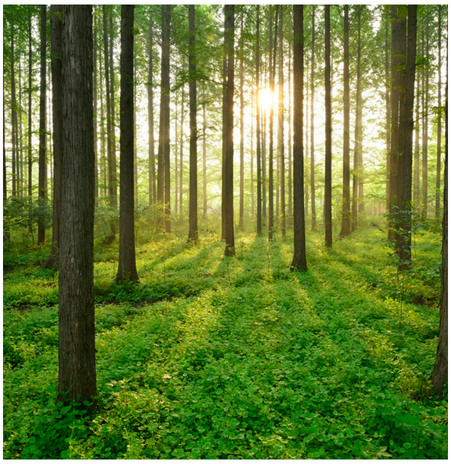
DISTRIBUTED HYDROLOGICAL MODEL SYSTEM IN UMEÄLVEN

REPORT 2023-980



HYDROLOGISKT UTVECKLINGS-
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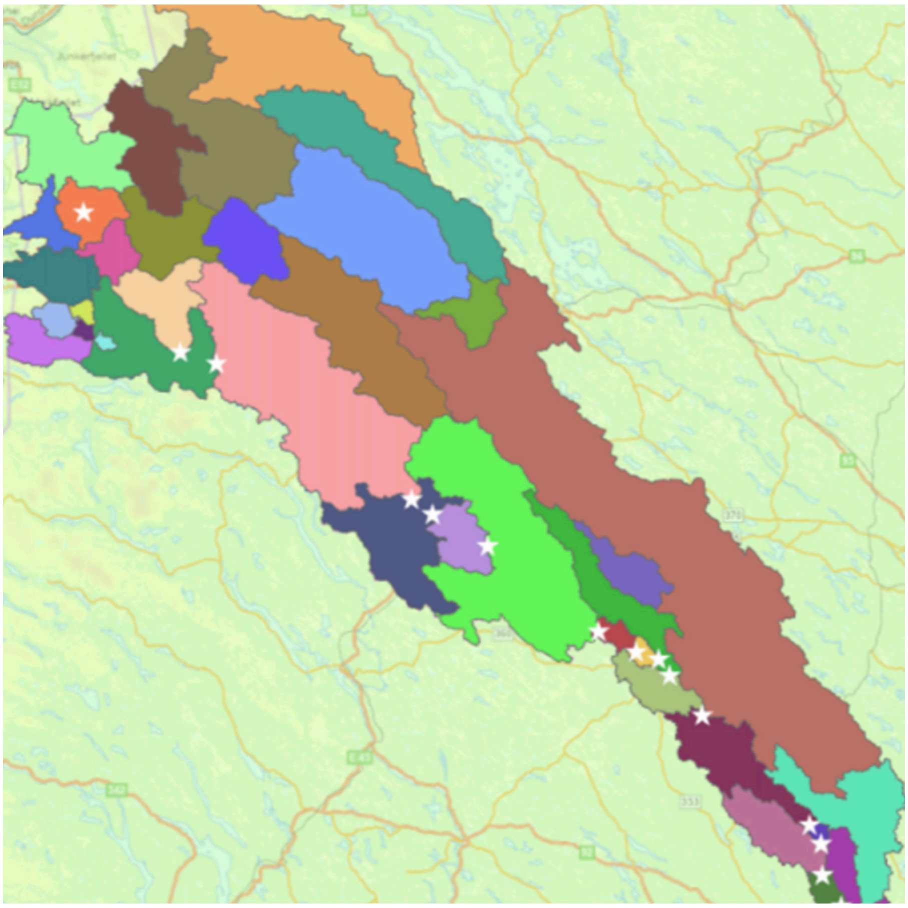

Energiforsk

Distributed hydrological model system ENKI in Umeälven

Demonstration of use of the distributed model system ENKI for hydropower inflow forecasting

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Foreword

The research and development programme Hydrological Development in the Hydropower Industry (HUVA) continuously strive to improve the precision of inflow forecasting. During 2023, programme activities have centred on discussions regarding how much further the industry will be able to improve using the same tools and models currently in use. This pilot study provided a good opportunity to explore a new model setup to get a glimpse of its potential.

Currently, the semi-distributed HBV model is used for hydropower forecasting. Since this model has a relatively simple structure it is computationally efficient but, as a result, has a limited resolution. Technological advancement is marked by increased computational capabilities and diverse data sources like satellite observations. This offers opportunities for more detailed input data, which has great potential in improving the reliability/accuracy of hydrological forecasts. As the demands on hydropower in the energy system increase, there is a growing need for enhanced precision in hydrological forecasts and for exploring alternatives to the HBV-model.

When the suggestion was put forth to set up a fully distributed hydrological model in the open-source platform ENKI it was an interesting opportunity for HUVA. Given the pilots results it will be of continued interest to develop the model further in coming R&D projects within the programme.

These are the results and conclusions of a project, which is part of a research programme run by Energiforsk. The author/authors are responsible for the content.

Summary

This study is a test of a distributed forecasting model setup, ENKI, in a typical Swedish watercourse. It is carried out in close cooperation with HUVA and Vattenregleringsföretagen (VRF) as a part of a 3-month internship at NTNU of an engineering bachelor student. Umeälven was selected as testcase.

ENKI is an open source distributed hydrological model system developed at SINTEF for the Norwegian hydropower industry. It is modular and can be implemented with different combinations of hydrological methods. Thus, Enki allows for combining and testing different hydrological process descriptions with varied complexity.

The intention of this study was to test the ENKI model in a simple setup and if time allowed, investigate the potential in using more advanced process descriptions. Due to challenges in model calibration, time did not allow for more advanced tests. Thus, this report shows results only based on the simple model setup using basic interpolation routines for temperature and precipitation and snow-, soil- and response routines corresponding to those used in the HBV model.

Water in Umeälven has a long travel time and as the simple model setup don't include routing it was attempted to calibrate the model using calculated local inflow data. Travel time and observational challenges make such calculations uncertain and can lead to high and unrealistic day-to-day (relative) variability and negative values. Using local inflow data did not give good calibration in this case.

By using total inflow data for the regulated part of Umeälven and unregulated total discharge observations in Vindelälven the calibration challenge was solved, and the results become very promising with a Nash-Sutcliffe R^2 of 0.80 where values from 0.75 indicate a well-established model and 1.0 a perfect fit.

As this was achieved with the simplest available setup it is reasonable to assume that there is high potential for further improvements by implementing more advanced hydrological methods. In particular for routing, but also for snow accumulation and snow melt. Further recommendations are listed below:

- To implement routing and more advanced interpolation and hydrological methods and evaluate towards operative HBV model simulations.
- To test gridded meteorological input data from SMHI combined with more advanced methods in the ENKI system for snow and evaporation simulations.
- To investigate the potential of using observed snow data (satellite, snow courses etc.) to update the model.
- To "educate" a user and test ENKI's performance and potential for operational use by comparing it against the model used operationally during a period of time.
- To engage students for further testing and development of the model.

Keywords

Distributed model, ENKI, Hydropower, Inflow forecasting

Sammanfattning

Denna studie är ett test av den distribuerade modellen ENKI för hydrologiska prognoser i ett typiskt svenskt vattendrag. Den genomförs i nära samarbete med HUVA och Vattenregleringsföretagen (VRF) och som en del av en 3-månaders praktik vid NTNU för en fransk ingenjörsstudent. Umeälven valdes ut som testfall.

ENKI är ett distribuerat hydrologiskt modellsystem med öppen källkod utvecklat vid SINTEF för den norska vattenkraftsindustrin. Det är modulärt och kan implementeras med olika kombinationer av hydrologiska metoder. Således möjliggör Enki att kombinera och testa olika hydrologiska processbeskrivningar med varierande komplexitet.

Avsikten med denna studie var att testa ENKI-modellen i en enkel uppsättning och om tiden tillåter, undersöka fördelar med hjälp av mer avancerade processbeskrivningar allt eftersom mer kunskap erhållits. På grund av utmaningar med att få en bra kalibrering tillät inte tiden mer avancerade tester. Således redovisas i denna rapport endast resultat baserat på den enkla modelluppställningen med grundläggande interpolationsrutiner för temperatur och nederbörd samt snö-, jord- och responsrutiner motsvarande de som används i HBV-modellen.

Vatten i Umeälven har lång restid och eftersom den enkla modelluppställningen inte inkluderar routing försökte man kalibrera modellen med hjälp av beräknade lokala inflödesdata. Restiden och observationsutmaningar gör sådana beräkningar osäkra och kan leda till hög och orealistisk (relativ) variabilitet och negativa värden. Att använda lokala inflödesdata gav inte bra kalibrering i detta fall.

Genom att använda totala inflödesdata för den reglerade delen av Umeälven och oreglerade totala tilflödeobservationer i Vindelälven löstes kalibreringsutmaningen och resultaten blir mycket lovande med en Nash-Sutcliffe R2 på 0,79 där värden från 0,75 indikerar en väletablerad modell och 1,0 a perfekt passform.

Eftersom detta var den enklaste tillgängliga uppställningen är det rimligt att anta att det finns stor potential för ytterligare förbättringar genom att implementera mer avancerade hydrologiska metoder. Särskilt för färdväg, men också för snöansamling och snösmältning.

Studien illustrerar potentialen i att använda distribuerade hydrologiska modeller för att prognostisera inflödet i en kaskad av vattenkraftsmagasin. Ytterligare rekommendationer listas nedan:

- Att testa griddade meteorologiska indata från SMHI kombinerat med mer komplexa metoder i ENKI-systemet för snö- och avdunstningssimuleringar.
- Att undersöka potentialen för att utnyttja observerade snödata (satellit, snölinjer etc.) för att uppdatera modellen.
- Att "utbilda" en användare av modellen och köra den parallellt under en period för att testa prestanda och potential för operativa syften.
- Att engagera studenter för vidare testning och utveckling av modellen.

List of content

1 Background

Vattenreglerings-företagen in HUVA currently use the HBV semi-distributed model for its hydrological forecasts in its operational activities and were interested to test the performance of a fully distributed hydrological model. Together with HUVA and Vattenreglerings-företagen (VRF) it was decided to test the ENKI model system in Umeälven. VRF carries out snow measurements in the upper part of Umeälven catchment and these have a potential use for model updating in a distributed model like ENKI.

The content and complexity of the project was designed to suit an internship student staying at NTNU in Trondheim for three months from June 2023.

This report contains:

- A description of the ENKI model concept and separately in highlighted sections, how to set up the model.
- a description of the ENKI model setup for Umeälven and the data used to set up and run the model.
- Results from the calibration and simulations including R2 values, plotted simulated runoff 2016-2021 and example of snow maps.
- A description of potential advantages using distributed hydrological models.
- Prospective improvements of the setup, input data and potential model development relevant for Swedish watercourses and the hydropower industry.

2 The ENKI model

ENKI is a modular framework for implementing hydrological or other environmental models. Both lumped and distributed models are supported. ENKI builds a model from a set of user-defined subroutines, which operate on GIS data within a defined region. Also providing calibration and evaluation functionality, ENKI makes it easy for model developers to implement and test single routines and various model compositions in a fixed framework. ENKI is released as open source under GNU LGPL.

The ENKI framework recognizes the number, types, and names of each subroutine variable. The framework then exposes the variables to the user within the proper context, ensuring that:

- The model is complete and consistently set up.
- Distributed maps coincide spatially where necessary.
- Time series exist for input variables.
- State variables are initialized for the correct date/time.
- GIS data sets exist for stationary map data.

ENKI offers functionality for three different levels of involvement in model construction:

<u>Model application:</u> Allows to run and evaluate pre-built models for any response using several objective functions, to choose the desired search algorithm for calibration, and to analyze uncertainty arising from input errors or parameter equifinality.

<u>Model analysis:</u> Here it is possible to add or replace subroutines, run multi-model ensembles, switch between calibrated and mapped parameters, and experiment with different distribution schemes without having to write or compile source code.

<u>Routine implementation and testing:</u> It makes it possible to code the core of a new lumped or distributed subroutine, include it in an ENKI model, and let ENKI handle all model administration and interface codes.

As ENKI continues to develop as an experimental tool, its core API can also be implemented in users forecast system for operational hydropower. This common core, the modular design, and the open-source license all facilitate rapid dissemination of new methods into operational use.

2.1 WHY A DISTRIBUTED MODEL SETUP?

Mountainous areas exhibit strong gradients in meteorology, topography and land surface properties. For nonlinear processes, the use of catchment averages in model equations leads to biased results. For catchment areas between 10^2 -10^3 km^2, model errors depend more on heterogeneity and uncertainty in input data, than on inadequate model equations. Spatial distribution allows for the simulation of differences in response from various parts of the catchments. Thus, it enhances the value of interpolation and downscaling of input data.

2.2 WHY A REGIONAL CALIBRATION APPROACH?

Regional calibration uses all available hydrometeorological information in a region to find a regional common set of parameters that gives the optimal common calibration for all sub-catchments in the region, based on one or a weighted average of various criterions such as water-balance, R^2, correlation and several others. The influence of each sub-catchment on the optimization can also either be equal or weighted based on average inflow or length of their inflow time series. This reduces the challenge with parameter equifinality and poor runoff data in regulated basins and reduces the information deficit and a set of gauged basins that can represent a specific region, enables estimation of uncertainty also for the ungauged parts. In Norwegian mountains, regional calibration reduces Nash-Sutcliffe values by 0.05-0.07 compared to catchment specific calibration. Sensitivity analyses emphasize the meteorology-related parameters as the most important.

Forecasts are needed for arbitrary spatial domains, stream intakes, electricity market regions, or river sections with legal flow requirements. Operationally, it is easier to maintain a common model for several sub-basins, than to calibrate, feed and update a model for each reservoir.

2.3 TECHNOLOGY

ENKI is written in C++ and uses a plug-in structure to invoke the subroutines. These are built separately as dynamic-link libraries (DLLs). All subroutines are coded as sub-classes of a generic method class, which is known by the ENKI framework. The subroutine programmer can rely on a few routines being called in specific situations:

- The constructor is called when the user includes the method in a model and informs the ENKI framework about the routine's variable interface.
- Init() is called when the model is linked to a specific region, and all the routine's variables are linked to GIS data objects with known spatial extent (optional).
- PreProcess() is called when all parameter values are set, thus for each iteration during auto-calibration (optional).
- Respond() is called for each time step, and implement the process equations.

Calc() may replace Respond() when the routine is purely vertical. Vertical routines implementing Calc() rely on the framework for spatial looping, and can be used in lumped or distributed models without adaptation. Other routines may combine variables with different geometry.

2.4 SETTING UP ENKI

2.4.1 Process description and model structure

ENKI offers a wide range of hydrological process simulation methods (Figure 1). To set up a model the user needs to know what each of the methods do. The description of methods is available. Depending on available input data and purpose of the model, the user selects, adds and combines different methods and stores the model setup. Each of the methods needs input specific for the region the model is used in, which is defined and available in the region interface.

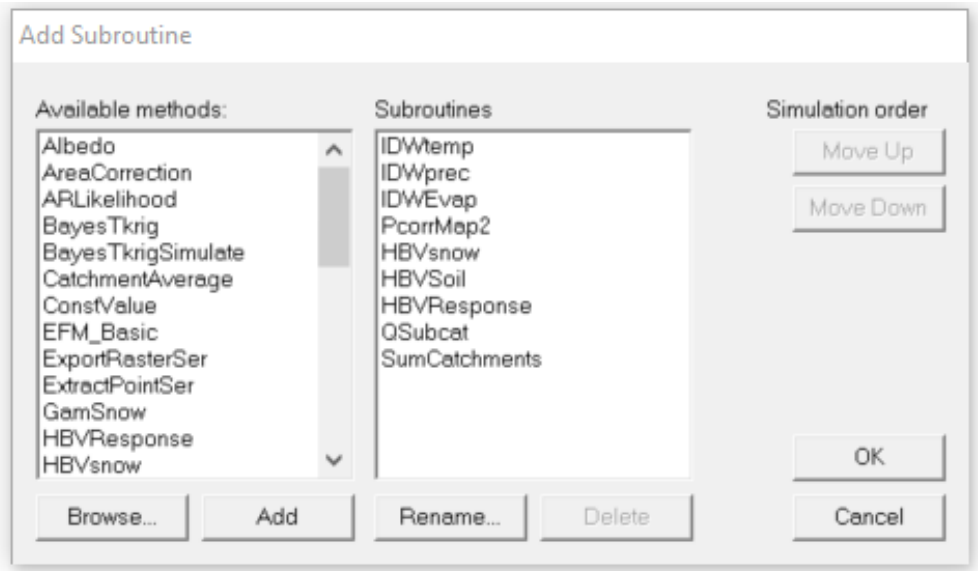

Figure 1. User Interface for selecting methods used for the model setup (left). Example of combination of methods (right).

2.4.2 Description of the region

The region must provide all information requested by the selected methods. The region consists of raster data such as elevation (DTM) for each of the grid cells, land-use, sub-catchments, etc. (Figure 2). These maps are provided using a GIS system. The region also holds network data such as observations of discharge and meteorological observations, all given with their identification, timeseries and locations through text files added to a database. Parameters specific for the region, resulting rasters for states such as snow water equivalent, etc. are also found in here. ENKI converts and stores input and output data in a NetCdf database file. The content of raster files and the database can be viewed and extracted to text output files through the interface.

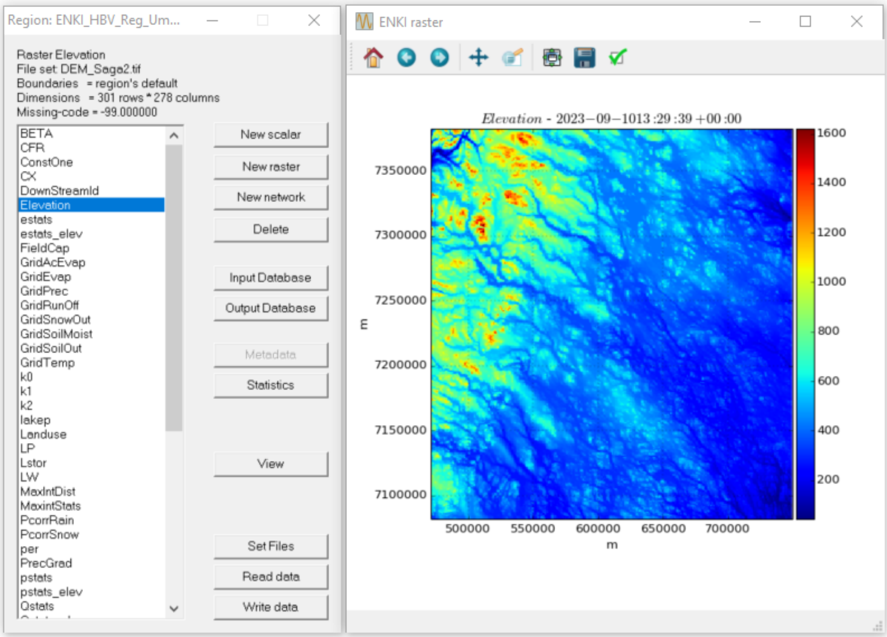

Figure 2. User interface for defining the Region (left). The elevation maps for Ume region shows an example of raster input from GIS (right).

2.4.3 Connection between the model and the region

The requested information in the selected methods needs to be linked to the relevant information given in the region (Figure 3). The types of information can be scalar, such as a parameter value that is not location dependent, or raster, with information that varies depending on location, such as elevation, and networks with information for specific locations such as meteorological observations and observed discharges. ENKI ensures that the method has the necessary information from the region and checks consistencies.

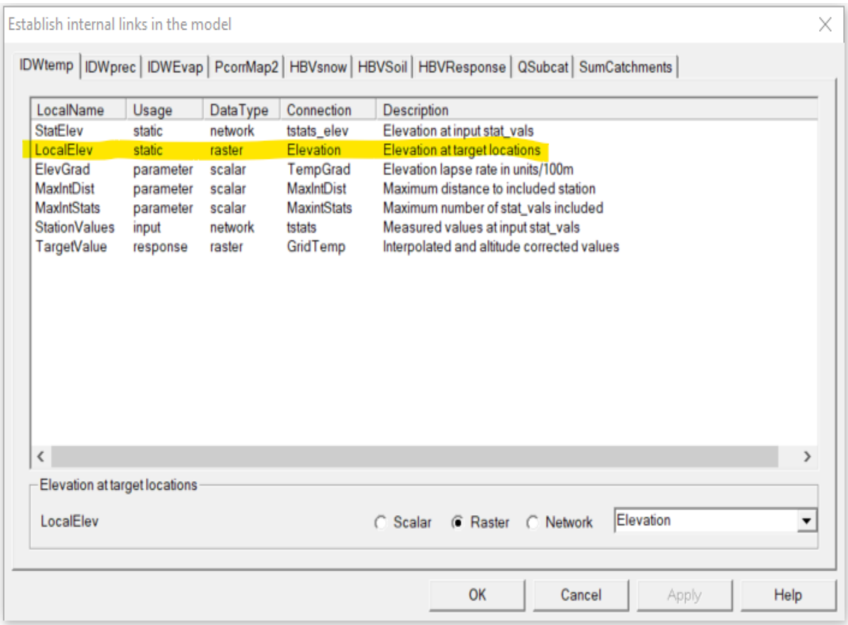

Figure 3. User interface for combining model setup and region.

2.4.4 Defining sub-catchments and calibration

In Enki, the user defines sub-catchments representing the inflow used for calibration (Figure 4, left). In addition, it can be defined as many sub-catchments as is necessary for the purpose of the model (Figure 4, right). The model will calculate runoffs for all the defined sub-catchments. It will calculate the goodness of fit for all sub-catchments with observed discharge. Based on the criteria for the calibration (r2, water balance, other objective criteria or a weighted combination of criteria) ENKI will try to identify the parameters that give the best total performance for all sub-catchments used in the calibration. The user can determine if the model shall be tuned to total upstream discharge or local discharge or to a weighted mixture of the two. The calibrated parameters will be the same for all sub-catchments in the region, but can be related to location-specific information, such as how the temperature gradient relates to the elevation of the grid cell.

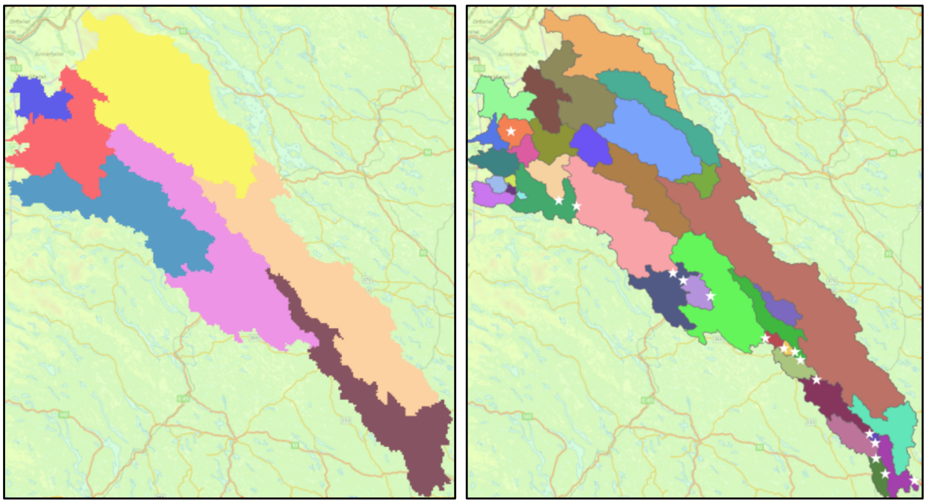

Figure 4. Example of sub-catchment deliniation used fo calibration (left). Subcatchments for operational forecasting (right).

3 ENKI setup for Umeälven

3.1 ENKI SETUP

As a first initial test of ENKI for Umeälven, methods with low demands for input data were selected. The model combines the temperature index model and the soil- and response routine, corresponding to the methods used in the traditional HBV model (Figure 5). The method uses observed temperature, precipitation, discharge, and evaporation at defined locations. For the interpolation of observed temperature and precipitation data, elevation information must be provided, as well as elevation for each of the grid cells. This is obtained from a DTM for the region. The Inverse-Distance-Weight (IDW) method was used for temperature, precipitation and evaporation interpolation. The IDWtemp method uses elevation differences and a temperature gradient, in addition to the distance to the observation sites, to calculate local temperature. IDWprec uses distance, local elevation and a precipitation gradient to calculate local precipitation. IDWevap uses distance to four locations where the evaporation is calculated based on observed temperature. The model handles water and land surfaces differently, and thus requires a land-use map that separates land and water. Qsubcat calculates accumulated inflow for each of the sub-catchments and SumCatchment accumulates upstream sub-catchments.

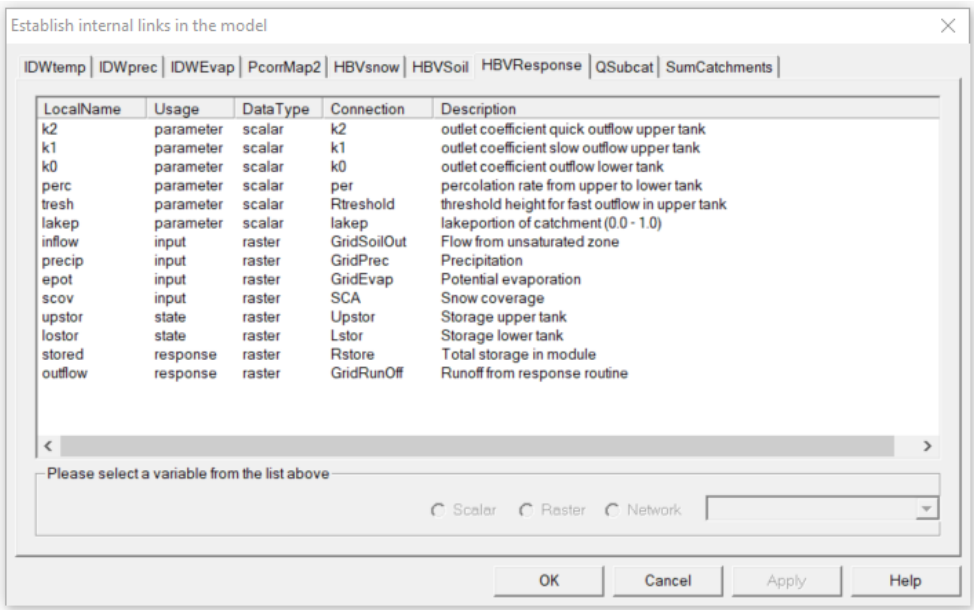

Figure 5. The model setup used for Umeälven.

3.2 THE REGION

The region needs to be in the shape of a rectangle covering the entire catchment (Figure 6). Elevation and land-use data were downloaded as tiles from https://www.lantmateriet.se/. The tiles were combined to cover the region using Arc-GIS. The resolution of the grid cells in the region was set to 1000 x 1000 m.

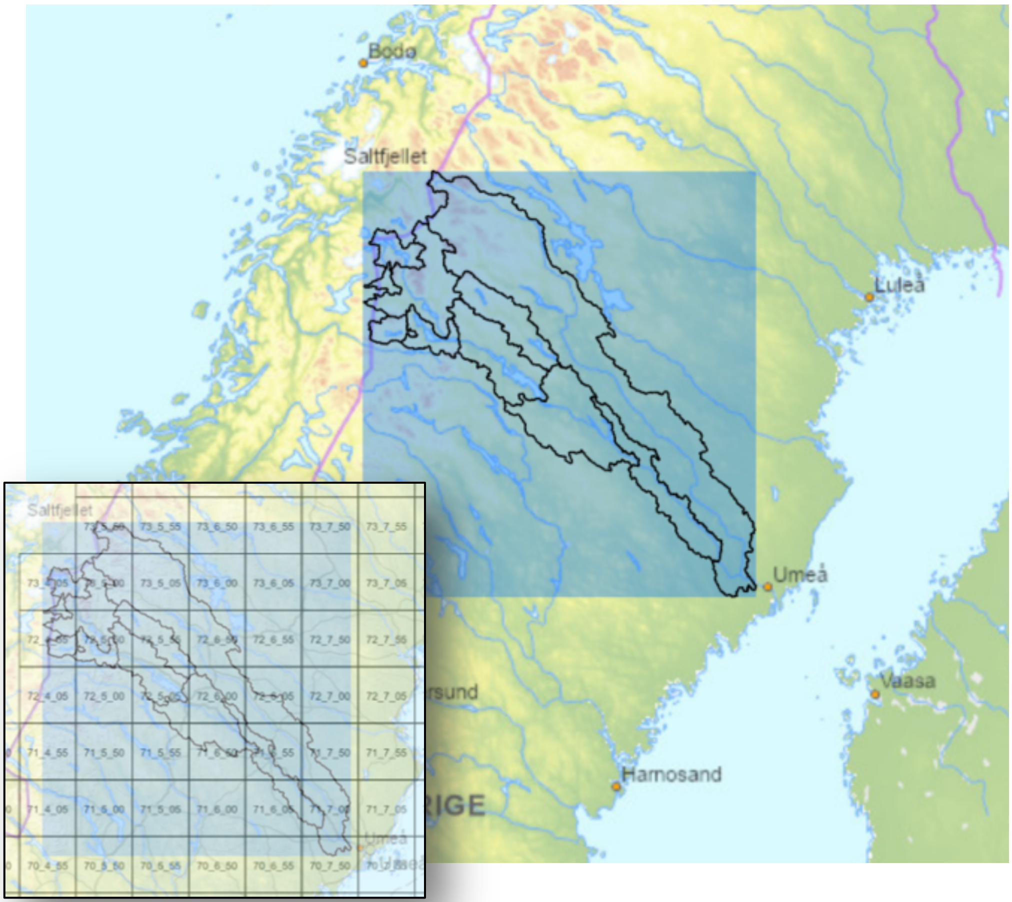

Figure 6. The extent of the region used for Umeälven. Embedded the map tiles from Lantmäteriet.

3.3 METEOROLOGICAL INPUT DATA

Daily observed precipitation data for 35 locations and temperature data for 14 locations were downloaded from SMHI's database together with their coordinates and elevation. Precipitation data only from operative observation sites were selected. See Figure 7 for the location of observation data in the catchment.

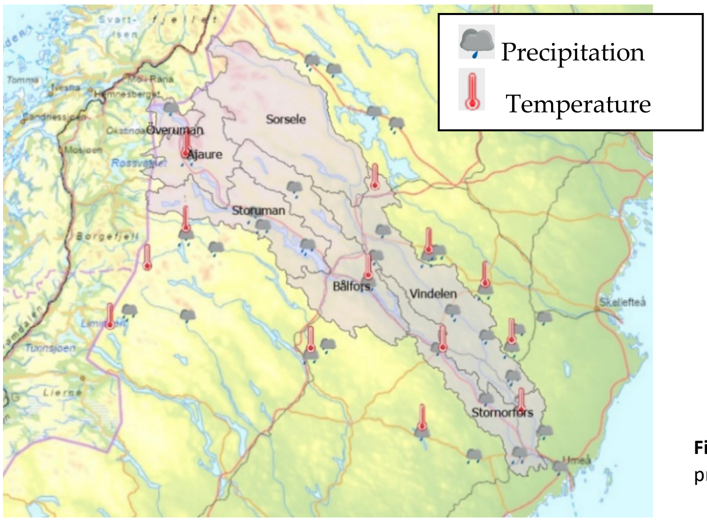

Figure 7. Location of temperature and precipitation observations.

Table 1. Precipitation and Temperature observations used in the model with their altitude and location.

Precipitation	HOH	Xcoord	Ycoord	Temperature	HOH	Xcoord	Ycoord
Umeå-Röbäck	10	757778	7086753	Gunnarn A	275	627236	7212495
Tavelsjö D	115	747708	7111412	Lycksele A	210	677956	7163301
Balsjö D	195	699067	7094997	Vindeln-Sunnan	237	731412	7120944
Granö D	190	707560	7133085	Hemavan Flygplats	458	503895	7298478
Vännäs D	87	730328	7096444	Gielas A	578	503004	7244889
Fredrika A	328	663942	7109632	Hemavan-G A	794	502852	7295535
Mosekälla	550	505207	7299172	Petistrask A	258	724795	7168399
Fjällsjönäs	410	576674	7277399	Vilhelmina A	348	588052	7162902
Arjeplog-Myrh. D	450	646266	7321270	Norsjo A	310	706729	7207282
Arjeplog A	428	631326	7328521	Mala-Brannan A	363	668428	7230101
Svartberget D	441	603838	7357804	Fredrika A	328	663942	7109632
Jäckvik	430	589216	7363958	Stekenjokk A	1037	476762	7218899
Gielas A	578	503004	7244889	Buresjon A	394	631800	7273636
Mjölkbäcken	535	493233	7331521	Jormlien	383	451506	7178654
Avasjö-Borgaf. D	541	504355	7190247				
Ankarvattnet D	460	464457	7193798				
Malkälen D	240	725871	7148911				
Petisträsk A	258	724795	7168399				
Brännforssund	223	707867	7176155				
Lycksele A	225	675115	7167491				
Latikberg D	441	599539	7170248				
Vilhelmina A	348	588052	7162902				
Gunnarn A	275	627215	7212219				
Malå-Brännan A	363	668428	7230101				
Malå	320	674984	7234111				
Sadiliden	400	632092	7230452				
Gargnäs D	301	637212	7247894				
Blaiken D	350	585866	7238427				
Bastansjö D	500	555637	7251524				
Norsjö A	310	706729	7207282				
Rusksele D	220	684642	7193490				
Grönliden	300	747123	7188512				
Kalvträsk D	287	729003	7180367				
Kittelfjäll D	560	523358	7236410				
Nordanås	403	550356	7260380				

Potential evapotranspiration was calculated from temperature data at 7 locations using the Thornthwaite method (Thornthwaite ,1948). Figure 8 shows the average of the calculated potential evaporation for the 7 locations.

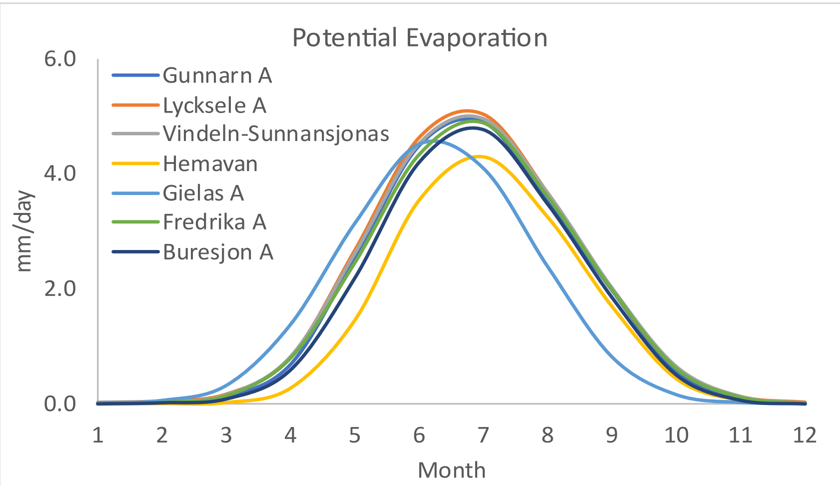

Figure 8. Potential Evaporation Input.

4 Discharge data for model calibration

Local and total inflow data for the region were provided by VRF. Local inflow is calculated as the difference between the discharge from the upstream catchments and the outflow from the local catchment plus the change in reservoir volume within the local catchment (Table 2).

Table 2. Observed discharge.

Location	Area km^2	From	Location	Area km^2	From
Överuman	652.6	31.12.1964	Grundfors	1069.2	01.10.1961
Tängvattnet	194.3	01.10.1961	Rusfors	3088.4	31.12.2010
Ahasjön	277.9	NoData	Bålforsen	3169.3	01.10.1961
Nedre Jovattnet	356.7	01.10.1961	Betsele	51.2	27.06.2005
Laisan	821.7	NoData	Hällforsen	582.2	27.06.2005
Solberg	1083.4	01.10.1961	Tuggen	843.3	31.12.1986
Göuta-Ajaure	2343.4	31.07.1967	Bjurfors_Ö	1403	27.06.2005
Ajaure total	3190.3	31.07.1967	Bjurfors_N	1436.6	27.06.2005
Abelvattnet	357.9	05.05.1968	Harrsele	1826.6	01.10.1961
Bleriken	449	30.11.1968	Harrsele total	13388.5	30.11.1968
Gardiken	723.3	30.11.1968	Granselet	2882.8	26.05.1979
Gardiken total	4362.7	30.11.1968	Sorsele	6054.2	01.10.1961
Storjuktan	1699.7	01.10.1961	Vindeln	11845.9	01.10.1961
Storuman	2330.2	01.10.1961	Pengfors	38.2	27.06.2005
Storuman total	6692.8	30.11.1968	Stornorrfors	13176.9	01.10.1961
Stensele	793.6	31.12.2010	Stornorrfors total	26565.4	30.11.1968

The quality of the calculated local inflow data was highly variable. Calculating local inflow in a watercourse with a cascade of reservoirs and long river stretches is difficult. This is because of long water transport times and delayed outflow (routing) in reservoirs and lakes. Often, the calculation is the difference between large numbers, which leads to negative values and high day-to-day (relative) variance. The quality of the discharge data is, according to VRF, highest over the last decade. Thus, inflow for the period of 2016– 2021 was used for calibration.

4.1 DATA CORRECTION

Periods of inflow-data with unrealistic relative variation were corrected using the trend over the period (See example in Figure 9). If this correction did not replace negative values, these were replaced with the average of the closest previous value above zero and the closest next value above zero (Figure 10).

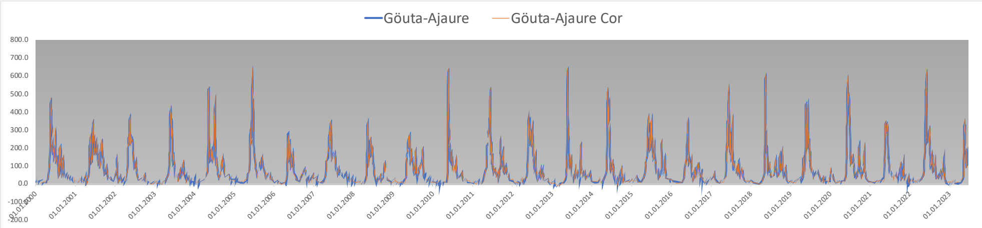

Figure 9. Example of corrected timeserie using the trend-over-the period method.

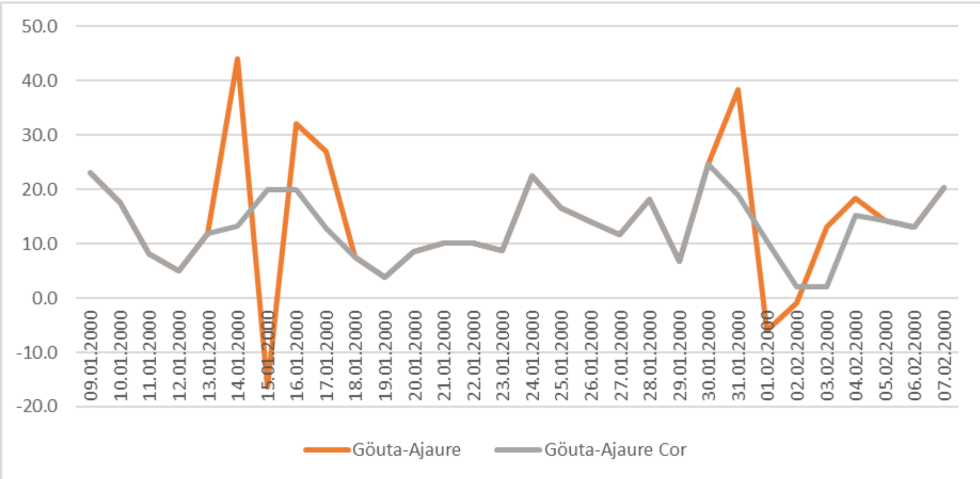

Figure 10. Example of the methodology used to replace negative values .

Plotting upstream timeseries together with the downstream timeseries gives an indication of the water's travel time and delays in lakes and reservoirs (Figure 11). The difference in time between flood peaks in Sorsele and Vindelen gauging stations is 6 to 8 days.

In Umeälven the time difference in the calculated series seems to be less than in the unregulated observations in Vindelälven.

As the simple model setup does not include routing, the delays were manually accounted for by shifting the timeseries in time to get the best correlation between the discharge timeseries. As the delays will partly depend on discharge, this modification is a rough approximation to get the best possible calibration without including a routing routine.

Överuman, Ajaure and Storuman were shifted 2 days back, Stornorrfors and Sorsele 8 days, and Vindelven 10 days back.

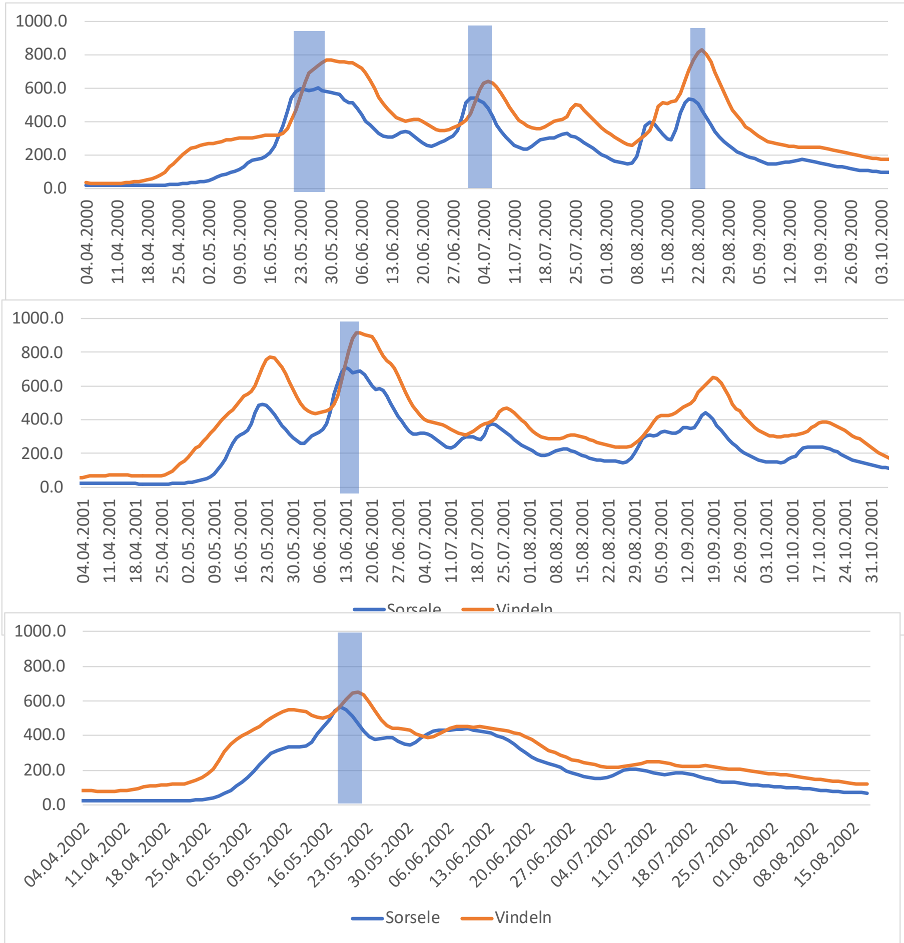

Figure 11. Days between flood peaks in Sorsele and Vindeln gauging stations.

5 Results and discussion

The model was auto-calibrated against the corrected total inflow timeseries for Överuman, Ajaure, Storuman, Sorsele, Vindelen and Stornorrfors (Figure 12. Sub-catchments used in calibration.) for the period September 2016 to September 2021 (Figure 13). The total inflow series for the respective catchments include all upstream sub-catchments, for example Ajaure_total includes Ajaure and Överuman, The Nash Sutcliff R^2 values varied from 0.58 for Överuman to 0.83 for Ajaure (**Fel! Hittar inte referenskälla.**).

The high day-to-day variation in observed discharge influences the R^2 values. This is particularly visible at Överuman. When averaging out the day-to-day variation (corrected series in Figure 13) the R^2 value for Överuman increased from 0.58 to 0.71. The difference is less pronounced for the other sub-catchments.

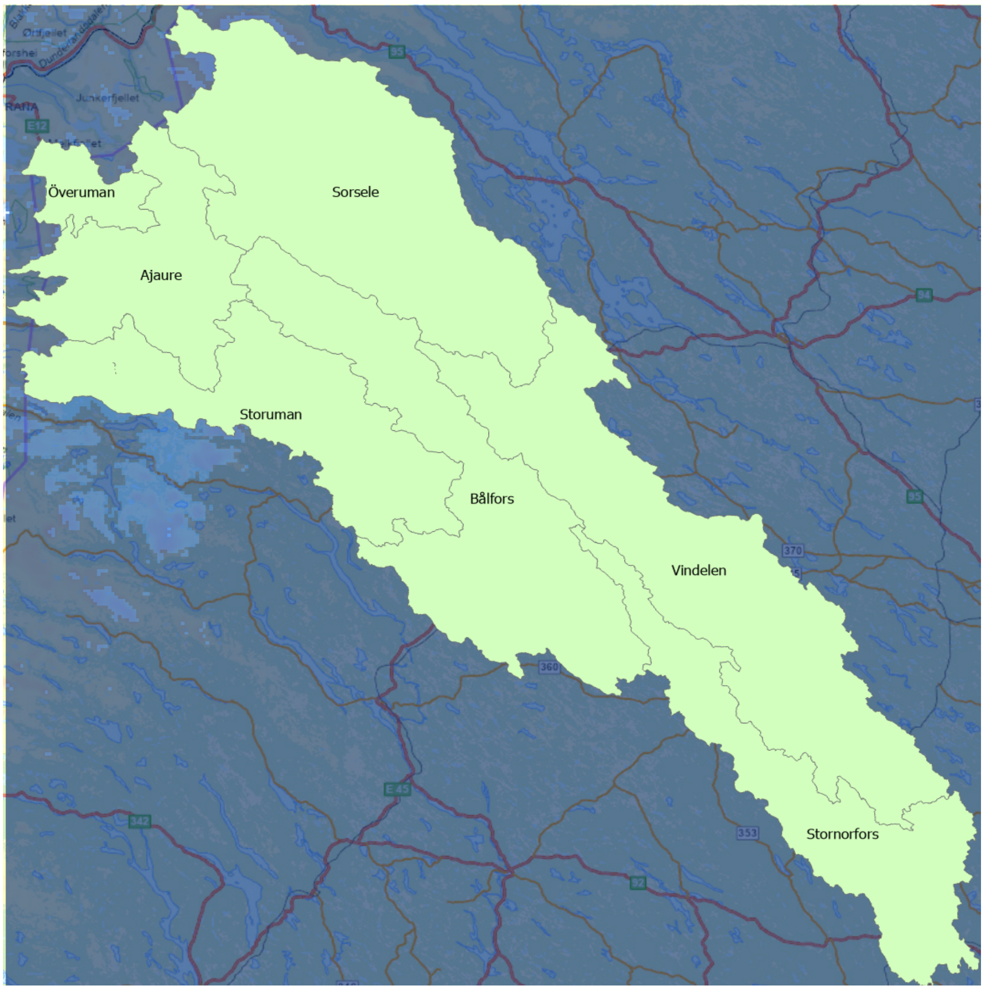

Figure 12. Sub-catchments used in calibration.

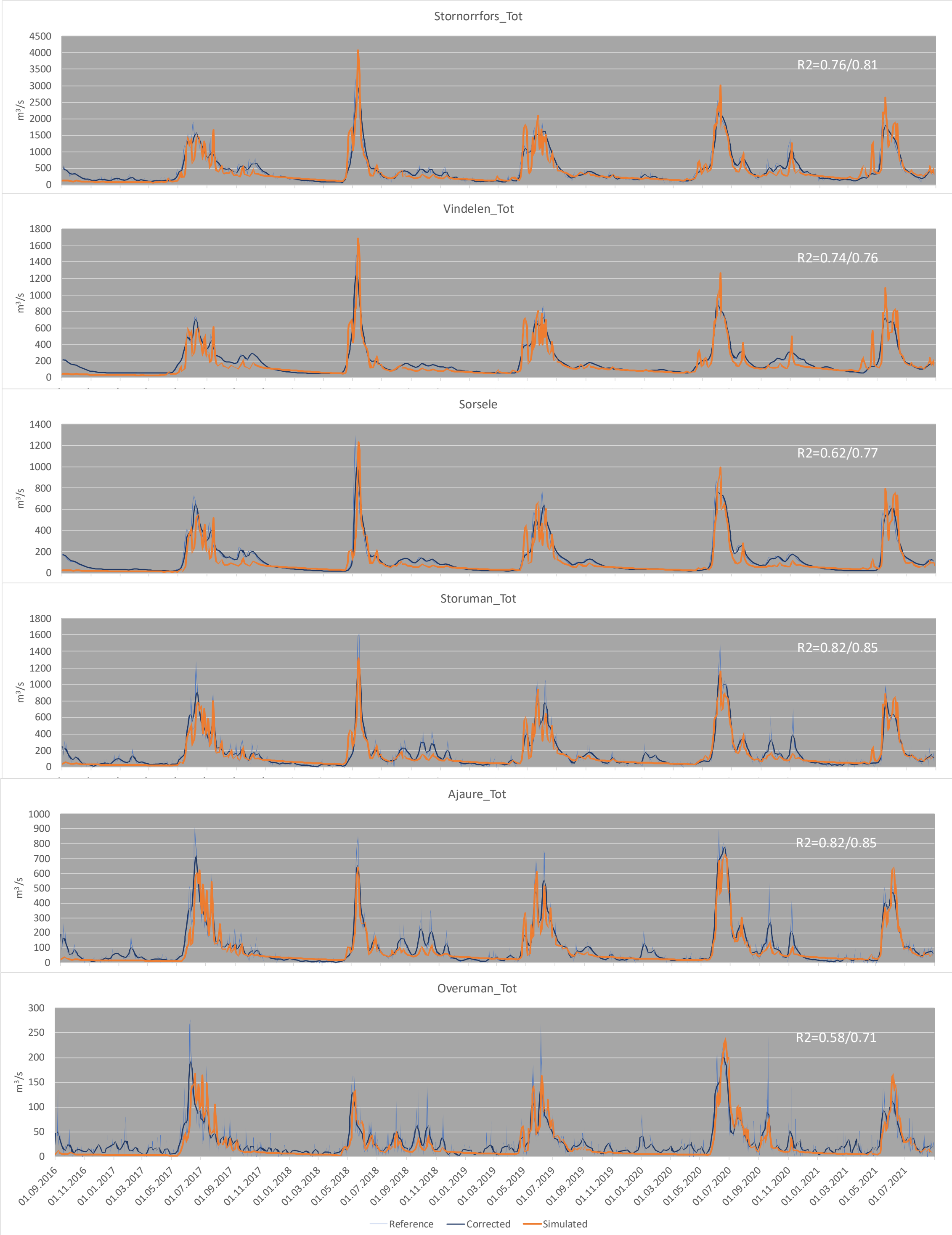

Figure 13. Simulated and observed discharge and corrected observed discharge.

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Table 3. Water balance and R^2 values

	Average flow m³/s		R^2	
	Observed	Simulated	Orig Inflow	Averaged Inflow
Stornorrfors_total	445.5	407	0.76	0.81
Vindeln_total	187.6	163	0.75	0.76
Sorsele	125.4	102	0.62	0.77
Storuman_total	163.1	144	0.83	0.85
Ajaure_total	101.2	84	0.83	0.85
Overuman	32.7	22	0.58	0.71
Average			0.73	0.80

The best overall R^2 parameter sets generally led to an underestimation of inflows at all catchments. Increasing the precipitation resulted in better simulations in the upper catchment, but reduced R^2 for the lower catchments. This indicates possible improvements by more/better input data (e.g. catch-loss corrections due to wind) and more sophisticated interpolation of the input.

Observed average windspeed at Hemavan-Gierevarto A at 793 masl is over 5 m/s while for most of the lower located stations it is much lower i.e at Norsjö A at 309 masl the average wind speed is 2.3 m/s. Even though the catch-loss at Hemavan makes these observations uncertain, the value of including stations from areas where observations are few, is high. To reduce uncertainty, gridded interpolated wind speed can be used in ENKI for precipitation correction. Observed air temperature and windspeed can be used for correcting the observed precipitation for wind-induced measurement errors. A preprocessing of the precipitation according to Kochendorfer et al (2017) can give a more precise correction and a more representative precipitation input. This methodology will especially improve the simulations for those parts of the catchment that are influenced by observation from precipitation gauges affected by high windspeeds.

Except in Överuman, the model simulates well the runoff during the winter, but overestimates during snowmelt and in the autumn for all sub-catchment. In Överuman the simulated winter discharge is too high while the difference is less during the summer and autumn period (Figure 14). The selection of temperature stations can influence the runoff and be part of the explanation. This can be analyzed by including more temperature stations in the model or by using temperature from the gridded data from SMHI. Another part of the explanation can be related to the simplification in the degree-day calculation of snow melt. Air humidity has a strong influence on snow melt and Överuman is covering the western most part of the catchment and might be influenced by more humid air from the Atlantic side. **A** comparison of Hemavan and Stoberget met stations shows that Hemavan has, on average, 8 % higher relative humidity. The effect of this could be tested by including more advanced snow-melt calculations including air humidity and the energy balance .

This also argues for more advanced modelling of the snow accumulation and melt processes and also for including water balance stronger in the calibration.

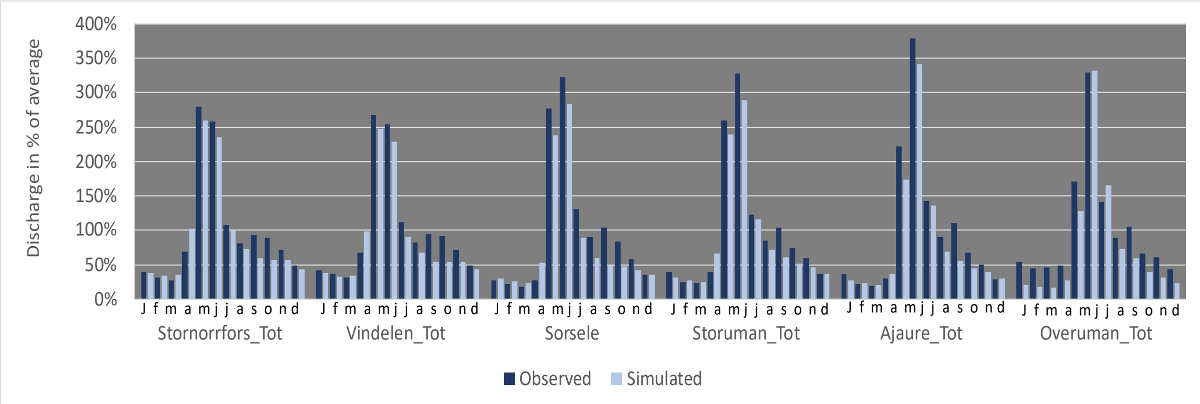

Figure 14. Observed and simulated discharge variability over the year.

5.1 SNOW STORAGE

ENKI gives the snow water equivalent (SWE) in every grid cell in the region (Figure 15 andFigure 16). This information can be directly compared to satellite observations and manual observations of snow cover and SWE.

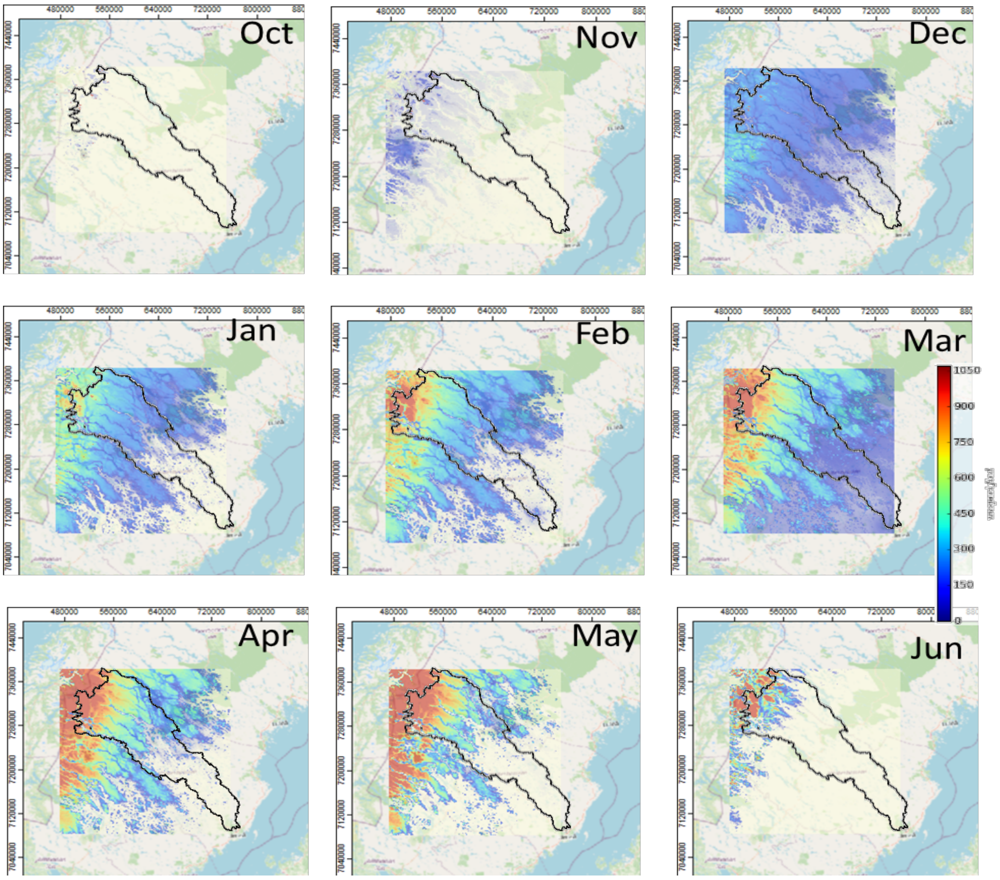

Figure 15. Snow storage development during a winter.

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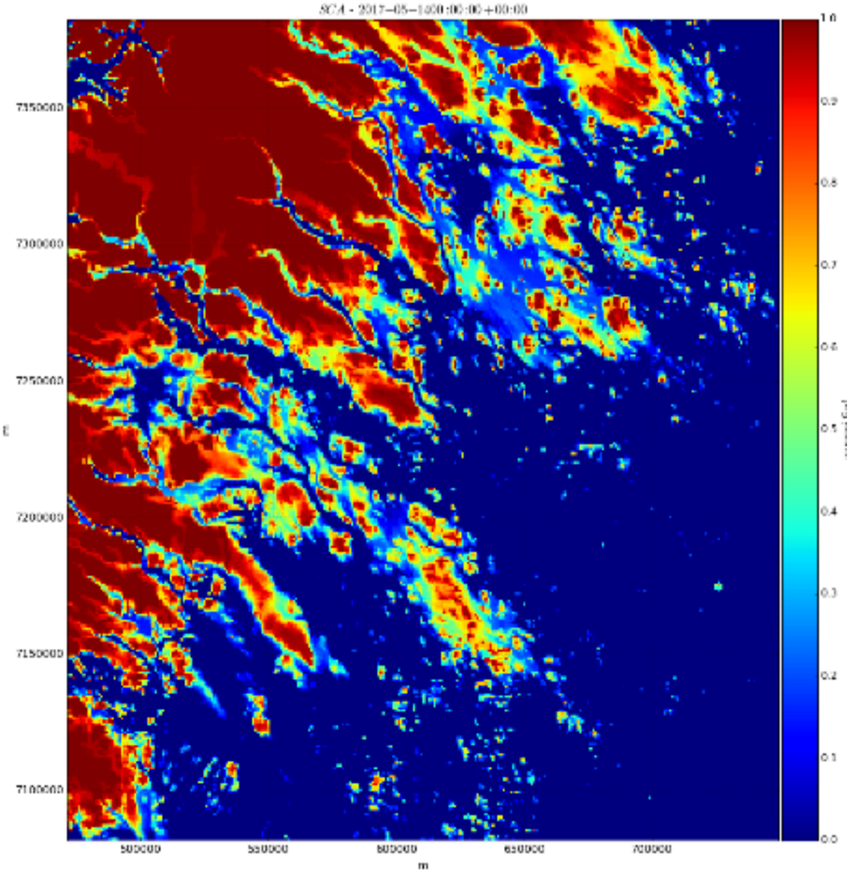

Figure 16. Snow covered area in each grid cell in fraction of 1.

5.2 MODEL UPDATING AND INFLOW FORECASTING

The model interpolates and produces maps of distributed inputs like precipitation, temperature, evaporation and additional variables, depending on the selection of method used in the setup. Furthermore, it produces maps of outputs and hydrological state as SWE, snow cover, soil moisture and additional variables, also depending on the methods involved. This information can be directly compared to observations and the states can be updated if there are significant differences. This one-to-one comparison of model state and real-world observations is one major advantage of using a distributed model system. This direct linkage between the model and real-world also simplifies communication and exchange of information about the hydrological state in the catchment and between the hydrological forecasters, the hydropower producers and other stakeholders.

Another important feature when using a distributed model like ENKI is the opportunity to get the runoff to any point, reservoir or intake in the catchment. The model accumulates the discharge within sub-catchments defined by the user. This enables the extraction of discharge simulations at any key intake or section of the river, such as sections with minimum flow.

6 Further work

The intention behind this project was to demonstrate the use of a distributed model in a watercourse in Sweden to highlight the potential of distributed models for various purposes. In this study, a simple ENKI model setup was used. Despite the setup simplicity, the model produced acceptable results and showed some of the benefits of using distributed models. To exploit the full potential of the system it is suggested for further work to:

- Implement and test more advanced methods available in ENKI e.g., routing, energy-balance based snow and evaporation calculations, and include more advanced calibration methods.
- Adapt the model to use NetCdf files as input and/or use the gridded meteorological products from SMHI.
- Implement routines for direct updating of snow storage based on observations (satellite, snow measurements).
- Compare simulations from existing operational models to simulations from ENKI and evaluate pros and cons of the alternatives.

7 Key findings Distributed hydrological model system ENKI in Umeälven

When ENKI was calibrated towards total discharges in Umeälven and the long travel time in for the water through the catchments was accounted even the simplest version of Enki gave good results with an R^2 between 0.71 and 0.85.

The local discharge data available for the test had a too high day to day variation in the inflow to be used in autocalibration routines. More advanced corrections of the local discharge compensating for negative discharges and local peculiarities could give a better basis for the calibration.

Incorporating the routing routine in ENKI is necessary in such long water courses as Ume. With routing implemented the total discharge is the best basis for calibration as uncertainties related to calculation of local discharges is avoided.

The simulations indicate that there is a high potential for improvements and added value of the system by using more complex methods and more and better input data.

8 Reference list

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DISTRIBUTED HYDROLOGICAL MODEL SYSTEM IN UMEÄLVEN

This report presents the results of a test of a distributed forecasting model setup, ENKI, in a typical Swedish watercourse Umeälven. The intention of the study was to test a simple setup to investigate the potential in using more advanced process descriptions than currently used by the Swedish hydropower industry.

Thus, this report shows results based on a setup using only basic interpolation routines for temperature and precipitation and snow-, soil- and response routines corresponding to those used in the HBV model.
Despite the simple set up the results were very promising with a Nash-Sutcliffe R2 of 0.80 where values from 0.75 indicate a well-established model and 1.0 a perfect fit. As such, it is reasonable to assume that there is high potential for further improvements by implementing more advanced hydrological methods in the model. In particular for routing, but also for snow accumulation and snow melt.

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