Rainfall – Runoff Modeling Using *NAM* Model

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1. Brief Description of *NAM* Model

Rainfall - Runoff (RR) module of Mike-11 software of DHI, Denmark includes the NAM model, which is a conceptual representation of the land phase of the hydrological cycle. The model simulates the rainfall-runoff processes occurring at the catchment scale. This rainfall-runoff module can either be applied independently or used to represent one or more contributing catchments that generate lateral inflows to the river network in a MIKE 11 Hydrodynamic (HD) model. It is possible to treat a single catchment or a large river basin containing numerous catchments and a complex network of rivers and channels within the same modelling framework. The model structure is shown in Figure - 1.

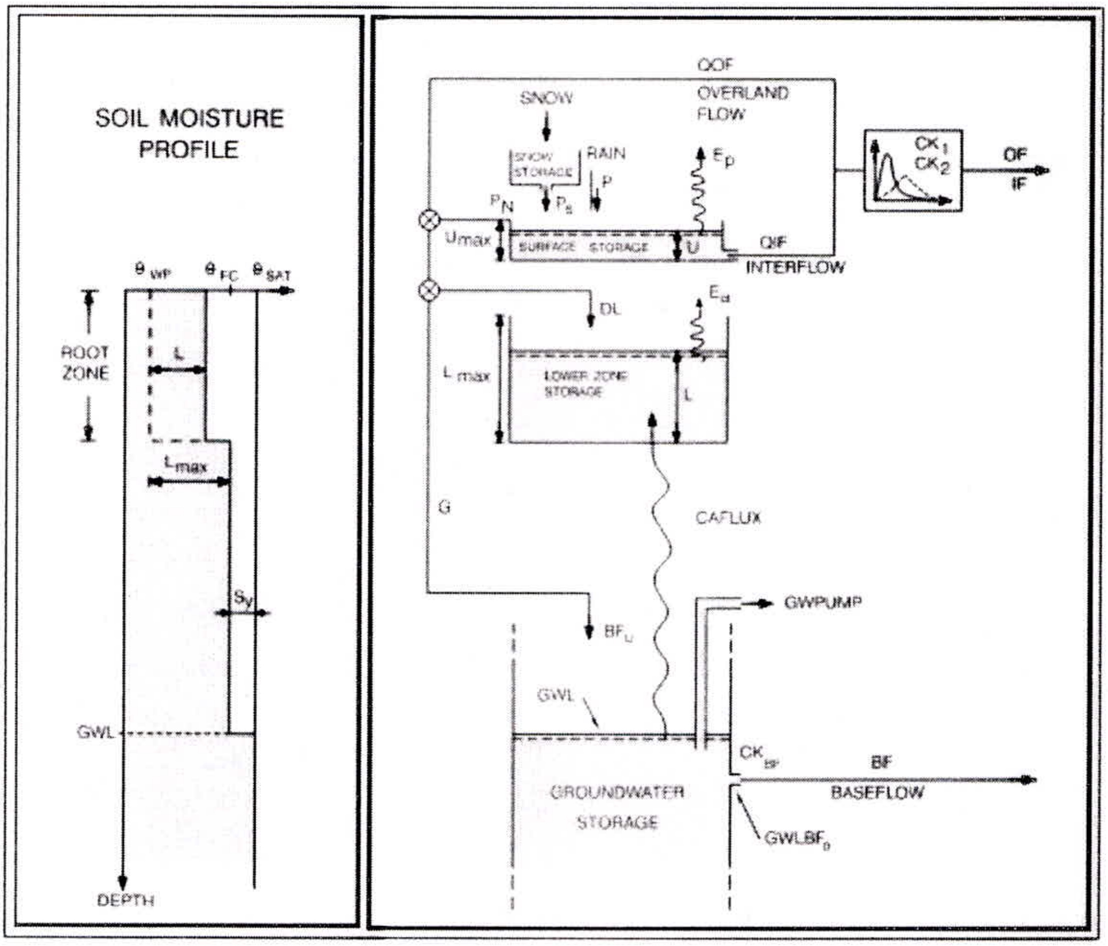


Figure – 1: Model structure of *NAM*

2. Data Requirements of *NAM* Model

Various modeling processes carried out in NAM are depicted in Figure – 2. The basic data input requirements for the MIKE 11 NAM model are meteorological data and discharge data for model calibration and verification, definition of the catchment parameters, and definition of initial conditions.

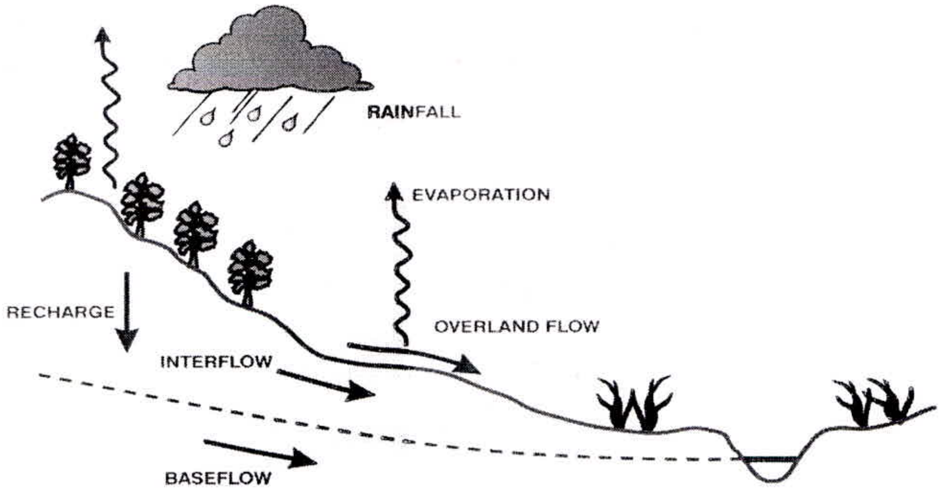


Figure – 2: Modeling processes in *NAM*

The basic meteorological data requirements are precipitation time series, potential evapo-transpiration time series, and temperature (and radiation) time series, if snow accumulation and melt is to be modelled. On this basis, the model produces a time series of catchment runoff, a time series of subsurface flow contributions to the channel, and information about other elements of the land phase of the hydrological cycle, such as soil moisture content and groundwater recharge.

The amount of infiltrating water recharging the groundwater storage depends on the soil moisture content in the root zone. Baseflow from the groundwater storage is calculated as the outflow from a linear reservoir using a time constant. The groundwater level is calculated from a continuity consideration accounting for recharge, capillary flux, net groundwater abstraction, and baseflow. The inclusion of capillary flux and groundwater pumping are optional. The model simulates the rainfall-runoff process by continuously accounting for the water content in four different and mutually interrelated storages that represent different physical elements of the catchment. These storages are:

- Snow storage
- Surface storage
- Lower or root zone storage
- Groundwater storage

In addition, the model allows for treatment of man-made interventions in the hydrological cycle such as irrigation and groundwater pumping. In these cases, time series of irrigation and groundwater abstraction rates are required to maintain the proper water balance in the model. The groundwater level is calculated continuously as a measure of the amount of water in the groundwater storage. This is influenced by:

- Infiltration, which depends on the soil moisture in the root zone.
- Baseflow, which is calculated as the outflow from a linear reservoir using a time constant.
- Capillary flux to the root zone (optional).
- Groundwater abstraction (optional)

The baseflow depends on the difference between the groundwater level and the level of the outflow point in the linear reservoir. The latter is normally constant, but may be given a seasonal variation to represent the baseflow conditions of catchments draining to large rivers, which have a seasonal variation independent of the local hydrological conditions. This typically occurs in delta regions.

The accumulation and melting of snow is incorporated as an integrated module within NAM. Two different models can be applied; a simple lumped calculation or a more general approach that divides the catchment into a number of altitude zones with individual snowmelt parameters, temperature and precipitation input for each zone.

3. Model Calibration

During calibration, the catchment parameters are adjusted until a good fit between the simulated flow contributions, (overland flow, interflow and baseflow) and gauged streamflow is attained. Table - 1 lists the parameters available for adjustment in calibrating *NAM*. The following objectives are usually considered during the model calibration:

a) A good agreement between the average simulated and observed catchment runoff, (i.e., a good water balance)

b) A good overall agreement of the shape of the hydrograph

c) A good agreement of the peak flows with respect to timing, rate and volume

d) A good agreement for baseflow.

In the calibration process, different calibration objectives should be taken into account. If the objectives are of equal importance, one should seek to balance all the objectives, whereas in the case of priority to a certain objective, that objective should be favored. For a general evaluation of the calibrated model, the simulated runoff is compared with discharge measurements. For individual calibration of the groundwater

Table – 1

Calibration parameters in *NAM*

Parameter	Description	Effects
U_{max}	Maximum water content in surface storage	Overland flow, infiltration, evapotranspiration, interflow
L_{max}	Maximum water content in lower zone/root storage	Overland flow, infiltration, evapotranspiration, baseflow
C_{QOF}	Overland flow coefficient	Volume of overland flow and infiltration
C_{KIF}	Interflow drainage constant	Drainage of surface storage as interflow
TOF	Overland flow threshold	Soil moisture demand that must be satisfied for overland flow to occur
TIF	Interflow threshold	Soil moisture demand that must be satisfied for interflow to occur
TG	Groundwater recharge threshold	Soil moisture demand that must be satisfied for groundwater recharge to occur
CK1	Timing constant for overland flow	Routing overland flow along catchment slopes and channels
CK2	Timing constant for interflow	Routing interflow along catchment slopes
CK_{BF}	Timing constant for baseflow	Routing recharge through linear groundwater recharge

parameters, the simulated average groundwater level can be compared with groundwater level measurements in the catchments. An automatic calibration module is available in NAM, allowing calibration of the 9 most important model parameters. The auto-calibration tool is based on a simultaneous optimization of up to four different objectives, including water balance, overall hydrograph shape, peak flows and low flows. For a model calibration that includes all 9 parameters, a maximum number of model evaluations in the range 1000-2000 normally ensure an efficient calibration. Physical significance of some of the NAM parameters are given in the following for purpose of calibration.

3.1 Calibration of NAM parameters

NAM has a maximum of 15 parameters out of which 5 are usually fixed and 10 need to be calibrated. Most important parameters for calibration of water balance are L_{max}, U_{max}, and CQOF. Remaining parameters are used for adjustment of peaks and for routing. A brief description of these parameters giving their physical significance, their effect and consequences of change are as follows:

L_{max} Max. Soil Moisture Content in Root Zone (Soil Moisture Storage Capacity)

L_{max} ~ (FC-WP) * Root Depth

Effects Mainly:

- Overland Flow/Infiltration
- Evapo-transpiration

- Baseflow

Consequence of Increasing L_{max}

- Higher Evapo-transpiration
- Reduced Overland Flow
- Higher Infiltration
- Reduced Baseflow

U_{max} Max. Water Content in Surface Storage (Capacity of Interception, Depressions and Surface Soil)

Effects Mainly:

- Overland Flow/Infiltration
- Evapo-transpiration
- Interflow

Consequence of Increasing U_{max}:

- Less Overland Flow (Especially in Start of Wet Periods)
- Higher Evapo-transpiration
- Reduced Infiltration
- Higher Interflow

Guidelines:

$U_{max} \sim 0.1 * L_{max}$

$U_{max} \sim$ 10-20 mm

CQOF: Overland Flow Coefficient (Determines Amount of Overland Flow and Infiltration)

CQOF ~ 0:

- Little Overland Flow
- High Infiltration

Flat, Highly Permeable Soils

CQOF ~ 1:

- Large Overland Flow
- Small Infiltration

Steep, Impermeable Soils, Rocks

CQIF Interflow Drainage Coefficient (Time Constant for Drainage of Surface Storage as "Interflow")
Usually Not Important Parameter
Usually Cqif = 500-1000 Hours

Consequence of Increasing CQIF:

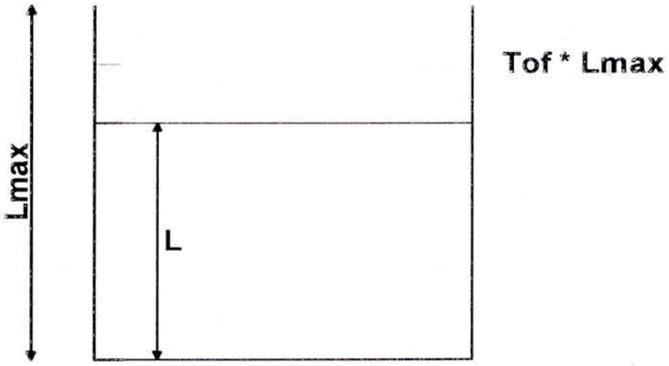
- Linear Amplification of Interflow
- Reduced Infiltration
- Reduced Overland Flow

TOF		Overland Flow
TIF	Threshold Values For	Interflow
TG		Groundwater Recharge

Value Between [0 -1]

No Flow is Generated if The Relative Soil Moisture Content
L/L_{max} < Threshold Value

<u>EXAMPLE</u>



⇒ No overland flow
generated from
surface storage

Consequence of Increasing TOF:	**<u>Later</u>** Start of Overland Flow in beginning of Wet Season ⇒ Higher Infiltration
Consequence of Increasing TIF:	**<u>Later</u>** Start of Interflow in beginning of Wet Season ⇒ Higher Infiltration and Overland Flow
Consequence of Increasing TG:	**<u>Later</u>** Start of Groundwater Recharge and Flow in beginning of Wet Season ⇒ Quicker Filling of Root Zone

Threshold Values Reflect Degree of Spatial Variability

CK1, <u>Time Constants for Routing</u>
CK2
CKBF Through Linear Reservoirs

CK1 and CK2 for routing Overland Flow and Interflow along Catchment Slopes and through Channels Down to Outlet of Catchment.

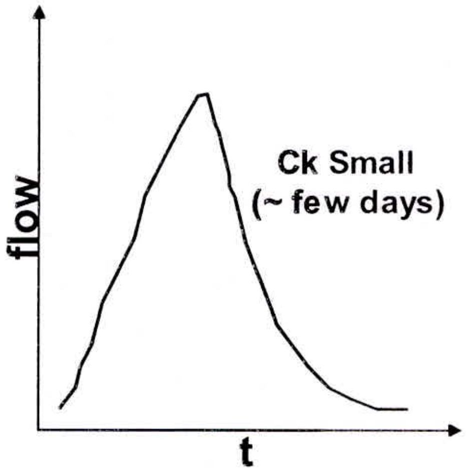
<u>Usually</u> Set **CK1 = CK2**

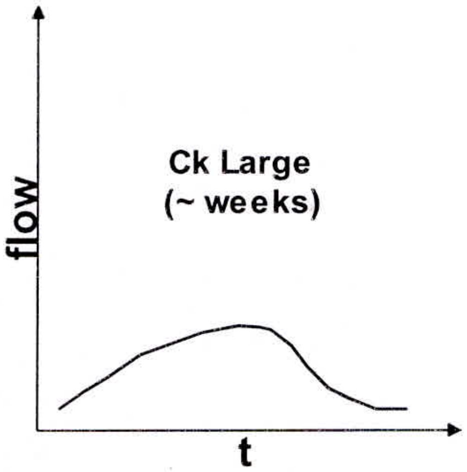
CKBF for Routing Recharge through Linear GW Storage.

Usually **CKBF >> CK1/CK2**

Consequence of Increasing Ck*: Longer Duration of Flow

Lower Peaks Components





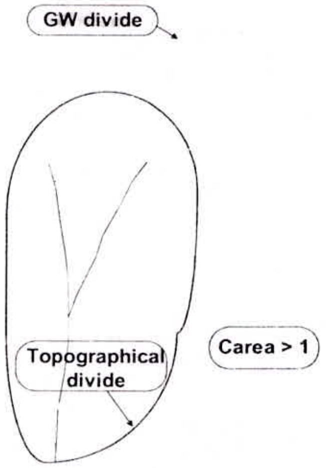
Note: The Actual values of CK* has <u>no</u> effect on generated flow volumes seen over long time, but only on the <u>shape</u> of the hydrographs.

S_Y Usually <u>Fixed (Default)</u> Values
GWL BF_0
GWL_{MIN} Except In Low-Lying, Flat Areas
$GWLFL_1$ With Shallow Gw Depths
(< 1-2 M Below Soil Surface)

<u>Default Values</u>

S_Y:	Specific Yield Of Gw Storage	0.1
GWL BF_0:	Max. GW Depth Causing Baseflow	10 m
GWL_{MIN}:	Min. GW Depth	0 m
GWL FL_1:	GW Depth for Unit Cap. Flux	0 m

Carea Ratio Between Groundwater Drainage Area And Topographical Area <u>Default Value 1.0</u>



3.1.1 Calibration Strategy

Following strategy could be adopted for calibration of various parameters:

a) Fit of Water Balance of Calibration Period

Adjust Actual Evapo-transpiration by Adjusting $\mathbf{L_{max}/U_{max}}$

b) Fit of Flood Peaks

Adjust Overland Flow
- Volume **CQOF**
- Magnitude
- Timing **TOF**
- Shape **CK1 = CK2**

c) Fit of Low Flows

Adjust Baseflow
- Volume : Adjust Overland Flow
  $\Rightarrow$ Adjusted Recharge
  i.e. Again **CQOF**
- Timing : **TG**
- Shape : **CKBF**

As the parameters often are inter-dependent, it is advisable first to do a rough calibration involving all of the three above items and then afterwards fine-tune the calibration.

4. Steps for Model Application

The NAM model is a well-proven engineering tool that has been applied to a large number of catchments around the world, representing many different hydrological regimes and climatic conditions. The purpose of NAM application is to extend flow series and generate series of groundwater recharge, so that we have realistic estimates of the surface and groundwater availability and its variation in time and space, preferably over many decades. We should make sure that the distribution of water in runoff peaks, interflow, baseflow, and corresponding recharge is as accurate as possible. Model is calibrated over a relatively short period of e.g. 10 years, depending on data availability, and subsequently it is run for many decades to generate long series. The steps for model application are as follows:

a) Before data is used for the modeling it should be checked for errors. Obvious errors can be found by comparing stations or by simple visual inspection of the data.

b) Assess the variation of rainfall inside the catchment from the map of average rainfall

c) Assess the availability of rainfall data by plotting the data coverage to see the need for specifying special weight combinations which consider missing data at some stations. It is not mandatory to specify more than one weight combination as missing data at a rainfall stations automatically will prompt the system to distribute the weight of that station to the other stations on that day. It may be desirable to specify the weighting to be used for some combinations of missing data, where the automatic distribution would not be suitable. This could be for stations with particularly high (or low) rainfall, which may substitute with data of a similar station.

d) Select a representative station with potential evaporation data. The elevation of the station should correspond to the average elevation of the catchment and it may be located (slightly) outside the catchment if no station is available at a suitable elevation inside the catchment. For pan data it may be required to apply a factor to the data (often 0.7) to obtain values of potential evaporation from the land area rather that open water. If the available series is not covering the full simulations period of several decades you may extend it by using average values for each month or day.

e) Auto-calibration NAM. Check the total runoff volume (in the calibration plot or RRSTAT.TXT) and assess possible explanations if it does not match. This could be rainfall weights, which are not leading to the best estimate of catchment rainfall, it could be non-representative potential evaporation data, or error in the applied discharge series. Make suitable correction and re-run the auto-calibration.

f) Validate the groundwater recharge. This can be done by checking that the baseflow is simulated accurately and by comparing the recharge to the GEC97 estimates, although these are also uncertain. You may also assess the groundwater depth variation (open the additional res11 file in Mike View) in comparison with the measured depth. This comparison may require changing the specific yield and specifying groundwater abstraction. If the groundwater recharge is unsatisfactory you may try adjusting NAM parameters manually to obtain better values. This should be done with due consideration to the simulation of surface runoff. The main parameters to modify are CQOF, TG, and L_{max}. The groundwater recharge will:

- Decrease significantly if CQOF is increased. This also increases flow peaks, however.
- Decrease slightly if TG is increased

g) L_{max} may be adjusted to retain the overall water balance after adjusting these parameters.

h) Combine the measured and simulated flow. The surface runoff should be taken as the measured daily flow, when possible. Use the NAM generated surface runoff only to gap-fill and extend the observed series. The surface runoff should be the total NAM runoff minus the NAM baseflow.

i) Generated series of surface runoff and groundwater recharge can be used in the river basin modeling tools.

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