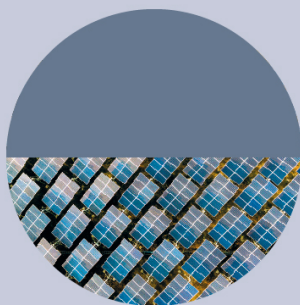


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# Evaluating the Effects of Watershed Subdivision on Hydrological Simulation by Swat Model in an Arctic Watershed

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**Abstract.** The hydrological model SWAT is a state-of-the-art tool for environmental and water resources management. Like other semi-distributed models, the whole river basin in the SWAT model is delineated into smaller sub-basins prior to conducting the simulation. Watershed delineation is an importance step since it could potentially influence the modelling results. The present study aimed to conduct an investigation of the effects of watershed delineation schemes on hydrological simulation in an Arctic watershed Målselv, north of Norway. Four delineation schemes were set up with different threshold drainage area (TDA) from fine to coarse including 100 ha, 2,000 ha, 5,000 ha and 10,000 ha. The model was run on monthly time step from 1979-2012. The results showed higher variation of average annual precipitation and runoff especially in the upstream sections of the watershed by the fine TDA schemes compared to the coarse ones. The average monthly precipitation and runoff slightly increased from the finest TDA scheme to the coarsest scheme. All TDA schemes reproduced the observed tendency of the average monthly and annual streamflow although the peak flow was over and under estimated at different hydro-gauging stations. The higher value of estimated streamflow was found at the coarsest scheme.

## 1. Introduction

The SWAT model is a physically-based, semi-distributed model which runs on a daily time step [1, 2]. Unlike lumped model considering the whole watershed as a single system [3] or distributed model discretizing the entire catchment into several grid cells [3, 4], the concept of semi-distributed models is delineating the whole river basin into smaller sub-basins [5, 6]. There are many options for watershed subdivision from the fine schemes to the coarse schemes according to threshold drainage areas (TDA) which is defined as the minimum upstream drainage area for a channel to originate [7] or as a percentage of total catchment area [8, 9]. Different delineation schemes may potentially affect the simulation results, such as the effect on results of runoff, soil erosion and pollution [10]. Also, the automated processing of morphological and hydrological parameters of a watershed is influenced by value of TDA [11].

Several previous studies have been conducted to investigate the influence of TDA on model performance. For instance, Gong et al. (2010) [10] conducted an investigation to assess the effect of watershed subdivision on SWAT model by setting up seven different TDA schemes from fine to coarse in the Upper Daning River watershed, Chongqing City, China. They found that the finest scheme provided the most inaccurate modelling result, while the moderate scheme gave the best

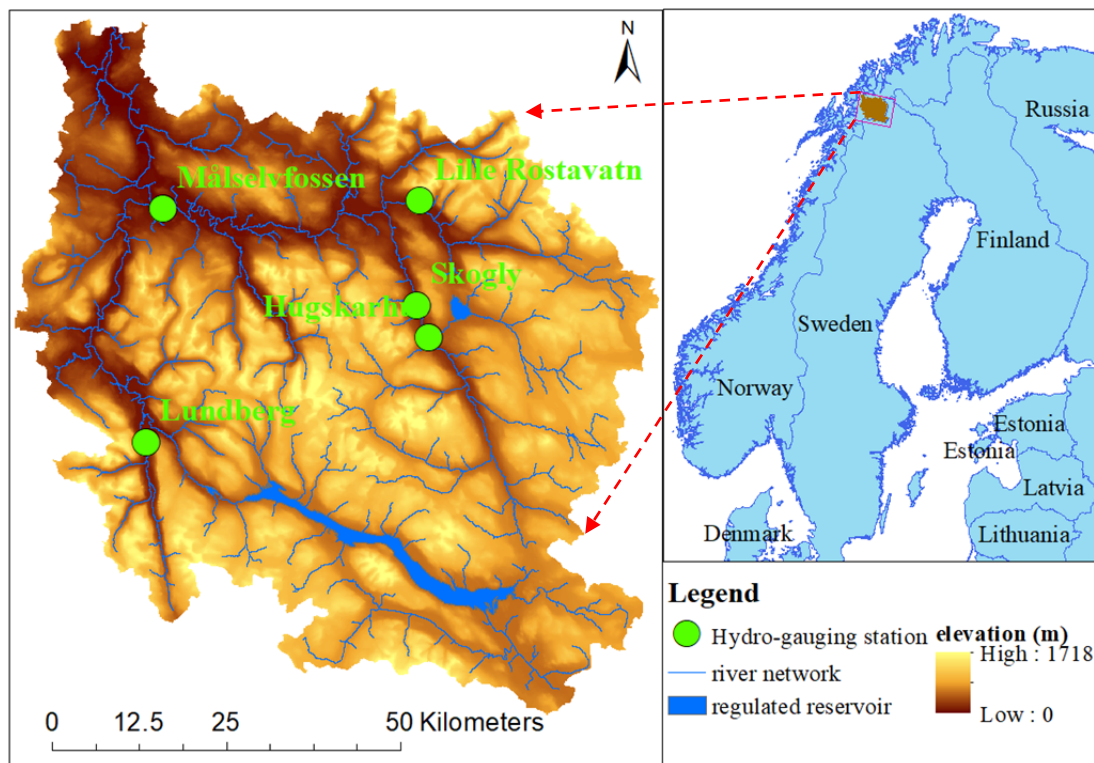


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model performance. Aouissi et al. (2013) [7] developed five different TDA schemes to assess the results of streamflow simulation in the Joumine watershed, north of Tunisia, and the results showed that watershed delineations had slightly influenced on model performance. Munoth and Goyal (2019) [11] stated in their study in the Tapi River, India that TDA had significantly influenced hydrological and morphometric parameters by defining six different TDA schemes. Also, they found that number of sub-basin and simulation result of runoff were impacted by TDA. As different studies have been conducted in various regions around the world and provided dissimilar results, it comes up with a question that if simulation results of hydrological model in the Arctic condition are also impacted by defining TDA schemes. The aim of this study is to figure out the answer.

## 2. Study area

A watershed namely Målselv in northern Norway and belonging to the Arctic region was selected as the case study to examine the influences of watershed delineation on hydrological simulation (Figure 1). The whole watershed covers an area of around 5,912.8 km<sup>2</sup>. The elevation of the ground surface is in the range of 0-1,718 m. According to long-term data from the Norwegian Water Resources and Energy Directorate, the average annual precipitation in this area fluctuates from below 500 mm up to 1,000 mm. The study area locates in the Arctic region which is dominated by cold climate with the average annual air temperature from -5 °C to 6 °C.



**Figure 1.** Map of study area, Målselv river basin

## 3. Material and methodologies

### 3.1. SWAT model

The SWAT model was used to examine the impacts of watershed delineation on hydrological simulation. The model includes two important phases i.e. land phase and routing phase [12] to describe the water cycle in the watershed. Particularly, the land phase works based on a water balance equation as follows:

$$SW_t = SW_0 + \sum_{i=1}^t (R_{\text{day}} - Q_{\text{surf}} - E_a - w_{\text{seep}} - Q_{\text{gw}}) \quad (1)$$

where:

- $SW_t$  is the final soil water content in mm  $H_2O$ ,
- $SW_0$  is the initial soil water content on day  $i$  in mm  $H_2O$ ,
- $t$  is time in days,
- $R_{day}$  is amount of precipitation on day  $i$  in mm  $H_2O$ ,
- $Q_{surf}$  is amount of surface runoff on day  $i$  in mm  $H_2O$ ,
- $E_a$  is amount of evapotranspiration on day  $i$  in mm  $H_2O$ ,
- $w_{seep}$  is amount of water entering the vadose zone from the soil profile on day  $i$  in mm  $H_2O$ ,
- $Q_{gw}$  is amount of return flow on day  $i$  in mm  $H_2O$ .

The routing phase describes the processes occurring in the mainstream including movement of water, sediments, mass flow in the channel, transformation of chemicals in the stream and streambed.

### 3.2. Data acquisition

Several spatial-temporal input data for SWAT model including climate data such as precipitation, maximum and minimum air temperature, wind speed, relative humidity, solar radiation, and grid data such as land use, soil and topography were collected from different sources. Details of data type, its resolution and source of data are illustrated as in Table 1.

**Table 1.** Data acquisition for SWAT model

Data type		Resolution	Source of data
Grid data	Digital Elevation Map (DEM)	10x10 m	Norwegian Mapping Authority: <a href="https://kartkatalog.geonorge.no/metadata/kartverket/dtm-10-terrengmodell-utm33/">https://kartkatalog.geonorge.no/metadata/kartverket/dtm-10-terrengmodell-utm33/</a>
	Soil	1:5 000 000	WATERBASE: <a href="http://www.waterbase.org/download_data.html">http://www.waterbase.org/download_data.html</a>
	Landuse	100x100 m	WATERBASE: <a href="http://www.waterbase.org/download_data.html">http://www.waterbase.org/download_data.html</a>
Climate data	Reanalysis data	Grid, daily data: 01/01/1979 to 31/07/2014	Global Weather Data: Climate Forecast System Reanalysis (CFSR): <a href="https://globalweather.tamu.edu/">https://globalweather.tamu.edu/</a>
Hydrological data	River discharge	5 stations, frequency of measurement: 30 minutes and 1 hour	Sildre, The Norwegian Water Resources and Energy Directorate (NVE): <a href="http://sildre.nve.no/">http://sildre.nve.no/</a>
	River network		The Norwegian Water Resources and Energy Directorate (NVE): <a href="https://www.nve.no/">https://www.nve.no/</a>

### 3.3. Methodologies

#### 3.3.1. Watershed delineation schemes

Schemes of watershed delineation were set up based on different threshold drainage area (TDA). In this study, four different threshold drainage areas of 100 ha, 2,000 ha, 5,000 ha and 10,000 ha were developed. TDA 100 ha is considered as the finest scheme, while TDA 10,000 ha is the coarsest one defining for this study.

#### 3.3.2. SWAT model simulation

The model ran on monthly time step over 34 years from 1979-2012. A nine-year warming up period was set up to let the model to reach an optimal state from the estimated initial condition. The remaining 25-year period was used to evaluate the modelling results.

### 3.3.3. Evaluating the influences of TDA schemes on sub-basin delineation and HRU definition

Prior to evaluate the results of hydrological simulation, results of sub-basin delineation and HRU definition by TDA schemes are firstly examined since further modelling tasks are based on such results. Moreover, the processing time could be influenced by the finest schemes of sub-basin and HRU. The study will figure out the TDA schemes with higher or smaller number of generated sub-basin as well as HRU.

### 3.3.4. Evaluating the influences of TDA schemes on number of weather data points integration

As number of weather data points, particularly rainfall, is decided based on result of watershed subdivision since SWAT model uses the nearest neighbour search (NNS) approach to pick up the weather data points for calculating the areal precipitation for each sub-basin. Therefore, number of weather data points integration is necessary to examine. Also, the number of integrated weather data points could influence the result of areal precipitation. The study will point out whether or not number of weather data points integration changes by defined TDA schemes.

### 3.3.5. Evaluating the influences of TDA schemes on results of rainfall and runoff simulation

Runoff is an important element to evaluate water resource of a watershed. Based on runoff in a watershed, it is possible to identify the associated environmental problems such as potential flooding, erosion, and possibility for pollutant transportation, etc. Runoff in a watershed is mainly determined by the amount of rainfall in that watershed beside other climate factors such as air temperature, evapotranspiration and other parameters such as land cover and soil type. In this study, value and spatial variation of rainfall and runoff over the watershed, particularly on each sub-basin, by different TDA schemes were compared. Particularly, it is focused on analysis the value of average monthly and annual rainfall and runoff.

### 3.3.6. Evaluating the influences of TDA schemes on results of streamflow simulation

Beside runoff, streamflow is also an important element to evaluate water resources of a river basin and other related environmental issues and ecosystem. In this study, the impacts of TDA on the average monthly and annual streamflow over 1988-2012 period was assessed at five hydro-gauging stations namely Høgskarhus, Skogly, Lille Rostavatn, Målselvossen, Lundberg.

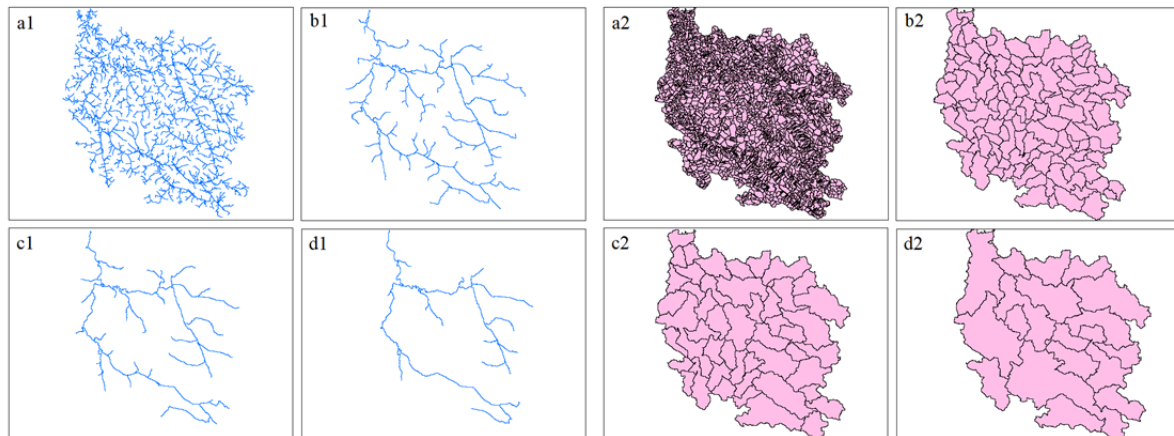
## 4. Results and discussion

### 4.1. Impacts of the threshold drainage area on results of sub-basin delineation & HRU definition

Table 2 illustrates the results of sub-basin delineation & HRU definition according to different TDA. The results showed that number of sub-basin as well as number of HRU decreases significantly with the increase of TDA. The finest scheme with 100 ha provides 2,196 sub-basins, whereas the coarsest scheme with 10,000 ha provides only 18 sub-basins (Figure 2a2-d2). Also, density of channel network decreases with increase of TDA (Figure 2a1-d1).

**Table 2.** Sub-basin delineation & HRU definition by different TDA

TDA (ha)	Number of sub-basins	Number of HRUs	Mean sub-basin size (ha)	Minimum channel length (m)
100	2,196	17,618	264.37	10
2,000	115	2,102	5,048.30	149
5,000	48	1,098	12,094.90	2,087
10,000	18	518	32,253	4,687.6



**Figure 2.** Stream network (a1-d1) and sub-basins (a2-d2) generating by different TDA schemes: a1,a2: 100 ha; b1,b2: 2,000 ha; c1,c2: 5,000 ha; d1,d2: 10,000 ha

#### 4.2. Impacts of the threshold drainage area on number of weather data points integration

Table 3 illustrates number of weather data points from CFSR-Climate Forecast System Reanalysis that were integrated in the model by different TDA schemes. It is clear that number of weather data points decreases with increasing TDA. Number of weather data points integration decreases from 22 to 20, 18 and 14 points corresponding to subdivision scenario of 100 ha, 2,000 ha, 5,000 ha and 10,000 ha.

**Table 3.** Number of weather data points integration by different TDA

TDA (ha)	Number of sub-basins	Maximum number of weather data points taken by the model
100	2,196	22
2,000	115	20
5,000	48	18
10,000	18	14

#### 4.3. Impacts of the TDA on rainfall and runoff simulation

Figure 3 provides the simulation result of average annual rainfall (a1-d1) and runoff (a2-d2) on each sub-basin over the whole watershed. The figure distinguished the locations with high or low rainfall and runoff. Particularly, high rainfall and runoff were found in the downstream section compared to the upstream. Noticeably, in the upstream, rainfall and runoff are more variant. Especially, the fine schemes have more variation compared to the coarse schemes. This is because of number of integrated rainfall points in the fine schemes is higher than the coarse schemes.

Figure 4 illustrates the average monthly precipitation (a) and water yield (b) over 1988-2012 period for the whole watershed. According to results from the figure, value of monthly precipitation and water yield slightly increased from the finest scheme (TDA 100 ha) to the coarsest scheme (TDA 1000 ha).

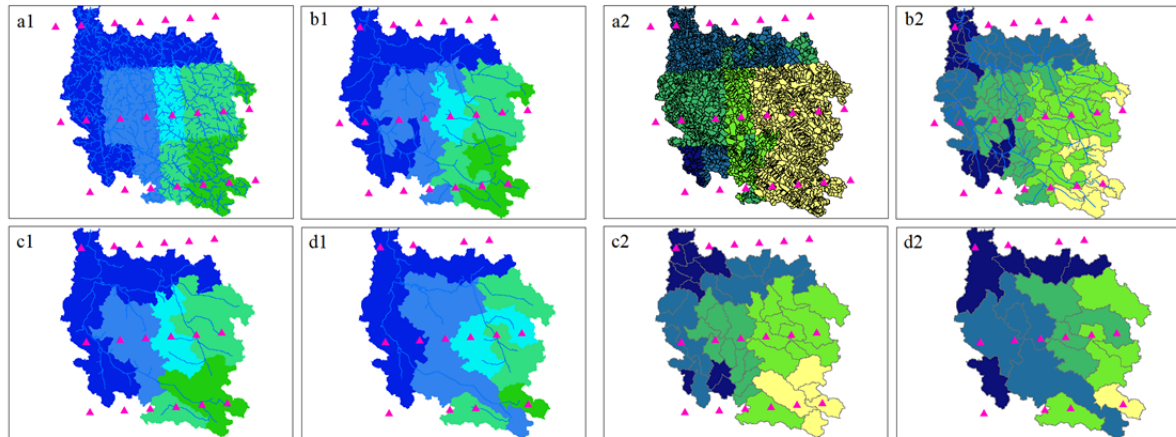
#### 4.4. Impacts of the TDA on simulation of average monthly streamflow

Figure 5 illustrates the simulation result of average monthly streamflow over 1988-2012 period. There were four hydro-gauging stations including Høgskarhus, Skogly, Målselvossen and Lundberg over totally five stations showed overestimated peak streamflow compared to observed data. Underestimation of peak flow was found at Lille Rostavatn. The curves of average monthly streamflow at Høgskarhus, Skogly, and Målselvossen, were not significantly different among TDA schemes. However, at Lille Rostavatn and Lundberg, the peak discharge showed deviation among TDA schemes. Noticeably, the peak discharge from the coarsest TDA scheme was higher the remaining schemes except at Lille Rostavatn station.

#### 4.5. Impacts of the TDA on simulation of average annual streamflow

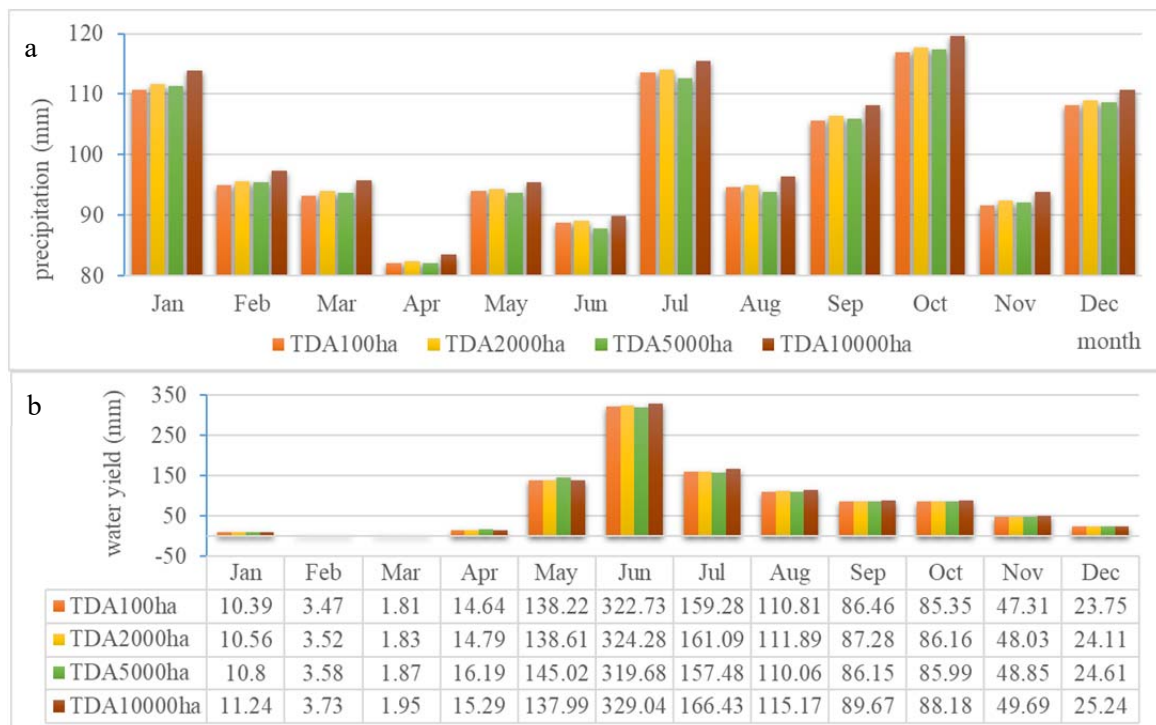


Figure 6 illustrates the simulation results of average annual streamflow at five hydro-gauging stations during 25 years from 1988-2012. The results showed underestimated annual streamflow at Lille Rostavatn station compared to the observed data and slightly overestimated streamflow at Skogly station compared to the observed data. At other hydro-gauging stations, the curves of simulated streamflow relatively agree with the observed data. Noticeably, average annual streamflow slightly fluctuated among TDA schemes at most of hydro-gauging stations. In there, the coarsest scheme with 10,000 ha provided the highest value of average annual streamflow compared to its finer schemes.

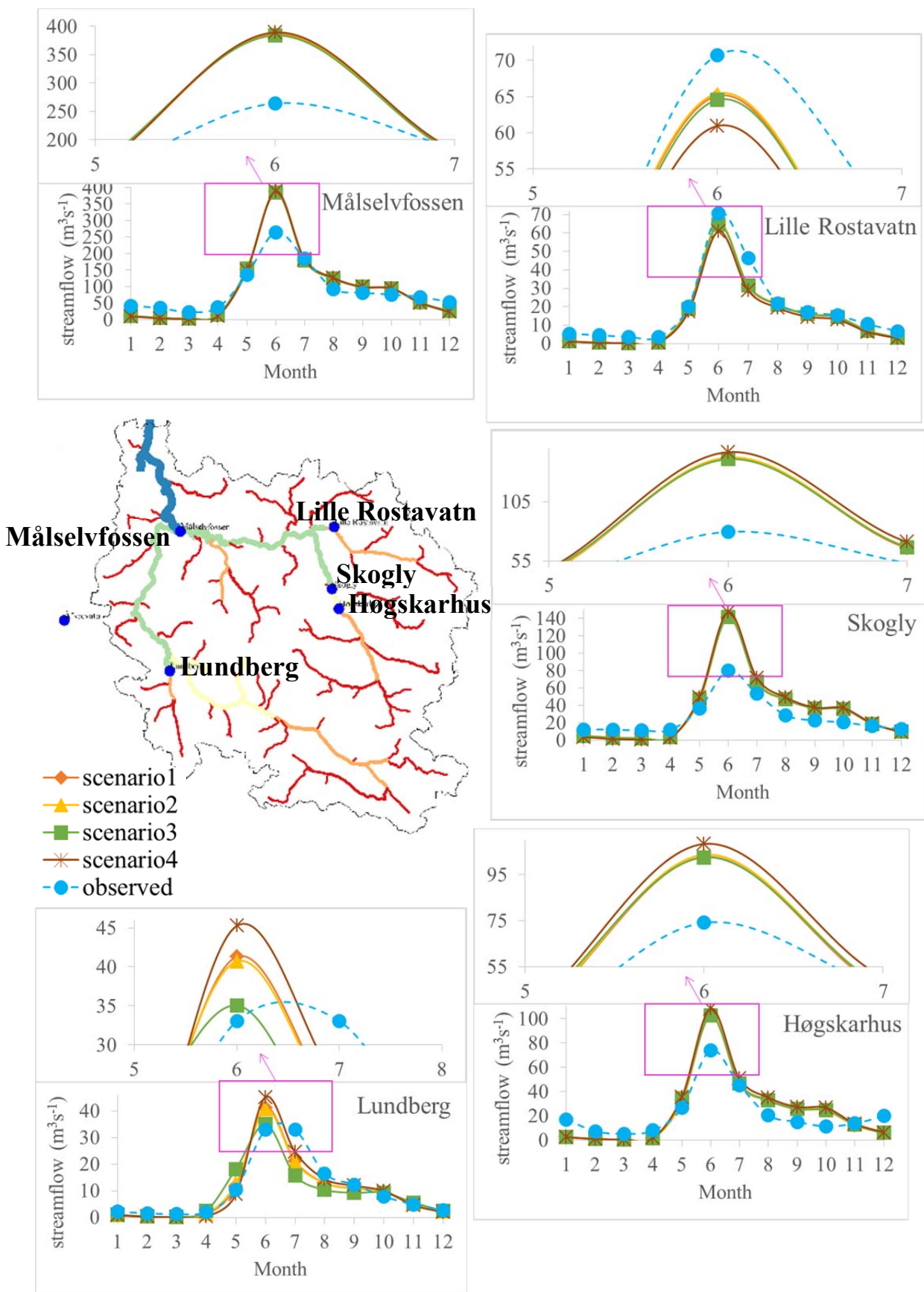


# rain gauge **annual mean precipitation** ■ 1000 - 1100 mm ■ 1200 - 1300 mm  
■ < 1000 mm ■ 1100 - 1200 mm ■ 1300 - 1460 mm  
**annual mean water yield** ■ 1000 - 1100 mm ■ 1200 - 1300 mm  
■ < 1000 mm ■ 1100 - 1200 mm ■ > 1300 mm

**Figure 3.** Simulation results of average annual precipitation (a1-d1) and runoff (a2-d2) by different TDA schemes: a1,a2: 100 ha; b1,b2: 2,000 ha; c1,c2: 5,000 ha; d1,d2: 10,000 ha

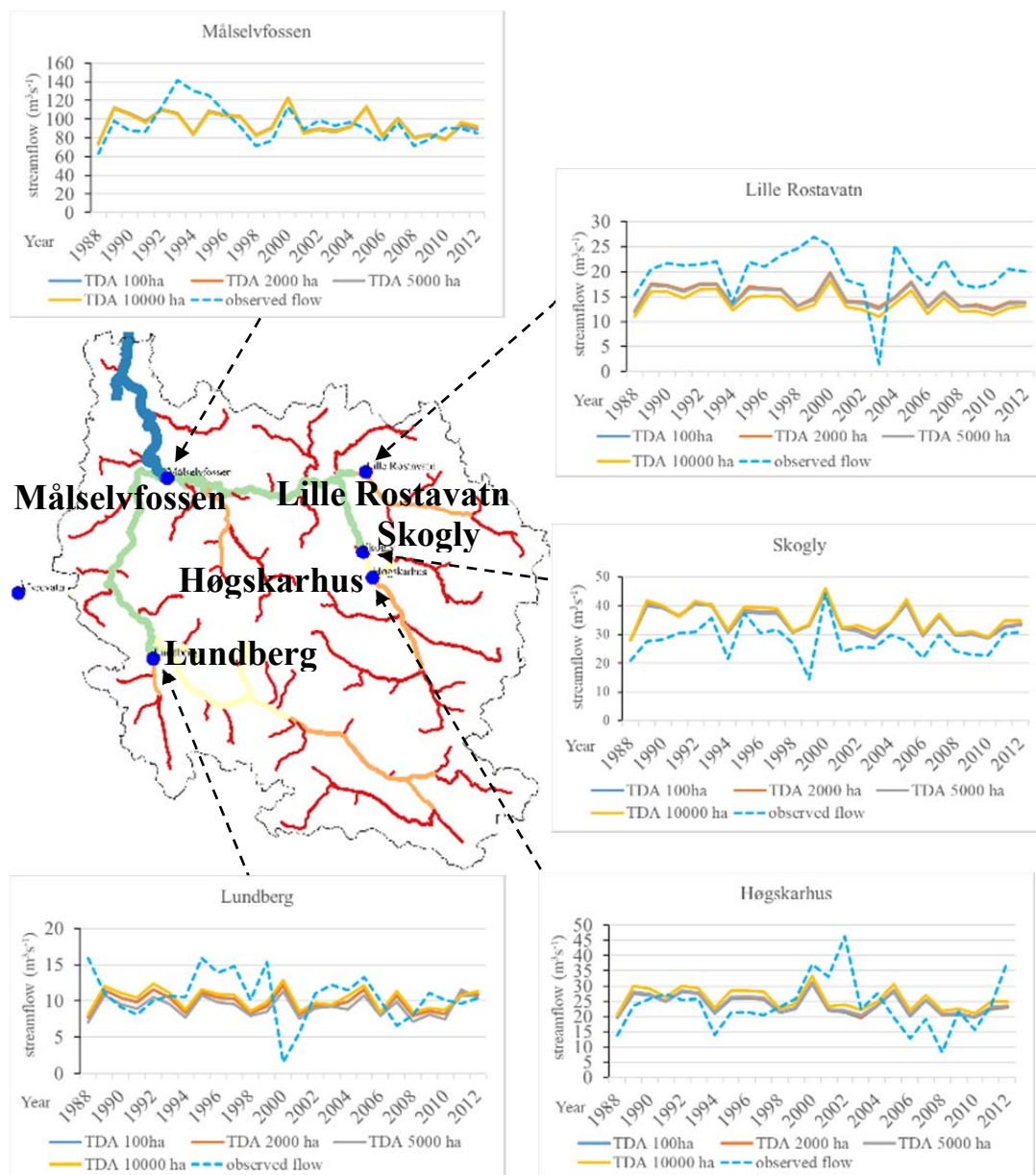


**Figure 4.** Simulation results of average monthly of a) precipitation and b) water yield over 1988-2012 period for the whole watershed by different TDA schemes: 100 ha, 2,000 ha, 5,000 ha, and 10,000 ha



**Figure 5.** Simulation of average monthly streamflow over 1988-2012 period





**Figure 6.** Simulation of average annual streamflow over 1988-2012 period

## 5. Conclusion

Defining the threshold drainage area (TDA) is the preliminary step of the modelling task. This study defined four different TDA schemes to investigate the effects of TDA on watershed delineation and hydrological simulation in SWAT model. It was found in this study that number of weather data points integration, sub-basins and HRU strongly decreased with increasing of TDA. The fine schemes provided more variation of precipitation and water yield especially in the upstream sections of the watershed, while the coarse schemes showed less variation. Also, values of average monthly precipitation and water yield for the whole watershed slightly increased with increasing TDA. All TDA schemes relatively reconstructed the simulation of average monthly streamflow although the peak discharge was over or under estimated at different hydro-gauging stations. The coarsest TDA scheme at most hydro-gauging stations produced the higher peak discharge compared to the finer schemes. Simulation of average annual streamflow relatively reproduced the observed tendency. Also, the higher value of average annual streamflow during 25 years from 1988-2012 was found at the coarsest scheme.

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