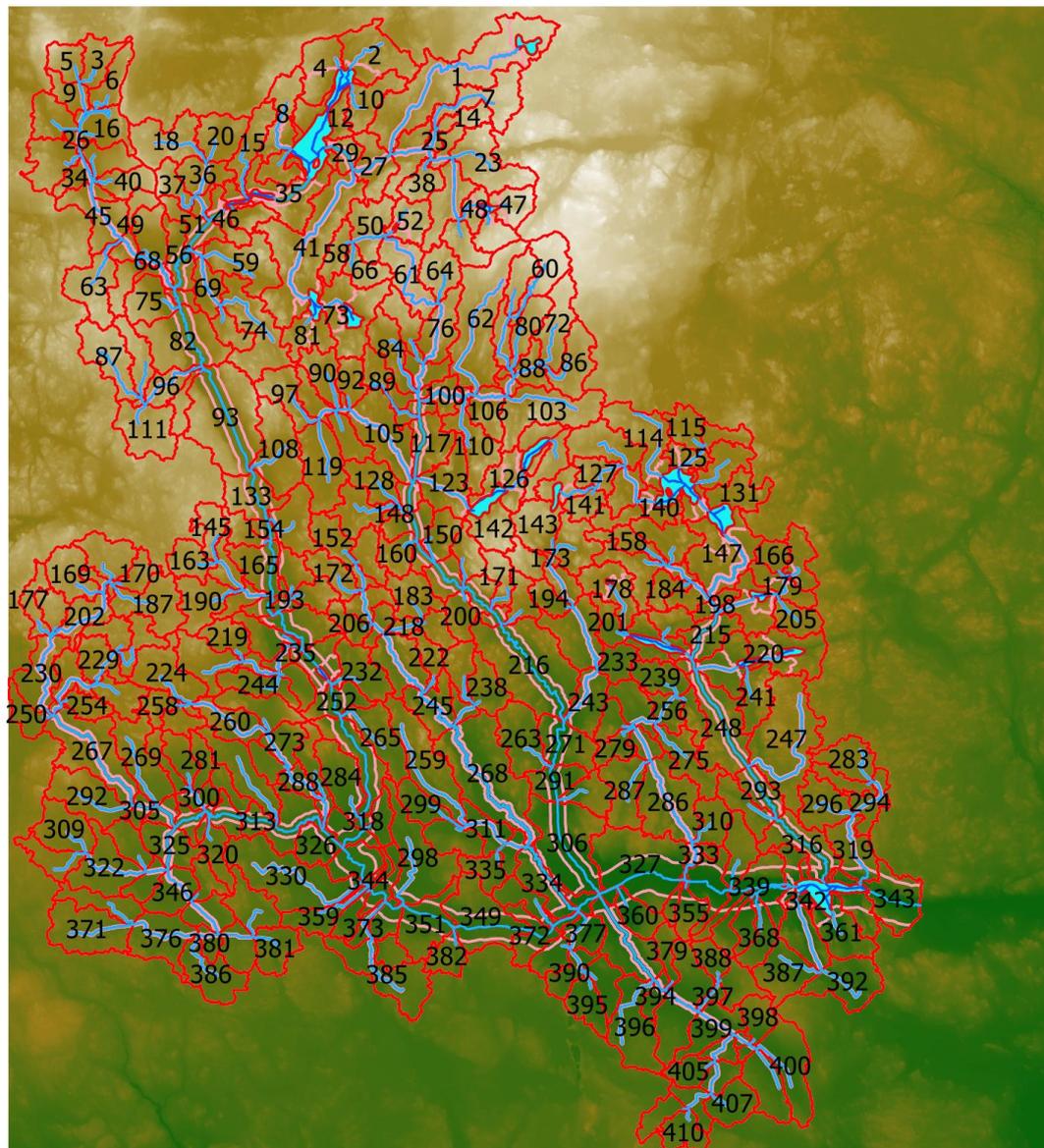


Figure 1. Watershed, subbasins and streams delineated by SWAT+. The stream gauge stations at C6 is at the outlet of # 394 and the main catchment outlet at #343.

## HRU creation

Land use	National landcover map (Naturvårdsverket, 2019).
Soil	Soil texture map from Digital soil map (Söderström & Piikki, 2016).
Slope classes	2 classes (0-2% and >2%).
HRU filtering	5% threshold for landuse, soil type and slope class.

### Final configuration:

# Total watershed area:	736 km <sup>2</sup>
# Subbasins:	394
# LSUs:	887 (including both upslope and floodplain LSUs)
# HRUs	22 966 (in total 58 565 HRUs were identified before applying 5% filter)

### Evaporation method

The standard Penmann/Montieth method was used.

### Water abstractions

None included.

### Inputs of external groundwater from areas outside topographical watershed

None included.

### Crop rotations and tile drainage

All agricultural land was divided into two crop rotations. The different crop rotations were based on the main crops grown in the area from statistics from the Swedish Board of Agriculture and their maps of grown crops in the catchment during the years 2016-2019 (Jordbruksverket, 2024). Crops representing >5% of the total crops were included. This resulted in the following crops: spring barley, ley, winter wheat, spring wheat, oats and pasture. Dates of sowing, harvest and amounts of fertilizer were collected from the same report used in the national modelling of nutrient load from agricultural land (Johnsson et al., 2024). Tile drainage was applied on all agricultural land.

### Calibration and validation

Parametrization, evaluation, soft calibration and hard calibration was performed following the OPTAIN protocol (where suitable) (Schürz et al., 2022). Firstly, evaluation of model processes including water balance, management and crop yields was done using R (R core team, 2025) and the R package *swatdoctR* (Plunge et al., 2024).

Secondly, soft calibration of water balance parameters was done using the built in soft calibration in SWAT+, as described in the OPTAIN modelling protocol (Schürz et al., 2022). Water yield ratio (WYR) was calculated based on average annual discharge and average annual precipitation. To calculate the baseflow ratio (BFR), baseflow was firstly calculated using the R package *grwat*, comparing the four different calculation methods available, finally using the method *jakeman*. Based on these results, BFR was calculated. The third parameter needed for soft calibration was crop yield for simulated crops. Average annual crop yields in tonnes/ha were based on standardized yields for the production area *Svealands slättbygder*, the year 2019 from Statistics Sweden and the Swedish Board of Agriculture (Jordbruksverket & SCB, 2019) for all crops. Standardized yield was the expected yield under normal conditions based on a regression model taking the last 15 years into account for all crops except for temporary grasses where a 10 year mean value was used.

Calibration for hydrology was performed using the R package *SWATrunR* (Schürz, 2019).

The following time periods were used:

- Model warmup: 1 January 2010 - 31. December 2012 (three years)
- Calibration: 1. January 2013 - 31. December 2017
- Validation: 1 January 2018 – 31 December 2021

Calibration was performed for the stream at the C6 gauge station and the main outlet by Örsundsbro. At C6 monitored data is available at a daily basis for water flow and on a two-week basis for nitrogen and phosphorous concentrations. At Örsundsbro modelled discharge and monitored nitrogen and phosphorous concentrations are available.

The calibration was performed by optimization of the Kling-Gupta Efficiency (KGE) and the Nash-Sutcliffe Efficiency (NSE), which is a correlative objective function. KGE was prioritized since it better describes the peaks in flow. Percent bias (PBIAS), which is a residual objective function, was also evaluated.

For discharge, 80 simulation runs were performed. This was based on time constraints involved with running the model, where more simulations would have been preferable. Dotty plots of the calibrated parameter combinations and KGE, NSE and PBIAS were evaluated to find patterns in the different parameters. *Latq\_co* and *awc* were the two parameters that showed any type of pattern in the different evaluation functions. For the gauge in C6 parameter combinations with  $KGE > 0.195$  and  $abs(PBIAS) < 15\%$  were chosen (based on dottyplots), and the discharge was plotted against observed values (Figure 2). For the main outlet the performance was in general better and runs with  $KGE > 0.41$  and  $abs(PBIAS) < 5\%$  was chosen, and the results were plotted against observed discharge at the main outlet (Figure 3).

*Table 2. Calibrated parameters, 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
esco	Soil evaporation compensation factor	none	absval	0.1	1.0	0.978
epco	Plant uptake compensation factor	none	absval	0.5	1.0	0.636
cn2	Curve Number for moisture condition II	none	abschg	5	10	8.746
cn3_swf	Soil water adjustment factor for CN3	none	abschg	0	0.5	0.1247
perco	Percolation coefficient	none	abschg	-0.5	0.5	-0.138
latq_co	Lateral flow coefficient	none	abschg	-0.5	0.5	0.1699
lat_ttime	Lateral flow travel time	days	absval	0.5	20	14.523
awc	Available water capacity of the soil layer	mm/mm	relchg	0	0.25	0.14658
k	Hydraulic conductivity of the soil layer	mm/hour	relchg	-0.5	1	-0.274
alpha	Alpha factor for groundwater recession curve	1/days	absval	0.001	0.9	0.7574

Simulated and observed calibration period C6

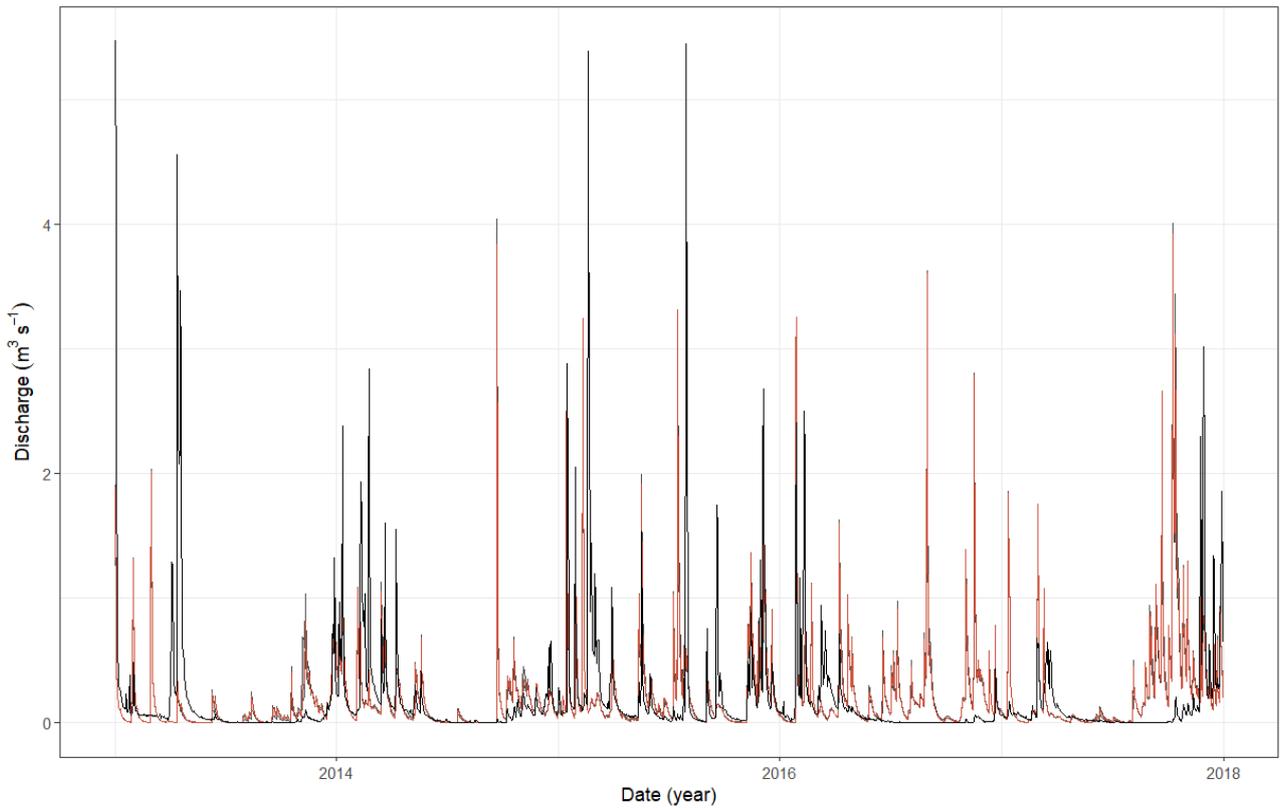


Figure 2. Observed discharge (black) and simulated discharge (red) for the calibration period at gauge C6.

Simulated and observed calibration period main outlet

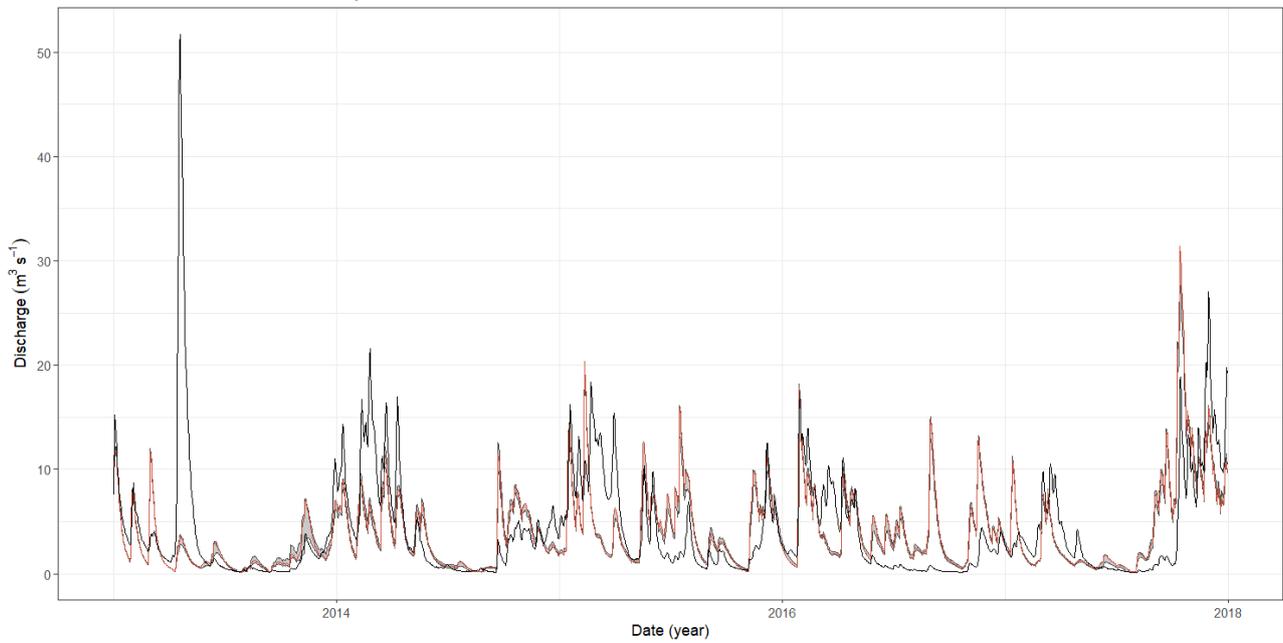


Figure 3. Observed discharge (black) and simulated discharge (red and shaded grey) for the calibration period at the main outlet.

To choose the best parameter combination, both gauges were compared and a combination that gave OK simulation (based on above criteria) in both gauges was chosen for the validation period and as the final value for the parameters (Tables 2 and 3).

Table 3 Model evaluation statistics for daily discharge during the calibration (Cal) and validation (Val) periods.

Gauge	KGE		PBIAS		NSE	
	Cal	Val	Cal	Val	Cal	Val
Örsundaån Örsundsbro (main outlet)	0.42	0.368	-3.6	-22	0.19	0.243
C6	0.19	0.489	14.7	-5.7	-0.24	0.15

For the validation period, the performance of the model increased at C6 for all performance measures, while for the main outlet the KGE and PBIAS were worse, but the NSE was slightly better (Table 3). It is clear at both gauges that the model is simulating too much flow at both gauges, but especially at the main outlet (Figure 4 and 5).

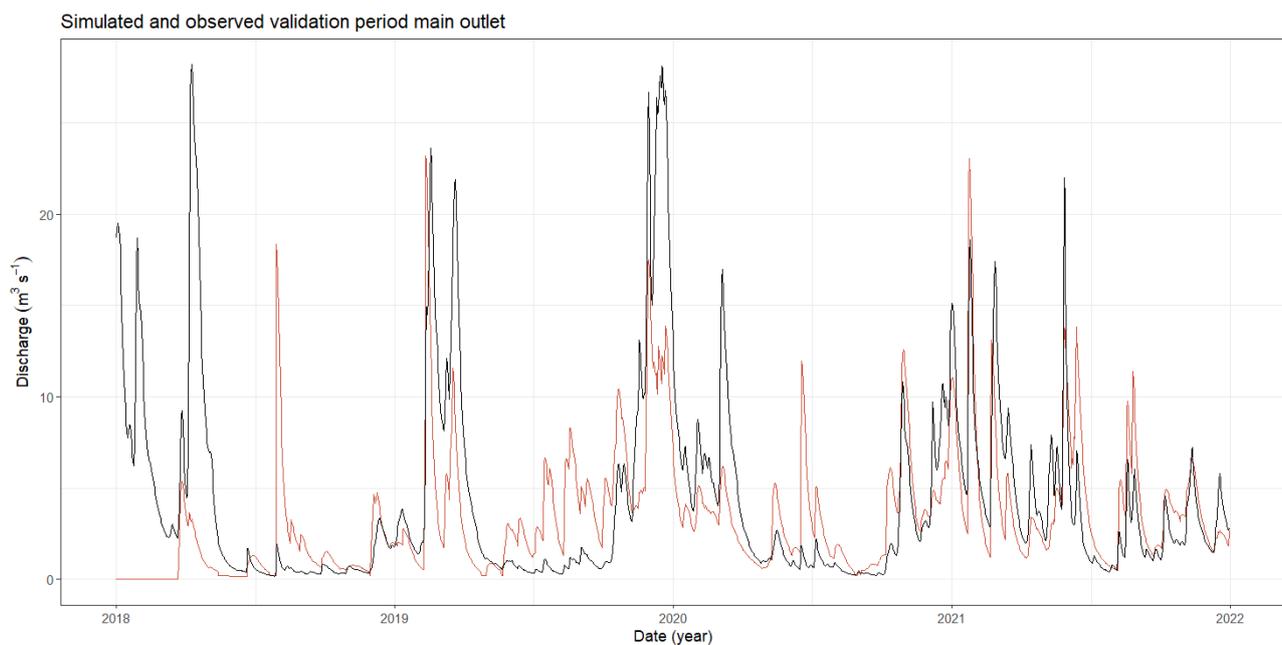


Figure 4. Observed discharge (black) and simulated discharge (red) for the validation period at the main outlet.

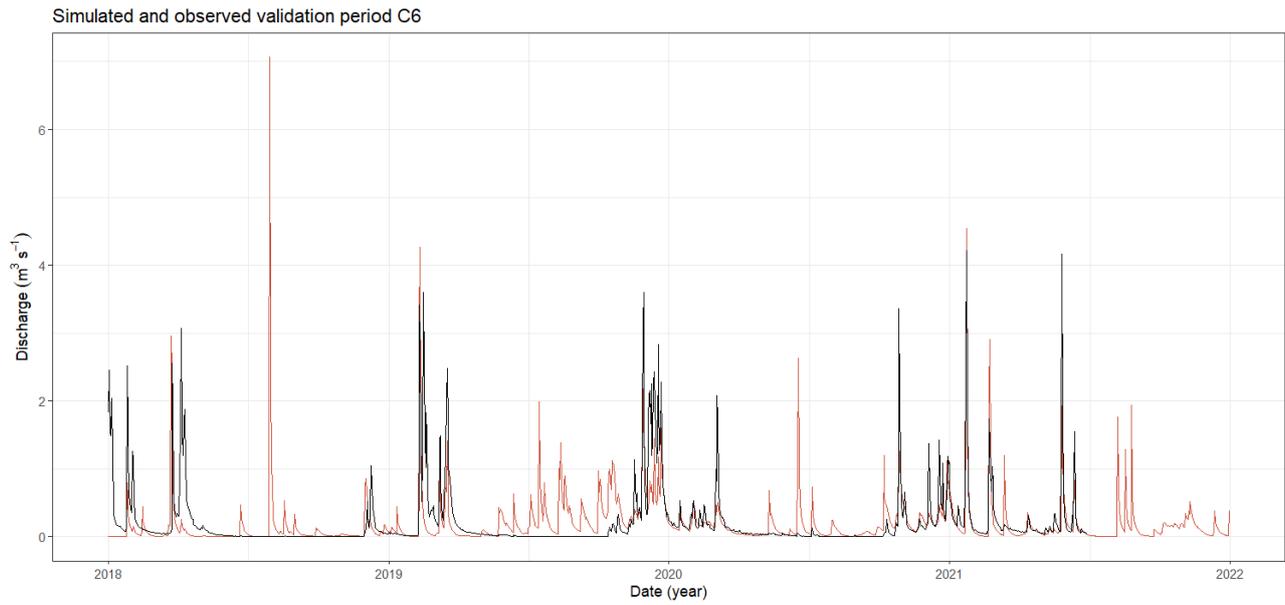


Figure 5. Observed discharge (black) and simulated discharge (red) for the validation period at the gauge in C6.

The annual water balance for the catchment looks ok (Figure 5). A more thorough calibration with more simulations and further investigations into BFR, repeating the soft calibration might make a better simulation for the discharge.

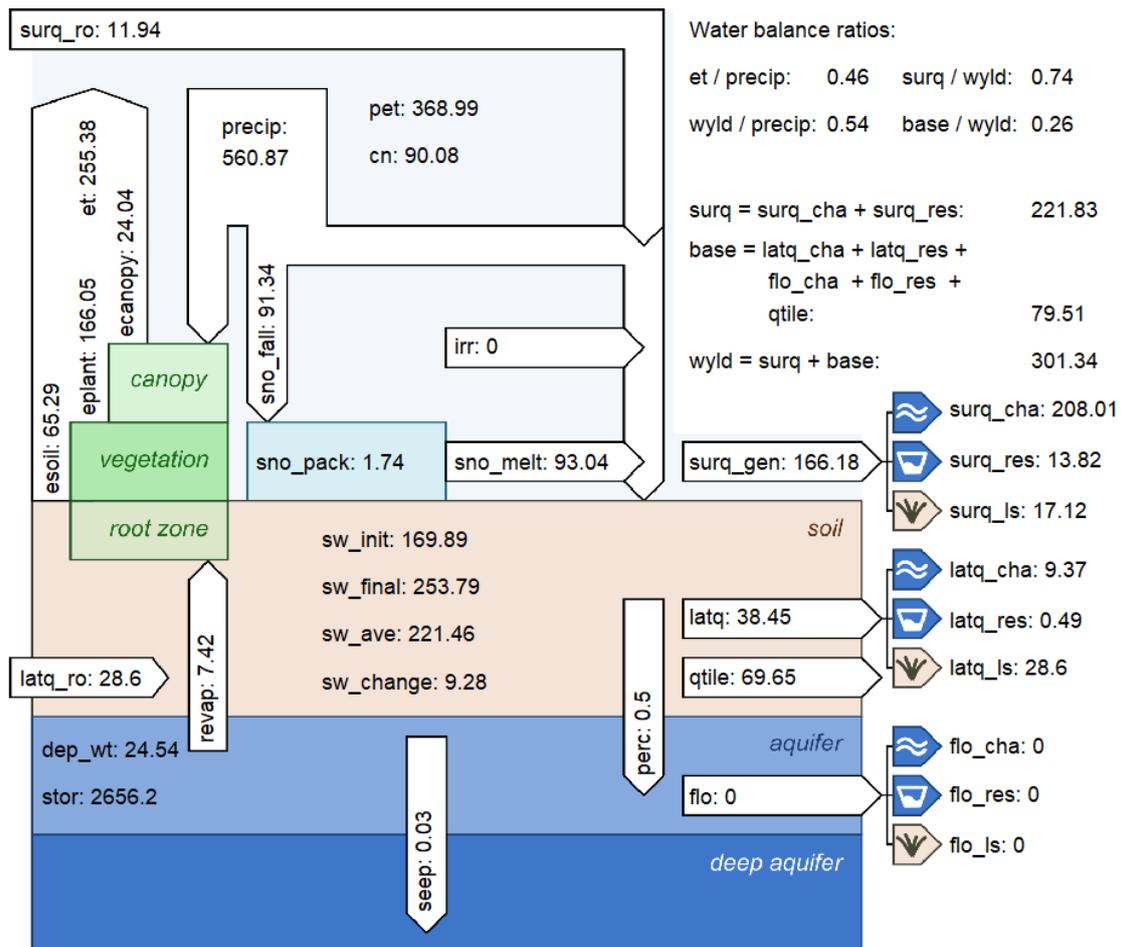


Figure 5. Key watershed-wide hydrology components simulated for period 2013-2021 (based on the current setup of the model).

## Summary

A SWAT+ model was set up from scratch for the Örsunda river system. Calibration of hydrology was done for the outlet at Örsundsbro and at gauge station C6. Patterns in daily discharge are OK simulated, but it seems that there is a disconnection between precipitation events and discharge, where the model simulates more discharge peaks than in reality. During the summer periods, the discharge is overrated by the model, while in winter it is instead underrated. Looking at the precipitation and observed discharge, there is no clear relationship, which indicates that precipitation events does not lead to fast responses in discharge, while the model simulates direct responses in discharge from precipitation events. A possible explanation is that the used weather stations are not located close enough to the discharge gauges. It could also be a problem with how evapotranspiration is represented in the model, that could be further investigated. Due to the discovery of an error in the model late in the modelling process (leading to long error search), together with long simulation times, it was unfortunately not possible to continue with the calibration process to achieve a better fit than this. The evaluation metrics are better at the outlet than at the smaller gauge at C6, and the outlet was prioritized for further calibration of nutrients. The annual water balance for the system is OK.

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