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Introduction

NAM model

NAM is and abbreviation of the Danish "Nedbor-Afstromnings-Model", meaning precipitation-runoff model. This was originally developed by the Hydrological Section of the Institute of Hydrodynamics and Hydraulic Engineering at the Technical University of Denmark, (Nielsen and Hansen, 1973). During the past decade it has been extensively applied and modified by the Danish Hydraulic Institute in a large number of projects.

A mathematical hydrological model like NAM is a set of linked mathematical statements describing, in a simplified quantitative form, the behavior of the land phase of the hydrological cycle. Numerous hydrological models exist.

NAM simulates the rainfall-runoff process in rural catchment. It operates by continuously accounting for the moisture content in four different and mutually interrelated storages, which represent physical elements of the catchment.

The input data to the model are precipitation, potential evapotranspiration and temperature (only if the snow routine is used). On this basis, it produces, as main results, runoff and groundwater level values as well as information about other elements of the land phase of the hydrological cycle, such as the temporal variation of the soil moisture content and the groundwater recharge.

A conceptual model like NAM is based on physical structures and equations used together with semi-empirical ones. Thus, some of the parameters can be evaluated from physical catchment data, but the final parameter estimation must be performed by calibration applying concurrent input and output time series.

The model structure is shown in Fig. 1. It is and imitation of the land phase of the hydrological cycle. Water is stored in four storages.

Purpose of study

The purpose of this exercise is to build a NAM model in Excel. It is set up, calibrated and validated for real data from the NAN catchment in Thailand so with a catchment area of 10,335 km^2.

NAN basin characteristic

Nan River Basin is located in northern part of Thailand. It shows mountainous and forest area and also it is one of four rivers contributing flow to the Chao-Phra-Ya River. Nan basin likewise shows a steep basin with flash floods therefore, Nan City frequently flooded. Furthermore, there is a Sirikit Dam down to Nan River.

Theoretical considerations

Methodology

First, we start at part of model built with known model parameters, initial condition and observed discharge, then try to build NAM model in excel and check the result of model calculation with NAM hand calculation

After this we apply this mathematical model to the actual situation of NAN river catchment area in Thailand with known observed discharge data and meteorological data (rainfall data, potential evaporation.). In this part, it will be divided into 2 parts:

Calibration of model to NAN river basin by using 3 years data to calculate the most appropriate parameters of model that will give the simulated result best matching to the actual observed data.

Checking that the validation of this mathematical NAM model and the parameters of this model can be applied to use with another period of NAN catchment.
In this step, 2 years rainfall data is the input of the model without changing parameters. From the same area as the one used for calibration, we compare the simulated discharge to the observed discharge to check validation of model.

For checking efficiency of NAM model to NAN catchment area, it can be observed from graph and using coefficient of determination R^2 (square of Pearson product moment correlation)

The calculation sequence in NAM

Add the rainfall (the precipitation) to the upper storage.
i.e. add P to U: $U_t=U_{t-1}+P$

Calculate the actual evaporation (E_a) – if the upper storage is full then the actual Evaporation = Potential evaporation otherwise apply the linear variation.

Adjust the upper storage (U) for the actual evaporation (E_a). If the actual evaporation (E_a) is taken from the upper storage (U) then $U_t = U_t - E_a$

Calculate the interflow (Q_{if}). Remember that $QIF_{max}= U_{max}/ CKIF$ where CKIF is the time constant for interflow

Subtract the Interflow (Q_{if}) from the upper storage (U); i.e. $U_t=U_t-Q_{if}$

Calculate the excess precipitation P_n :

$P_n = U_t-U_{max}$ if $U_t > U_{max}$
$P_n = 0$ if $U_t \leq U_{max}$

If the excess precipitation $P_n > 0$ then set $U_t \leq U_{max}$ meaning tat the upper storage is full.

Calculate the overland flow “volume” OF

Calculate the groundwater recharge G

Calculate the change in the lower storage DL

Adjust the lower storage (L) with DL

Routing of the flow

Calculate the overland flow OF:

$$OF = QOF\left(1 - e^{(-24/overlandflow\ routingtime)}\right) + Of_{time-1}e^{(-24/overlandflow\ routingtime)}$$

Calculate the base flow BF:

$$BF = G\left(1 - e^{(-24/baseflow\ routingtime)}\right) + BF_{time-1}e^{(-24/Baseflow\ routing\ time)}$$

Calculate the total Q tot

Table 1 NAM model parameters

Parameter	Range of value	Description	Calibration
U_{max} [mm]	10 – 25	Maximum water content in the surface storage. This storage can be interpreted as including the water content in the interception storage, in surface depression storages, and in the uppermost few cm's of the soil.	Large value causes less overland flow and infiltration, and higher evapotranspiration and interflow.
L_{max} [mm]	50 – 250	Maximum water content in the lower zone storage. L_{max} can be interpreted as the maximum soil water content in the root zone available for the vegetative transpiration.	Large value causes higher in evapotranspiration and infiltration, and less in overland flow and base flow.
CQOF [-]	0.01 – 0.99	Overland flow runoff coefficient. CQOF determines the distribution of excess rainfall into overland flow and infiltration.	Large value causes high overland flow, and small infiltration.
TOF [-]	0.0 – 0.7	Threshold value for overland flow. Overland flow is only generated if the relative moisture content in the lower zone storage is larger than TOF.	Large value causes the delay of the threshold of overland flow in wet period, and higher infiltration.
TIF [-]	0.0 – 0.7	Threshold value for interflow. Interflow is only generated if the relative moisture content in the lower zone storage is larger than TIF.	Large value causes the delay of the threshold of interflow in wet period, and higher infiltration and overland flow.
TG [-]	0.0 – 0.7	Threshold value for recharge. Recharge to the groundwater storage is only generated if the relative moisture content in the lower zone storage is larger than TG.	Large value causes the delay of the threshold of groundwater flow in wet period, and quicker filling of root zone.
CK_{IF} [hours]	500 – 1000	Time constant for interflow from the surface storage. It is the dominant routing parameter of the interflow because CK_{IF} >> $CK_{1,2}$.	Large value causes higher interflow, and less infiltration and overland flow.
$CK_{1,2}$ [hours]	3 - 48	Time constant for overland flow and interflow routing. Overland flow and interflow are routed through two linear reservoirs in series with the same time constant $CK_{1,2}$.	Increasing CK_* cause longer duration and lower peaks of flow components.
CK_{BF} [hours]	500 – 5,000	Baseflow time constant. Baseflow from the groundwater storage is generated using a linear reservoir model with time constant CK_{BF}.	Changing CK_* has no effect on generated flow volumes over long time but changing the shape of hydrographs.

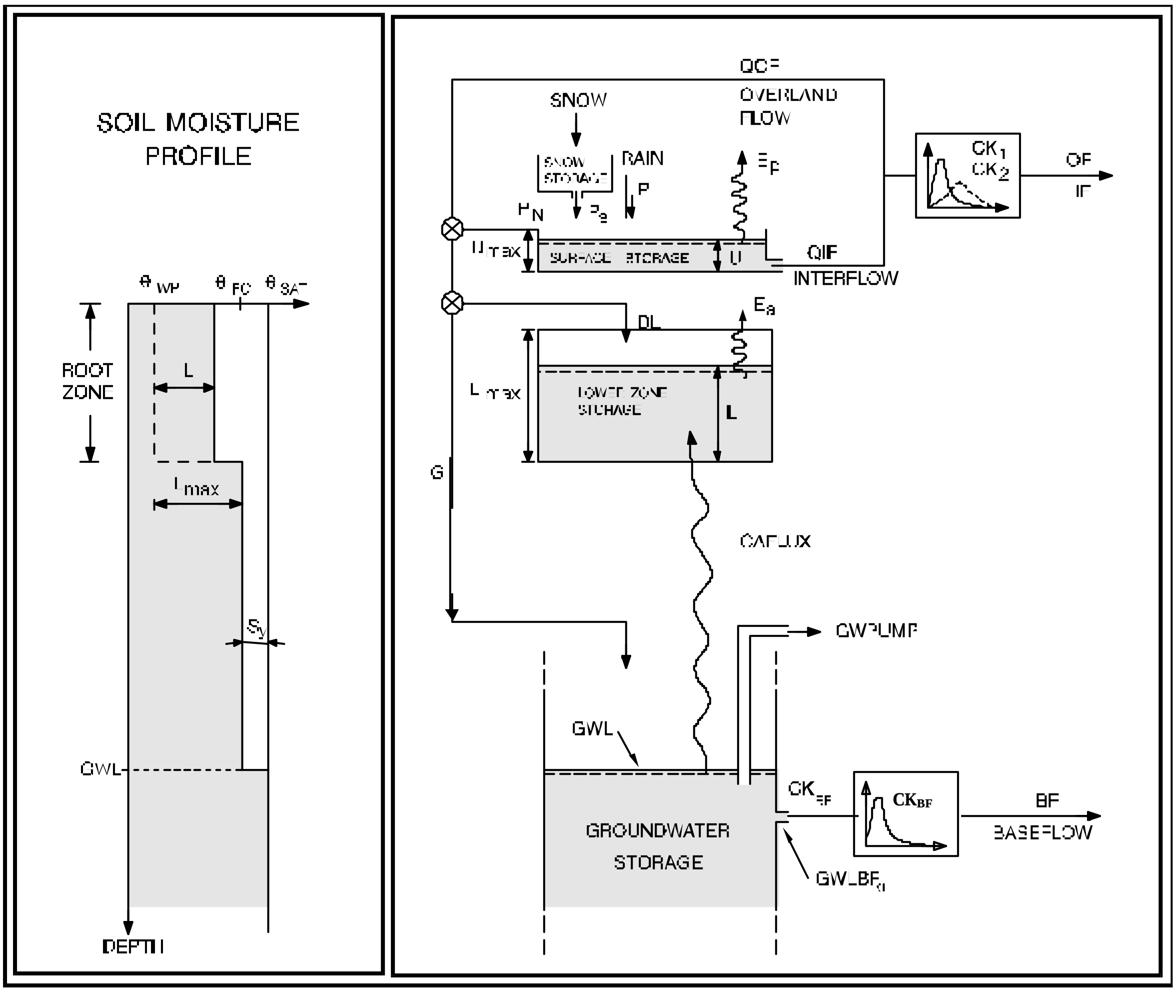

Fig. 1 The structure of NAM model

Statistical measurements:

- In this study, we use mass balance consideration for model built.

$$Mass\ \ balance = \frac{total\ of\ \ observed\ \ flow}{total\ of\ simulated\ \ flow}$$

- Goodness of fit and accuracy criteria

  - The square of the Pearson product moment correlation coefficient , R^2

    Where

$$R = \frac{\sum_{i=1}^{n}\left(QOBS_i - \overline{QOBS}\right)\left(QSIM_i - \overline{QSIM}\right)}{\sqrt{\sum_{i=1}^{n}\left(QOBS_i - \overline{QOBS}\right)^2 \sum_{i=1}^{n}\left(QSIM_i - \overline{QSIM}\right)^2}}$$

  - The Root Mean Square Error

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(QOBS_i - QSIM_i\right)^2}$$

where

$QOBS_i$	*observed value at time step i*
$QSIM_i$	*simulated value at time step i*
$\overline{QOBS}$	*average observed value*
$\overline{QSIM}$	*average simulated value*
n	*number of value time step*

Calibration of the NAM model.

The calibration of the model is very difficult, because of the size of the catchment and the duration of the time period. There are a lot of peaks that has to be fitted, and at the same time the ratio of the simulated and measured flow has to fit for maintaining the mass balance which makes the calibration even more complicated.

To cancel the impact of initial values we use the first year to fill the tanks in the model. This is one of the advantages of the NAM modal, that it has a virtual memory, but this virtual memory has to be filled up. The initial value therefore has an negligible influence on the final results. To check this we changed the initial value of Lt in the calibrated model from 20 into 500. This showed an increment in the water mass ration of 0.0003.

The calibration method we use is trial and error. Simply adjust one of the parameters and see if the results get better. After a rough calibration has been made the calibration is done again with vary small changes. To check the quality of the results we built a graph over the simulated runoff and observed runoff. Also a graph of the accumulated simulated and observed runoff is drawn.

The objective of the calibration we have chosen to be water balance. This has the first priority. The purpose of making water balance first priority of the calibration is, even though the NAN city is frequently flooded, to check or forecast the dimension of the Sirikit Dam and operation of this reservoir.

Also the square of the Pearson product moment correlation coefficient method is looked upon to get a good calibration. The same with the root mean square.

Calibrating with above method and objectives we get following results:

Umax	20
Lmax	133
CQOF	0.40
CKIF	400
TOF	0.60
TIF	0.30
TG	0.03
CK1-2	48
CKBF	1500
GWLBF0	10.00

These values are all connected in some way so the calibration is not unique. That is the same simulation can be obtained with combination of other values. To determine these values with higher accuracy we have to do more field measurements.

The ratio of simulated flow and measured flow is, with the values about: 1.0025. //TJEK DEN
R^2 value is 0.65. The mass balance is very good, since we calibrated the model targeting the mass balance.

R^2 is not good, but this value is not trustable in this case. A little time delay of a peak will have a very large influence on R^2.

The graph of accumulated water mass balance is very good fitted. The graph is fitted OK. Not as good as the water balance though. Especially the large peak in the first year is fitted perfectly. The rest of the peaks are either a little bit above or a little bit below. Both is included in appendix.

Validation of the model

The validation of the model means that the calibrated model can be used appropriately not only the using in the calibration data period but still work rightly in another time.

In this study, the effective model parameters are obtained from the calibration process. The first year (1987), second year (1988) and third year data (1989) remains in the model. These have to be in the model to keep it "warm". That is, they are used to fill up the virtual memory.

The fourth (1990) and the fifth (1991) are used for checking the model and the calibration of the model. The criteria used for considering the validation are mass balance and the statistical measurement are "The square of the Pearson product moment correlation coefficient, R^2" and the "root mean square error, RMSE" as shown below:

year	Mass balance factor	R^2	RMSE
Fourth year (1990)	1.1648	0.76088	77.227
Fifth year (1991)	1.3664	0.75887	69.028

It is noticed that the ratio of measured flow and simulated is very high as 1.17 for the fourth year. For validation of the fifth year the ratio is: 1.37. Therefore it is seen that the production of runoff increases as time goes.

This could indicate that there are some changes in the catchment area. Urbanisation or changing of land use may be occurred and may cause of this increasing runoff. E.g. cutting down trees can increase the runoff because the trees will not consume the and contribute to the evaporation of the water.
Urbanization decreases the amount of infiltration because of the impermeable surface.

It could also mean that we did not calibrate the model properly. To determine, if there is a tendency to more runoff we would need a longer period of data, or data of cutting down trees in the catchment area for the observed time period.

In addition, NAN catchment area is the steep basin and flash flood and there is a Sirikit Dam down to Nan River. So actually the observed flow is greater than simulated flow and for using only mass balance in consideration (single objective), it cannot fit the peak of the hydrograph of observed and simulated flow.

Mass balance consideration is used for water resource planning in long term period.

Finalization

Conclusion

The model that we have build would describe as a good model. The validation of the model is shown a rather large difference between the observed and simulated flow. But because of the systematic error we are able to conclude that there has been a change in the properties of the catchment area. The R^2 (square of Pearson product moment correlation) value even increases in the validation. This means that the shape of the validation curve actually comes closer to the curve representing measured data. Only the difference between the mass of water is very inaccurate.

Sensitivity Analysis

All parameters are changed within their ranges and then compare accumulated simulated flows from both upper range and lower values will be compare as shown in appendix.

Therefore, the significant parameters are U_{max}, L_{max} and CK_{BF} because they result in the high differences of flow. This analysis helps very much in improvement in calibration on which parameters have to be focused on.

It is notice that the way to analyze sensitivity depends on the restricted ranges of each parameter. Actually the range must be carry out from characteristics of basin by field measurement. It is also noticed that the peak and timing of peak are not concerned in this analysis by the reason of large scale of time series.