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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.

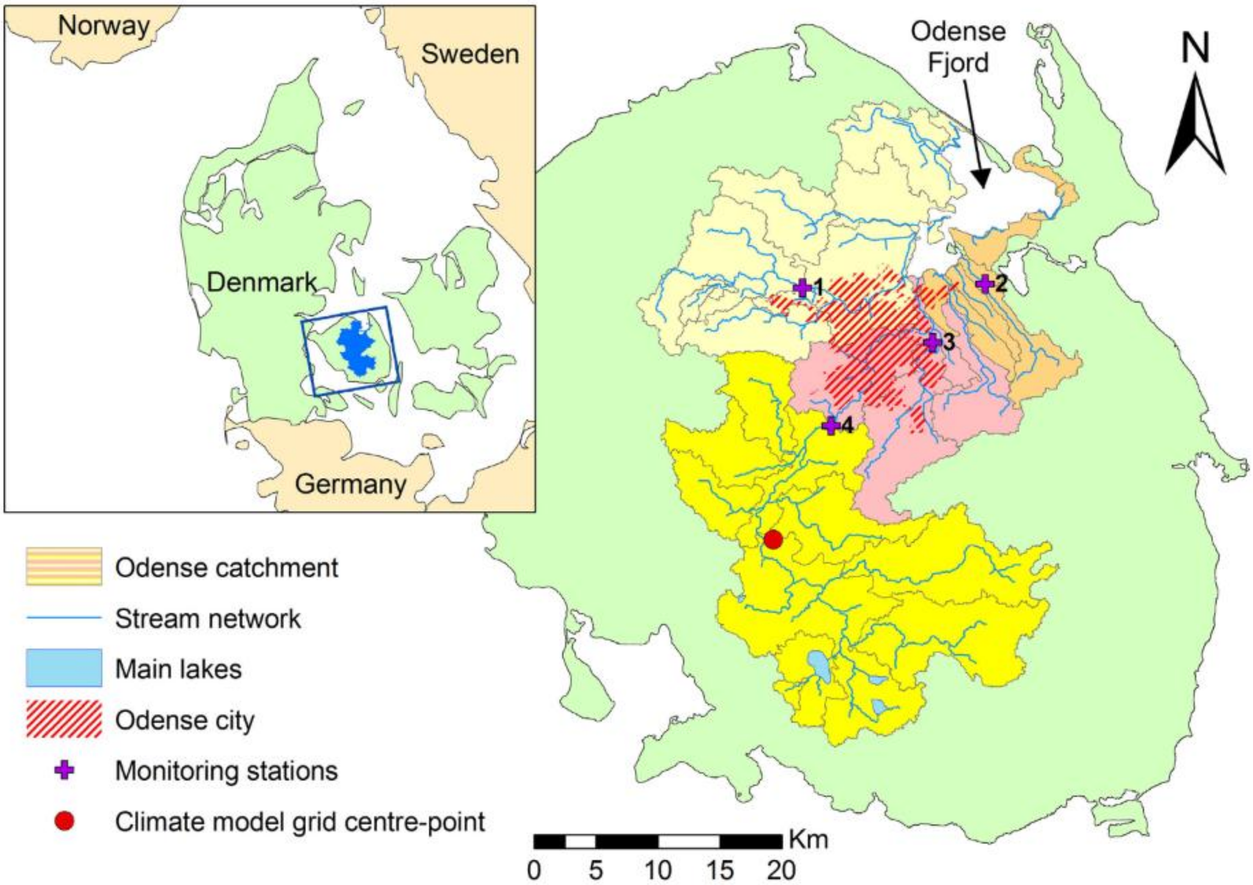

Figure 1. Location of the Odense Fjord Catchment in Denmark and overview of the stream network, large lakes, and monitoring stations (from Molina-Navarro et al., 2018)

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)	2025.61.0.2.11-104-gfcb8738	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	3 stations	Downloaded from odaforalle.au.dk.
Nitrogen loads	daily	1 station	Downloaded from odaforalle.au.dk. provide internally, daily is calculated from grab samples

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+.

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: 0-9999%

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 the 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, a farm type was assigned to each field in the Odense Fjord Catchment. 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.

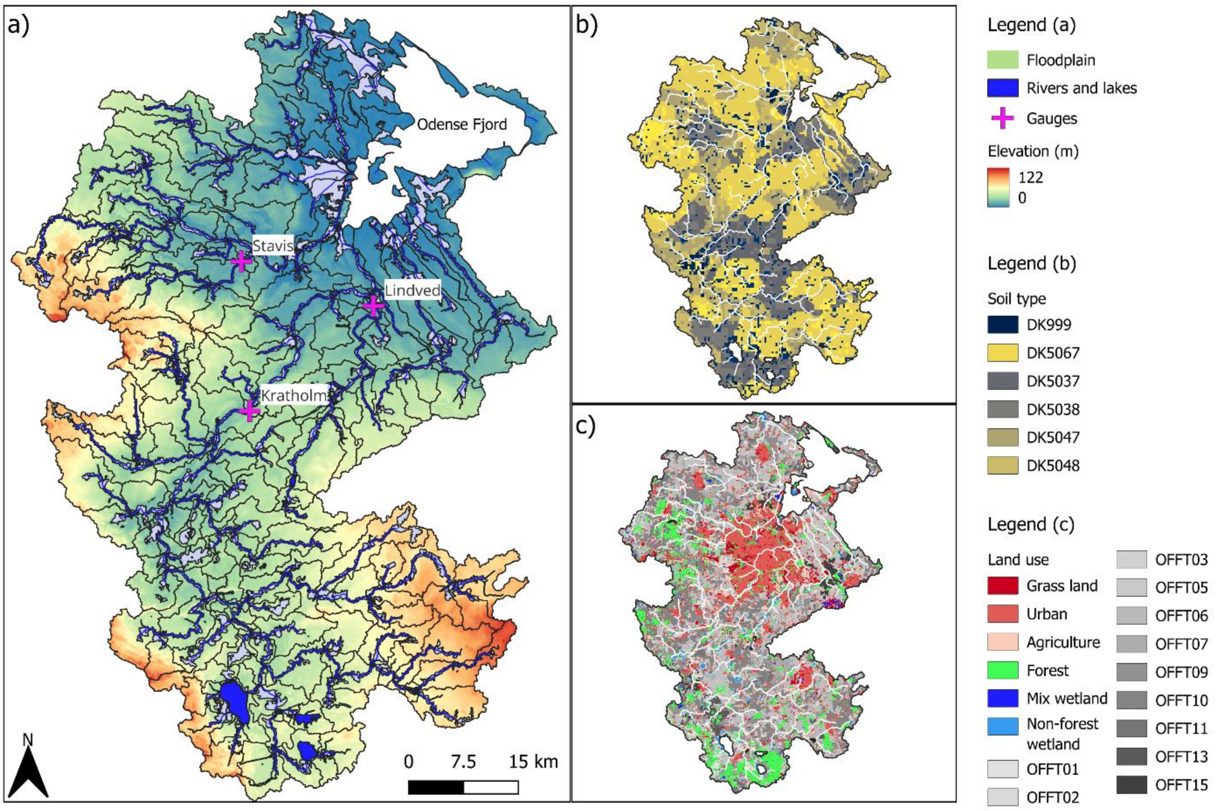

Figure 2. (a) Watershed, subbasins, lakes, and streams delineated by SWAT+ with floodplain delineation, also the monitoring gauges used for calibration and validation; (b) soil types (see Appendix A, Table 1A for the physical properties of the Danish soils); (c) land use (the OFFT land uses represent the different farm types in the Odense Fjord Catchment. More information on the crop rotations used for the farm types can be found in Table 1 and in the SWAT+ input files landuse.lum and management.sch).

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 and channels:	213
LSUs:	420 (including both upslope and floodplain LSUs)
HRUs:	13630
Number of lakes:	8

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

Soft calibration

The soft calibration was performed using SWATtunR, a tool developed in R to run, evaluate, and modify SWAT+ (see https://github.com/biopsichas/SWATtunR). The tool offers two steps for soft calibration: crop and water yield. Here we applied only the crop calibration; the most important water yield parameters (esco and epco) were incorporated during the hard calibration process. For the crops, values of maximum, minimum, and average observed yields were used for comparison. First, the days to maturity of each crop were tuned to match the crop characteristics and the implemented management schedules (Figure 3). Second, additional crop parameters were fine-tuned (Figure 4).

Figure 3 shows the crops selected for soft calibration: corn, barley (dk_barl), rapeseed (dk_cana), potatoes (dk_pota), winter wheat (dk_wwht), field peas (dk_fpea), and oats. The “dk” in the name-code indicates that the crop type was previously adjusted for Danish conditions (e.g., changes in base temperature). The final days to maturity were selected based on the PHU fraction at harvest time (within the range of 1 to 1.2), yields (within the range of observed yields), and biomass. The final values were corn = 50, barley = 95, rapeseed = 100, potatoes = 120, winter wheat = 110, field peas = 120, and oats = 100.

Figure 4 shows the variation in four plant parameters (lai_pot, harv_idx, tmp_base, and bm_e) during the second step of crop evaluation. The parameters were modified across 100 simulations, and the best value was selected based on comparison with observed yields (https://www.statistikbanken.dk/HST77). Figure 5 shows the results for the final parameters for PHU (plant heat unit) fraction at harvest, yield, and biomass. The simulated crop yields are all within the Danish yield norms. Figure 6 shows the water balance components after the soft calibration; the results align with expectations for Danish catchments.

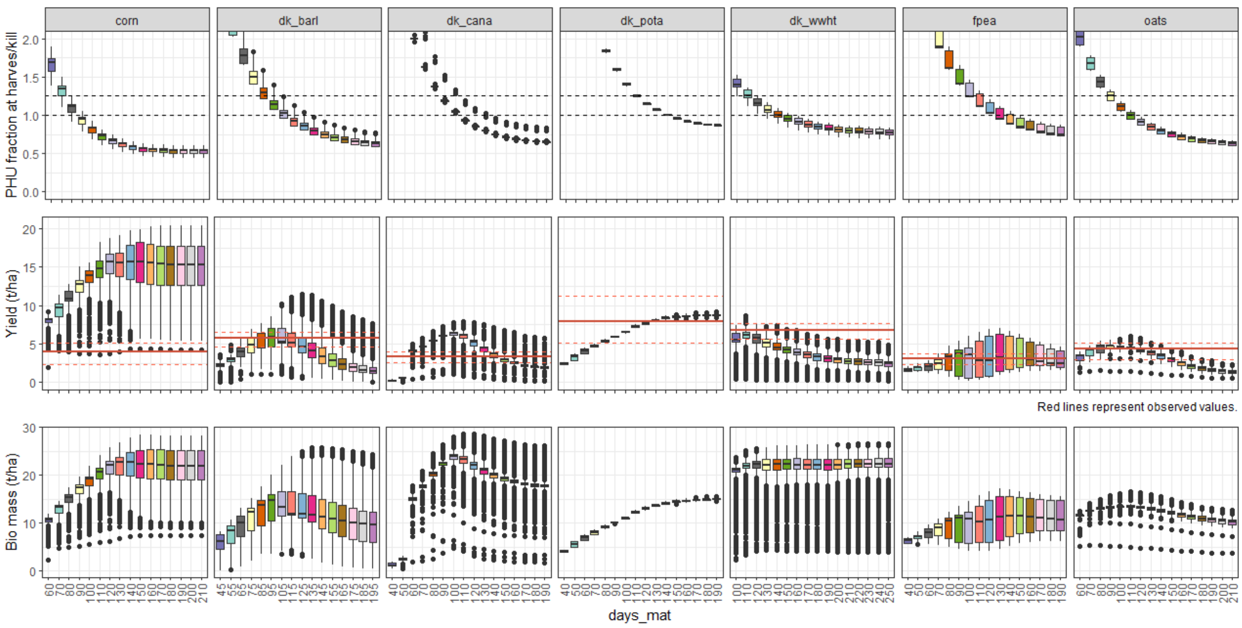

Figure 3. Crops selected for soft calibration; each box plot represents a different day to maturity for simulation. The crops are corn, barley (dk_barl), rapeseed (dk_cana), potatoes (dk_pota), winter wheat (dk_wwht), field peas (dk_fpea), and oats.

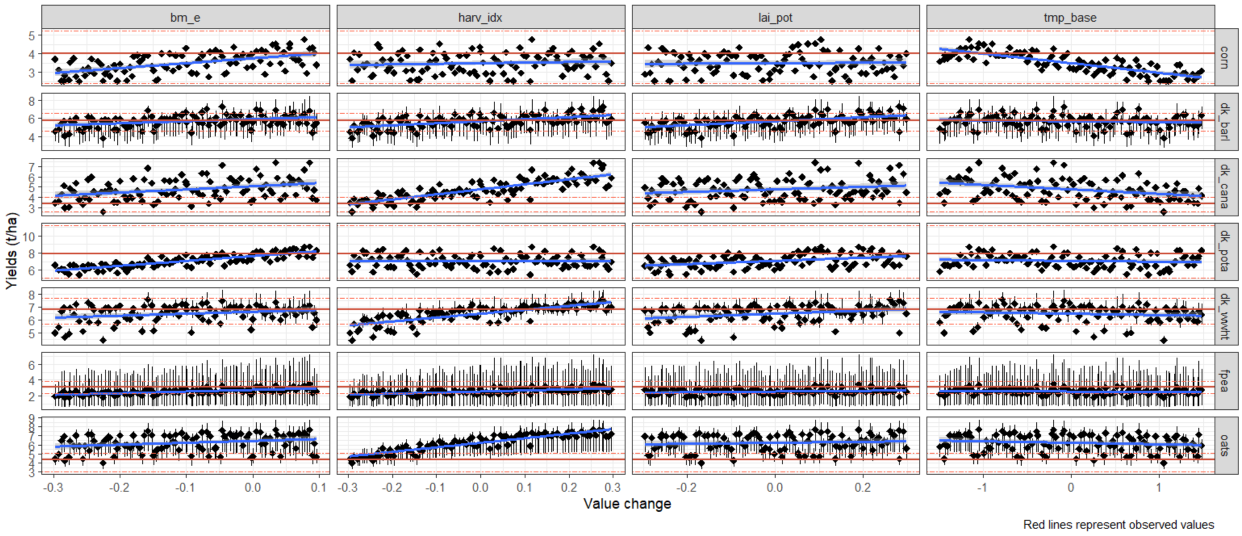

Figure 4. Crop parameter calibration for 100 simulations. The following types of change and parameter ranges were used: lai_pot: relative change, -0.3, 0.3; harv_idx: relative change, -0.3, 0.3; tmp_base: absolute change, -1.5, 1.5; bm_e: relative change, -0.3, 0.1. The relative change will increase or decrease the initial value by a relative value, and the absolute change will add or subtract an absolute value to the initial value.

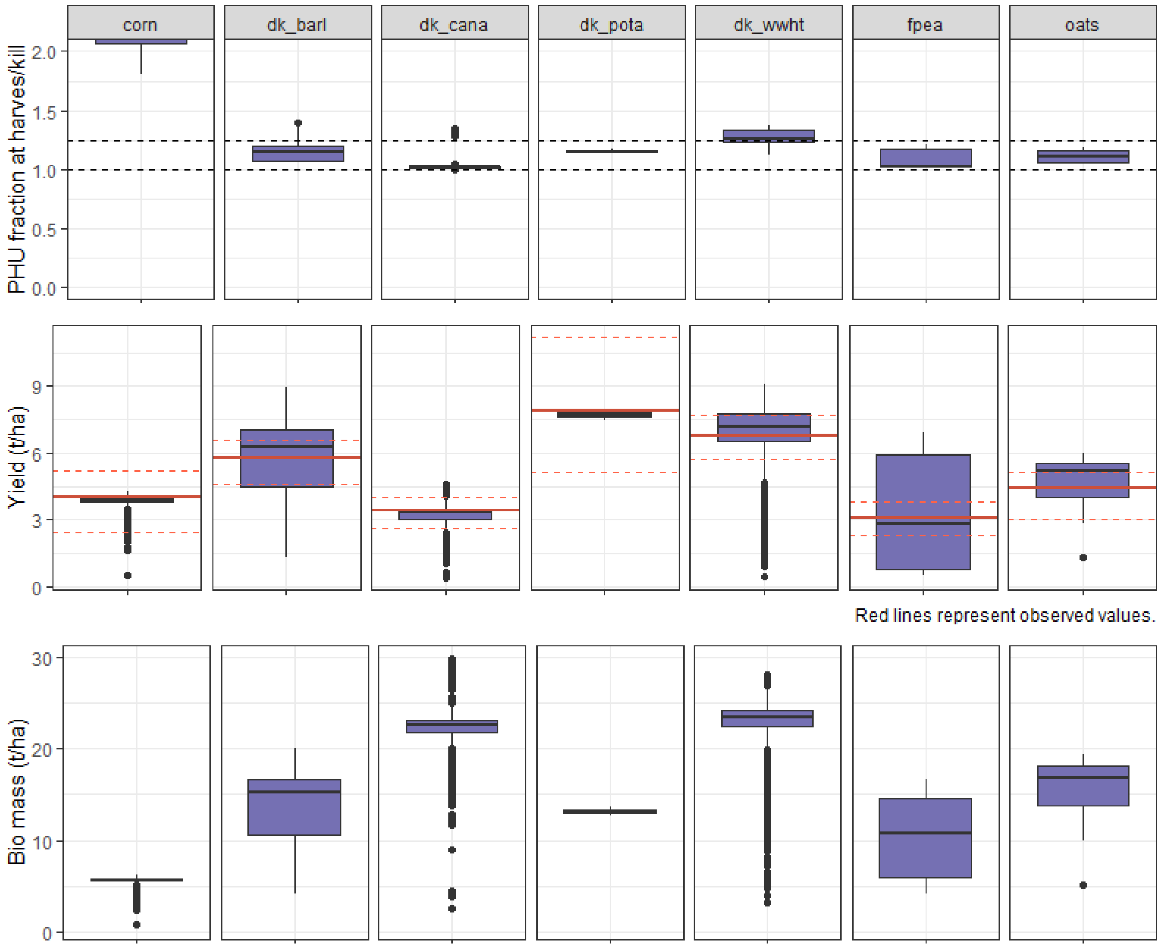

Figure 5. Boxplots of the ranges of biomass, yield, and PHU fraction at harvest across all HRUs in the Odense Fjord Catchment after calibration of crop yields.

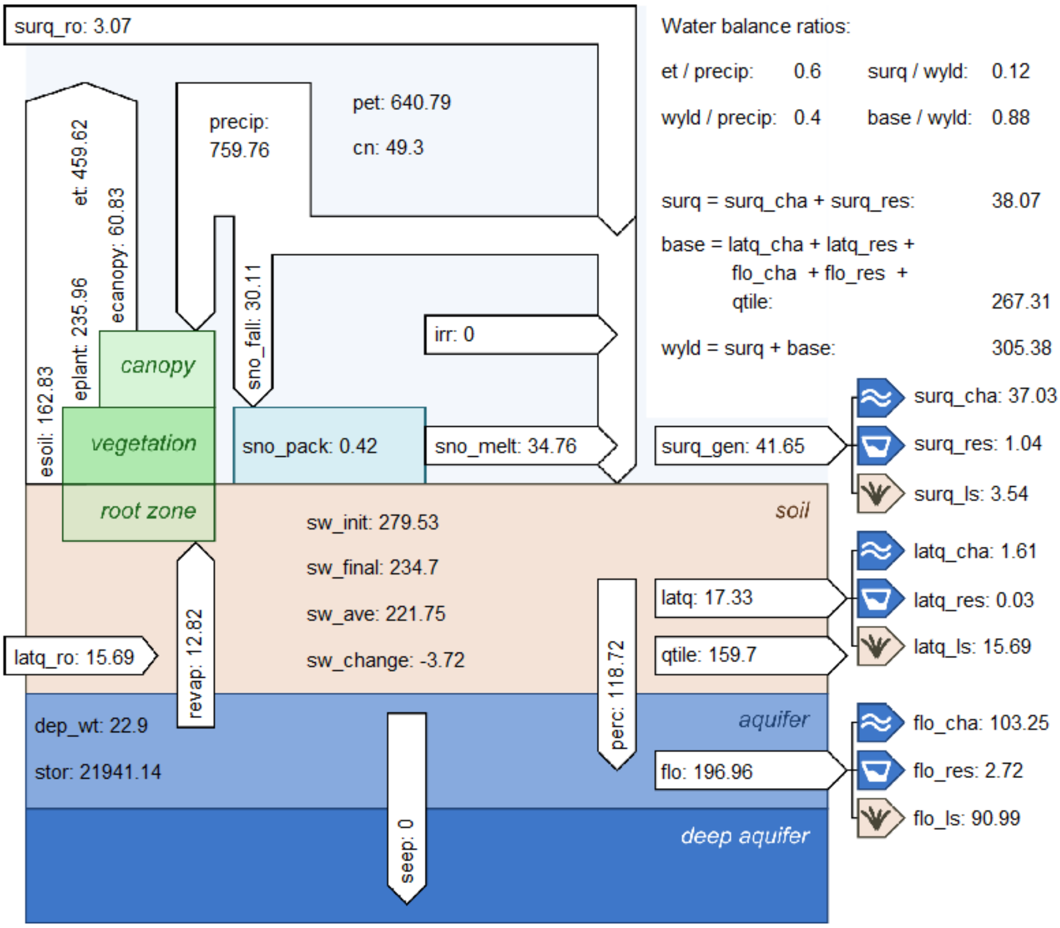

Figure 6. Water balance components after the soft calibration.

Hard calibration

Hard calibration and validation of daily discharge and total nitrogen was performed at three gauges for streamflow and one gauge for total nitrogen: Odense Å at Kratholm (discharge and total nitrogen), Stavis Å (discharge), and Lindved Å (discharge). The following time periods were used:

- Model warm-up: 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, 1200 values were sampled within the range specified in Table 2 using Latin Hypercube Sampling and simulations were run using the resulting 1200 parameter sets. The 1200 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 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 was reasonable.

*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 percentage value), minimum and maximum value, and final value after calibration. *d = discharge; n= total nitrogen.*

Parameter	Parameter description	Type of change*	range		Final value
			min	max	
surlag	Surface runoff lag coefficient (none)	absval [d]	0.162	0.48	0.205
esco	Soil evaporation compensation factor (none)	absval [d]	0.123	0.368	0.1
epco	Plant uptake compensation factor (none)	absval [d]	0.241	0.722	0.4
awc	Available water capacity of the soil layer (mm/mm)	relchg [d]	-4.4	-13.2	-12
cn2	Curve Number for moisture condition II (none)	abschg [d]	-4.12	-12.35	-11
ovn	Overland flow Manning’s n value (none)	abschg [d]	0.14	0.421	0.24
tile_dep	Depth of drain tube from the soil surface (mm)	absval [d]	800	1306	861
tile_dtime	Time to drain soil to field capacity (h)	absval [d]	29	87	75
tile_lag	Drain tile lag time (h)	absval [d]	27	81	77
tile_drain	Drainage coefficient (mm/day)	absval [d]	17	50	20
cn3_swf	Soil water adjustment factor for CN3 (none)	abschg [d]	0.077	0.231	12
lat_ttime	Lateral flow travel time (days)	absval	3.5	10.4	4.4
latq_co	Lateral flow coefficient (none)	abschg [d]	0.034	0.102	0.059
k	Hydraulic conductivity of the soil layer (mm/h)	relchg [d]	48	144	118
z	Depth of the soil layer (mm)	relchg [d]	9	26	13
perco	Percolation coefficient (none)	abschg [d]	-0.061	-0.182	-0.12
alpha	Alpha factor for groundwater recession curve (none)	absval [d]	0.025	0.25	0.043
sp_yld	Specific yield of the aquifer (m3/m3)	absval [d]	0.127	0.38	0.24
chn	Channel Manning’s value	relchg [d]	1.5	4.4	2.5
erorgn	Organic nitrogen enrichment ratio	absval [n]	0	5	4.7
biomix	Biological mixing efficiency	absval [n]	0	1	0.99
lat_orgn	Organic nitrogen concentration in lateral flow	absval [n]	0	200	31
cbn	Amount of organic carbon in the layer (%)	absval [n]	0.05	10	3.85
cmn	Rate coefficient for mineralization of the humus active organic nutrients	abschg [n]	0.001	0.003	0.003
nperco	Nitrate percolation coefficient	abschg [n]	0	1	0.5
cdn	Rate coefficient for denitrification	absval [n]	2.5	3	2.9
sdnco	Threshold value of nutrient cycling water factor for denitrification to occur	absval [n]	0.01	0.85	0.69
n_updis	Nitrogen uptake distribution parameter	absval [n]	1	10	3
organicn	Fraction of fertilizer that is organic N	absval [n]	1	90	50
cbn_init	Initial amount of organic carbon in the layer	absval [n]	1	20	3
hlife_n	Half-life of nitrate in the shallow aquifer (days)	abschg [n]	1	365	343
no3_init	Initial nitrate in the aquifer	absval [n]	1	30	9

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	0.77	0.90	-15.7	-6.7	0.81	0.86
Stavis Å	0.83	0.77	11.1	17.7	0.73	0.69
Lindved Å	0.86	0.74	-4.2	11.9	0.73	0.71

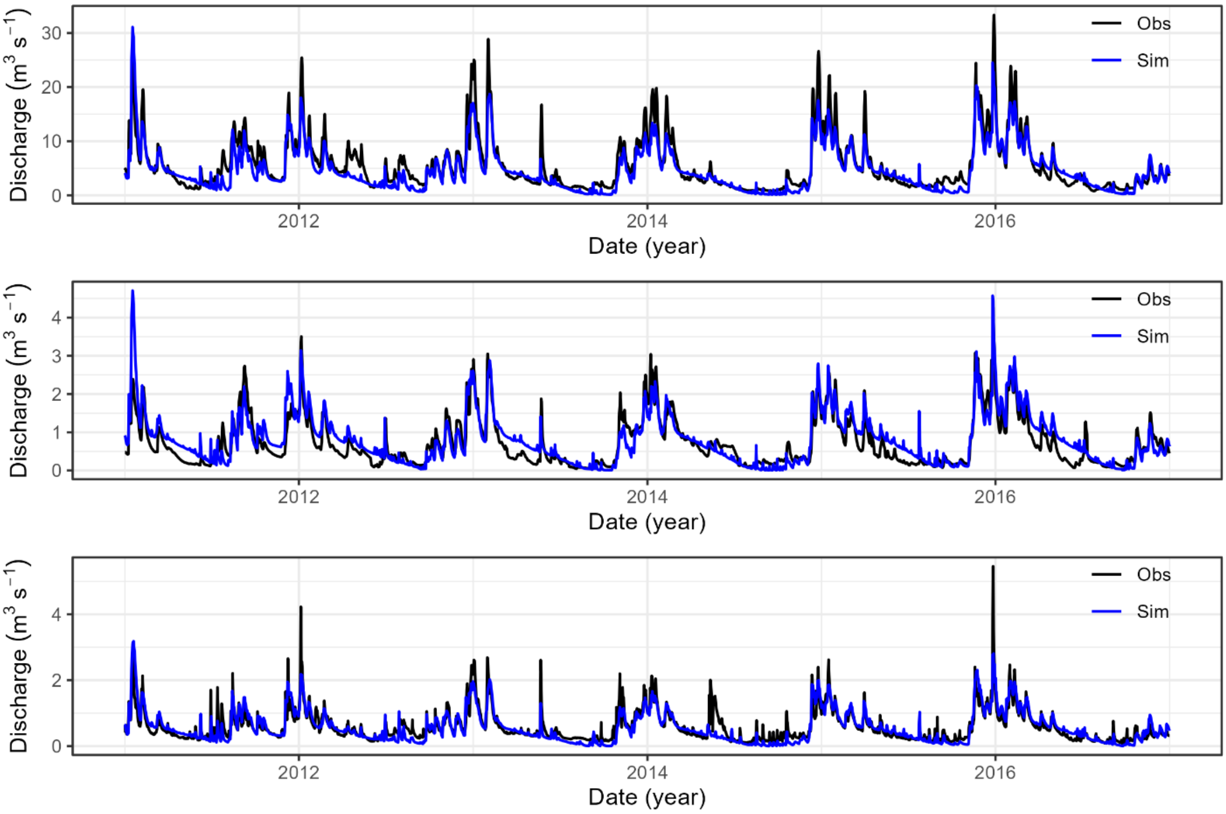

Figure 3. Observed and simulated discharge for Odense Å at Kratholm, Lindved Å and Stavis Å during the calibration period.

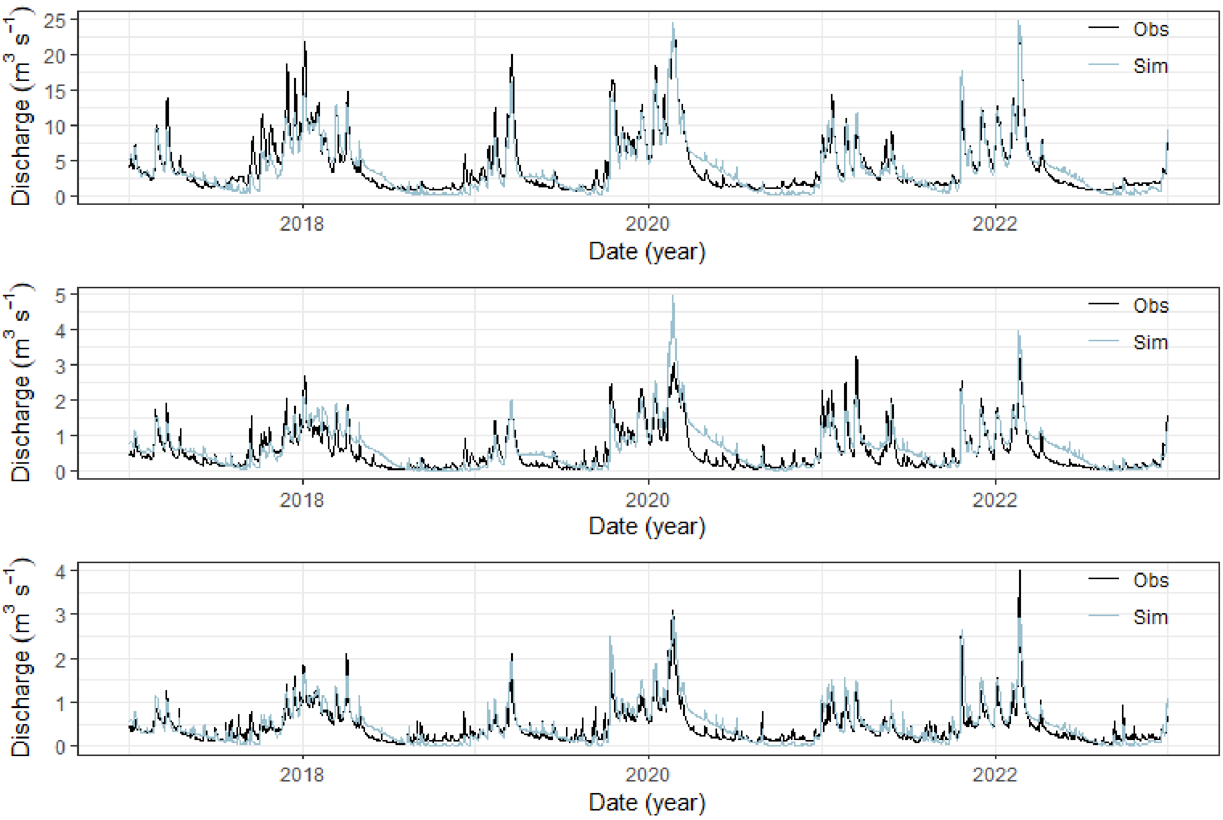

Figure 4. Observed and simulated discharge for Odense Å at Kratholm, Lindved Å, and Stavis Å during the validation period.

Automatic calibration of total nitrogen followed the same approach as for discharge. During the calibration, the best parameters identified during the streamflow calibration were fixed, while the total nitrogen parameters were sampled 300 times using Latin Hypercube sampling (Table 2). The 300 total nitrogen calibration runs were ranked based on the fit between observed and simulated values (NSE, KGE, and Pbias), and the run that ranked highest was selected. Figures 5 and 6 show the time series of observed versus simulated values for calibration and validation, respectively.

Table 4. Model evaluation statistics for daily total nitrogen load during the calibration (Cal) and validation (Val) periods.

Gauge	KGE		Pbias		NSE	
	Cal	Val	Cal	Val	Cal	Val
Odense Å at Kratholm	0.75	0.90	-14.9	-4.1	0.58	0.83

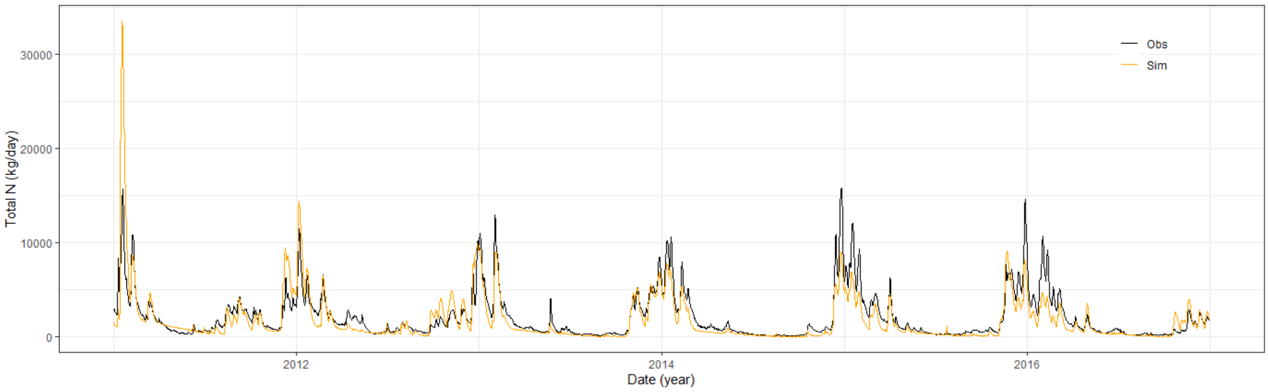

Figure 5. Observed and simulated total nitrogen for Odense Å at Kratholm during the calibration period.

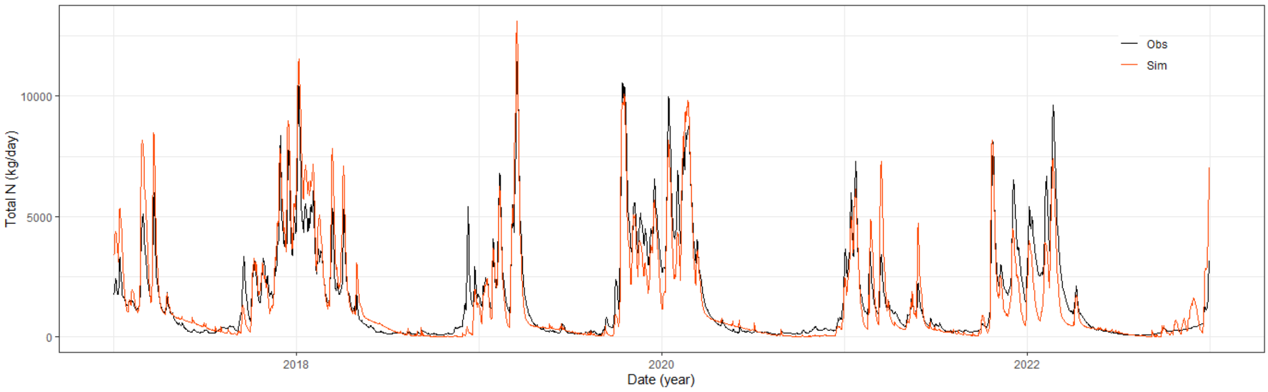

Figure 6. Observed and simulated total nitrogen for Odense Å at Kratholm during the validation period.

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, discharge, and total nitrogen. 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. A meaningful calibration of phosphorus loads can only be achieved once the bank erosion algorithms in SWAT+ have been tested and potentially adjusted to reflect Danish conditions and is thus not included in this report.

References

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.

Gupta HV, Kling H, Yilmaz KK, Martinez GF, 2009. Decomposition of the mean squared error and NSE performance criteria: Implications for improving hydrological modelling. Journal of Hydrology 377:80–91.

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.

Nash JE, Sutcliffe JV, 1970. River flow forecasting through conceptual models Part I - A discussion of principles. Journal of Hydrology 10:282–290.

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.

Sechu GL, Nilsson B, Iversen BV, Greve MB, Børgesen CD, Greve MH, 2021. A Stepwise GIS Approach for the Delineation of River Valley Bottom within Drainage Basins Using a Cost Distance Accumulation Analysis. Water 13:827.

Appendix A

The soil map was derived from approximately 45,000 soil samples, which were interpolated using ordinary kriging (Greve et al., 2007). Table 1A shows the soil type and parameters used in the model setup.

Table 1A. Soil types and parameters used for Odense Fjord Catchment.

snam	nlayers	hydgrp	sol_zmx	anion_excl	sol_crk	texture	sol_z1	sol_bd1	sol_awc1
DK999	3	A	800	0.5	0.5	fk4	300	0.7	0.24
DK5037	3	A	1500	0.5	0.5	fk3	300	1.48	0.18
DK5038	3	A	1000	0.5	0.5	fk3	300	1.4	0.19
DK5047	3	A	1500	0.5	0.5	fk3	300	1.41	0.19
DK5048	3	A	1000	0.5	0.5	fk3	300	1.38	0.2
DK5067	3	B	1500	0.5	0.5	fk4	300	1.54	0.18
snam	**sol_k1**	**sol_cbn1**	**clay1**	**silt1**	**sand1**	**rock1**	**sol_alb1**	**usle_k1**	**sol_ec1**
DK999	23.43	12.6	8.71	14.83	76.45	0	0.01	0.21	0
DK5037	26.98	1.45	7.99	15.51	76.5	0	0.01	0.22	0
DK5038	35.14	1.45	7.99	15.51	76.5	0	0.01	0.2	0
DK5047	27.73	1.4	8.71	20.06	71.23	0	0.01	0.23	0
DK5048	30.54	1.4	8.71	20.06	71.23	0	0.01	0.22	0
DK5067	15.86	1.42	12.5	22.63	64.87	0	0.01	0.24	0
snam	**sol_z2**	**sol_bd2**	**sol_awc2**	**sol_k2**	**sol_cbn2**	**clay2**	**silt2**	**sand2**	**rock2**
DK999	700	0.9	0.22	13.87	7.93	9.4	12.81	77.79	0
DK5037	700	1.7	0.15	6.43	0.59	15.86	21.14	63	0
DK5038	700	1.46	0.17	20.14	0.57	7.98	16.16	75.86	0
DK5047	700	1.7	0.15	6.43	0.59	15.86	21.14	63	0
DK5048	700	1.46	0.17	20.14	0.57	7.98	16.16	75.86	0
DK5067	700	1.7	0.15	6.43	0.59	15.86	21.14	63	0
snam	**sol_alb2**	**usle_k2**	**sol_ec2**	**sol_z3**	**sol_bd3**	**sol_awc3**	**sol_k3**	**sol_cbn3**	**clay3**
DK999	0.01	0.21	0	1200	1.6	0.16	11.94	0.64	9.59
DK5037	0.01	0.22	0	1200	1.67	0.15	6.38	0.15	18.96
DK5038	0.01	0.2	0	1200	1.66	0.15	10.86	0.16	8.22
DK5047	0.01	0.23	0	1200	1.67	0.15	6.38	0.15	18.96
DK5048	0.01	0.22	0	1200	1.66	0.15	10.86	0.16	8.22
DK5067	0.01	0.24	0	1200	1.67	0.15	6.38	0.15	18.96
snam	**silt3**	**sand3**	**rock3**	**sol_alb3**	**usle_k3**				
DK999	16.05	74.36	0	0.01	0.21				
DK5037	20.21	60.83	0	0.01	0.22				
DK5038	13.37	78.4	0	0.01	0.2				
DK5047	20.21	60.83	0	0.01	0.23				
DK5048	13.37	78.4	0	0.01	0.22				
DK5067	20.21	60.83	0	0.01	0.24				