MOUSE

Rainfall Dependent Inflow and Infiltration

Reference Manual

The expert in **WATER ENVIRONMENTS**

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MOUSE RDII

Reference Manual

1 Background

When studying the real flow conditions in sewer systems, flow peaks during rain events are often found to exceed the values that can be attributed to the contribution from participating impervious areas. Also, the flows are often increased in the system long after the rainfall and the surface runoff have stopped. This is a consequence of the phenomenon, usually named **Rainfall Induced Infiltration**. This differs from the **Rainfall Induced Inflow** by the fact that it does not depend only on the actual precipitation, but is heavily affected by the actual hydrological situation, i.e. the “memory” from earlier hydrological events. For a certain rainfall event, the increase in flow will therefore differ, depending on hydrological characteristics of a previous period. The Rainfall Induced Infiltration is also distinguished by a slow flow response, which takes place during several days after the rainfall event.

From a hydrological point of view, parts of the infiltration behave in the same way as the inflow. Therefore, classification to infiltration and inflow is not suitable for modeling approach. Rather, to describe appropriately the constitutive components of a flow hydrograph, distinguished by their hydrological behavior, the following concept is used instead:

- **FRC** - Fast Response Component
- **SRC** - Slow Response Component

Distinctive for the FRC component is that it is not influenced by the previous hydrological situation, i.e. high or low soil moisture content. It is a direct consequence of a rainfall. The FRC component consists of the inflow to the sewer system and the fast flow component of the infiltration, not dependent on previous hydrological conditions.

On the other hand, characteristic of the SRC component is that it is highly dependent on the previous hydrological conditions and usually responses slowly to a rainfall. The SRC component consists of the rest of the precipitation-induced infiltration and dry weather infiltration/inflow.

When performing a numerical simulation of flows in sewer systems based on a traditional approach, it is difficult to describe the effects of the SRC component. These effects can, however, be of a great importance, especially when analyzing volumes, e.g. simulation of the total inflow to the wastewater treatment plant and overflow volumes.

Figure 1.1 shows an example illustrating the influence of previous hydrological conditions for the two components and their response to a rainfall.

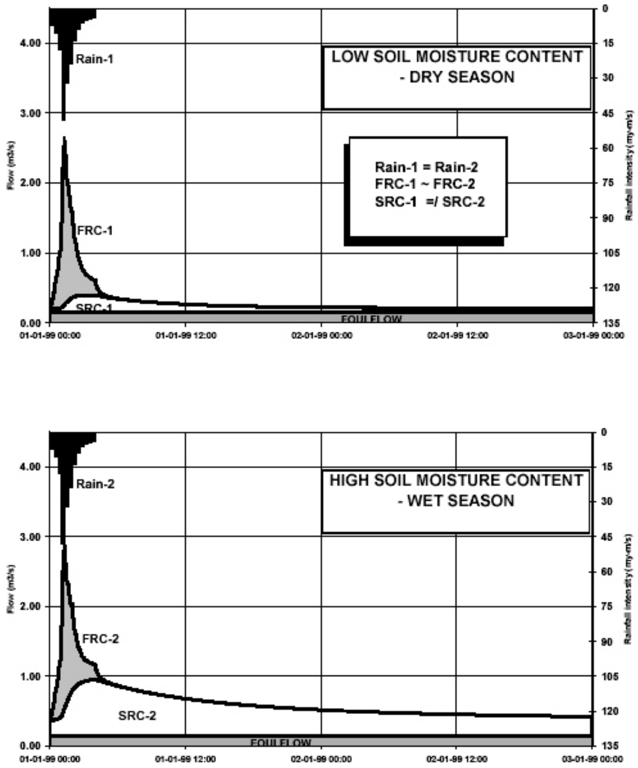

Figure 1.1 Example of the effect of high or low soil moisture content on the generated discharge hydrograph.

To accomplish a description of the discharge generated in sewer systems influenced by the SRC component, a computation tool that considers the effects of previous hydrological events is required. For that purpose, in addition to the ordinary description of the FRC component, obtained by the MOUSE Surface Runoff Model, which is fully satisfactory when modeling drainage water, a more general hydrological model - MOUSE RDI has been developed. MOUSE RDI permits simulation of single events as well as simulation of very long periods, e.g. 10 years.

2 Model Structure

2.1 General Information

MOUSE RDI can be combined with MOUSE Surface Runoff model (A, B or UHM) for the description of the FRC component, and the RDI hydrological model for description of the SRC component. The MOUSE RDI model is based on the DHI's NAM hydrological model. This model has been developed by the Hydrological Section of the Institute of Hydrodynamics and Hydraulic Engineering at the Technical University of Denmark.

A computational hydrological model such as RDI is a set of linked mathematical statements describing, in a simplified quantitative form, the behavior of the land phase of the hydrological cycle. The RDI model is a deterministic, conceptual, lumped type of model with moderate input data requirements.

Spatial characterization of constitutive parts of the analyzed area is achieved through definition of sub-catchments, each of them described with a unique set of data. This means that the model treats every sub-catchment as one unit. The parameters and variables therefore represent an average for the whole sub-catchment.

MOUSE RDI calculates the total discharge within the catchment area as a sum of surface runoff and the inflow/infiltration. This means that the hydraulic processes in the sewer system which affect the mass balance (e.g. overflow) are not described and, therefore, this effect is not accounted for when the total discharge from the catchment is calculated, see User Guide.

A description of the model structure is given below. For further details see ref./5/ and ref./6/.

2.2 Surface Runoff Models

The computation of surface runoff in a combination with RDI is almost identical as for stand-alone surface runoff computations. The full reference on these computations can be found in respective User Guide and Technical Reference documentation (ref. /3/ and ref. /4/).

The differences associated with surface runoff computations in combination with RDI, if compared to “pure” surface runoff computations, arise in two aspects:

- snow storage and snow melt process;
- evapo-transpiration process.

These two processes, normally not available in surface runoff computations, are included in the computation of surface runoff exactly in the same way as it is done for the RDI part of the runoff model. In other words, for a catchment with activated RDI component, snowmelt and evaporation processes are computed, using the same snowmelt coefficient, temperature and evaporation time series as for the RDI part of the catchment. Any of the two processes can be switched On/Off according to the actual needs. The default status of snowmelt is Off, while evapo-transpiration is per default set to On. For full details, refer to the following paragraph.

2.3 General Hydrological Model - RDI

Using various meteorological data, RDI calculates overland discharge, groundwater levels, and relative ground moisture and base flow, for the fraction (%) of the catchment area defined as RDI area.

The RDI model is based partly on physical, and partly on empirical equations. The model structure, actually a simplified description of the behavior of the land phase of the hydrological cycle, retains water in four types of mutually interrelated storages:

- Snow storage;
- Surface storage;
- Root zone storage;
- Groundwater storage.

The model structure is shown in Figure 2.1.

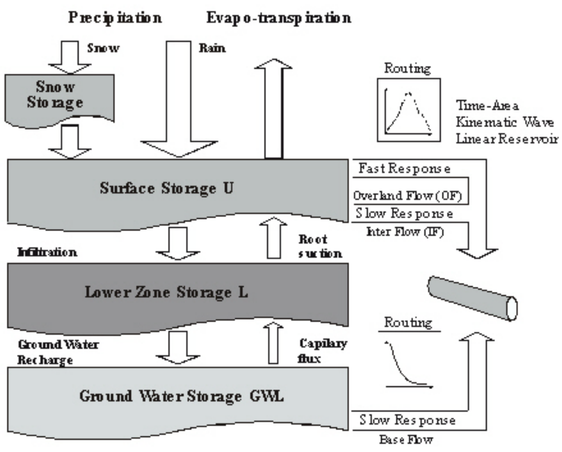

Figure 2.1 Model structure for the RDI model

The precipitation passing through the snow storage is controlled by the temperature conditions and the current amount of snow on the catchment surface.

Moisture interception on the vegetation, as well as water trapped in depressions and in the upper-most cultivated part of the ground is represented as surface storage.

Moisture in the root zone, a ground layer below ground surface from where the vegetation can draw water for transpiration, is described as a storage in the lower ground zone, i.e. root zone storage.

The amount of water in the surface storage is continuously diminished by evapo-transpirative consumption set as potential evapo-transpiration, as well as by horizontal leakage (interflow) in the upper ground level. In situations when there is a maximum surface storage achieved, some of the excess water will enter the streams as overland flow, whereas the remainder is diverted as infiltration into the lower zone and further as percolation into the groundwater storage.

Moisture in the lower zone is subject to consumptive loss from evapo-transpiration. This process starts when the surface storage is completely exhausted, and in that situation the actual evaporation depends on the relative contents of the moisture in the lower zone. Additionally, the amount of moisture in the lower zone influences the process of overland flow and amount of water that enters the groundwater storage as recharge.

3 RDI Input Data and Model Parameters

The specific input requirements for the MOUSE RDI model comprise:

1. General catchment description,
2. RDI parameters,
3. initial conditions,
4. meteorological data (boundary conditions).

Additionally, for catchments containing urban part, appropriate surface runoff model data and parameter set must be specified.

3.1 General Catchment Description

The set of general catchment data for a RDI catchment is identical as for any of the MOUSE Surface runoff models. It contains the following items: ID, Location, X- and Y-co-ordinates, Catchment Area, Inhabitants and Additional flow. For details, refer to the MOUSE Surface Runoff Reference Manual (ref. /4/).

3.2 Model Specific data

RDI Area [%] - fraction of the total catchment area [ha] which contributes to the RDI (i.e. SRC) runoff component.

3.3 RDI Parameters

Snow Melting

- *Cme* [mm/°C/day]:The parameter determines the rate at which snow and ice are melted, i.e. converted into the liquid phase of the snow storage. The snow melting starts when the temperature exceeds 0°C.

The default value is 3.00 mm/°C/day.

Storage Capacity

- U_{max}, L_{max} [mm]:Define the maximal water contents in the surface and root zone storage, respectively.

The default values are 10 and 100 mm.

Overland Flow Coefficient

- CQ_{OF}: Determines the extent to which excess rainfall (after the surface storage is retained) runs off as overland flow and the infiltrating quantity.

$0 \leq CQ_{OF} \leq 1$. The default value is 0.300.

Time Constant for Overland Flow

- CK_{OF} [hours]:Determines how fast the flow responds to a rainfall. The CK_{OF} has also some effect on the routing of the interflow.

The default value is 20 hours.

Time Constant for Interflow

- CK_{IF} [hours]:Together with U_{max} determines the amount of interflow. This time constant is the dominant parameter for routing the interflow because usually CK_{IF} is much larger then CK_{OF}.

The default value is 500 hours.

Time Constant for Baseflow

- CK_{BF} [hours]:Determines the hydrograph recession during dry periods.

The default value is 2000 hours.

Groundwater Depth

- GWL_{min} [m]:Minimal depth of groundwater below surface, at which the groundwater recharge is diverted to the overland flow.

The default value is 0.00 m.

Groundwater Depth

- $GWLBF_0$ [m]: Maximal depth of groundwater below surface causing baseflow.

The default value is 10.00 m.

Groundwater Depth

- $GWLFL_1$ [m]:Depth of groundwater table below surface, at which unit capillary flux (1 mm/day) occurs.

The default value is 0.00 m.

Baseflow Yield

- S_y [-]:Specific yield of the groundwater reservoir.

The default value is 0.10.

Size of Groundwater Catchment

- C_{area}: Proportion of the groundwater catchment to the surface catchment area.

The default value is 1.00.

Threshold Values

- T_{OF} , T_{IF} , T_G [-]:The parameters affect the flow, so that no overland flow, interflow or recharge of the groundwater storage is generated until the relative moisture content of the lower zone storage, L/L_{max}, exceeds the values of T_{OF}, T_{IF} and T_G, respectively.

$0 \leq T_{OF}$, T_{IF} , $T_G < 1$. Default values for all three thresholds are 0.00.

3.4 Initial Conditions Data

The initial conditions data including the water depth in snow cover, surface and lower zone storage, values of interflow and overland flow and the groundwater depth at the start of the simulation are parts of the RDI parameter set.

Both for the validation procedure and other simulations with MOUSE RDI it is important that the initial conditions are reasonable. The initial conditions can be estimated by analyzing results of previous simulations for a period of few years, by noting the normal value for the water content in the root zone storage and the groundwater depth for the time of the year when the simulation is to start.

To eliminate the effects of errors in the initial conditions it is recommended to disregard the simulation results for the period of about half a year to one year from the start of the simulation.

For the validation, (see MOUSE RDI - User Guide), the simulation should therefore start half to one year before available measured discharge data. This initiation period should be recalculated after each major change of RDI parameters. If an initiation period of one year is chosen, with start during or just after a wet period, e.g. at the New Year for Nordic conditions, the initiation conditions can usually be set to:

- U_{init} = Umax,
- L_{init} = approx. 75 % of L_{max}
- *OF* = 0.0
- *IF* = 0.0
- GWL = approx. 9.5 m

The initial value of groundwater depth, *GWL*, is related to the RDI parameter *GWLBF0*, defining the groundwater depth which generates a groundwater recharge of zero. The above-recommended value for GWL is suitable if the parameter $GWLBF_0$ is set to 10.0 m, a standard value in MOUSE RDI.

When changing the values of U_{max} and L_{max}, correspondingly the initiation values U_{init} and L_{init} have to be changed.

3.5 Meteorological Data

The boundary conditions for simulations with MOUSE RDI take the form of measured or otherwise obtained time series of meteorological data. These include the following:

- Precipitation;
- Temperature;
- Potential evapo-transpiration.

Some comments about the required data are given below.

3.5.1 Precipitation

Precipitation data are specified either in a form of intensities ((m/sec) or as depth (mm). For details about internal treatment of precipitation data see the User Guide and Runoff Reference Manual.

Generally, the time resolution of the precipitation data used in the model should reflect the character of the study. E.g., when studying overflow conditions, or when establishing connections between maximal discharge and return period, the precipitation data with high resolution in time are required.

For the validation process, resolution of the precipitation time series should correspond to the time resolution of measured discharges, e.g. daily average discharge.

Resolution in depth of approximately 0.2 mm is satisfactory for most applications.

The spatial variation of the precipitation is of great importance, especially when simulating larger areas, see ref./6/. In MOUSE RDI there is a possibility to specify several rain time series, measured at different locations within the model area. The discharge from each sub-catchment is then calculated using the precipitation time series belonging to the nearest precipitation gauge. The center point of the sub-catchment, as defined by co-ordinates, is taken as a basis for calculation of the distance to the rain gauge. However, there is also a possibility to define a specific precipitation time series for a certain sub-catchment, irrespective the distance.

It is important that the “raw” measured precipitation data are corrected prior to application in the model, as to account for different sources of measuring errors. For complete discussion on the measuring errors and correction methods, see e.g. ref./8/ and ref./9/.

3.5.2 Temperature

Temperature data (°C) are only necessary if the snow routine is activated in MOUSE RDI.

Like the precipitation, the resolution in time for the temperature should reflect the discharge velocity of the simulated area. This especially concerns areas where the snow melting process is of great importance. In most cases, two values per day are sufficient, if the measurements are taken so that the minimal and maximal daily values are obtained for periods with snow cover.

3.5.3 Potential Evapo-Transpiration

The evapo-transpiration is a physical process where water is transformed into vapor. Real evaporation or, more correctly, the actual evaporation includes evaporation from snow and ground surfaces of all types, interception from vegetation and its transpiration.

Interception is a part of precipitation that never reaches the ground but adheres to the vegetation and thereafter evaporates. Transpiration is water evaporation from inner surfaces in the plants, leafs and needles.

The evaporation specified in MOUSE RDI is the potential evaporation, i.e. the possible evaporation (mm) during the period since the last entered value. From this, and the model parameters the actual evaporation is calculated. Usually monthly values provide a sufficient accuracy, see ref./7/.

4 Conceptual Models for Processes Simulated by RDI

The implemented conceptualization of the physical processes treated by RDI is exposed below in full detail.

4.1 Snow Storage and Melting

The physical description of the snow storage and melting process implemented in MOUSE RDI distinguishes between freezing phase and melting phase.

4.1.1 Freezing Phase

If the actual temperature T [°C] is below the reversal temperature T_{mf} [~0 °C], the precipitation is turned to snow and water in the surface storage freezes to ice. This means that, instead of leaving the catchment as runoff, the existing water and precipitation is retained on the catchment surface in the form of ice and snow.

The snow and ice storage is filled both by the freezing water in the surface storage and by the current snow precipitation. The continuity equation for the water retained in the snow and ice storage due to freezing, V_{lq} [mm] is written as:

$$\frac{dV_{lq}}{dt} = q_{fr} \tag{4.1}$$

where t [h] is time and q_{fr} [mm/h] is the transition speed from water to snow (ice). The transition speed is linearly dependent on the actual temperature, but also on the actual snow (ice) storage:

$$q_{fr} = -\frac{C_{fr}}{2 \cdot V_{fr} \cdot 24h/day} \cdot (T - T_{mf}) \tag{4.2}$$

where C_{fr} [~10 mm^2/day/°C] is 'degree-day' transition factor from water to snow (ice) and V_{fr} [mm] is snow (ice) storage. The amount of water which can be transferred to ice is limited by the water actually present in the surface storage.

The continuity equation for the snow (ice) storage V_{fr} [mm] is written as:

$$\frac{dV_{fr}}{dt} = p + q_{fr} \tag{4.3}$$

where p [mm/h] is the precipitation (snow!) intensity.

The water can leave the snow (ice) storage and contribute to the runoff only if the content of a liquid (i.e. non-frozen) phase in the storage exceeds the threshold of 8% of the total storage. This means that for short freezing periods the runoff is still continued until the fraction of the liquid phase on the surface drops below 8% of the total storage.

Initially, if the simulation starts at a time with negative temperature, all water assumed to be initially present on the catchment surface is considered to be frozen, and the contribution to runoff p_s is set to zero.

4.1.2 Melting Phase

If the actual temperature T [°C] is higher than or equal to the reversal temperature T_{mf} [~0°C] then the precipitation takes the form of rain and snow and ice accumulated on the surface melt. The continuity equation for the snow (ice) storage V_{fr} [mm] is written as:

$$\frac{dV_{fr}}{dt} = -q_{me} \tag{4.4}$$

where q_{me} [mm/h] is transition speed from snow (ice) to water. The transition speed is linearly dependent on the actual temperature, according to:

$$q_{me} = \frac{C_{me}}{24h/day}(T - T_{mf}) \tag{4.5}$$

where C_{me} [~2.5-3.00 mm/day/°C] is degree-day factor from snow (ice) to water. The continuity equation for the water in the surface storage V_{lq} [mm] is written as:

$$\frac{dV_{lq}}{dt} = p + q_{me} - p_s \tag{4.6}$$

with the following limit on the retained water storage:

$$V_{lq} \leq V_{lq\ max} = C_{wr}V_{fr} \tag{4.7}$$

where C_{wr} [~8%] is the water retention capacity of snow. If the retained water storage (V_{lq}) determined by Eq. 4.7 is less than equal the maximum retained water storage (V_{lqmax}) then the excess water contribution (p_s) is zero. Else, the excess water contribution (p_s) is adjusted so that the retained water storage (V_{lq}) is equal the maximum retained water storage (V_{lqmax}).

Practically, this means that the runoff from the catchment with accumulated snow and ice storage will start only after the liquid phase exceeds 8% of the actual total storage, and not immediately following the increase of temperature above the reversal temperature.

This is of extreme importance for a realistic simulation of snow melting process in the periods with alternated positive (daily maximum) and negative (night minimum) temperatures, when no snowmelt is actually observed.

4.2 Surface Storage

Moisture intercepted on the vegetation, as well as water trapped in depressions and in the uppermost, cultivated part of the ground is represented as surface storage. U_{max} denotes the upper limit to the amount of water in Surface Storage.

Rain and melted snow are subject, first, to the functions of the Surface Storage. The amount of water, U, in Surface Storage is continuously diminished by evaporative consumption as well as by horizontal leakage (Interflow).

When the surface storage spills, i.e. when $U \geq U_{max}$, the excess water, P_n gives rise to overland flow as well as to infiltration.

The value of U_{max} should account for the fact that the surface storage represents the interception storage (on vegetation), the surface depression storage and the uppermost few millimeters of the ground.

As a rule, the relationship $U_{max} = 0.1\ L_{max}$ can be used unless special catchment characteristics or hydrograph behavior indicate otherwise.

One important characteristic of the model is that the surface storage must be at its capacity, i.e. $U \geq U_{max}$ before any excess water, P_n, occurs. In dry periods, the amount of net rainfall that must occur before any overland flow occurs can be used to estimate U_{max}.

4.3 Evapo-transpiration

Evapo-transpiration demands are initially met, if possible, at the potential rate from the surface storage. If the moisture content, U, in the surface storage is less than these requirements, the remaining fraction is assumed to be withdrawn by root activity from the lower zone storage at an actual rate, E_a. The value of E_a is set to be proportional to the potential evapo-transpiration, E_p according to:

$$E_a = E_p \cdot L / L_{max} \tag{4.8}$$

L and L_{max} are the actual and maximum possible moisture contents respectively in the lower zone storage (see below).

4.4 Overland Flow

When the surface storage exceeds the maximum, U_{max}, the excess water, P_n, gives rise to overland flow as well as to infiltration, see also Surface Storage.

OF denotes the part of P_n which contributes to overland flow. It is assumed to be proportional to P_n and to vary linearly with the relative soil moisture content, L/L_{max}, of the lower zone storage.

$$OF = \begin{cases} CQ_{OF}\dfrac{L/L_{max} - T_{OF}}{1 - T_{OF}} \cdot P_n & \text{for} \quad L/L_{max} > T_{OF} \\ 0 & \text{for} \quad L/L_{max} \le T_{OF} \end{cases} \tag{4.9}$$

The overland flow runoff coefficient, CQ_{OF}, is a very important parameter determining the extent to which excess rainfall runs off as overland flow and that which infiltrates.

CQ_{OF} is without dimension and has a value between 0 and 1. Physically, in a lumped way, it reflects the infiltration and also to some extent the recharge conditions. Small values of CQ_{OF} are expected for a flat catchment with coarse, sandy soil and a large unsaturated zone. Large CQ_{OF} values are expected for catchments with low permeability such as clay soils or bare rock. CQ_{OF} values in the range of 0.01-0.90 have been experienced.

See Threshold Values for details on $T_{OF.}$

The overland flow is routed through two linear reservoirs in series, with reservoir time constants CK_1 and CK_2 taken equal to CK_{OF} in both reservoirs, according to:

$$CK_{OF} = \begin{cases} CK_{OF} & OF \le OF_{min} \\ CK_{OF} \cdot \left(\dfrac{OF}{OF_{min}}\right)^{-\beta} & OF > OF_{min} \end{cases} \tag{4.10}$$

where:

OF	=	overland flow intensity (mm/hour)
CK_{OF}	=	model parameter, identical for both linear reservoirs (hour)
OF_{min}	=	lower limit for non-linear routing dynamics (OF_{min} = 0.4 mm/hour)
b	=	coefficient, *b*= 0.33 according to the Chezy's flow dynamics

Equation (4.10) ensures in practice that the routing of real surface flow follows a kinematic flow representation, while sub-surface flow, being interpreted by RDI as *OF* (in catchments with no real surface flow component), is routed linearly, corresponding to groundwater flow dynamics.

4.5 Interflow

The interflow contribution, *IF*, is assumed to be proportional to *U*, the water in surface storage, and to vary linearly with the relative moisture content, L/L_{max}, of the lower zone storage.

$$IF = \begin{cases} (CK_{IF})^{-1} \cdot \dfrac{L/L_{max} - T_{IF}}{1 - T_{IF}} \cdot U & \text{for} \quad L/L_{max} > T_{IF} \\ 0 & \text{for} \quad L/L_{max} \le T_{IF} \end{cases} \tag{4.11}$$

The parameters, CK_{IF} and T_{IF}, are both positive constants. CK_{IF} has the dimension of time, while T_{IF} is without dimension. T_{IF} can take values between 0 and 1.

Physical interpretation of the interflow is difficult and will vary somewhat from one catchment to another. As interflow is seldom the dominant stream flow component, CK_{IF} is not usually a very important parameter. Normally, CK_{IF} values are in the range of 500-1000 hours.

The interflow is routed through two linear reservoirs in series with time constants CK_1 and CK_2, taken equal to CK_{OF} in both reservoirs. The parameter CK_{OF} is usually much smaller than CK_{IF}, and therefore the CK_{IF} is dominating time constant for routing of the interflow.

4.6 Lower Zone Storage

The soil moisture in the root zone (a soil layer below the surface from which the vegetation can draw water for transpiration) is represented as Lower Zone Storage.

L_{max} denotes the upper limit of the amount of water in this storage and can be interpreted as the maximum soil moisture content in the root zone available for the vegetative transpiration. Ideally, L_{max} can then be estimated by multiplying the difference between field capacity and wilting point of the actual soil with the effective root depth. However, L_{max} represents the average value for an entire catchment in which there are various soil types and different root depths of the individual vegetation types. Therefore, L_{max} cannot in practice be estimated from field data, but an expected range can be defined.

As the actual evapo-transpiration is highly dependent on the water content of the two storages, U_{max} and L_{max} are the parameters to be adjusted in order to calibrate the water balance in the simulations.

4.7 Groundwater Recharge

The proportion of net excess rainfall, P_n, that does not run off as overland flow infiltrates into the lower zone storage representing the root zone. A portion, *dL*, of the amount of infiltration, (P_n-*OF*), is assumed to increase the moisture content, *L*, in the lower zone storage. The remaining amount of infiltrating water, *G*, is assumed to percolate deeper and recharge the groundwater storage. The *G* and *dL* are calculated from:

$$G = \begin{cases} (P_n - OF) \cdot \dfrac{L/L_{max} - T_G}{1 - T_G} & for \quad L/L_{max} > T_G \\ 0 \quad for \quad L/L_{max} \leq T_G \end{cases} \tag{4.12}$$

and:

$$dL = (P_n - Q_{OF}) - G \tag{4.13}$$

where T_G is the root zone threshold value for groundwater recharge (*0 £ TG < 1*).

4.8 Capillary Flux

The capillary flux of water from the groundwater table to the lower zone storage, *CAFLUX*, is assumed to depend on the depth of the groundwater table, *GWL*, as well as on the relative moisture content, L/L_{max}, of the lower zone storage.

$$CAFLUX = (1 - L/L_{max})^{½} \cdot \left(\frac{GWL}{GWLFL_1}\right)^{-\alpha} \tag{4.14}$$

where

α = $1.5 + 0.45\ GWLFL_1$

The parameter $GWLFL_1$ is the groundwater depth at which the capillary flux is 1 mm/day when the lower zone storage is completely dry. Equation (4.14) gives a good fit to the theoretical relationship between the capillary flux, the depth to the water table and the soil moisture content proposed by Rijtema (1969).

The process is activated if a value of $GWLFL_1$ different than zero is specified.

4.9 Groundwater Storage and Baseflow

Groundwater storage empties continuously by groundwater flow, i.e. baseflow, *BF*. The baseflow calculation is founded on the linear reservoir description, as:

$$BF = \begin{cases} (GWLBF_0 - GWL) \cdot S_y \cdot (CK_{BF})^{-1} & for \quad GWL \leq GEWLBF_0 \\ 0 & for \quad GWL > GWLBF_0 \end{cases} \tag{4.15}$$

where:

GWL	=	Actual groundwater depth
$GWLBF_0$	=	Max. groundwater depth at which baseflow occurs
S_y	=	Specific yield of groundwater reservoir
CK_{BF}	=	reservoir time constant.

The computed baseflow *BF* is multiplied by $C_{area,}$ as to account for difference in the size of the surface catchment and underground catchment. This means that for parameter C_{area} smaller than 1, the baseflow discharge will be proportionally diminished.

The groundwater depth is calculated from a continuity consideration accounting for recharge *G*, capillary flux *CAFLUX* and baseflow *BF*.

4.10 Routing of the Infiltration as Overland Flow

During the periods when the groundwater level reaches GWL_{min} (by default set to zero, i.e. at ground surface) the computed groundwater recharge *G* is diverted to the overland flow *OF*. Actual recharge is set to zero.

This process has a very little importance for analysis of the urban catchments. Necessity for the adjustment of the parameter GWL_{min} is therefore very much restricted.

4.11 Threshold Values

T_{OF}, T_{IF} and T_G are threshold values in the equations for overland flow, interflow, and recharge. No flow will be generated as long as the relative moisture content in the Lower Zone Storage, L/L_{max}, is less than the corresponding threshold value. Please note that $0 \leq T_{OF}, T_{IF}, T_G < 1$.

The function of the threshold value is illustrated by the overland flow equation in Figure 4.1.

Physically, the threshold values should reflect the degree of spatial variability in the catchment characteristics, so that a small homogeneous catchment is expected to have larger threshold values than a large heterogeneous catchment.

For catchments with cyclic alternation of dry and wet periods, the threshold values determine the start times of the flow components in the periods where the root zone is being filled up. This can be used in the parameter estimation. For instance, T_{OF} can be estimated on the basis of such situations where even very heavy rainfall does not give rise to the quick response of the overland flow component.

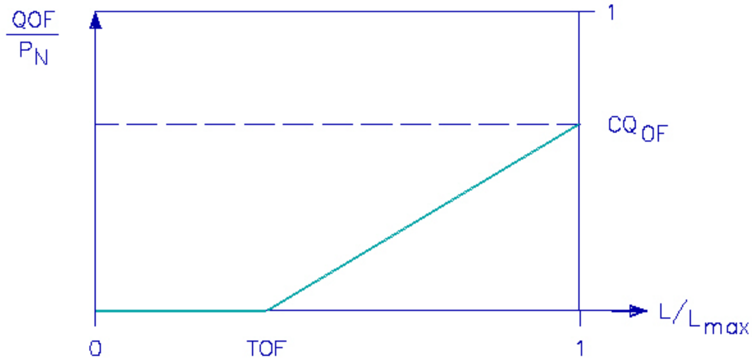

Figure 4.1 The function of the threshold value from the overland flow equation

It should be noticed that the threshold values have no importance in wet periods when $L = L_{max}$. The importance of the threshold value varies from catchment to catchment and is usually larger in semiarid regions. The parameters are relatively easy to estimate through calibration.

5 NOMENCLATURE

BF	baseflow, (mm/hour)
C_{area}	relative size of the underground catchment
$CAFLUX$	capillary flux, (mm/day)
CK_1, CK_2	time constants in linear reservoirs for routing of interflow and overland flow, (hours)
CK_{BF}	time constant, baseflow, (hours)
CK_{IF}	time constant, interflow, (hours)
CK_{OF}	time constant, overland flow, (hours)
CQ_{OF}	overland flow coefficient (-)
C_{me}	snow melting “degree-day” parameter, (mm/day/°C)
C_{fr}	“degree-day” factor for transition from water to ice (mm²/day/°C)
dL	proportion of infiltrating water added to the lower zone storage, (mm/hour)
dt	calculation time step
E_a	actual evapotranspiration, (mm/hour)
E_p	potential evapo-transpiration, (mm/hour)
G	proportion of infiltrating water added to groundwater storage, (mm/hour)
GWL	groundwater depth, (m)
$GWLBF_0$	maximum groundwater depth causing baseflow, (m)
$GWLFL_1$	groundwater depth at unit capillary flux, (m)
IF	interflow, (mm/hour)
L	actual moisture content in lower zone storage, (mm)
L_{max}	max. moisture content in lower zone storage, (mm)
L_{init}	initial moisture content in lower zone storage, (mm)
OF	overland flow, (mm/hour)
OF_{min}	minimum overland flow for non-linear dynamic routing, (0.4 mm/hour)
P_n	net excess rainfall, (mm/hour)
P_s	excess rainfall from snow storage, (mm/hour)
q_{me}	transition “speed” snow->water, (mm/hour)
q_{fr}	transition “speed” water->snow, (mm/hour)
S_y	specific yield of groundwater reservoir
T	actual temperature (°C)
T_{mf}	reversal temperature (~0°C)
T_G	threshold value, groundwater recharge (-)
T_{IF}	threshold value, interflow (-)
T_{OF}	threshold value, overland flow (-)
U	surface storage, (mm)
U_{max}	maximum surface storage, (mm)
U_{init}	initial surface storage, (mm)
V_{fr}	snow storage, (mm)
V_{lq}	liquid phase in the snow storage, (mm)
$ß$	coefficient in dynamic routing of overland flow

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