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SWAT+ model protocol for Hobølelva catchment, Norway

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Introduction

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.

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)

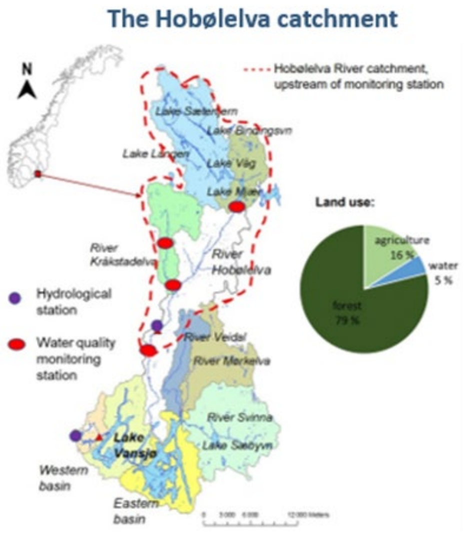

Figure 1. The Hobølelva catchment within the Vansjø-Hobøl river system

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/
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
Miljøtools Handling MetNordic	0.3.2	R-package for downloading the Met Norway re-analyses dataset https://moritzshore.github.io/miljotools/
SWATprepR (input data preparation)	1.0.4	R-package for preparing input data for the SWAT+ model. https://biopsichas.github.io/SWATprepR/
SWATdoctR (model setup verification)	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
SoftCal	0.2.0.	R-script for SWAT+ model soft calibration, focusing specifically on crop parameters, crop development and yields. Available from EU OPTAIN Project coordinators (UFZ) up to request.
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
SWATrunR	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 km grid	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 km grid	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.
Relative humidity	Daily	1 km grid	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.
Wind speed	Daily	1 km grid	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.
Radiation	Daily	1 km grid	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.

GIS input data used

Data	**Map**	**Resolution**	**Availability**
DEM	SRTM	10m raster	Terrain model of Norway in UTM33. The database can be downloaded from the Norwegian national website for map data and location information in Norway. https://hoydedata.no/LaserInnsyn2/ https://nedlasting.geonorge.no/Help/Api/GET-api-capabilities-metadataUuid
Landuse	Corine	100m raster	The CORINE Land Cover (CLC) inventory from 2018. Raster and SWAT+ lookup table downloaded from https://wateritech.com/datalab. Dataset may be cited as EEA (2018).
Soil for cultivated areas	Jordsmonn	1km raster	Raw vector layer of soil types for agricultural areas (Jordsmonn, NIBIO) https://kart8.nibio.no/nedlasting/dashboard
Soil for forested areas	Løsmasser	raster	Soil forming materials, derived from the geological map of Norway (Løsmasser, NGU) for the forested areas. https://www.ngu.no/geologiske-kart/datasett
Lakes (optional)	HydroLakes	Vector (shape file)	https://temakart.nve.no/link/?link=innsjodatabase; https://www.hydrosheds.org/products/hydrolakes In Norway there are only information for large lakes. In this study we also rely on global lake database which has information for lakes larger than 10ha. I.e. seven lakes of our case study.
Rivers (optional)	Channel layer	Vector (shape file)	Catchment boundaries and stream network from the Norwegian Water and Energy Directorate (NVE) https://nedlasting.nve.no/gis/ and https://nevina.nve.no/
Catchment boundary (optional)		Vector (shape file	

Stream discharge data used for calibration

Data	**Temporal resolution**	**Spatial resolution**	**Availability**
Stream discharge	daily	Provided from Høgfoss monitoring station	Observed daily discharge data was downloaded from https://hip.dataforsyningen.dk/ for the Grejs river “Planteskolen” station, and the Vejle river “Haraldskær” station, respectively.
Stream TN and TP concentrations	Every 2nd week or monthly	Provided from Kure monitoring station	

Additional data

Atmospheric deposition	European Monitoring and Evaluation Programme (EMEP)	EMEP data was processed using SWATprepR
Crop sequence map	Ministry of Agricultural register on subsidies received by the farmers for implementing various measures	Information on crop sequence was derived from the "subsidy database". Autumn cereals were assumed for areas that were not included in the database.
Management schedules	Norwegian Agricultural Environmental Monitoring Programme (JOVA)	Schedules were derived using information available for the Skuterudbekken catchment, which is located in the neighborhood of the pilot catchment. The JOVA database contains field-level detailed information for Skuterud on management and crop rotations for 30 years.

Model setup

Delineation

Channel threshold: 2.5 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). This threshold was adjusted to the size of the catchment. Before using the final value, several other options were tested visually.

Stream threshold: 12.5 km^2 (minimum size of sub-watershed, where a main stream is created)

Upslope/Floodplain LSUs: This is optional and was not used in the Hobølelva SWAT+ setup.

Lakes: The Global Lake Database was used to implement the lakes in the model setup.

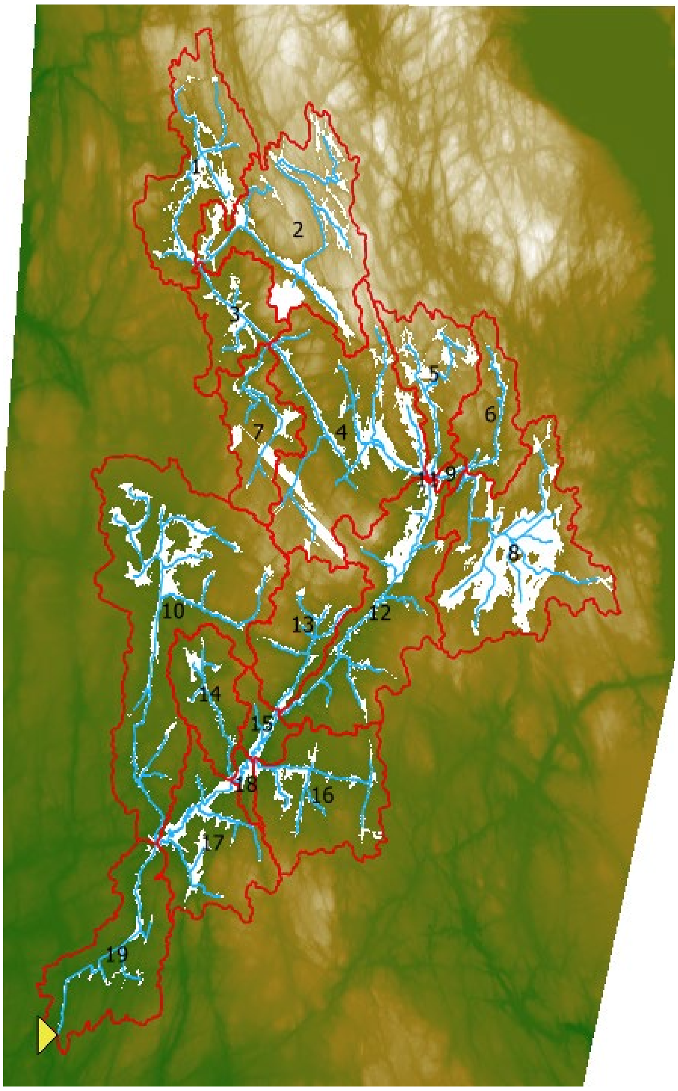

Figure 1. Watershed, subbasins and streams delineated by SWAT+ with floodplain delineation (areas delineated as floodplains are indicated by white areas). The stream gauge stations at Hobølelva river (Høgfoss, at outlet of channel # 184) is indicated by a yellow triangle.

HRU creation

The HRU's were creating using the land use map, the soil map and the defined slope classes. The following maps and tables were used:

Land use	Corine land cover raster by EEA 2018 and lookup table by NIBIO ECOSAFE team.
Soil	Soil map created by the NIBIO ECOSAFE team using the Jordsmonn soil raster (NIBIO) and the geological map of Norway (NGU). The look up table was taken from the OPTAIN project SWAT+ setup for Kråkstadelva, which contained almost all the needed soil types (Shore and Farkas, 2023). For the remaining soil types pedotransfer functions were used.
Slope classes	4 classes (0-2%, 2-6%, 6-10% and > 10%).
HRU filtering	5% threshold for landuse, 10% for soil type and slope class.

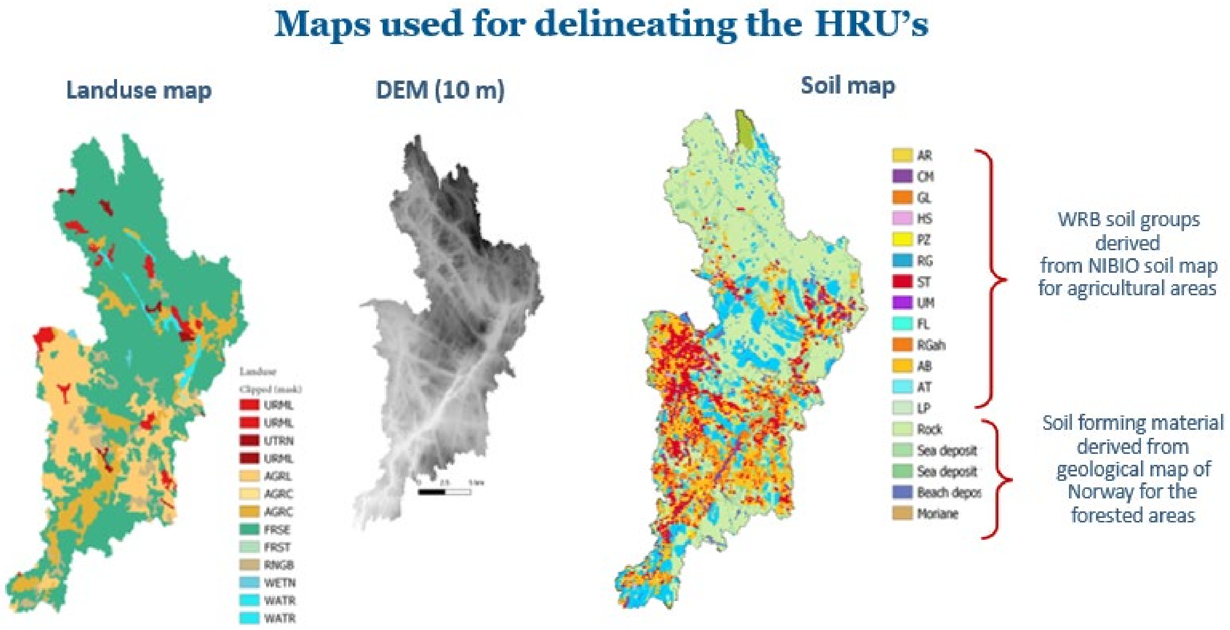

Figure 2. Illustration of the maps used for HRU delineation

Final configuration:

# Total watershed area:	334.8 km^2
# Subbasins:	19
# LSUs:	184
# HRUs	2,706

Selecting the method for calculating the potential evapotranspiration

SWAT+ includes the choice of different evapotranspiration methods including Hargreaves, Penmann-Montieth, 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 a pilot area in Norway.

Within the ECOSAFE project, the SWATDoctR R-script was used to compare the two methods in simulating the evapotranspiration for the Hobølelva catchment. The evapotranspiration values simulated using different methods were compared with available data, information from literature review and expert estimates, collected within the frame of the IRIDA project (http://www.waterjpi.eu/joint-calls/joint-call-2015-waterworks-2014/irida). Similarly to the results reported by Trolle and Nielsen (2020), the Penmann-Montieth method performed better for the Hobølelva catchment.

Water abstractions

No water abstraction is included.

Verification, Calibration and Validation

Model calibration consisted of model verification, soft- and hard calibration in accordance with the following steps:

- *Model verification* using SWATdoctR. This R-package includes functions and routines for the evaluation of model performance, visualization, and diagnosis of simulation outputs. The verification of the SWAt+ model setup for Hobølelva was performed using the following steps:
    - Simulation of climate variables for the calibration period and analyzing the water balance components. Literature data, data from monitoring systems and expert judgment were used to verify the potential evapotranspiration (pet), plant transpiration (eplant) and evaporation from soil surface (esoil).

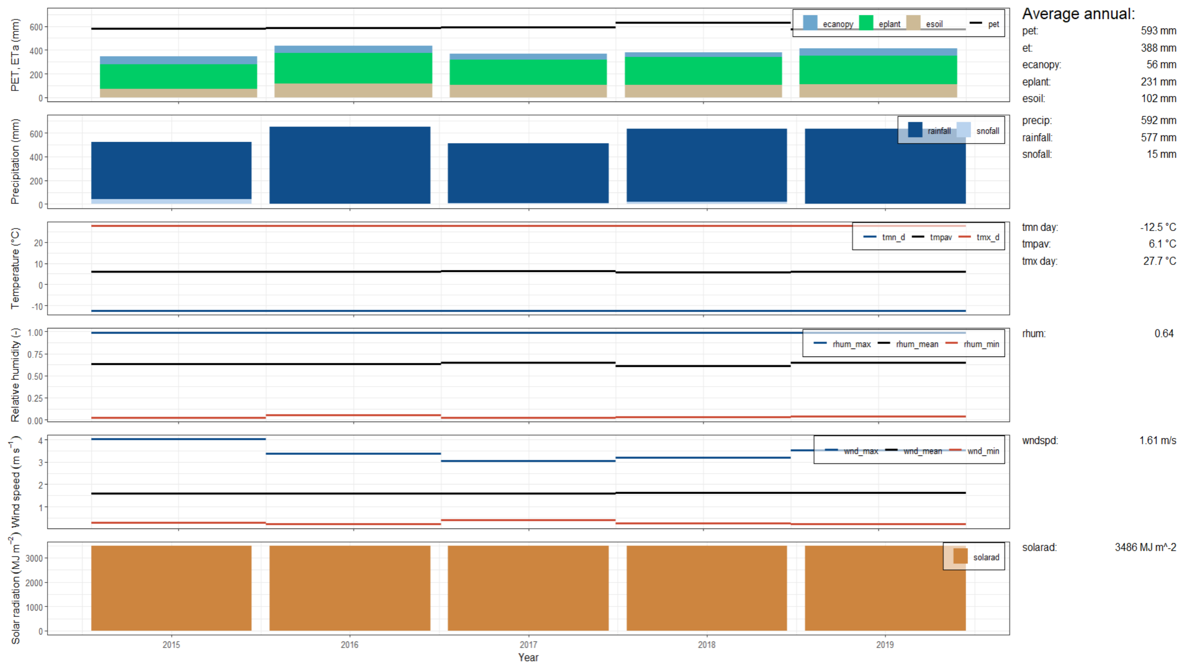

Figure 3. Summary of climate data checks for Hobølelva by the SWATdoctR

- Analyzing the annual average water balance elements with specific focus on water yield, drainage outflow (qtile), baseflow and seepage to the deep aquifer, whether their values and those of other water balance elements meet the expert's expectations.
- Checking the yields for the main crops (winter wheat and summer wheat) if they are comparable with the reported yields for the same period.

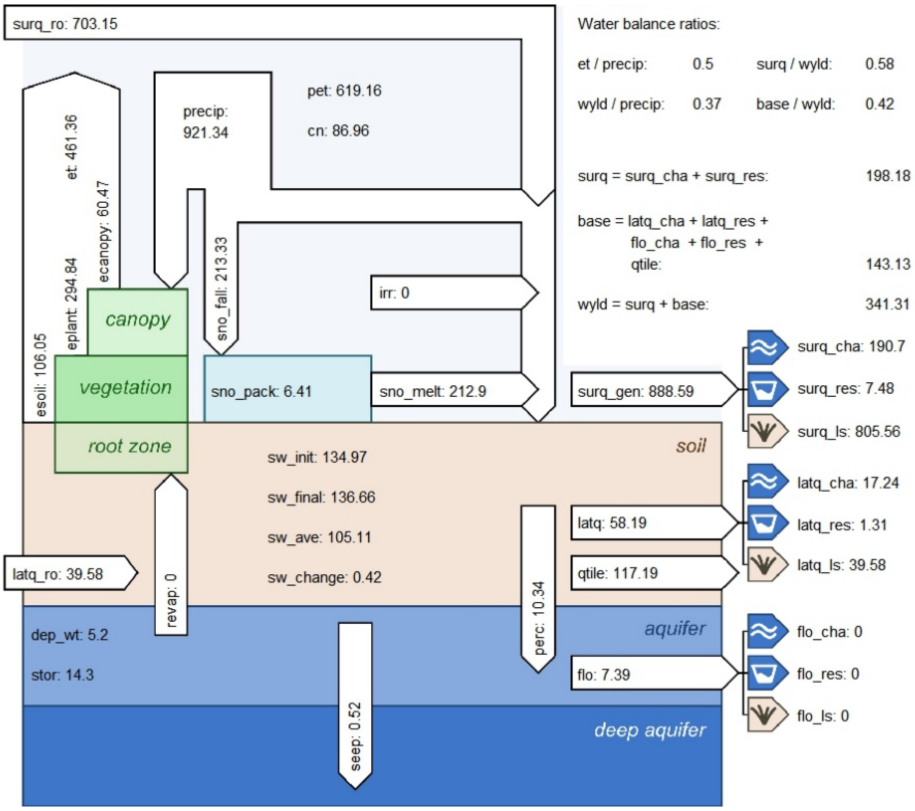

Figure 4. Water balance elements, simulated for the Hobølelva catchment

- *Soft calibration* using the SoftCal R-script developed within the OPTAIN project. The script is capable to adjust the crop parameters via a sensitivity analyses by keeping the simulated yields within the observed range and the potential fraction of heat units at harvest (PHU) between 1 and approx. 1.1.

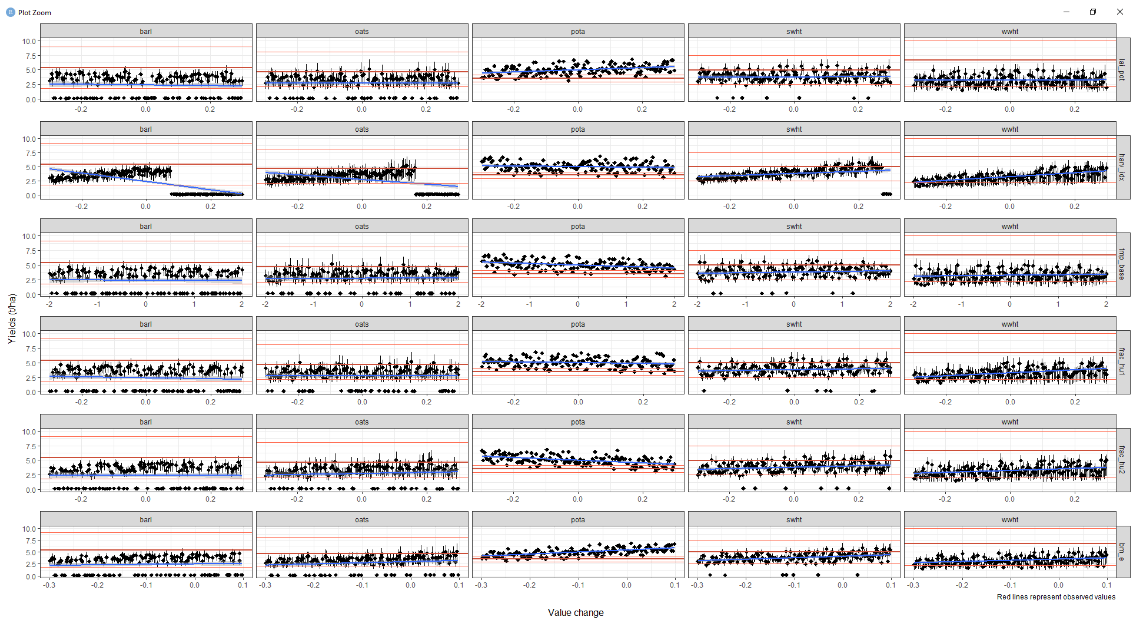

Figure 5. Sensitivity of yield simulated for different crops against various crop parameters.

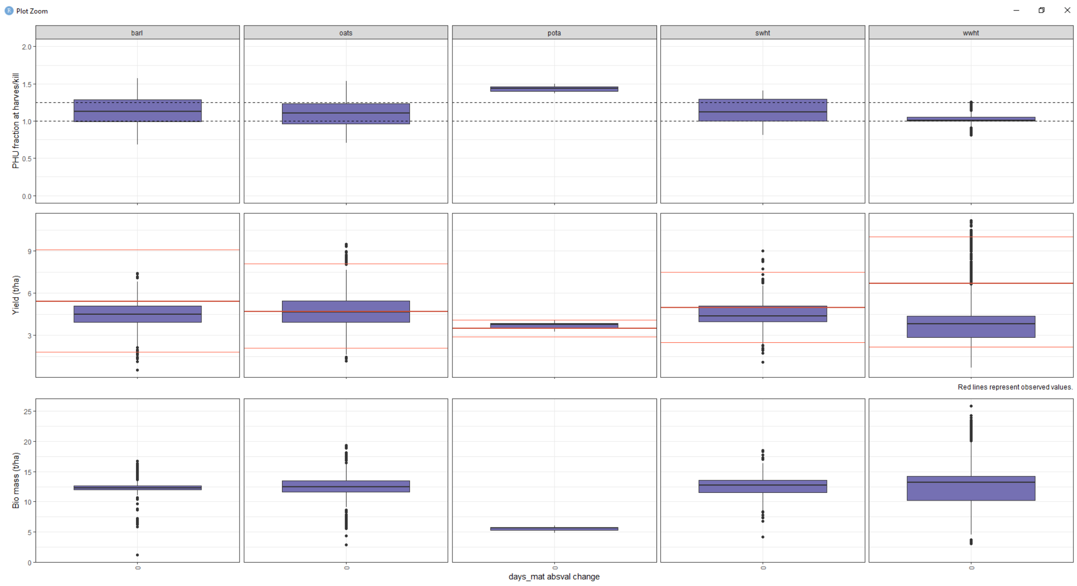

Figure 6. Boxplots of simulated yields, biomass and PHU values.
Red lines represent observed data (yields) and expected PHU range.

- *Hard calibration* using SWATrunR. The calibration was performed by optimization of the Nash-Sutcliffe Efficiency (NSE). 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 followed time periods were used:

  - Warm-up period: 1. January 2012 - 31. December 2013 (2 years)
  - Calibration period: 1 January 2014 - 31. December 2016 (2 years)
  - Validation period: 1 January 2017 - 31. December 2018 (1 year)

Table 1. Crop parameters variations for target PHU fraction and yields calibration (Absolute change ** Relative change).*

parameter	Crops				
	barl	oats	pota	swht	wwht
	spring barley	spring oats	potato	spring wheat	winter wheat
d_mat*	-10	-5	+50	+5	-40
lai_pot**	0.20	0.25	-0.12	0.10	0.63
harv_idx*	0.11	0.18	-0.20	0.16	0.29
bm_e**	0.00	0.11	-0.17	-0.09	0.00
frac_hu1*	-0.03	-0.03	0.00	0.00	-0.25
tmp_base*	0.0	0.0	-4.4	0.0	0.0
tmp_opt*	-8.0	-0.5	-2.0	-1.0	7.0

Table 2 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	$R^2 > 0.85$	$0.75 < R^2 \le 0.85$	$0.60 < R^2 \le 0.75$	$R^2 \le 0.60$
	Sediment/P	M	$R^2 > 0.80$	$0.65 < R^2 \le 0.80$	$0.40 < R^2 \le 0.65$	$R^2 \le 0.40$
	N	M	$R^2 > 0.70$	$0.60 < R^2 \le 0.70$	$0.30 < R^2 \le 0.60$	$R^2 \le 0.30$
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

[1] D, M and A denote daily, monthly, and annual temporal scales, respectively.
[2] Includes stream flow, surface runoff, base flow, and tile flow, as appropriate, for watershed models.

Table 3. Performance of SWAT+ model the Hobølelva river at Høgfoss

	CALIBRATION				**VALIDATION**			
	DAY		MONTH		DAY		MONTH	
NSE	0.73	good	0.84	very good	0.70	good	0.74	good
PBIAS	3.3	very good	3.3	very good	6.2	good	6.2	good

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

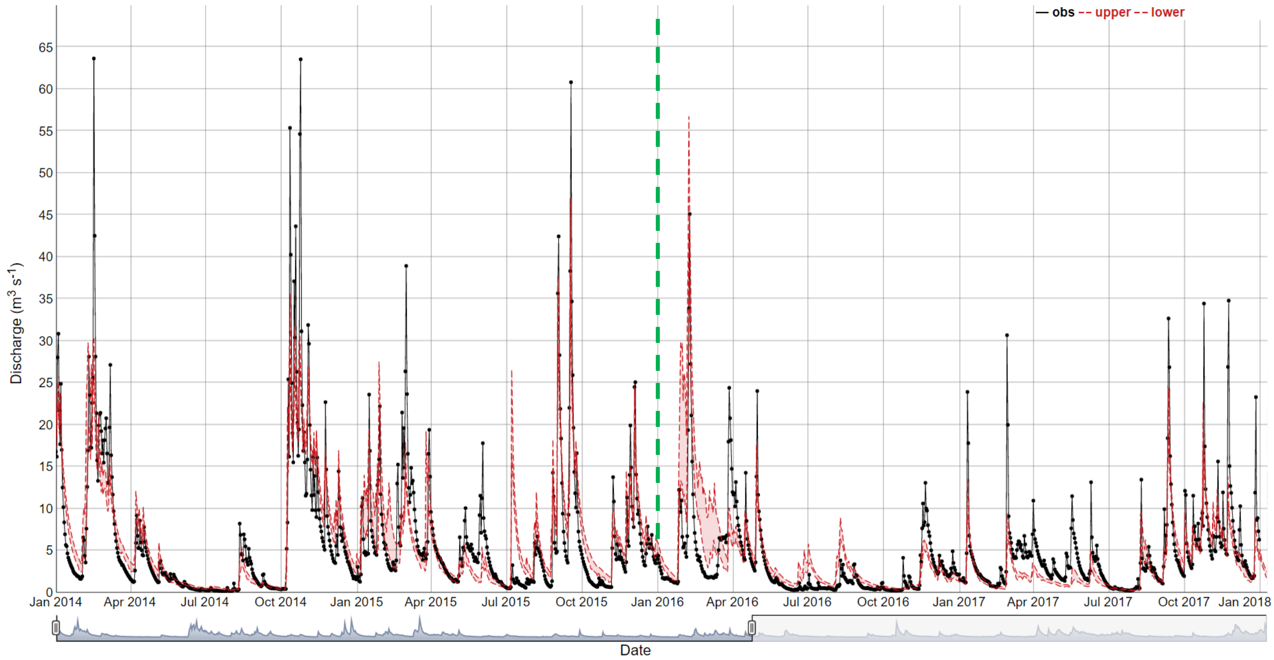

Figure 7. Observed and simulated discharge for Hobølelva river, at the "Høgfoss" gauge station for the calibration (2014-2015) and validation (2016-2017) periods for the calibrated model.

Summary

A SWAT+ model was set up from scratch for the Hobølelva catchment rivers systems. Data used in the SWAT+ project are all available at national level, and therefore the SWAT+ approach used in the project can be applied all across Norway. The SWAT+ model was calibrated on a daily time step and produced generally very good results for river discharge at the Høgfoss monitoring station.

The calibration work for water quality indicators is still in progress. We use the SWATrunR R-package for this, as the SWAT+ Toolbox is not capable to calibrate TN and TP.

References

Please, note, that most of the references are given as links within the text of the report.

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.

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