MOUSE

Runoff

Reference Manual

The expert in **WATER ENVIRONMENTS**

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PLEASE NOTE

MOUSE SURFACE RUNOFF MODELS

Reference Manual

1 General Information

1.1 Runoff Models Available in MOUSE

Different surface runoff computation concepts are available in MOUSE as four different runoff models:

Model A- Time/area Method,

Model B- Non-linear Reservoir (kinematic wave) Method,

Model C- Linear Reservoir Method, in two sub-variants:
Model C1 - Dutch runoff model
Model C2 - French runoff model

UHM- Unit Hydrograph Model

Surface runoff computations in MOUSE can be based on any of the four concepts, provided that the necessary data have been specified for each catchment specified in the set-up. However, in one simulation run it is not possible to combine different runoff computation concepts for various model areas.

Runoff computed by any of the surface runoff models except UHM can be complemented by a continuous runoff component, i.e. rainfall-induced infiltration can be added to the computed surface runoff hydrographs as the catchments "base flow". This option is available only with a valid MOUSE RDI license. For more information, refer to the "MOUSE RDI - User Guide" and "MOUSE RDI - Technical reference".

1.2 Organisation of Runoff Model Data

Use of different runoff models for the same catchment in subsequent simulations may result in very different simulated runoff. This is because each of the models uses different set of input data and model parameters, as well as different runoff computation concept. It is therefore of utmost importance to understand the background for the runoff computations applied in each of the models, as well as the meaning and interpretation of the various data and model parameters.

The runoff model data and model parameters are organised in the following clusters:

- General catchment data
- Model-specific catchment data
- Model parameters.

The general catchment data are independent of the choice of the runoff model. They include basic information about catchment size, connection point to the network, geographical position (co-ordinates) and specification of additional, constant inflow.

The model-specific catchment data comprise different sets for each of the models. These data basically provide further information about the catchments' geometry and a more or less detailed land use description. Reference to a specific parameter set is also a part of this group.

Model parameters are organised in parameter sets. A parameter set is comprised of all editable parameters needed to execute certain type of runoff computation. Surface runoff computation for an individual catchment is based on the parameters contained in the set associated with the catchment. Initially, MOUSE provides a "DEFAULT" parameter set for each of the models. User can create an arbitrary number of parameter sets under user-specified names.

Some parameters (for model A all parameters) from the parameter set currently associated with certain catchment can be individually edited as "Individual data", so that the edits are applied only for the individual catchment.

2 Surface Runoff MODEL "A" - Time-area method

2.1 Concept

The concept of surface runoff computation of MOUSE Runoff Model A is founded on the so-called "Time-Area" method. The runoff amount is controlled by the initial loss, size of the contributing area and by a continuous hydrological loss.

The shape of the runoff hydrograph is controlled by the concentration time and by the time-area (T-A) curve. These two parameters represent a conceptual description of the catchment reaction speed and the catchment shape.

2.2 Input Data

2.2.1 General Catchment Data

ID - an identifier string of up to 25 ASCII characters.

Location - MOUSE network node identifier, defines the catchment connection point.

X- and **Y-co-ordinates -** catchment co-ordinates used for the allocation of spatially distributed rain data. Per default, the fields are filled-in by the connection node co-ordinates. For better accuracy for larger catchments, the co-ordinates may be edited and replaced with e.g. centrepoint co-ordinates.

Catchment Area [ha] - the total horizontal surface area of the catchment.

Inhabitants - number of inhabitants associated with the catchment. Does not have any effect on runoff computation - used by catchment loads.

Additional flow [m^3/s] - a constant flow to be added to the computed runoff hydrograph for the catchment. Usually used for a simplified description of a constant infiltration component in single-event simulations.

2.2.2 Model Specific Data

Impervious area - fraction of the catchment area, [%], considered to contribute to the runoff.

2.2.3 Hydrological Parameters

Initial Loss - defines the precipitation depth, [m], required to start the surface runoff. This is a one-off loss, comprising the wetting and filling of catchment depressions.

The default value is 6.00E10^{-4} m.

Hydrological Reduction - runoff reduction factor, accounts for water losses caused by e.g. evapo-transpiration, imperfect imperviousness, etc. on the contributing area.

The default value is 0.90.

Time/Area Curve - accounts for the shape of the catchment layout, determines the choice of the available T/A curve to be used in the computations.

Three pre-defined types of the T/A curves are available:

TACurve1 - rectangular catchment
TACurve2 - divergent catchment
TACurve3 - convergent catchment

The user-defined T/A curve can be specified, thus allowing correct description of irregular catchments.

The default T/A type is a pre-computed curve type 1.

Time/Area Coefficient this formula has been introduced covering curve shapes “in between” the three standard ones (and outside). The formulae has been suggested by Nittaya Wangwongwiroj at AIT. The curves “in between” are specfied by giving the Time Area Coefficient directly in MOUSE in stead of specifying a Time/Area Curve .

$$y = 1-(1-x)^{\frac{1}{a}} \quad \text{for } 0 < a < 1 \tag{2.1}$$

$$y = x^{a} \quad \text{for} \quad 1 \le a$$

where

y	=	Accumulated dimensionless area
x	=	Dimensionless concentration time
a	=	Time area curve coefficient

Below is seen a plot of the curves.

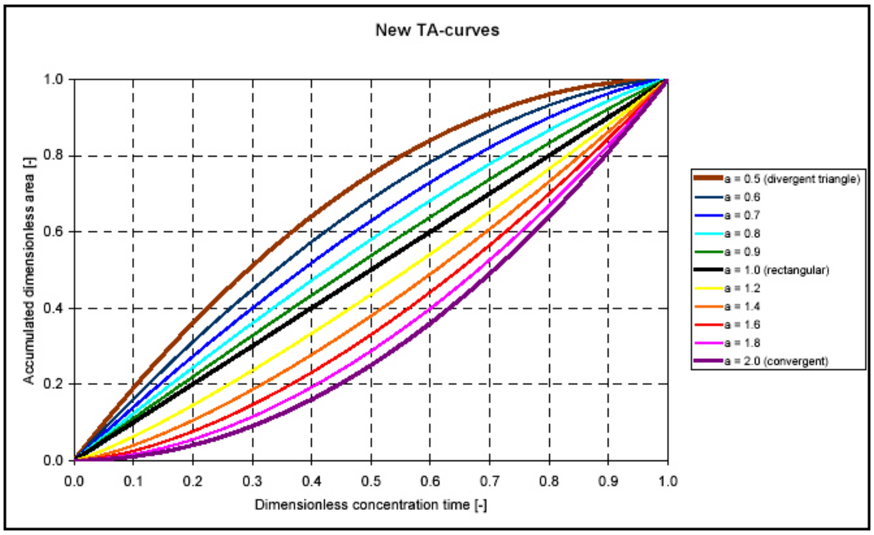

Figure 2.1 Time-area coefficient variations

Concentration Time - defines the time, [min], required for the flow of water from the most distant part of the catchment to the point of outflow.

The default value is 7 min.

2.3 Runoff Computation

The continuous runoff process is discretised in time by the computational time step Δt. The assumption of the constant runoff velocity implies the spatial discretisation of the catchment surface to a number of cells in a form of concentric circles with a centre point at the point of outflow. The number of cells equals to:

$$n = \frac{t_c}{\Delta t} \qquad (2.2)$$

where:

t_c	=	concentration time
Δt	=	simulation time step

MOUSE calculates the area of each cell on the basis of the specified time-area curve. The total area of all cells is equal to the specified impervious area.

A time-area curve characterises the shape of the catchment, relating the flow time i.e. concentric distance from the outflow point and the corresponding catchment sub-area. There are three pre-defined time/area curves available in MOUSE. Irregularly shaped catchments can be more precisely described by the user-specified T/A curves.

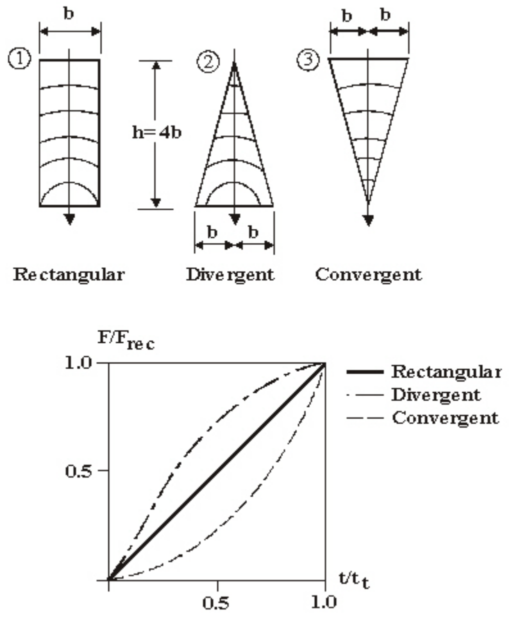

Figure 2.2 The three pre-defined time/area curves available in MOUSE

The runoff starts after the rain depth has exceeded the specified initial loss for the catchment. The runoff stops when the accumulated rain depth on the whole catchment surface regresses below the specified initial loss for the catchment.

At every time step after the start of the runoff, the accumulated volume from a certain cell is moved to the downstream direction. Thus, the actual volume in the cell is calculated as a continuity balance between the inflow from the upstream cell, the current rainfall (multiplied with the cell area) and the outflow to the downstream cell. The outflow from the most downstream cell is actually the resulting surface runoff hydrograph.

To account for the specified hydrological reduction, the runoff from the impervious surface is reduced by the catchments hydrological reduction factor.

2.4 Multiple-Event Simulations

If the Surface Runoff Model A is used for a continuous simulation of multiple rainfall events (without RDI component activated), a special solution is applied for the simulation of dry periods between the consecutive events. The solution accounts for the loss of water caused by drying out of the initial loss (representing wetting and surface storage), i.e. allowing the occurrence of the initial loss at the beginning of each simulated event, in accordance with reality.

In this context, start of a dry period is defined if two conditions are fulfilled simultaneously:

- All connected rain gauges show no rain, i.e. intensity = 0.00
- The runoff has fallen to zero from all catchments included in the simulation.

At the start of a dry period, the initial loss storage would be fully or partially filled up, the latter being the only case for small events of the total depth smaller than the initial loss storage depth. Recovery of the initial loss capacity, i.e. the process of surface drying is simulated as a constant "decay" rate, which replaces the actual evaporation. As a consequence of the recovery process, the initial loss storage would be fully or partially emptied, which depends on the actually applied loss recovery rate and the duration of the dry period.

Default value for the "loss recovery rate" is 0.0005 m/h, and can be controlled through DHIAPP.INI file (see relevant documentation).

The recovery process is only activated during dry periods, i.e. the evaporative action during rain events is neglected. In order to rationalise the size of the result file, entire dry period between two events is saved as a single time step in the result file.

3 Surface Runoff MODEL "B" - Kinematic Wave (non-linear reservoir)

3.1 Concept

The concept of surface runoff computation of MOUSE Runoff Model B is founded on the kinematic wave computation. This means that the surface runoff is computed as flow in an open channel, taking the gravitational and friction forces only. The runoff amount is controlled by the various hydrological losses and the size of the actually contributing area.

The shape of the runoff hydrograph is controlled by the catchment parameters length, slope and roughness of the catchment surface. These parameters form a base for the kinematic wave computation (Manning equation).

3.2 Input data

3.2.1 General Catchment Data

The general catchment data are identical for all MOUSE Surface runoff models. For details, refer to section 2.2.1 General Catchment Data *(p. 11)*.

3.2.2 Model Specific Data

Length [m] **-** conceptually, definition of the catchment shape, as the flow channel. The model assumes a prismatic flow channel with rectangular cross section. The channel bottom width is computed from catchment area and length.

Slope [‰] - average slope of the catchment surface, used for the runoff computation according to Manning.

Surface type areas [% of total area] - fractions of the catchment surface belonging to different surface types:

- impervious steep
- impervious flat
- pervious -small impermeability
- pervious - medium impermeability
- pervious - large impermeability

The model applies different hydrological parameters for each of the surface types.

3.2.3 Hydrological Parameters

Wetting loss [m]- one-off loss, accounts for wetting of the catchment surface.

The default value for all surface types is 5.00E10^{-5} m.

Storage loss [m]- one-off loss, defines the precipitation depth required for filling the depressions on the catchment surface prior to occurrence of runoff.

The default value depends on the surface type (see Table 3.1)

Start infiltration [m/s] - defines the maximum rate of infiltration (Horton) for the specific surface type.

The default value depends on the surface type (see Table 3.1).

End infiltration [m/s] - defines the minimum rate of infiltration (Horton) for the specific surface type.

The default value depends on the surface type (see Table 3.1).

Horton's Exponent - time factor "characteristic soil parameter" [s^{-1}]. Determines the dynamics of the infiltration capacity rate reduction over time during rainfall. The actual infiltration capacity is made dependent of time since the rainfall start only.

The default value depends on the surface type (see Table 3.1).

Inverse Horton´s Equation [s^{-1}] **-** time factor used in the "inverse Horton's equation", defining the rate of the soil infiltration capacity recovery after a rainfall, i.e. in a drying period.

The default value depends on the surface type (see Table 3.1).

Manning's number [$m^{1/3}s^{-1}$] - Describes roughness of the catchment surface, used in hydraulic routing of the runoff (Manning's formula).

The default values depend on the catchment surface category (see Table 3.1).

Table 3.1 Default hydrological parameters for surface runoff model B

Default values for hydrological parameters - Runoff Model B					
Parameter	Impervious		Pervious		
	Roof	Flat area	Small Inf.	Medium Inf.	Large Inf.
Wetting (m)	5.00E.-5	5.00E-5	5.00E-5	5.00E-5	5.00E-5
Storage (m)	-	6.00E-4	1.00E-3	1.00E-3	2.00E-3
Start.inf.(m/s)	-	-	1.00E-6	1.00E-5	2.00E-5
End.inf. (m/s)	-	-	5.00E-7	1.00E-6	5.00E-6
Exponent (s^{-1})	-	-	1.50E-3	1.50E-3	1.50E-3
Inverse Exp. (s^{-1})	-	-	5.00E-6	1.00E-5	5.00E-5
Manning ($m^{1/3}s^{-1}$)	80	70	30	30	12

3.3 Runoff Computations

The model computations are based on the volume continuity and the kinematic wave equations.

The first step is the calculation of effective precipitation intensity. The effective precipitation intensity is the precipitation which contributes to the surface runoff.

Next, the hydraulic routing based on the kinematic wave formula (Manning) and volume continuity is applied. The sketch with schematics of the model computation is shown in Figure 3.1.

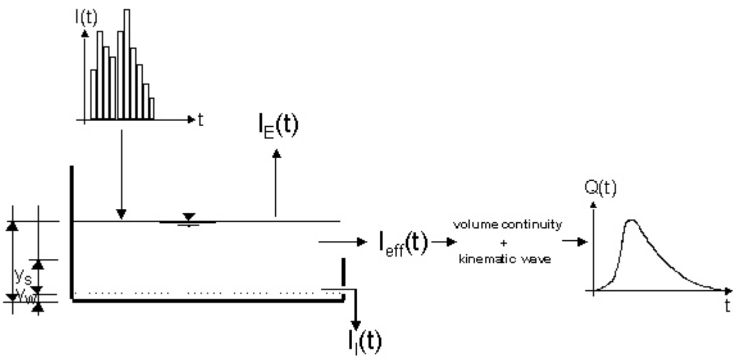

Figure 3.1 The simulated processes in the Surface runoff model B.

Computing Effective Precipitation

The simulated hydrologic processes account for various losses calculated - evaporation, wetting, infiltration and surface storage -according to the conventions and equations presented below. The remaining precipitation is called **effective precipitation**, defined generally as:

$$I_{eff}(t) = I(t) - I_E(t) - I_W(t) - I_I(t) - I_S(t) \tag{3.1}$$

$$I_{eff} \geq 0$$

where:

$I(t)$ = Actual precipitation at time t,
$I_E(t)$ = Evaporation loss at time t. It should be noted that the evaporation loss for the catchment is accounted only if the RDI runoff computation is activated.
$I_W(t)$ = Wetting loss at time t,
$I_I(t)$ = Infiltration loss at time t,
$I_S(t)$ = Surface Storage loss at time t.

The individual terms in the loss equation are fundamentally different, as some terms are continuous where others are discontinuous. If the calculated loss is negative, it is set to zero. The losses have a dimension of velocity [LT^{-1}].

The actual precipitation, $I(t)$, is assumed to be uniformly distributed over the individual catchments. Otherwise, it may vary as a random time function.

The evaporation, $I_E(t)$, is a continuous loss that is normally of less significance for single event simulations. However, on a long-term basis, evaporation accounts for a significant part of hydrological losses. If included in the computation, the evaporation is the first part subtracted from the actual precipitation, according to the following:

$$I_E(t) = \begin{cases} I_{PE}(t) & for \quad (I(t) \geq I_{PE}(t)) \quad OR \quad (y(t) > 0) \\ I(t) & for \quad (I(t) < I_{PE}(t)) \quad AND \quad (y(t) = 0) \end{cases} \tag{3.2}$$

where:

$I(t)$ = Actual precipitation at time t,
$I_E(t)$ = Evaporation loss at time t.
$I_{PE}(t)$ = Potential evaporation at time t,
$y(t)$ = Accumulated depth at time t.

The wetting, $I_W(t)$, is a discontinuous loss. When the precipitation starts, a part of the precipitation is used for wetting of the surface if the surface is initially dry. The model assumes that the precipitation remaining after subtraction of the evaporation loss is used for wetting of the catchment surface. When the surface is wet, the wetting loss, I_W, is set to zero. This is summarised in the following expression:

$$I_W(t) = \begin{cases} I(t) - I_E(t) & for \quad y(t) < y_w \\ 0 \quad for \quad (I(t) \le I_E(t)) \quad OR \quad (y(t) \ge y_w) \end{cases} \tag{3.3}$$

where:

I(t)	=	Actual precipitation at time *t*,
$I_E(t)$	=	Evaporation loss at time *t*.
$I_W(t)$	=	Wetting loss at time *t*,
y_W	=	Wetting depth,
y(t)	=	Accumulated depth at time *t*.

The infiltration, *I(t)*, is the water loss to the lower storage caused by the porosity of the catchment surface. It is assumed that the infiltration starts when the wetting of the surface has been completed. The infiltration loss is calculated according to the following relation:

$$I_I(t) = \begin{cases} I_H(t) \quad for \quad (y(t) \ge y_w) \quad AND \quad (I(t) - I_E(t) - I_W(t) \ge I_H(t)) \\ I(t) - I_E(t) - I_W(t) \quad for \quad (I(t) - I_E(t) - I_W(t)) < I_H(t) \\ 0 \quad for \quad y(t) < y_w \end{cases} \tag{3.4}$$

where:

$I_I(t)$	=	Infiltration loss at time *t*.
$I_H(t)$	=	Horton's infiltration at time *t* (see below),
y_W	=	Wetting depth,
y(t)	=	Accumulated depth at time *t*.

The infiltration is a complex phenomenon, dependent on the soil porosity, moisture content, groundwater level, surface conditions, storage capacity, etc. The model calculates the infiltration loss capacity using the well-known Hortons's equation, per default in its original form:

$$I_H(t) = I_{Imin} + (I_{Imax} - I_{Imin}) \cdot e^{-K_a \cdot t} \tag{3.5}$$

where:

$I_H(t)$	=	Infiltration loss calculated according to Horton
I_{Imax}	=	Maximum infiltration capacity (after a long dry period),
I_{Imin}	=	Minimum infiltration capacity (at full saturation),
t	=	Time since the start of the storm,

k_a = Time factor (characteristic soil parameter) for wetting conditions.

The Horton's equation in its original form Equation (3.5) yields in realistic results only if applied to events for which the rainfall intensity always exceeds the infiltration capacity. However, typical values for infiltration capacity parameters I_{Imax} and I_{Imin} are often greater than typical rainfall intensities. Thus, when equation (3.5) is used, with infiltration capacity I_H being the function of time only, I_H will decrease even if rainfall intensities are very small. In other words, this results in a reduction in infiltration capacity regardless of the actual amount of water entering the soil. This problem is solved by implementing the integrated form of the Equation (3.5):

$$I_{I_{CUM}}(t_p) = \int_0^{t_p} I_H dt = I_{I_{min}} \cdot t_p + \frac{I_{Imax} - I_{Imin}}{k_a} \cdot (I - e^{-k_a t_p}) \qquad (3.6)$$

where $I_{CUM}(t_p)$ is a cumulative infiltration (m) at time t_p, i.e. the area under the Horton's curve. This assumes that the actual infiltration has been equal to the infiltration capacity at any time within the period $0 \rightarrow t$. Since this is only the case for rainfall intensities higher than the infiltration capacity, this needs to be corrected as:

$$I_{CUM}(t) = \int_0^{t} I_I dt \qquad (3.7)$$

i.e. the cumulative infiltration at the elapsed time t is calculated using the actually occurred infiltration.

At any elapsed time t, the two equations (3.6) and (3.7) can be used to determine the "equivalent" time t_p. This is done iteratively, since equation (3.6) cannot be solved explicitly for t_p.

The time t_p on cumulative Horton's curve will always be less or equal than the actually elapsed time, implying that the available infiltration capacity at time t_p will be greater than or equal to that given by the equation (3.5). By these means, the infiltration capacity has been made a function of actual water infiltrated and not just a function of time.

Application of a "standard" Horton's equation (3.5) or its integrated form (Equations (3.6) and (3.7)) is controlled by the switch **"IntegratedHorton"**, found in the *DHIAPP.INI* file (see relevant documentation for reference). Per default, the program is set to "standard" Horton's equation.

In the dry period following the rainfall, the infiltration capacity is gradually recovered to the initial value, using an inverse form of the Horton's equation:

$$I_H(t) = I_{IT} + (I_{I_{max}} - Q_{I_T}) \cdot e^{-1/K_h t} \tag{3.8}$$

where:

$I_H(t)$	=	Infiltration loss capacity calculated according to Horton,
I_{Imax}	=	Maximum infiltration capacity (after a long dry period),
I_{IT}	=	Infiltration capacity at the threshold between the wetting and drying period,
t	=	Time since the start of the recovery process,
k_h	=	Time factor (characteristic soil parameter) for drying conditions.

The surface storage, $I_S(t)$, is the loss due to filling the depressions and holes in the terrain. The model begins with the surface storage calculation after the wetting process is completed. The surface storage is filled only if the current infiltration rate is smaller than the actual precipitation intensity reduced by evaporation. The actual surface storage loss is calculated according to the following:

$$I_S(t) = \begin{cases} I(t) - I_E(t) - I_W(t) - I_I(t) & for \quad y(t) \le (y_w + y_s) \\ 0 \quad f & y(t) > (y_w + y_s) \end{cases} \tag{3.9}$$

where:

$I(t)$	=	Precipitation intensity at time t,
$I_S(t)$	=	Surface storage loss at time t,
$I_I(t)$	=	Infiltration loss at time t,
$I_W(t)$	=	Wetting loss at time t,
$I_E(t)$	=	Evaporation loss at time t,
y_W	=	Wetting depth,
y_S	=	Surface storage depth,
$y(t)$	=	Accumulated depth at time t.

The Surface Runoff Routing

The runoff starts when the effective precipitation intensity is larger than zero. The hydraulic process is described with the kinematic wave equations for the entire surface at once. This description assumes uniform flow conditions on the catchment surface, i.e. equal water depth over the entire surface of certain category.

This type of runoff model is also called a non-linear reservoir model.

The surface runoff at time *t* is calculated as:

$$Q(t) = M \cdot B \cdot I^{1/2} \cdot y_R(t)^{5/3} \tag{3.10}$$

where:

M	=	Manning's number,
B	=	Flow channel width, computed as:
		B [m] = A [m^2] / L [m]
I	=	Surface slope,
$y_R(t)$	=	Runoff depth at time *t*.

The depth $y_R(t)$ is determined from the continuity equation:

$$I_{eff}(t) \cdot A - Q(t) = \frac{dy_R}{dt} \cdot A \tag{3.11}$$

where:

I_{eff}	=	Effective precipitation,
A	=	Contributing catchment surface area,
dt	=	Time step,
dy_R	=	Change in runoff depth.

3.3.1 Impact of Catchment Surface Type on Computations of Hydrological Losses

Surface Runoff Model **B** distinguishes between up to 5 different catchment surface types. This is practically handled by the model so that the individual catchment is split into up to five sub-catchments, each with the area according to the specified percentages for specific surface categories.

For each surface type, only relevant processes are simulated. An overview of the processes associated with different surface types is shown in

Table 3.2.The model treats every area with different surface category as a

Table 3.2 Processes included for various types of catchment surfa

Surface Type MOUSE	Hydrological Loss Simulated
Impervious surface Roof	Evaporation (only with RDI) Wetting
Impervious surface Flat area	Evaporation (only with RDI) Wetting Storage
Pervious surface Infiltration small	Evaporation (only with RDI) Wetting Infiltration Storage
Pervious surface Infiltration medium	Evaporation (only with RDI) Wetting Infiltration Storage
Pervious surface Infiltration large	Evaporation (only with RDI) Wetting Infiltration Storage

sub-catchment, and the runoff computations are performed individually. The total runoff from the entire catchment is obtained then as a sum of runoffs from up to five different sub-catchments.

3.3.2 Definition of the Sub-catchment Geometry

The length and width for each sub-catchment (sub-area) are calculated so that the length/width ratio for each sub-area is kept equal to the length/width ratio of the corresponding catchment. Based on the information for the whole catchment and the principle of constant length/width ratio, equivalent values of the runoff width and length are computed for all sub-areas, as illustrated in the example below (Figure 3.2).

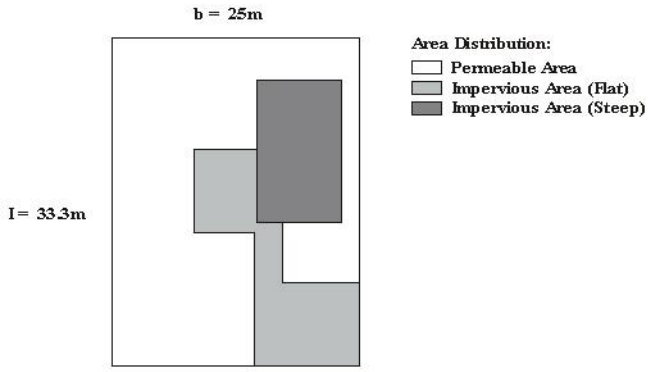

Figure 3.2 Sub-catchments with total area = 833 m^2.

The ratio between the catchment length and width in the given example corresponds to 1.33. 15% of the total area is impervious roof surface corresponding to 125 m^2. Hence the runoff length is 12.9 m and the runoff width is 9.7 m for this surface type, as 12.9 * 9.7 = 125 and 9.7 * 1.33 = 12.9.

3.4 Multiple-Event Simulations

If the Surface Runoff Model B is used for a continuous simulation of multiple rainfall events (without RDI component activated), a special solution has been applied for the simulation of dry periods between the consecutive events. The solution accounts for the following phenomena:

- Recovery of the soil infiltration capacity

  According to Horton, the soil infiltration capacity is getting reduced as the soil gets more saturated by rain. In dry periods, an inverse process occurs, with gradual recovery of the infiltration capacity. Computation of both processes is detailed in section 3.3 Runoff Computations *(p. 19)*. As a consequence of wet and dry period alternation in a multiple event simulation, the model alternates between the two computation modes. Switching to the "dry" mode is triggered by the exhaustion of all water available for infiltration. Consecutively, switch to the "wet" mode at the start of a new rain event.

- Recovery of the initial loss capacity during dry intervals, i.e. occurrence of the initial loss at the beginning of each simulated event, in accordance with reality.

  In this context, start of a dry period is defined if three conditions are fulfilled simultaneously:

  – All connected rain gauges show no rain, i.e. intensity = 0.00
  – Infiltration has stopped from all catchments

– The runoff from each catchment included in the simulation has fallen below the "low flow" limit. Per default, the low flow limit is set to 0.0001 m^3/s. The threshold can be controlled through the parameter **RUNOFF_B_LOW_FLOW** found in the *DHIAPP.INI* file (see relevant documentation for reference).

At the start of a dry period, the initial loss storage would appear fully or partially filled up. For flat impervious surfaces, the full initial loss storage would contain the water used for wetting and filling of the surface storage, while for all other surface types only wetting loss will apply. The latter case, i.e. partially filled storage would apply for small events with the total depth smaller than the corresponding initial loss storage capacity.

Recovery of the initial loss capacity, i.e. the process of surface drying is simulated as a constant "decay" rate, which replaces the actual evaporation. As a consequence of the recovery process, the initial loss storage would be fully or partially emptied, which depends on the actually applied loss recovery rate and the duration of the dry period.

Default value for the "loss recovery rate" is 0.0005 m/h, and can be controlled through *DHIAPP.INI* file (see relevant documentation for reference).

The recovery process is only activated during dry periods, i.e. the evaporative action during rain events is neglected. Note that if actual evaporation process is activated (available only in conjunction with RDI!), the recovery process is suppressed and evaporative action is activated throughout the simulation period.

In order to rationalise the size of the result file and speed up the simulation, dry periods between events are per default simulated with longer time steps. Per default, the dry period time step is set to 12 hours. This can be controlled through the parameter **RUNOFF_B_LOW_FLOW** found in the *DHIAPP.INI* file (see relevant documentation for reference).

Switching to long time step in dry period can be suppressed by setting the parameter **RUNOFF_B_Variable_dT** found in the *DHIAPP.INI* file to **OFF** (see relevant documentation for reference).

4 Surface Runoff Model C

4.1 Concept

The surface runoff computation of MOUSE Runoff Model C is founded on the routing of the runoff through a linear reservoir. This means that the surface runoff from a catchment is made proportional to the current water depth on the catchment. The implemented two versions of the model are equivalent to the surface runoff model used in the Netherlands (C1) and in France (C2).

The runoff amount is controlled by the initial losses, size of the actually contributing area and by infiltration losses. The shape of the runoff hydrograph (phase and amplitude) is controlled by the catchments time constant.

4.2 Input Data

4.2.1 General Catchment Data

The general catchment data for all MOUSE Surface runoff models. For details, refer to section 2.2.1 General Catchment Data *(p. 11)*.

4.2.2 Model-Specific Data

Model C1

Effective area - fraction of the catchment area, [%], considered to contribute effectively to the runoff.

Model C2

Impervious area - fraction of the catchment area, [%], considered to contribute to the runoff.

Length [m] **-** Catchment length, used in the empirical calculation of the catchments lag time constant. Represents the estimation of the maximum runoff length from the periphery of the catchment to the point of connection.

Slope [‰] - Catchment slope, used in the empirical calculation of the catchments lag time constant. Represents the estimation of the average runoff slope.

4.2.3 Hydrological Parameters

Model C1

Initial Loss - defines the precipitation depth, [m], required to start the surface runoff. This is a one-off loss, comprising the wetting and filling of catchment depressions.

The MOUSE default value is $5.00E10^{-4}$ m.

Time constant - the linear reservoir time constant (1/min), controls the shape of the runoff hydrograph (reaction time).

The MOUSE default value is 0.20 1/min.

Infiltration - maximum capacity (mm/h) - defines the maximum rate of infiltration (Horton) for the specific surface type.

The MOUSE default value is 2.00 mm/h.

Infiltration - minimum capacity (mm/h) - defines the minimum rate of infiltration (Horton) for the specific surface type.

The MOUSE default value is 0.50 mm/h.

Infiltration - time coefficient (wet conditions) (1/h) **-** time factor "characteristic soil parameter" [s^{-1}]. Determines the infiltration capacity rate reduction during rainfall.

The MOUSE default value is 3.00 h^{-1}.

Infiltration - time coefficient (dry conditions) (1/h) - time factor used in the "inverse Horton's equation", defining the rate of the soil infiltration capacity recovery after a rainfall, i.e. in a drying period.

The MOUSE default value is 0.10 h^{-1}.

Recommended parameter values for various types of catchments are presented in Table 4.1.

Table 4.1 Recommended values of parameters for model C1 for various types of catchment surfaces.

Surface type	Runoff type	Time constant (1/min)	Initial loss (mm)	Infiltration Capacity (mm/h)		Time coefficient (1/h)	
				max.	min.	max.	min.
Fuly impervious ground	steep	0.5	0.0	-	-	-	-
	flat	0.2	0.5	-	-	-	-
	extended flat	0.1	1.0	-	-	-	-
Partially impervious ground	steep	0.5	0.0	2.0	0.5	3.0	0.1
	flat	0.2	0.5	2.0	0.5	3.0	0.1
	extended flat	0.1	2.0	2.0	0.5	3.0	0.1
Roof	steep	0.5	0.0	-	-	-	-
	flat	0.2	2.0	-	-	-	-
	extended flat	0.1	4.0	-	-	-	-
Pervious ground (soil)	steep	0.5	2.0	5.0	1.0	3.0	0.1
	flat	0.2	4.0	5.0	1.0	3.0	0.1
	extended flat	0.1	6.0	5.0	1.0	3.0	0.1

Model C2

The set of parameters for model C2 includes additionally the **reduction factor**, which accounts for various hydrological losses not accounted explicitly in the computation.

The MOUSE default value is 0.90.

The time constant is replaced by its reciprocal equivalent - **time lag** (min).

The MOUSE default value is 5.0 min.

4.3 Runoff Computation

The runoff model C computations are based on the volume continuity and the linear reservoir equations.

The first step is the calculation of effective precipitation intensity. The effective precipitation intensity is the precipitation, which contributes to the surface runoff. Next, the hydraulic routing based on the linear reservoir principle and volume continuity is applied.

The hydrologic and hydraulic processes involved are shown in the diagram in Figure 4.1.

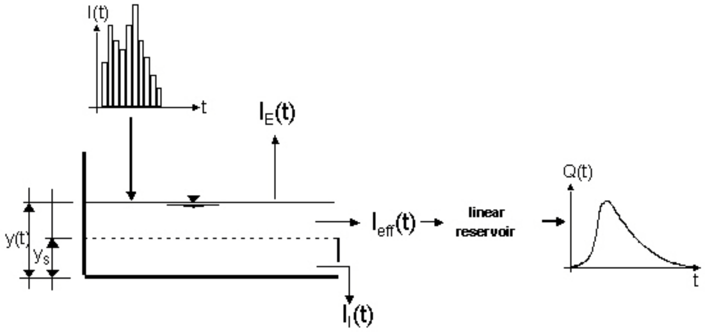

Figure 4.1 The processes simulated in the surface runoff model C

Hydrology: Computing Effective Precipitation

The simulated hydrologic processes account for the losses - evaporation, infiltration and surface storage - calculated according to the conventions and equations presented below. The remaining precipitation is called **effective precipitation**, defined generally as:

$$I_{eff}(t) = I(t) - I_E(t) - I_I(t) - I_S(t) \tag{4.1}$$

where:

$I(t)$	=	Actual precipitation intensity at time *t*,
$I_E(t)$	=	Evaporation loss at time *t*. It should be noted that the evaporation loss for the catchment is accounted only if the RDI runoff computation is activated. Otherwise, it is replaced by a constant "decay" rate.
$I_S(t)$	=	Initial loss (wetting and surface storage) at time *t*,
$I_I(t)$	=	Infiltration loss at time *t*.

The individual terms in the loss equation are fundamentally different, as some terms are continuous where others are discontinuous. If the calculated loss is negative, it is set to zero. The losses have a dimension of velocity [LT^{-1}].

The actual precipitation, *I(t)*, is assumed to be uniformly distributed over the individual catchments. Otherwise, it may vary as a random time function.

The evaporation, $I_E(t)$, is a continuous loss that is normally of less significance for single event simulations. However, on a long-term basis, evaporation accounts for a significant part of hydrological losses. If included in the computation, the evaporation is the first part subtracted from the actual precipitation, according to the following:

$$I_E(t) = \begin{cases} I_{PE}(t) & for \quad (I(t) \geq I_{PE}(t)) \quad OR \quad (y(t) > 0) \\ I(t) & for \quad (I(t) < I_{PE}(t)) \quad AND \quad (y(t) = 0) \end{cases} \tag{4.2}$$

where:

$I(t)$	=	Actual precipitation at time t,
$I_E(t)$	=	Evaporation loss at time t.
$I_{PE}(t)$	=	Potential evaporation at time t,
$y(t)$	=	Accumulated depth at time t.

If the evaporation has not been included in the simulation explicitly (i.e. through RDI), a constant "loss" rate is applied instead (see section 4.4 Multiple-Event Simulations *(p. 36)*).

The infiltration, $I_I(t)$, is the water loss to the lower storage caused by the porosity of the catchment surface. It is assumed that the infiltration starts when the wetting of the surface has been completed. The infiltration loss is calculated according to the following relations:

$$I_I(t) = \begin{cases} I_H(t) & for \quad I(t) - I_E(t) \geq I_H(t) \\ I(t) - I_E(t) & for \quad I(t) - I_E(t) < I_H(t) \\ 0 & for \quad I(t) \leq I_E(t) \end{cases} \tag{4.3}$$

where:

$I_I(t)$	=	Infiltration loss at time t.
$I_H(t)$	=	Horton's infiltration at time t (see below),
$y(t)$	=	Accumulated depth at time t.

The infiltration is a complex phenomenon, dependent on the soil porosity, moisture content, groundwater level, surface conditions, storage capacity, etc. The model calculates the infiltration loss capacity using the well-known Hortons's equation, per default in its original form:

$$I_H(t) = I_{Imin} + (I_{Imax} - I_{Imin}) \cdot e^{-k_a \cdot t} \tag{4.4}$$

where:

$I_H(t)$	=	Infiltration loss calculated according to Horton
I_{Imax}	=	Maximum infiltration capacity (after a long dry period),
I_{Imin}	=	Minimum infiltration capacity (at full saturation),
t	=	Time since the start of the storm,
k_a	=	Time factor (characteristic soil parameter) for wetting conditions.

The Horton's equation in its original form (Equation (4.4)) yields in realistic results only if applied to events for which the rainfall intensity always exceeds the infiltration capacity. However, typical values for infiltration capacity parameters I_{Imax} and I_{Imin} are often greater than typical rainfall intensities. Thus, when equation (4.4) is used, with infiltration capacity I_H being the function of time only, I_H will decrease even if rainfall intensities are very small. In other words, this results in a reduction in infiltration capacity regardless of the actual amount of water entering the soil. This problem is solved by implementing the integrated form of the Equation (4.4):

$$I_{CUM}(t_p) = \int_0^{t_p} I_H dt = I_{Imin} \cdot t_p + \frac{I_{Imax} - I_{Imin}}{k_a} \cdot (1 - e^{-k_a t_p}) \tag{4.5}$$

where $I_{CUM}(t_p)$ is a cumulative infiltration (m) at time t_p, i.e. the area under the Horton's curve. This assumes that the actual infiltration has been equal to the infiltration capacity at any time within the period $0 \rightarrow t$. Since this is only the case for rainfall intensities higher than the infiltration capacity, this needs to be corrected as:

$$I_{CUM}(t) = \int_0^{t} I_I dt \tag{4.6}$$

i.e. the cumulative infiltration at the elapsed time *t* is calculated using the actually occurred infiltration.

At any elapsed time *t,* the two equations (4.5) and (4.6) can be used to determine the "equivalent" time t_p. This is done iteratively, since equation (3.7) cannot be solved explicitly for t_p.

The time t_p on cumulative Horton's curve will always be less or equal than the actually elapsed time, implying that the available infiltration capacity at time t_p will be greater than or equal to that given by the equation (3.5). By these means, the infiltration capacity has been made a function of actual water infiltrated and not just a function of time.

Application of a "standard" Horton's equation (4.4) or its integrated form (Equations (4.5) and (4.6)) is controlled by the switch

"IntegratedHorton", found in the *DHIAPP.INI* file (see relevant documentation for reference). Per default, the program is set to "standard" Horton's equation.

In the dry period following the rainfall, the infiltration capacity is gradually recovered to the initial value, using an inverse form of the Horton's equation:

$$I_H(t) = I_{IT} + (I_{Imax} - I_{IT}) \cdot e^{-1/(k_h t)} \tag{4.7}$$

where:

$I_H(t)$	=	Infiltration loss capacity calculated according to Horton,
I_{Imax}	=	Maximum infiltration capacity (after a long dry period),
I_{IT}	=	Infiltration capacity at the threshold between the wetting and drying period,
t	=	Time since the start of the recovery process,
k_h	=	Time factor (characteristic soil parameter) for drying conditions.

The surface storage, $I_S(t)$, is the loss due to wetting and filling the depressions and holes in the terrain. The model begins with the surface storage calculation after the wetting process is completed. The surface storage is filled only if the current infiltration rate is smaller than the actual precipitation intensity reduced by evaporation. The actual surface storage loss is calculated according to the following:

$$I_S(t) = \begin{cases} I(t) - I_E(t) - I_I(t) & for \quad y(t) \le y_S \\ 0 & for \quad y(t) > y_S \end{cases} \tag{4.8}$$

where:

$I(t)$	=	Precipitation intensity at time t,
$I_S(t)$	=	Surface storage loss at time t,
$I_I(t)$	=	Infiltration loss at time t,
$I_E(t)$	=	Evaporation loss at time t,
y_S	=	Surface storage depth,
$y(t)$	=	Accumulated depth at time t.

The Surface Runoff Routing

The runoff starts when the effective precipitation intensity is larger than zero. The hydraulic process is described with the linear reservoir equation.

The surface runoff at time t is calculated as:

$$Q(t) = C \cdot y_R(t) \tag{4.9}$$

where:

C	=	Linear reservoir constant,
$y_R(t)$	=	Runoff depth at time t.

The depth $y_R(t)$ is determined from the continuity equation:

$$I_{eff}(t) \cdot A - Q(t) = \frac{dy_R}{dt} \cdot A \tag{4.10}$$

where:

I_{eff} = Effective precipitation,
A = Contributing catchment surface area,
dt = Timestep,
dy_R = Change in runoff depth.

The linear reservoir constant is calculated in different ways for the models C1 and C2.

For the model C1, the constant *C* is calculated as:

$$C = A \cdot T_C \tag{4.11}$$

where:

A = Total catchment surface area,
T_C = Catchment time constant.

For the model C2, the constant *C =1/K* is calculated as:

$$C = A / T_L \tag{4.12}$$

where:

A = Total catchment surface area,
T_L = Catchment lag time.

Additionally, the model provides an empirical formula for the calculation of the reciprocal value K of the reservoir constant C as:

$$K = 0.494 \cdot A^{-0.0076} \cdot C^{-0.512} \cdot S^{-0.401} \cdot L^{0.608} \tag{4.13}$$

where:

A = Total catchment surface area (ha),
C = Impervious part of the catchment (0…..1.0),
S = Catchment slope (%),
L = Catchment length (m).

4.4 Multiple-Event Simulations

If the Surface Runoff Model C is used for a continuous simulation of multiple rainfall events (without RDI component activated), a special solution has been applied for the simulation of dry periods between the consecutive events. The solution accounts for the following phenomena:

- Recovery of the soil infiltration capacity

According to Horton, the soil infiltration capacity is getting reduced as the soil gets more saturated by rain. In dry periods, an inverse process occurs, with gradual recovery of the infiltration capacity. Computation of both processes is detailed in section 3.3 Runoff Computations *(p. 19)*. As a consequence of wet and dry period alternation in a multiple event simulation, the model alternates between the two computation modes. Switching to the "dry" mode is triggered by the exhaustion of all water available for infiltration in a certain catchment. Consecutively, switch to the "wet" mode at the start of a new rainfall, i.e. for the entire group of catchments subject to one rainfall time series simultaneously.

- Recovery of the initial loss capacity during dry intervals, i.e. occurrence of the initial loss at the beginning of each simulated event, in accordance with reality.

  The initial loss capacity recovery takes place as a consequence of a continuous action of constant "decay" rate, which replaces the actual evaporation. As a consequence of the recovery process, the initial loss storage would be fully or partially emptied, which depends on the actually applied loss recovery rate and the duration of the dry period.

  Default value for the "loss recovery rate" is 0.0005 m/h, and can be controlled through *DHIAPP.INI* file (see relevant documentation for reference). Note that if actual evaporation process is activated (available only in conjunction with RDI!), the recovery process is suppressed and evaporative action is activated instead.

In order to rationalise the size of the result file, dry periods between events are saved as a single time step. Alternation between "normal" and "long" result save time steps follows the alternation of the soil infiltration capacity computations, with the switch of the last catchment to "dry" conditions causing a change to "long", and the occurrence of the first rain switching back to "normal" (see above for details).

5 Unit Hydrograph Surface Runoff Model (UHM)

5.1 Concept

The UHM module simulates the runoff from **single storm events** for any number of catchments defined in the MOUSE model setup, by the use of the well-known unit hydrograph technique. As such, UHM constitutes an alternative to the other runoff models available in MOUSE, for the runoff simulation in the areas where no flow records are available or where unit hydrograph technique has already been well established.

The unit hydrograph model calculates the excess rainfall (precipitation) assuming that the losses to infiltration can be described as a fixed initial and constant loss, a proportional loss (the rational method) or by the U.S. Soil Conservation Service (SCS) curve number method or finally by the generalises SCS method.

The excess rainfall is routed by the unit hydrograph method. The module applies the SCS-dimensionless hydrographs or the Snyder Unit Hydrograph.

5.2 The Loss Model

During a rainstorm, a part of the rainfall infiltrates to the soil. Subsequently, a large part of the infiltrated water evaporates, while only a relatively small fraction reaches the drainage network. Hence, in single-event models such as UHM, it is reasonable to describe the major part of the infiltration as a loss. The amount of precipitation actually reaching the sewer system, i.e. the total amount of rainfall reduced by the loss, is termed the excess precipitation.

The unit hydrograph model includes **four optional methods** for calculation of excess precipitation. They are all lumped models, considering each catchment as one unit and hence the parameters represent average values for the catchment.

All the methods include an area adjustment factor, accounting to some extent for a non-uniform distribution of precipitation over the catchment.

5.2.1 Proportional Loss (The Rational Method)

In this method the losses are assumed to be proportional to the precipitation rate and thus the excess precipitation is given by:

$$P_{excess} = a \cdot A_f \cdot P \tag{5.1}$$

where:

P_{excess} = Excess precipitation (mm/hr),
a = User-defined run-off coefficient between 0 and 1,
A_f = Area adjustment factor,
P = Precipitation rate (mm/hr).

5.2.2 Fixed Initial Loss and Constant Loss

According to this method, no excess precipitation will be generated before a user-specified initial loss has been met. Subsequently, excess precipitation will be generated whenever the precipitation rate exceeds a specified constant loss rate, i.e.:

$$P_{excess} = \begin{cases} 0; & for \quad P_{sum} < I_a + I_c \cdot dt \\ A_f \cdot P \cdot I_c; & for \quad P_{sum} > I_a \end{cases} \tag{5.2}$$

where:

P_{excess}	=	Excess precipitation (mm/hr).
P_{sum}	=	Accumulated precipitation since start of storm event (mm).
I_a	=	User-defined initial loss (mm).
I_c	=	User-defined constant loss rate (mm/h).
A_f	=	Area adjustment factor.
P	=	Precipitation rate (mm/hr).
dt	=	Calculation time step (hr).

To some extent this method accounts for the fact that losses are greatest at the start of the storm.

5.2.3 SCS Loss Model

The U.S. Soil Conservation Service (SCS), /1/, developed this method for computing losses from storm rainfall in 1972.

For the storm as a whole, the depth of excess precipitation or direct runoff P_e is always less than or equal to the depth of precipitation P. Likewise, after the run-off begins, the additional depth of water retained in the catchment, F_a, is smaller than or equal to some potential maximum retention S (see Figure 5.1). There is a certain amount of rainfall I_a, (initial loss before ponding) for which no runoff occurs. Consequently, the potential runoff amounts to $P - I_a$.

The hypothesis of the SCS method is that the ratios of the two actual to the two potential quantities are equal, i.e.:

$$\frac{F_a}{S} = \frac{P_e}{P - I_a} \tag{5.3}$$

The continuity principle results in:

$$P = P_e + I_a + F_a \tag{5.4}$$

Combining Equations (5.3) and (5.4) gives:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \tag{5.5}$$

which is the basic equation for computing the depth of excess precipitation or direct runoff from a storm by the SCS method.

The results from many small experimental watersheds were used to obtain an empirical relationship:

$$I_a = 0.2S \tag{5.6}$$

The basic equation used in this model is derived by combining Equations (5.5) and (5.6):

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{5.7}$$

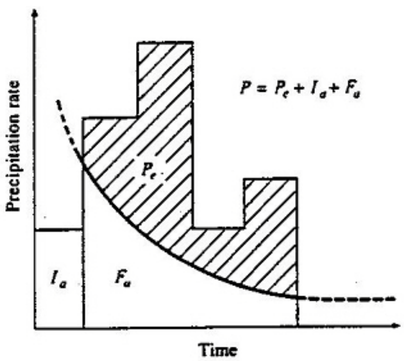

Figure 5.1 Variables in the SCS method of rainfall abstractions: I_a = initial abstraction, P_e = accumulated excess rain, F_a = continuing abstraction, P = total rainfall

The potential maximum retention *S* is calculated from a dimensionless curve number (*CN*) using the empirical formula derived by SCS on the basis of rainfall-runoff analyses from a large number of catchments:

$$S = ((1000/CN) - 10) \cdot 25.4 \qquad [mm] \tag{5.8}$$

The curve number depends on the soil type, the land use and the antecedent moisture condition (AMC) at the beginning of the storm.

CN varies between 0, resulting in no runoff and 100, which generates an excess precipitation equal to the actual precipitation. For natural catchments normally 50 < CN < 100 applies.

The model operates with three different antecedent moisture conditions namely:

AMC(I)	=	dry conditions close to wilting point,
AMC(II)	=	average wet conditions close to field capacity.
AMC(III)	=	wet conditions close to saturation.

For each calculation time step, the excess precipitation is calculated as the difference between the accumulated excess precipitation $\mathbf{P}_e$ at the start and the end of the time step.

The SCS method was developed on the basis of daily rainfall and consequently the program considers the beginning of a new 24-hour period at the beginning of a new storm event, i.e.:

- Each 24 hours *AMC* is updated by one class for each 16 mm of rain falling during the simulation period.
- *CN* and **S** are recalculated in correspondence with the updated *AMC*. The conversion of *CN* due to *AMC* is done using Table 5.1.
- The accumulated rainfall amount $\mathbf{P}_e$ is reset to zero.

Table 5.1 *Correlation between SCS Curve numbers and the* antecedent moisture condition as given in /1/

Antecedent moisture conditions								
II	I	III	II	I	III	II	I	III
0	0	0	34	18	54	68	48	84
1	0	3	35	18	55	69	50	84
2	1	5	36	19	56	70	51	85
3	1	8	37	20	57	71	52	86
4	2	10	38	21	58	72	53	86
5	2	13	39	21	59	73	54	87
6	2	15	40	22	60	74	55	88
7	3	17	41	23	61	75	57	88
8	3	18	42	24	62	76	58	89
9	4	20	43	25	63	77	59	89
10	4	22	44	25	64	78	60	90
11	4	24	45	26	65	79	62	91
12	5	25	46	27	66	80	63	91
13	5	27	47	28	67	81	64	92
14	6	28	48	29	68	82	66	92
15	6	30	49	30	69	83	67	93
16	7	31	50	31	70	84	68	93
17	7	33	51	31	70	85	70	94
18	8	34	52	32	71	86	72	94
19	8	36	53	33	72	87	73	95
20	9	37	54	34	73	88	75	95
21	10	38	55	35	74	89	76	96
22	10	39	56	36	75	90	78	96
23	11	41	57	37	75	91	80	97
24	11	42	58	38	76	92	81	97
25	12	43	59	39	77	93	83	98
26	13	44	60	40	78	94	85	98
27	13	46	61	41	78	95	87	98
28	14	47	62	42	79	96	89	99
29	14	49	63	43	80	97	91	99
30	15	50	64	44	81	98	94	99
31	16	51	65	45	82	99	97	100
32	16	52	66	46	82	100	100	100
33	17	53	67	47	83			

5.2.4 SCS Generalised Loss Model

Research has shown that it may be beneficial to apply another loss model than the standard SCS loss model. The SCS generalised loss model does not make use of the concept of an antecedent moisture content (AMC) but applies a general antecedent storage depth. This loss model in combination with the SCS unit hydrograph routing model complies completely with the TP108 approach often used in e.g. New Zealand and the United States.

The SCS generalised loss model corresponds closely to the SCS standard loss model. However, it differs in a few important ways. The excess precipitation is still calculated by Equation (5.5)

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \tag{5.9}$$

but in this model the initial loss (initial abstraction depth) I_a is given directly as an input parameter.

The potential maximum retention **S** is calculated from a dimensionless curve number (*CN*) using the formula:

$$S = ((1000)/CN) - 10) \cdot 25.4 \qquad [mm] \tag{5.10}$$

The curve number is an input parameter and is not changed during the simulation as for the SCS standard loss model.

5.3 Unit Hydrograph Routing Model

5.3.1 Basic Assumptions

The unit hydrograph method is a simple linear model that can be used to derive the hydrograph resulting from any amount of excess precipitation.

The unit hydrograph is a unit pulse response function of a linear hydrological system, i.e. the direct runoff hydrograph resulting from one unit of excess precipitation with the duration tr.

The following basic assumptions are inherent in this model:

- Excess precipitation has a constant intensity within the effective duration,
- Excess precipitation is uniformly distributed over the whole catchment area.
- The base time of the direct runoff hydrograph resulting from an excess precipitation with a given duration is constant.
- The ordinates of all direct runoff hydrographs of a common base time are directly proportional to the total amount of excess precipitation represented by each hydrograph.
- The principle of superposition applies to hydrographs resulting from continuous and/or isolated periods of uniform-intensity excess precipitation, as illustrated in Figure 5.2.
- For a given catchment, the hydrograph resulting from a given excess precipitation reflects the unchanging conditions of the catchment.

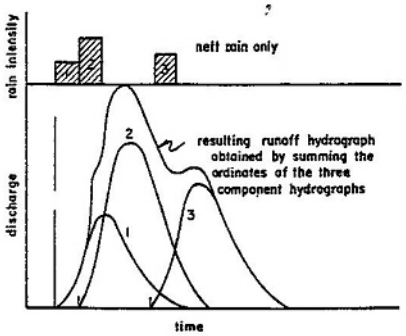

Figure 5.2 Principle of superposition applied to hydrographs

Under natural conditions, the above assumptions cannot be perfectly met. However, in many cases the hydrological conditions come close enough to the above assumptions to generate satisfactory results. A more detailed discussion of the above assumptions can be found in /2/.

5.3.2 Principle of Calculation

In accordance with the principle of superposition, for each calculation time step the model determines the hydrograph corresponding to the excess rainfall, as generated by the loss model during this time step, and adds the response to the flow contributions generated in previous time steps.

5.3.3 SCS Unit Hydrographs

A unit hydrograph can be characterised by the duration of the unit rainfall t_r, resulting in the hydrograph and the lag time t_l, defined as the time difference between the centre of the unit rainfall event and the runoff peak.

From these two characteristics, the time to peak T_p, i.e. the time from the beginning of the storm event until the occurrence of peak runoff can be calculated as:

$$T_P = t_r/2 + t_l \tag{5.11}$$

In reality, the unit hydrograph of a given catchment is unique. However, large efforts have been put into the development of synthetic unit hydrographs which are more or less generally applicable. Two such hydrographs, namely the SCS triangular unit hydrograph and the SCS dimensionless hydrographs are prespecified in the model (see Figure 5.3).

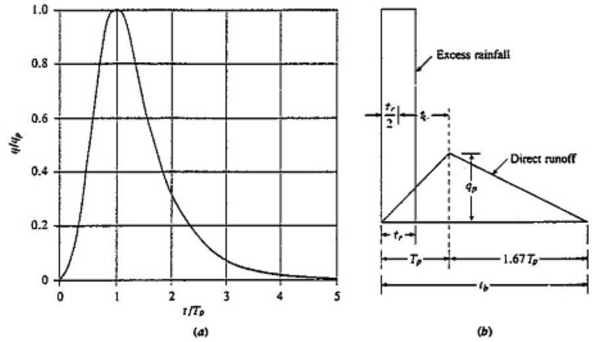

Figure 5.3 SCS Synthetic Hydrographs: (a) Dimensionless hydrograph; (b) Triangular hydrograph.

The user must specify the lag time to be used in a given calculation. The program will then scale the applied hydrograph accordingly, ensuring that the area under the curve equals to unity.

The lag time can either be specified directly or may be calculated from catchment characteristics using the standard SCS formula:

$$t_l = (L \cdot 3.28 \cdot 10^3)^{0.8} \cdot (1000/CN - 9)^{0.7} / (1900 \cdot Y^{0.5}) \tag{5.12}$$

where:

t_l	=	lag time in hours,
L	=	hydraulic length of the catchment in km,
CN	=	the SCS curve number,
Y	=	the average catchment slope in per cent.

A unit-hydrograph derived from a time-area curve is considered as catchment-specific. Consequently, specification of arbitrary lag times are not allowed if the time-area method is applied. The program will simply use the lag time implicitly given by the time-area curve.

The time-area method in the UHM-model performs a pure translation of the excess precipitation hydrograph via the drainage network described using the channel travel time. This results in an outflow hydrograph, which ignores catchment storage effects.

5.3.4 Snyder Unit Hydrograph

From an analysis of ungaged watersheds varying in size from 30 to 30,000 km^2 in the Appalachian Highlands in the United States, Snyder published a description of a standard and required synthetic unit hydrographs in 1938. He published a relationship for estimating the unit hydrograph parameters from watershed characteristics. The relationship is shown below.

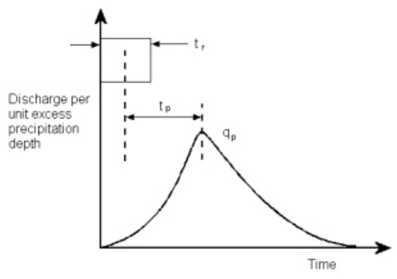

Figure 5.4 Snyder's Synthetic Unit Hydrograph

For the standard unit hydrograph, Snyder defined the basin lag time t_p in hours to be related to the rainfall duration t_r in hours as follows:

$$t_p = 5.5 t_r \tag{5.13}$$

For the required unit hydrograph, Snyder defined the basin lag time to be related to the watershed characteristics as follows:

$$t_p = C_1 C_t (L L_c)^{0.3} \tag{5.14}$$

where:

t_p	=	lag time in hours,
C_1	=	conversion constant of 0.75,
C_t	=	watershed coefficient,
L	=	length of main stream from the outlet to the divide in km,
L_c	=	length of main stream from the outlet to a point nearest the watershed centroid in km.

The peak discharge per unit drainage area is found with the following relationship:

$$q_p = \frac{C_2 C_p}{t_p} \tag{5.15}$$

where:

q_p=	peak discharge per unit drainage area in m^3 per sec km^2,
C_2=	conversion constant of 2.75,
C_p=	peaking coefficient,
t_p=	lag time in hours,

If the duration of the required unit hydrograph is significantly different from that specified by Equation (5.11) the following relationship could be used to relate the effective rainfall t_R in hours to the lag time t_{pR} in hours and peak discharge q_{pR} per unit area in m^3 per sec km^2.

$$t_{pR} = t_p - \frac{t_r - t_R}{4} \tag{5.16}$$

$$q_{pR} = \frac{q_p t_p}{t_{pR}} \tag{5.17}$$

The base time of the hydrograph t_b in hours can be found using the following relationship between peak discharge q_{pR} and the conversion constant C_3 which equals 5.56:

$$t_b = \frac{C_3}{q_{pR}} \tag{5.18}$$

The width W in hours of the unit hydrograph at a discharge equal to a certain percent of the peak discharge q_{pR} can be calculated using the following equation:

$$W = C_w q_{pR}^{-1.08} \tag{5.19}$$

where:

C_w= 1.22 for the 75 percent width and 2.14 for the 50 percent width.

As part of a watershed study program completed in 1994, Alameda County, California developed site-specific equations to be used in conjunction with the Snyder unit hydrograph. The site-specific equations are documented in the September 1994 *Hydrologic Modeling Evaluation Summary Report for Alameda County, California* prepared by Alameda County Public Works Agency. There are two SUH equations that were modified as part of the Alameda County watershed study program. The first equation replaces the basin lag t_{pR} and the second equation replaces peaking factor C_p. The site specific equations should be used with caution outside of Alameda County, California.

$$t_{pR} = Kn\left[\frac{LL_c}{\sqrt{S}}\right]^{0.38} \tag{5.20}$$

For $L > 1.7$ miles: $K = 24$

For $L < 1.7$ miles: $K = 15.22 + 2.1464L + \frac{8.6981}{L}$

where:

t_{pR} = lag time in hours,
K = watershed coefficient,
n = watershed factor specific to Alameda County, California,
L = length of main stream from the outlet to the divide in miles,
L_c = length of main stream from the outlet to a point nearest the watershed centroid in miles,
S = average stream slope in ft per mile

Note: if K > 40 then K = 40

$$C_p = 0.6e^{0.06(So/A)} \tag{5.21}$$

where:

C_p = peaking coeffiecient (C_p = 0.85 if C_p from Equation (5.21) is greater than 0.85),
S_o = average overland slope in percent (S > 5%)
A = drainage area in square miles (for drainage area less than 5 square miles use 5)

Note: When overland slope < 5%, C_p = 0.6

5.3.5 Calculation Time Step

If the SCS hydrographs are used, SCS suggests the calculation time step to be selected as 22% of the lag time and that it should not exceed 27% of the lag time.

6 Precipitation Data

The surface runoff is generated under the impact of precipitation. The precipitation (rainfall) is specified in form of time series, i.e. as a sequence of measured or synthetic values for rainfalls with time and date labels.

The precipitation time series to be used as input for the MOUSE Surface Runoff computation must be stored as a time series with an item type of Rainfall Intensity. Link between the rainfall time series and the MOUSE surface runoff model is created in the MOUSE boundary file.

Different rain time series can be applied to the different catchments in the current model set-up, i.e. spatially distributed rain can be simulated. This can be achieved automatically by associating the rain gauge co-ordinates with the time series. MOUSE allocates the geographically closest rainfall time series to the specific catchments. Alternatively, individual explicit allocation of specific time series to specific catchments can be applied.

The rain time series can have irregular intervals between the subsequent values. The computational time step for runoff computations is not conditioned by the resolution of the rain time series.

The runoff models calculate the rain intensity for each particular time step, so that the rain volume applied by the model in the time interval covered by the current time step remains preserved, i.e. the applied volume is equal to the volume contained in the same interval of the input data. This principle is illustrated in Figure 6.1.

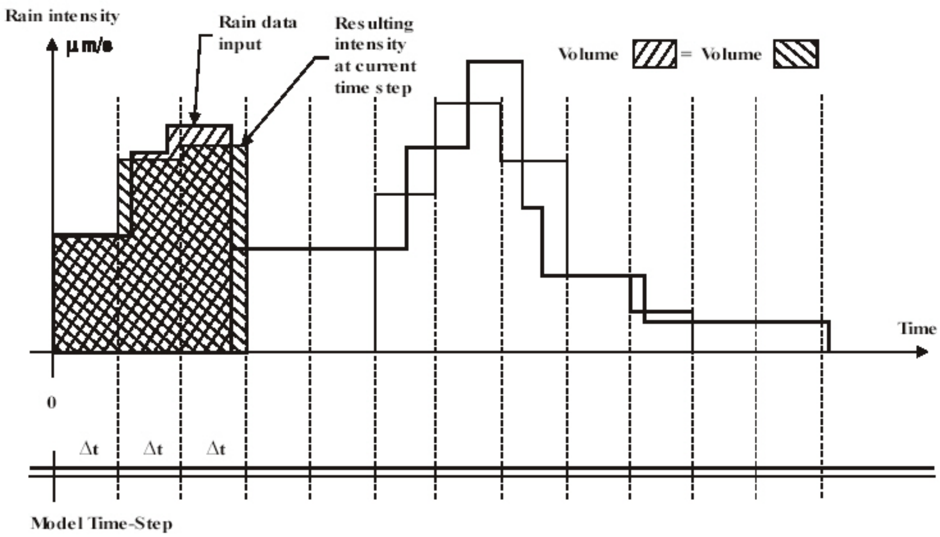

Figure 6.1 Rain Input Data vs. Model-applied data

7 NOMENCLATURE

A	contributing catchment area, (ha)
A_{tot}	total catchment area (ha)
B	runoff width, (m)
I, S	surface slope, (1/m,%)
$I_E(t)$	evaporation loss at time t, (ms^{-1})
$I_{PE}(t)$	potential evaporation loss at time t, (ms^{-1})
$I_I(t)$	infiltration loss at time t, (mmh^{-1},ms^{-1})
$I_{ICUM}(t_p)$	cumulative infiltration loss at time t_p, (mm,m)
$I_S(t)$	surface storage loss at time t, (m)
$I_H(t)$	Horton's infiltration capacity at time t, (ms^{-1})
$I_W(t)$	wetting loss at time t, (m)
I_{Imax}	maximum infiltration capacity, (mmh^{-1},ms^{-1})
I_{Imin}	minimum infiltration capacity, (mmh^{-1},ms^{-1})
$I(t)$	actual precipitation intensity at time t, (ms^{-1})
$I_{eff}(t)$	effective precipitation intensity at time t, (ms^{-1})
K_a,K_h	time factor (Horton's characteristic soil parameter) for wetting and drying conditions, respectively
M	Manning number, ($m^{1/3}s^{-1}$)
$Q(t)$	runoff, discharge, (m^3s^{-1})
t	time, (min or s)
t_c	concentration time, (min or s)
t_p	equivalent time, for use with Horton´s equation (min or s)
Δt, dt	simulation time step, (s)
$y(t)$	precipitation depth accumulated on the catchment surface at time t, (m),
$y_R(t)$	runoff depth, i.e. precipitation depth accumulated on the catchment surface at time t, (m), reduced by wetting and surface storage depth (m),
y_S	surface storage depth (m),
y_W	wetting depth (m),
dy_R	change in runoff depth, (m)

8 REFERENCES

/1/ SCS, National Engineering Handbook, Section 4, Hydrology, Soil Conservation Service, U.S. Department of Agriculture, 1972.

/2/ Chow, V.T., David R. Maidment, Larry W. Mays. Applied Hydrol.

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