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SWAT+ model protocol for Odense Fjord Catchment, Denmark

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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 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.

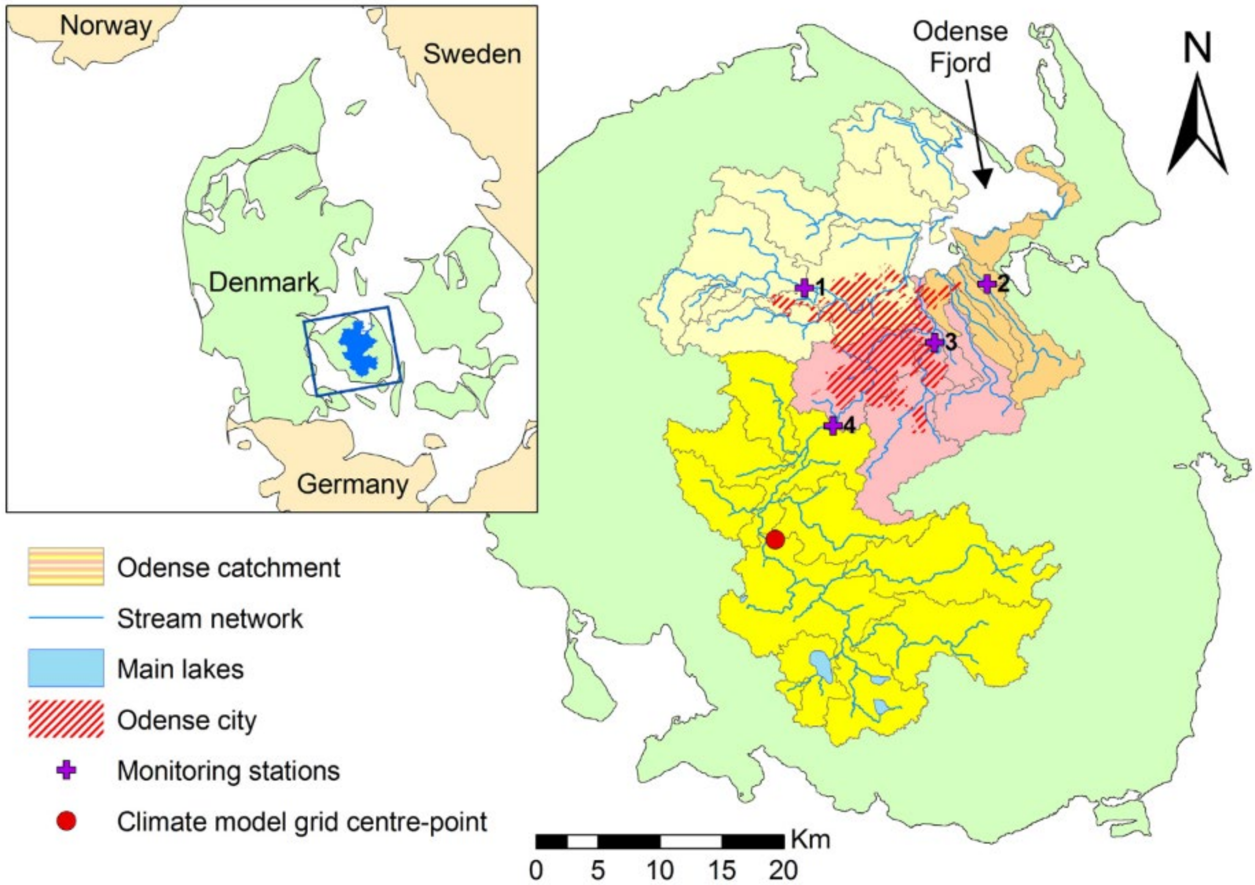

Figure 1. Location of the Odense Fjord Catchment in Denmark and overview of the stream network, large lakes, and monitoring stations (from Molina-Navarro et al., 2018)

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	Appr. bi-weekly	4 stations	Downloaded from odaforalle.au.dk.
Phosphorus loads	Appr. bi-weekly	4 stations	Downloaded from odaforalle.au.dk.

Model setup

Delineation

Channel threshold: 3 km^2

Stream threshold: 3 km^2

Upslope/Floodplain LSUs: Branch Length Method with a Slope Position Threshold of 0.1

Lakes: Shapefile with lakes > 5 ha.

To include areas that drain directly to coastal waters in the model setup, the landscape units delineated by QSWAT+ based on the DEM and stream network were edited manually in QGIS and subsequently loaded into the interface as a pre-defined catchment.

The delineated floodplains were compared to the river valley bottom map by Sechu et al. (2021) and a map of lowland soils in Denmark.

Some lakes were not located on the stream network and thus excluded from the setup by QSWAT+.

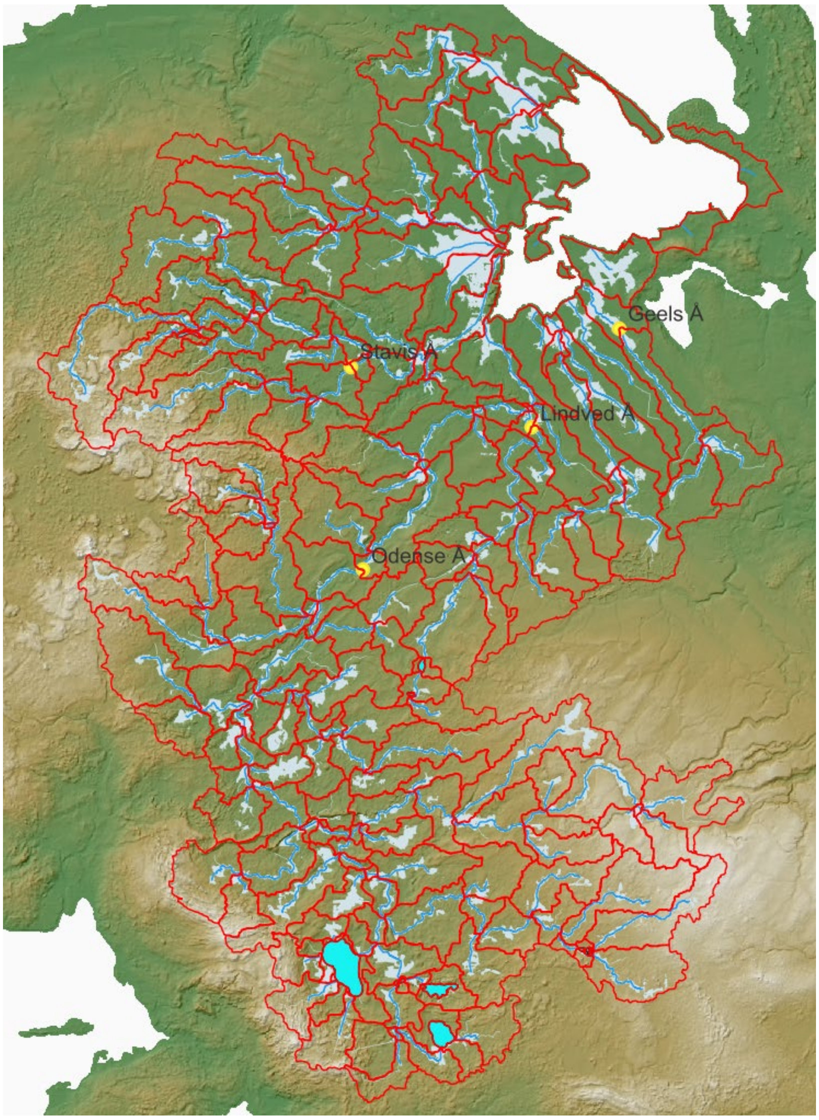

Figure 2. Watershed, subbasins, lakes, and streams delineated by SWAT+ with floodplain delineation (light shaded areas). The gauging stations are indicated by yellow points.

HRU creation

Land use	Customized land use map created by combining the general DK land use map and a field boundary map from 2020.
Soil	National Topsoil Texture Map
Slope classes	0-2%, >2%
HRU filtering	none

The Danish Ministry of Agriculture collects data on field-level crop coverage on an annual basis. The data from the year 2020 were utilized to derive representative crop rotations and fertilizer and manure application rates for the Odense Fjord Catchment. Subsequently, the agricultural area was divided into farm types, including arable (plant) farms, pig farms, and dairy farms. These farm types were further subdivided based on specific plant type, livestock groups according to the reported usage of nitrogen in organic manure, and conventional/organic production, resulting in a total of 13 unique farm types with one to three unique five to eight-year crop rotations each. Finally, each field in the Odense Fjord Catchment was assigned a farm type. The dates for plowing, sowing, fertilizer applications, and harvesting were obtained from an internal report provided by SEGES Innovation.

Representing all farm types and crop rotations in the SWAT+ setup for the Odense Fjord Catchment results in a very large number of HRUs, which directly impacts model runtime and thus makes it difficult to calibrate the model. Therefore, some minor farm types were combined and only one crop rotation per farm type was implemented in the initial setup.

Table 1. Farm types in the Odense Fjord Catchment

Farm type	% of catchment	% of agricultural land
Potato farm with min. 15% potatoes (conventional)	1,45	2,4
Vegetables with min 20% vegetables (conventional)	0,97	1,6
Seed production with min. 15% seed grass and < 80 kg N (conventional and organic)	2,33	3,9
Pig farm < 80 kg N/ha (conventional)	2,00	3,3
Pig farm > 80 kg N/ha (conventional)	12,34	20,5
Cattle 80 – 170 kg N/ha and < 20% roughage (conventional and organic)	2,27	3,8
Cattle 80 – 170 kg N/ha and > 20% roughage (both conventional and organic)	6,58	10,9
Plant farm with > 75% rape + spring seed + winter seed + oilseeds (conventional and organic)	19,99	33,2
Grass in rotation	4,77	7,9
Permanent grassland	3,35	5,6
Not in agricultural production	0,23	0,4
Fixed landuse (fruit orchards, berry farms, plant nurseries)	2,53	4,2
Unknown	0,21	0,3
Other	1,17	1,9

Final configuration

Total watershed area: 1053 km^2

Subbasins: 213

LSUs: 420 (including both upslope and floodplain LSUs)

HRUs 20,012

Evaporation method

Hargreaves

Point sources

Recall files with flow data were added for the 10 largest wastewater treatment plants. Each point source was connected to its nearest channel.

Other changes to the model setup and parameterization

Some of the default values used by the SWAT+ Editor did not reflect the specific characteristics of the Odense Fjord Catchment, so several input files were edited manually before model calibration:

- Subsurface tile drains were implemented in all agricultural HRUs with a mean slope of less than 5%, which resulted in approximately 80% of the agricultural land in the catchment being tile-drained.
- The values of three parameters that control the runoff and leaching potential of the HRUs (perco, cn3_swf, latq_co) were edited based on recommendations from the model development team.
- Management schedules were implemented to define agricultural management operations (sowing, harvest, fertilizer and manure applications, and tillage) for the different crop rotations. implemented in the model.
- An outlet object was added to the model setup, which summarizes the discharge and nutrient loads from all streams draining into Odense Fjord.

Calibration and validation

Hard calibration of daily discharge was performed at four gauges: Odense Å at Kratholm, Stavis Å, Lindved Å, and Geels Å. The followed time periods were used:

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

Automatic calibration of discharge was performed using SWATrunR, a tool developed in R. For each parameter included in the calibration, 280 values were sampled within the range specified in Table 2 using Latin Hypercube Sampling and simulations were run using the resulting 280 parameter sets. The 280 discharge calibration runs were ranked based on the fit between observed and simulated discharge as indicated by the Nash-Sutcliffe Efficiency (NSE; Nash & Sutcliffe, 1970), the percent bias (pbias), and the Kling-Gupta Efficiency (KGE; Gupta et al., 2009) and one run that ranked among the best 40 runs for all stations was selected and evaluated using the model evaluation statistics and visual comparison. It was also made sure that the landscape water balance for the selected run and crop yields were reasonable. The simulated crop yields were close to the Danish yield norm for spring barley and peas, whereas it was slightly underestimated but still reasonable for winter wheat and corn and overestimated for winter barley. On a catchment average, actual evapotranspiration was slightly underestimated, but increasing it would have resulted in an underestimation of discharge at three of the four gauging stations.

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
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

Table 1 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

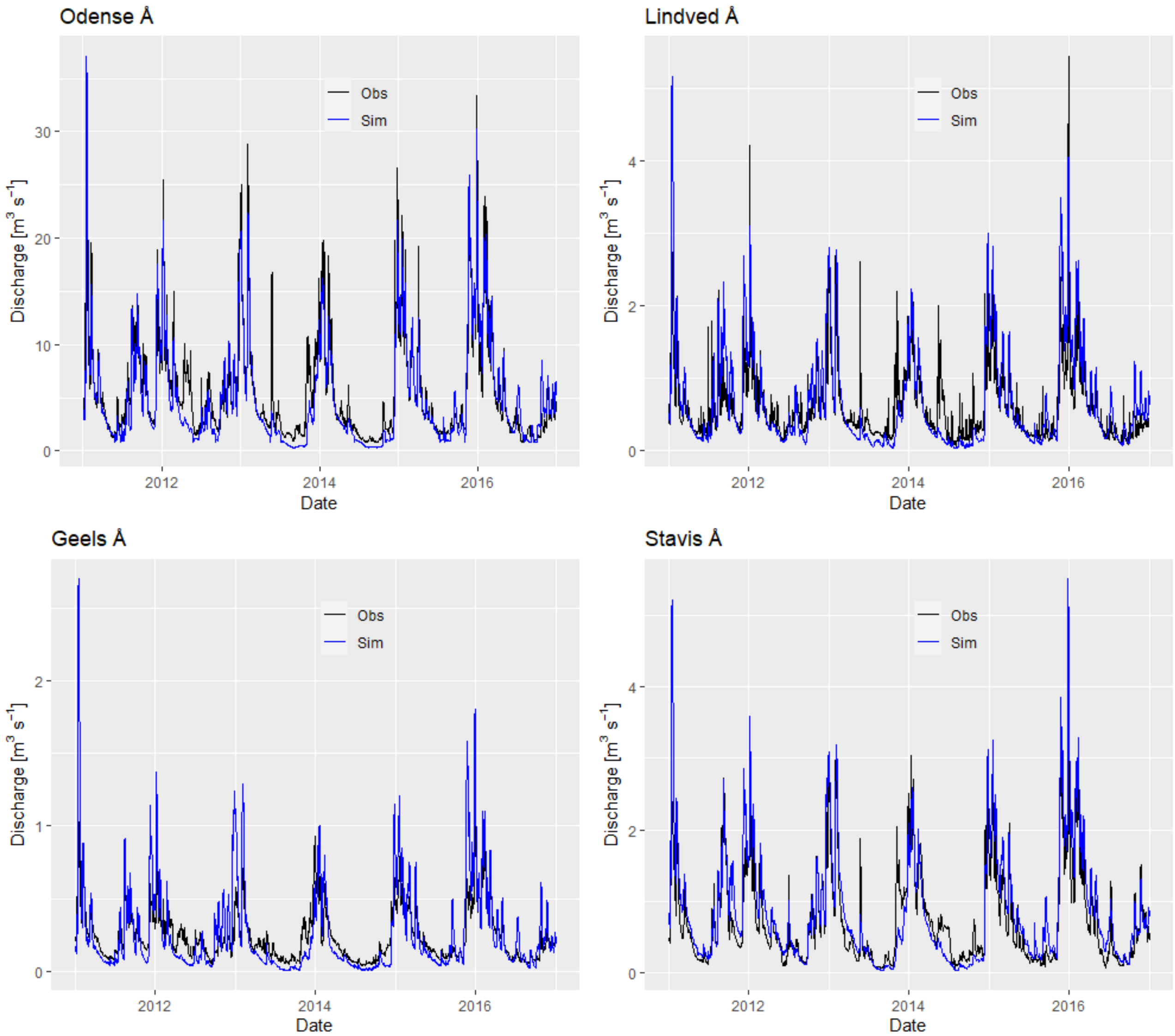

Figure 3. Observed and simulated discharge for Odense Å at Kratholm, Lindved Å, Geels Å and Stavis Å during the calibration period.

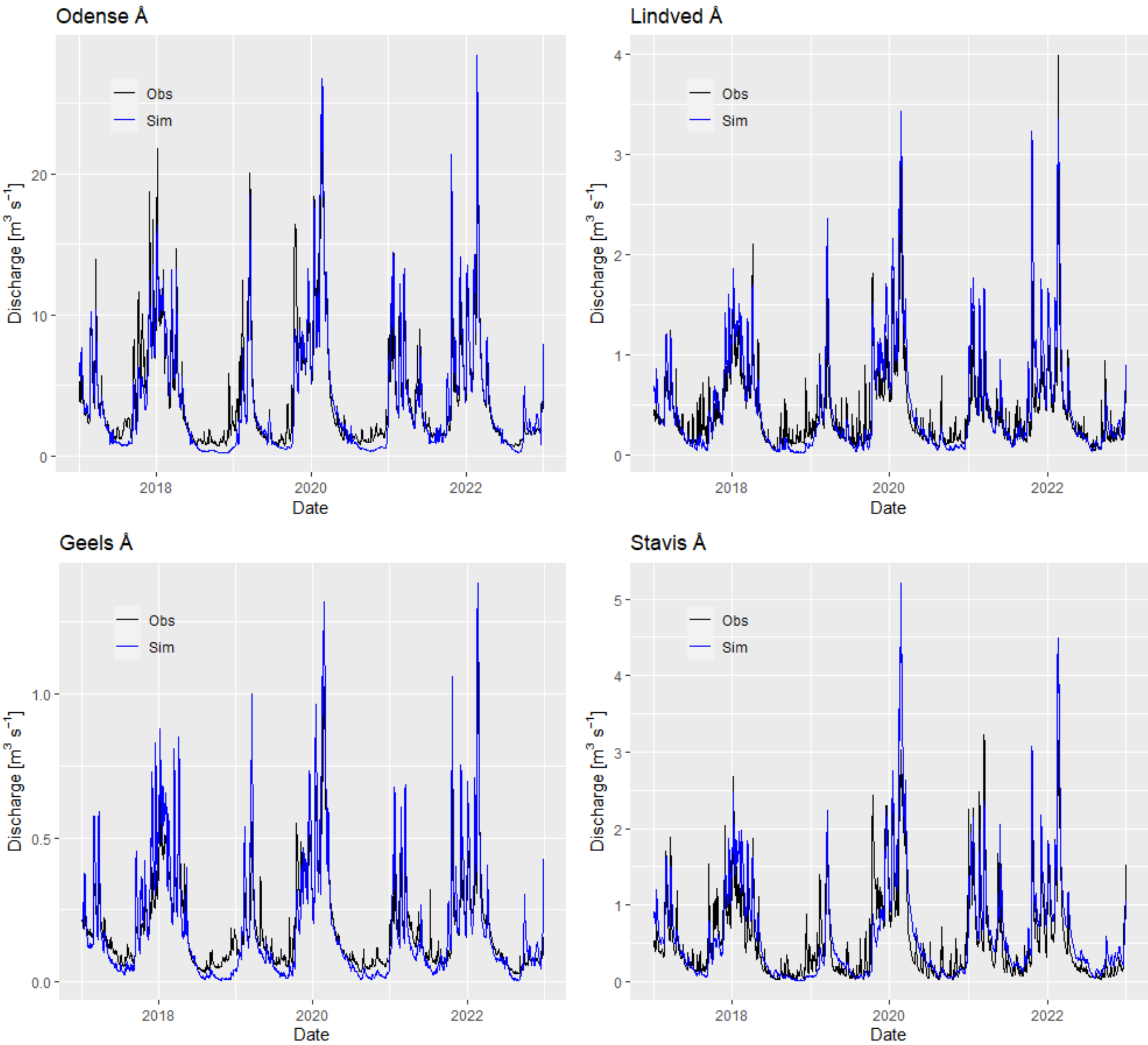

Figure 4. Observed and simulated discharge for Odense Å at Kratholm, Lindved Å, Geels Å and Stavis Å during the validation period.

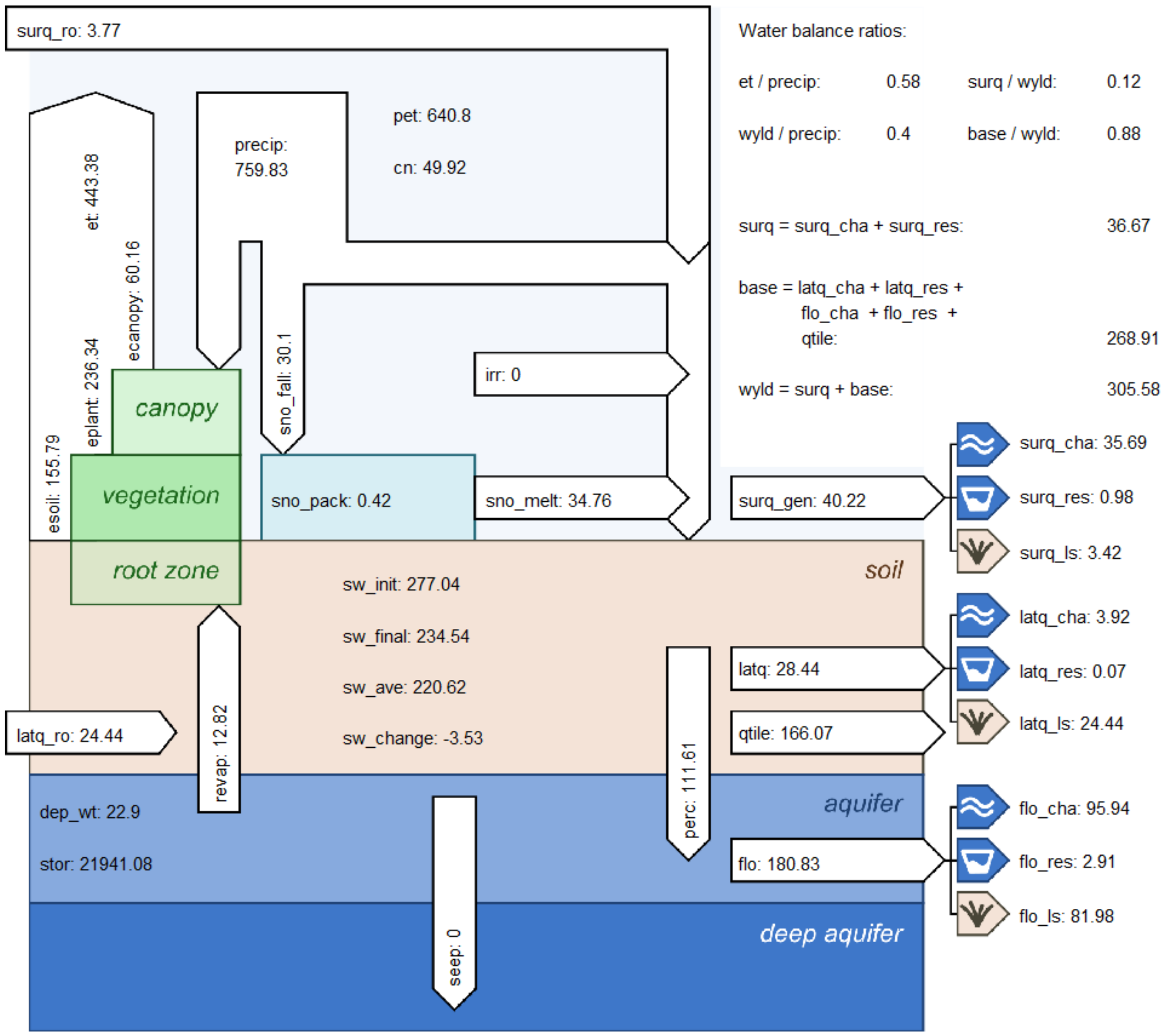

Figure 5. Calibrated water balance for the entire simulation period (2011-2022).

A preliminary manual calibration of daily nitrogen loads (nitrate + nitrite) was performed at three gauges: Stavis Å, Lindved Å, and Geels Å by adjusting the values of the parameters n_perc (nitrate percolation coefficient), nperco_lchtile (nitrogen concentration coefficient for tile flow and leaching from bottom layer), and denit_frac (denitrification threshold water content). The model performance was evaluated by visual comparison of the observed and simulated data. Due to the infrequent monitoring (roughly bi-weekly grab samples), there is considerable uncertainty in the observed data, so for this initial calibration it was considered most important to achieve a realistic simulation of the general seasonal variability.

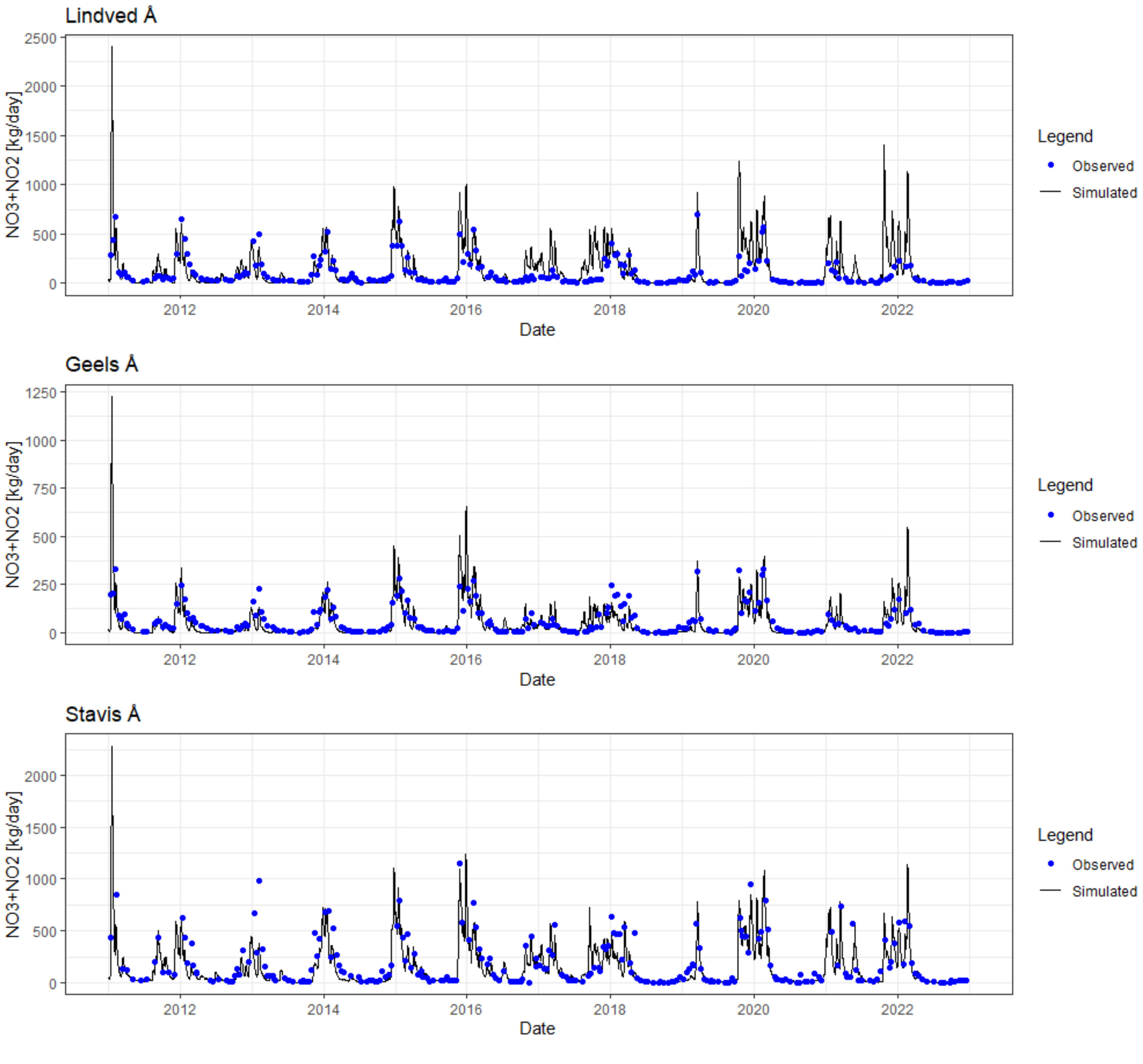

Figure 2. Results of the preliminary calibration of nitrogen (nitrite + nitrate) loads for the entire simulation period (2011-2022).

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 reasonable simulation of crop yields, water balance, and discharge. A preliminary calibration of nitrogen loads yielded promising results but will be further improved. For simulating phosphorus loads, the model is currently tested against bank erosion data from the Odense Fjord Catchment, as bank erosion is the main source of phosphorus transported in the Odense River and its tributaries.

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