1D/2D modelling suite for integral water solutions

SOBEK Suite

Deltares systems

D-Rainfall Runoff in Delta Shell

Deltares
Enabling Delta Life

Technical Reference Manual

D-Rainfall Runoff

Rainfall Runoff in Delta Shell

Technical Reference Manual

Version: 0.00
Revision: 41712

14 September 2015

D-Rainfall Runoff, Technical Reference Manual

Published and printed by:
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1.1 Hydrology (Rainfall Runoff modules)

1.1.1 SOBEK-Rural RR (Rainfall Runoff) concept

1.1.1.1 Alpha reaction factor

The reactionfactor α is an important parameter in the De Zeeuw-Hellinga equation which is used in SOBEK to calculate the different components of the groundwater/subsurface flow:

$$q_t = q_{t-1}e^{-\alpha\Delta t} + (I + S)(1 - e^{-\alpha\Delta t}) \tag{1.1}$$

q_t	specific discharge at time t $[m/d]$
q_{t-1}	specific discharge at time $t-1$ $[m/d]$
Δt	time step $[d]$
α	reaction factor $[1/d]$
I	infiltration $[m/d]$
S	seepage (percolation) $[m/d]$

In SOBEK, the De Zeeuw-Hellinga equation is used to calculate the following components of flow:

- groundwater drainage (towards drainpipes or channels);
- surface run-off;
- infiltration from open water.

For each process, the user must define specific reaction factors.

Reaction factor groundwater drainage
In SOBEK, the ground can be divided into different ground layers, each with it's own a. The total specific discharge is calculated by applying the De Zeeuw-Hellinga equation to all layers, and summing the result (see Figure 1.1)

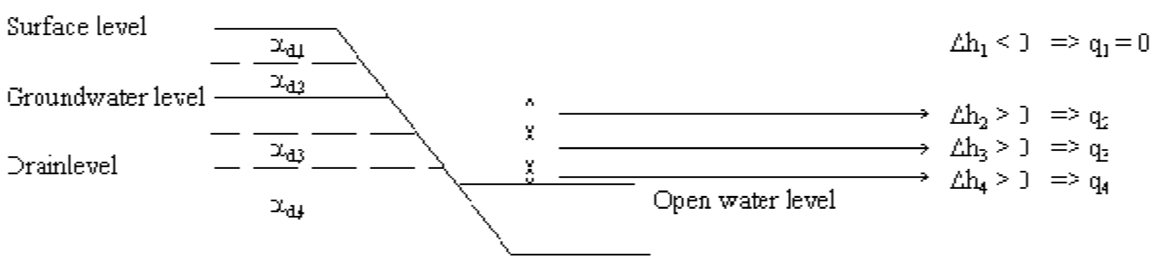


Figure 1.1: *Drainage levels*

Usually, the division between the ground layers is placed at the level of the drains, which are then simulated by giving the above drain level ($\alpha_{d,1}$ to $\alpha_{d,3}$ in the figure) a much higher value than the a below drain level ($\alpha_{d,4}$ in Figure 1.1).

To obtain indications for the values of the reaction factor one can:

- use the values in the Table below (Vademecum, 1988):
  α Discharge type

100–200	Surface runoff from steep slopes
1–10	Surface runoff from soils with impervious subsoil
0.3–0.7	Drainage discharge from well-drained agricultural soil
0.03–0.07	Discharge from grassland without drainage system

- ◇ Measure the decrease of discharge in time. This only can be done after a period of (heavy)rain, and no additional precipitation, and no (or very little) evaporation.
- ◇ Derive the α value from

$$q = \alpha\mu\Delta h \tag{1.2}$$

and

$$q = \frac{\Delta h}{W} \tag{1.3}$$

and equals

$$\alpha = \frac{1}{\mu W} \tag{1.4}$$

q	specific discharge $[m/d]$
Dh	groundwater level above drainage depth or open water level $[m]$
α	reaction coefficient $[1/d]$
m	storage coefficient $[-]$
W	drainage resistance $[d]$

Reaction factor surface run-off

When the groundwater level reaches the surface level or the precipitation excess exceeds the infiltration capacity, water is stored on land. When the storage on land is filled in a SOBEK-RR unpaved node the surface runoff process starts.

Therefore, the user must define a reaction factor α_s. The above table gives indications for the values of this reaction factor.

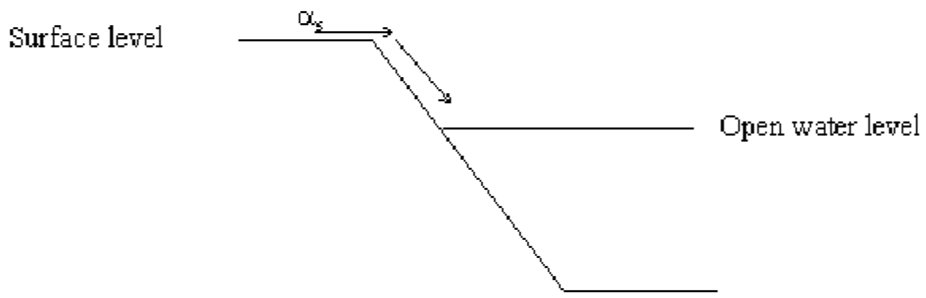


Figure 1.2: *Surface run-off*

Reaction factor infiltration from open water

In dry periods the groundwater level can decrease. When the groundwater level is lower than the open water level, infiltration from the open water occurs. In SOBEK-RR, this process is described by the modified De Zeeuw-Hellinga equation. Again, the user must define a specific reaction factor, α_i

1.1.1.2 Capillary rise

Capillary rise describes the unsaturated flow in the subsoil from the groundwater to the root zone. Capillary rise occurs in case of a water deficit in the root zone. Water deficit is defined as a water content less than equilibrium moisture storage. If the water content in the root zone exceeds equilibrium the excess water percolates to the groundwater. The excess water is the potential root zone volume minus the equilibrium moisture content. To assess whether capillary rise or percolation will occur over a time step, the *potential root zone volume* is determined from the net precipitation and the evapotranspiration, based on the soil moisture storage in the root zone at the previous time step:

$$V'(t) = V(t - \Delta t) + (P_n - E)\Delta t \tag{1.5}$$

where:

$V'(t)$	potential root zone volume at time t [m]
$V(t-\Delta t)$	root zone volume after the previous time step [m]
P_n	net precipitation [m/d]
E	evapotranspiration [m/d]
Δt	time step [d]

In case of a water deficit in CAPSIM the capillary rise flux is calculated in 2 steps. First the potential capillary rise flux is calculated. The potential capillary rise flux depends on the groundwater level, the soil physical unit and the root zone thickness:

$$q_{pot} = f(s, d_g, d_r) \tag{1.6}$$

with:

q_{pot}	Potential capillary rise [mm/d]
s	Soil physical unit [-]
d_g	Depth groundwater level [m]
d_r	Root zone thickness [m]

The potential capillary rise flux is calculated with the 1-D, steady state simulation model CAPSEV (Wesseling, 1991), assuming $pF = 3$ in the root zone. The potential capillary rise fluxes are tabulated.

Secondly SOBEK-CAPSIM uses the potential capillary rise flux, the actual moisture storage in the root zone and the equilibrium moisture storage to calculate the actual capillary rise flux, according to:

$$q_{act} = \begin{cases} q_{pot}\frac{v_{eq}-v_{act}}{v_{eq}-v_{pF3}} & v_{act} > v_{pF3} \\ q_{pot} & v_{act} < v_{pF3} \end{cases} \tag{1.7}$$

where:

q_{act}	Actual capillary rise flux [mm/d]
v_{eq}	Equilibrium soil moisture content [m]
v_{act}	Actual soil moisture content [m]

Equilibrium soil moisture content v_{eq}

The moisture storage of the root zone at equilibrium condition is calculated with the function:

$$V_{eq} = f(s, d_g, d_r) \tag{1.8}$$

where:

V_{eq}	the moisture storage of the root zone at equilibrium condition $[m]$
s	soil physical unit [-]
d_r	thickness of root zone $[m]$
d_g	depth of the groundwater level $[m]$

***Soil moisture content at** $pF = 3$, v_{pF3}*

The moisture storage of the root zone at $pF = 3$ is calculated assuming steady conditions and a groundwater level of 10 m minus soil surface.

1.1.1.3 Crop factors agricultural crops

The fixed input file with crop names and crop factors as a function of time. 1 year of data is enough, since it is assumed that the crop factors are constant over the years; the variation is taken into account in the reference evaporation data and not in the crop factors.

The header of the file contains the number of crops and crop names.

```
*Number of crops
16
*Names
'1 grass '
'2 corn '
'3 potatoes '
'4 sugarbeet '
'5 grain '
'6 miscellaneous '
'7 non-arable land '
'8 greenhouse area '
'9 orchard '
'10 bulbous plants '
'11 foliage forest '
'12 pine forest '
'13 nature '
'14 fallow '
'15 vegetables '
'16 flowers '
*Year/Month/Day/Cropfact 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
 0000 1 1 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
 0000 1 2 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
 0000 1 3 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
 0000 1 4 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
 0000 1 5 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
 0000 1 6 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
 0000 1 7 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
 0000 1 8 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
 0000 1 9 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
 0000 1 10 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
 0000 1 11 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
 0000 1 12 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
 0000 1 13 0.95 1.00 1.00 1.00 1.00 0.95 1.00 0.00 1.00 0.00 0.90 1.20 0.95 1.00 1.00 0.00
etc.
```

1.1.1.4 Crop factors open water

The fixed input file with open water evaporation factors is a function of time. 1 year of data is enough; it is assumed that the evaporation factors are the same for all years.

```
*Surface water
1
*Names
```

```
'0.0 Surface water '
*Year/Month/Day/Cropfact 1
 0000 1 1 0.50
 0000 1 2 0.50
 0000 1 3 0.50
 0000 1 4 0.50
 0000 1 5 0.50
 0000 1 6 0.50
 0000 1 7 0.50
 0000 1 8 0.50
 0000 1 9 0.50
 0000 1 10 0.50
 0000 1 11 0.50
 0000 1 12 0.50
 0000 1 13 0.50
etc.
```

1.1.1.5 De Zeeuw-Hellinga drainage formula

To simulate the flow of groundwater towards the drainage system (i.e. drain pipes and/or channels) the modified equation of De Zeeuw-Hellinga is used in the Rainfall-Runoff module. The theory behind this equation is treated here.

The head loss of groundwater flowing to a drain can be subdivided in head loss caused by:

- ◇ vertical flow;
- ◇ horizontal flow;
- ◇ radial flow nearby the drain/channel;
- ◇ entrance in the drain/channel.

In the equation of De Zeeuw-Hellinga it is assumed that the head loss is mainly caused by radial flow and entrance loss. The head loss by horizontal flow and vertical flow is neglected.

This equation is based on a reservoir containing a volume of ground. The reservoir discharges through a capillary tube. The discharge depends on the difference in pressure head. Thus:

$$Q = c\Delta h \tag{1.9}$$

Q	discharge [m^3/d]
c	proportional coefficient [m^2/d]
Δh	difference in pressure head [m]

and

$$q = \frac{Q}{A} = c_2 h = \alpha\mu h \tag{1.10}$$

q	specific discharge [m/d]
Q	discharge [m^3/d]
A	area [m^2]
c_2	proportional coefficient [$1/d$]
h	groundwater level above drainage depth [m]
α	reaction coefficient [$1/d$]
μ	storage coefficient

The water balance for time dt is:

$$(I + S - q)\Delta t = \mu\Delta h \tag{1.11}$$

I	infiltration [m/d]
S	seepage (percolation) [m/d]
t	time [d]

This equals:

$$\Delta t = \frac{\mu}{I + S - \alpha\mu h}\Delta h \tag{1.12}$$

and eliminating the integration constant ($t = 0$, $q = q_0$) they lead to the equation of De Zeeuw-Hellinga:

$$q_t = q_0 e^{-\alpha t} + (I + S)(1 - e^{-\alpha t}) \tag{1.13}$$

q_t	specific discharge at time t [m/d]
q_0	specific discharge at time 0 [m/d]

With this equation the groundwater flow to a drain can be calculated for a constant $I + S$. When $I + S$ is not constant, the $I + S$ series can be seen as a series of constant $I + S$, positive and negative. For each constant $I + S$ in the series the q_t can be calculated, with t depending on the start of the component. Because the De Zeeuw-Hellinga equation is linear, superposition may be applied. It is easier though to calculate the q_t for several short successive periods wherein $I + S$ is constant. This results in the following modified equation:

$$q_t = q_{t-1} e^{-\alpha\Delta t} + (I + S)(1 - e^{-\alpha\Delta t}) \tag{1.14}$$

q_{t-1}	specific discharge at time $t - 1$ [m/d]
Δt	time step [d]

For each time step infiltration and seepage must be constant.

The total volume of water flowing to the drain can be calculated by integrating the equation of De Zeeuw-Hellinga and multiplying it with the area:

$$V_t = A\int_0^{\Delta t} q_t \, dt \tag{1.15}$$

V_t	Volume of groundwater flow to drain at time t [m^3]

V_t becomes:

$$\begin{aligned}
V_t &= A\int_0^{\Delta t} q_t \, dt && (1.16)\\
&= A\left[-\frac{1}{\alpha}q_0 e^{\alpha t} + (I + S)(t + \frac{1}{\alpha}e^{-\alpha t})\right]_0^{\Delta t} && (1.17)\\
&= A\left[-\frac{1}{\alpha}q_0 e^{\alpha\Delta t} + (I + S)(\Delta t + \frac{1}{\alpha}e^{-\alpha\Delta t}) + \frac{1}{\alpha}q_0 - \frac{1}{\alpha}(I + S)\right] && (1.18)\\
&= A\left[\frac{q_0 - (I + S)}{\alpha}(1 - e^{-\alpha\Delta t}) + (I + S)\Delta t\right] && (1.19)
\end{aligned}$$

and

$$q_0 = \alpha\mu\Delta h_0 \tag{1.20}$$

Substituting gives:

$$V_t = \frac{A\alpha\mu\Delta h - A(I+S)}{\alpha}(1 - e^{-\alpha\Delta t}) + A(I+S)\Delta t \tag{1.21}$$

The average discharge $Q_{t,average}$ $[m^3/d]$ is computed by

$$Q_{t,average} = \frac{V_t}{\Delta t} \tag{1.22}$$

Thus the average discharge in a time step to the drain as is used by the Rainfall-Runoff module is:

$$Q_{t,average} = \frac{A\alpha\mu\Delta h - A(I+S)}{\alpha\Delta t}(1 - e^{-\alpha\Delta t}) + A(I+S) \tag{1.23}$$

This is the so-called modified equation of De Zeeuw-Hellinga. Two important differences from the ‘normal’ equation of De Zeeuw-Hellinga:

- the storage coefficient μ is explicit, and
- the pressure head Δh is in the Rainfall-Runoff module calculated per time step as the difference between the groundwater level and the open water level.

1.1.1.6 `DrainageDeltaH` option

```
DrainageDeltaH=-1 ! -1=parallell systems (default), 0=stacked system;
```

Given the definition of the drainage levels, and the Hellinga-de Zeeuw alfa reaction factors α, or the Ernst drainage resistances γ, there are two options for computing the relevant heads on which the α factors or drainage resistances are applied to.

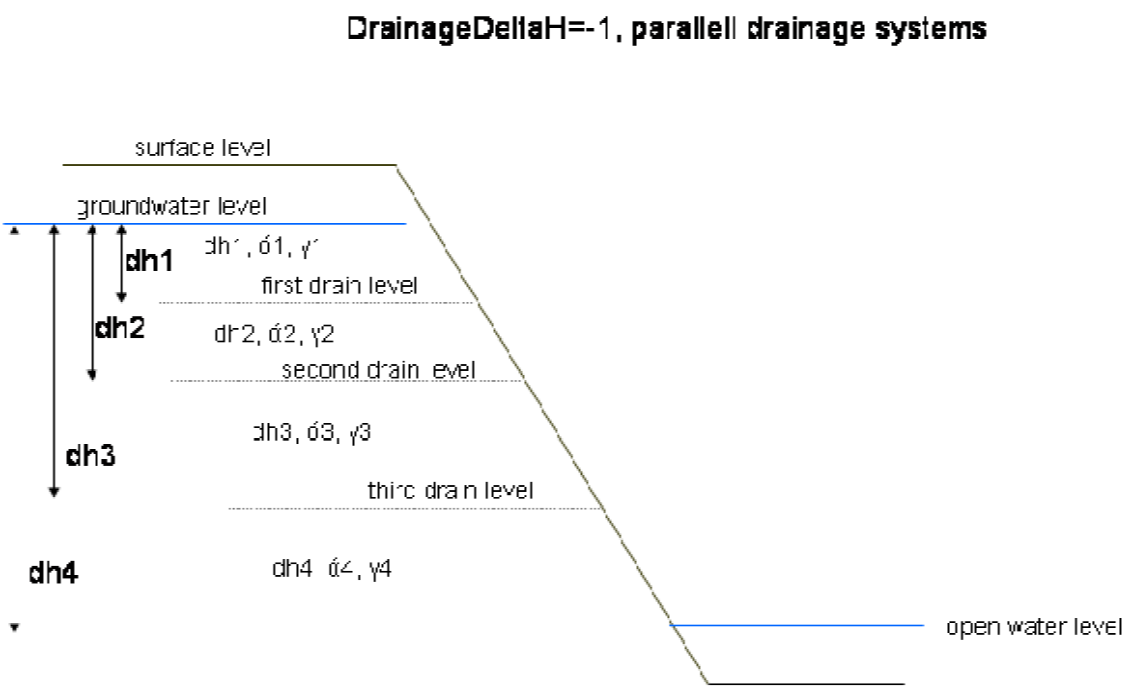


Figure 1.3: *Parallell drainage systems (default:* `DrainageDeltaH=-1`*)*

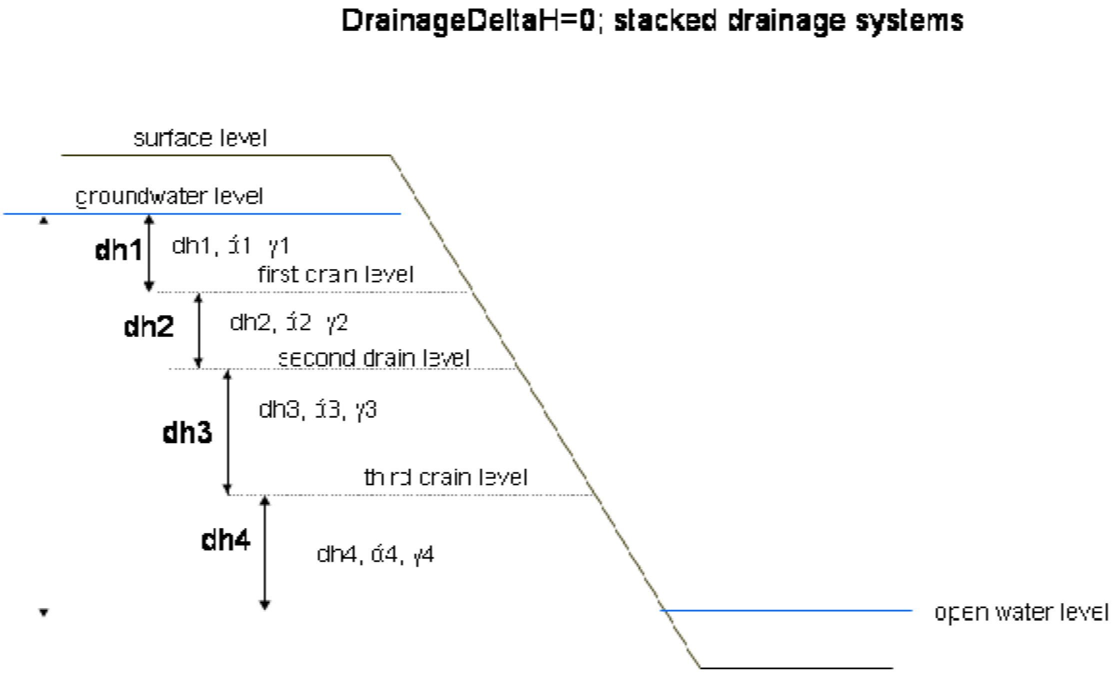


Figure 1.4: *Stacked drainage systems (*`DrainageDeltaH=0`*)*

See also: <Delft_3B.Ini> as described in SOBEK input file formats.

1.1.1.7 Dry Weather Flow (DWF)

The DWF or dry weather flow can be taken into account at the RR-paved node. Also the DWF is part of the formulation in the RR-NWRW node, Nationale Werkgroep Riolering en Waterkwaliteit (NLingenieurs, 1978).

The dry weather flow represents return flow from domestic use, like showers, washing, flushing the toilets, etc.

The dry weather flow can be specified in one of the following ways:

- as a constant flow $[m^3/s]$ during the whole day
- as a variable flow $[m^3/s]$ for 24 hours; 1 value for each hour.
- as a constant flow $[m^3/s]$ per day per person, multiplied with the number of persons
- as a variable flow $[m^3/s]$ per hour per person, multiplied with the number of persons

For paved area, the dry weather flow is discharged into the DWF sewer in case of a separated or improved separated system. In case of a mixed system it is discharged into the mixed sewer system, where it is mixed with sewer inflow due to rainfall.

For a NWRW node the dry weather flow is added to the computed sewer inflow with the NWRW rainfall-runoff model.

1.1.1.8 Ernst drainage formula

One of the options of modelling the drainage from unpaved area towards open water is the Ernst formulation (Ernst, 1978). Other options available are the De Zeeuw-Hellinga formulation and the Krayenhoff van de Leur formulation.

The following figure illustrates the principles of the Ernst method.

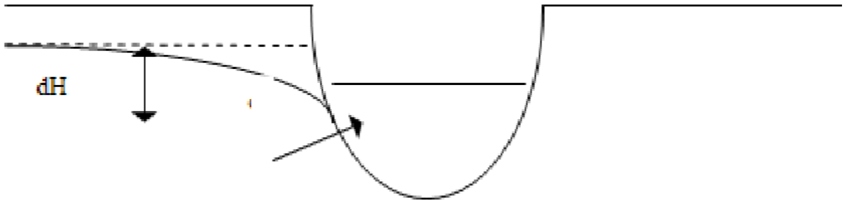


Figure 1.5: *Principles of Ernst method*

The equation reads:

$$q = \frac{dH}{\gamma f} \tag{1.24}$$

where:

q	drainage $[m/d]$
dH	difference between groundwater level and drainage basis $[m]$
γ	drainage resistance $[d]$
f	factor (0.65 - 0.85 (Ernst, 1978)), depending on the shape of the groundwatertable $[-]$

The f factor can not be entered via the User Interface of SOBEK. Instead, the user has to take this factor into account in the drainage resistance.

1.1.1.9 Evaporation (when using capsim)

The actual evapotranspiration ET_{act} is calculated as:

$$ET_{act} = \alpha_E E_r \tag{1.25}$$

with

$$\alpha_E = f\left(\frac{V}{V_{eq}}\right) \tag{1.26}$$

where:

α_E	relative evapotranspiration factor $[-]$
V	actual soil moisture storage in the root zone $[m]$
V_{eq}	equilibrium soil moisture storage in the root zone $[m]$
E_r	potential evapotranspiration $[m]$

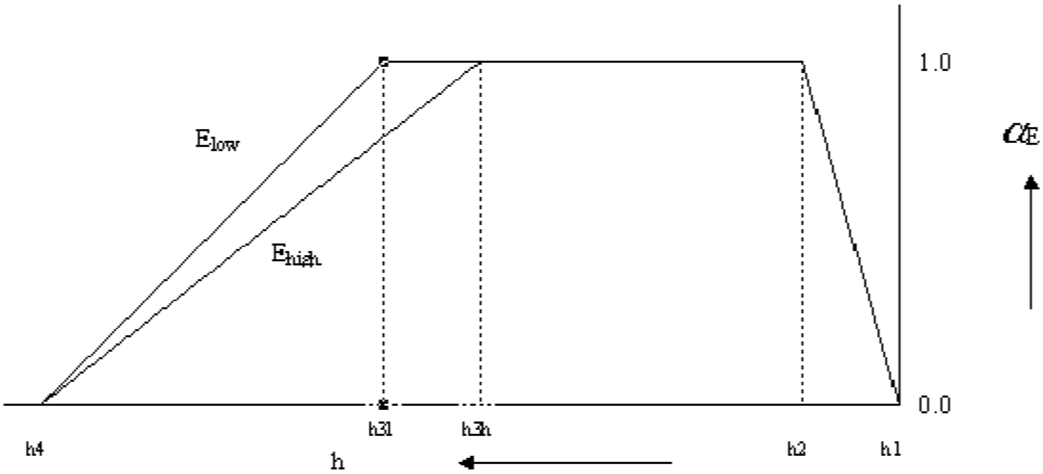


Figure 1.6: Reduction coefficient for root water uptake, α_E, as a function of soil water pressure head h (Feddes et al., 1978).

Water uptake by roots is zero at soil water pressure h_4 which is assumed to be the wilting point, see Figure 1.6. Soil water pressure h_3 is called the reduction point. In between the wilting point and the reduction point the potential evapotranspiration rate is linearly reduced. The location of the reduction point depends on the potential evapotranspiration. If the potential evapotranspiration is less than or equal to 1 mm/d then the curve E_{low} is used. If the potential evapotranspiration is equal to or greater than 5 mm/d then the curve E_{high} is used. In between SOBEK-CAPSIM linearly interpolates between the reduction curves E_{low} and E_{high}.

Between soil water pressures h_2 and h_3 the evapotranspiration is at maximum ('potential'). As a result of oxygen deficiency in the root zone, water uptake is hampered for some crops between soil water pressures h_2 and h_1. SOBEK-CAPSIM does not take this reduction into account ($\alpha_E = 1$ between soil water pressures h_2 and h_1).

SOBEK-CAPSIM doesn't compute the soil waterpressure head directly, but uses the relative root zone storage V/V_{eq}. The relative root zone storages for h_4, h_{3l}, h_{3h}, h_2 and h_1 are calculated by CAPSEV and tabulated in SOBEK-CAPSIM. Then Figure 1.6 can be better explained by:

$$\alpha_E = 0 \quad \text{when} \quad 0 \leq V/V_{eq} < V/V_{eq}(h_4) \tag{1.27}$$

$$0 \leq \alpha_E \leq 1 \quad \text{when} \quad V/V_{eq}(h_4) \leq V/V_{eq} < V/V_{eq}(h_{3l} \text{ or } h_{3h}) \tag{1.28}$$

$$\alpha_E = 1 \quad \text{when} \quad V/V_{eq} \geq V/V_{eq}(h_{3l} \text{ or } h_{3h}) \tag{1.29}$$

1.1.1.10 Evapo(transpi)ration

Open water

For open water, related to Makkink evapotranspiration, the following 'crop' factors are used. These values are based on Hooghart and Lablans (1988).

Decade[1)]	**Value**	**Decade**	**Value**	**Decade**	**Value**
jan-01	0.50	may-01	1.30	sep-01	1.17

jan-02	0.50	may-02	1.30	sep-02	1.17
jan-03	0.70	may-03	1.30	sep-03	1.17
feb-01	0.80	jun-01	1.31	oct-01	1.00
feb-02	1.00	jun-02	1.31	oct-02	0.90
feb-03	1.00	jun-03	1.31	oct-03	0.80
mar-01	1.20	jul-01	1.29	nov-01	0.80
mar-02	1.30	jul-02	1.27	nov-02	0.70
mar-03	1.30	jul-03	1.24	nov-03	0.60
apr-01	1.30	aug-01	1.21	dec-01	0.50
apr-02	1.30	aug-02	1.19	dec-02	0.50
apr-03	1.30	aug-03	1.18	dec-03	0.50

[1] Decades are parts of a month, defined as: first 10 days, second 10 days and rest of the month.

Related input file:
crop factor open water

Unpaved areas

The potential evapotranspiration in unpaved areas depends on the vegetation. The standard way to determine the potential evapotranspiration is to multiply the reference evaporation (p.e. Makkink) by a so called crop factor. The crop factor can differ per vegetation, in time and per location on earth. The default crop factors are orientated towards the Dutch situation for a limited number of crops, listed in the table below.

crop nr.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
decade	**grass**	**corn**	**potatoes**	**sugarbeet**	**grain**	**miscellaneous**	**non-arable land**	**greenhouse area**	**orchard**	**bulbous plants**	**foliage forest**	**pine forest**	**nature**	**fallow**	**vegetables**	**flowers**
jan-01	0.95	1.00	1.00	1.00	1.00	0.95	1.00	0.00	1.00	1.00	0.90	1.20	0.95	1.00	1.00	0.00
jan-02	0.95	1.00	1.00	1.00	1.00	0.95	1.00	0.00	1.00	1.00	0.90	1.20	0.95	1.00	1.00	0.00
jan-03	0.95	0.71	0.71	0.71	0.71	0.95	0.71	0.00	0.71	0.71	0.90	1.20	0.95	0.71	0.71	0.00
feb-01	0.95	0.63	0.63	0.63	0.63	0.95	0.63	0.00	0.63	0.63	0.90	1.20	0.95	0.63	0.63	0.00
feb-02	0.95	0.50	0.50	0.50	0.50	0.95	0.50	0.00	0.50	0.50	0.90	1.20	0.95	0.50	0.50	0.00
feb-03	0.95	0.40	0.40	0.40	0.40	0.95	0.40	0.00	0.40	0.40	0.90	1.20	0.95	0.40	0.40	0.00
mar-01	0.95	0.33	0.33	0.33	0.33	0.95	0.33	0.00	0.33	0.33	1.00	1.20	0.95	0.33	0.33	0.00
mar-02	0.95	0.23	0.23	0.23	0.23	0.95	0.23	0.00	0.23	0.23	1.00	1.20	0.95	0.23	0.23	0.00
mar-03	0.95	0.23	0.23	0.23	0.23	0.95	0.23	0.00	0.23	0.78	1.00	1.20	0.95	0.23	0.23	0.00
apr-01	1.00	0.23	0.23	0.23	0.65	1.00	0.23	0.00	1.04	0.91	1.05	1.20	1.00	0.23	0.23	0.00
apr-02	1.00	0.23	0.23	0.23	0.78	1.00	0.23	0.00	1.04	0.91	1.05	1.20	1.00	0.23	0.52	0.00
apr-03	1.00	0.23	0.23	0.23	0.91	1.00	0.23	0.00	1.04	0.91	1.05	1.20	1.00	0.23	0.65	0.00
may-01	1.00	0.52	0.15	0.52	1.04	1.00	0.15	0.00	1.43	1.04	1.15	1.20	1.00	0.15	0.78	0.00
may-02	1.00	0.52	0.65	0.52	1.04	1.00	0.15	0.00	1.43	1.04	1.15	1.20	1.00	0.15	0.91	0.00
may-03	1.00	0.52	0.91	0.52	1.04	1.00	0.15	0.00	1.43	1.04	1.15	1.20	1.00	0.15	1.04	0.00
jun-01	1.00	0.79	1.05	0.79	1.18	1.00	0.15	0.00	1.57	1.05	1.20	1.20	1.00	0.15	1.18	0.00
jun-02	1.00	1.05	1.05	1.05	1.18	1.00	0.15	0.00	1.57	1.05	1.20	1.20	1.00	0.15	1.18	0.00
jun-03	1.00	1.18	1.18	1.18	1.18	1.00	0.15	0.00	1.57	0.92	1.20	1.20	1.00	0.15	1.18	0.00
jul-01	1.00	1.29	1.16	1.16	1.03	1.00	0.16	0.00	1.68	0.77	1.25	1.20	1.00	0.16	1.03	0.00
jul-02	1.00	1.27	1.14	1.14	0.89	1.00	0.16	0.00	1.65	0.64	1.25	1.20	1.00	0.16	0.76	0.00
jul-03	1.00	1.24	1.12	1.12	0.74	1.00	0.16	0.00	1.61	0.50	1.25	1.20	1.00	0.16	0.16	0.00
aug-01	1.00	1.21	1.09	1.09	0.61	1.00	0.17	0.00	1.33	0.17	1.10	1.20	1.00	0.17	0.17	0.00
aug-02	1.00	1.19	0.83	1.07	0.17	1.00	0.17	0.00	1.31	0.17	1.10	1.20	1.00	0.17	0.17	0.00
aug-03	0.90	1.18	0.83	1.06	0.25	0.90	0.25	0.00	1.18	0.25	1.10	1.20	0.90	0.25	0.25	0.00
sep-01	0.90	1.17	0.70	1.05	0.26	0.90	0.26	0.00	1.17	0.26	1.05	1.20	0.90	0.26	0.26	0.00
sep-02	0.90	1.17	0.26	1.05	0.26	0.90	0.26	0.00	1.17	0.26	1.05	1.20	0.90	0.26	0.26	0.00
sep-03	0.90	1.17	0.26	1.05	0.26	0.90	0.26	0.00	1.17	0.26	1.05	1.20	0.90	0.26	0.26	0.00
oct-01	0.90	0.40	0.30	0.40	0.30	0.90	0.30	0.00	0.30	0.30	1.00	1.20	0.90	0.30	0.30	0.00

crop nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
decade	grass	corn	potatoes	sugarbeet	grain	miscellaneous	non-arable land	greenhouse area	orchard	bulbous plants	foliage forest	pine forest	nature	fallow	vegetables	flowers
oct-02	0.95	0.45	0.44	0.44	0.44	0.95	0.44	0.00	0.44	0.44	1.00	1.20	0.95	0.44	0.44	0.00
oct-03	0.95	0.50	0.50	0.50	0.50	0.95	0.50	0.00	0.50	0.50	1.00	1.20	0.95	0.50	0.50	0.00
nov-01	0.95	0.50	0.50	0.50	0.50	0.95	0.50	0.00	0.50	0.50	0.95	1.20	0.95	0.50	0.50	0.00
nov-02	0.95	0.71	0.71	0.71	0.71	0.95	0.71	0.00	0.71	0.71	0.95	1.20	0.95	0.71	0.71	0.00
nov-03	0.95	0.83	0.83	0.83	0.83	0.95	0.83	0.00	0.83	0.83	0.95	1.20	0.95	0.83	0.83	0.00
dec-01	0.95	1.00	1.00	1.00	1.00	0.95	1.00	0.00	1.00	1.00	0.90	1.20	0.95	1.00	1.00	0.00
dec-02	0.95	1.00	1.00	1.00	1.00	0.95	1.00	0.00	1.00	1.00	0.90	1.20	0.95	1.00	1.00	0.00
dec-03	0.95	1.00	1.00	1.00	1.00	0.95	1.00	0.00	1.00	1.00	0.90	1.20	0.95	1.00	1.00	0.00

Related input file:
crop factor agricultural crops

Remarks:

- ◇ The crop factor file is specified for a limited number of crops and suitable for the Dutch situation or for simular conditions only. In other situations (or other crops) please define your own crop factors. This can be done by changing the input file <../../fixed/cropfact>. We recommend saving the default crop factor file first. We also recommend to save the changed crop factor file at a different location as well, because when installing a new release of SOBEK the crop factor file will be replaced by a new default crop factor file.
- ◇ The values in the table above are based on the Makkink evapotranspiration. The used information comes from the Dutch Cultuurtechnisch Vademecum (3rd edition), Hooghart, Spieksma et. al, Lysimeter results and PAWN (DEMGEN) documentation.
- ◇ The growing season of the specified crops is marked yellow. Outside the growing season the values are the same as the values for fallow (bare soil).
- ◇ Non-arable land is assumed to be the same as fallow.
- ◇ Miscellaneous is assumed to be the same as grass.
- ◇ Nature depends entirely on the kind of nature. Therefore it is assumed to be the same as grass.
- ◇ For greenhouse crops (greenhouse and greenhouse-flowers), the values are set to zero. For proper use, please use the greenhouse node. Other flowers are assumed to be bulbous plants.
- ◇ For vegetables peas and beans are assumed.
- ◇ For both open water as well as unpaved areas a fatal error (the programm stops) will occur when a crop factor is used with a value lower than 0 or higher than 2.5.
- ◇ When a crop factor with value 0 is used, a warning will be given in the log file (<SOBEK_3B.log>). The programm continues.

The actual evapotranspiration can be determined by using the potential evapotranspiration (default) or by taking into account the reduction for root water uptake as a function of soil water pressure head (using Capsim).

1.1.1.11 Hydrologic Cycle

Water circulates through the hydrosphere through a maze of paths, in a cycle without a beginning or an end. Water evaporates from the oceans, is transported to other parts of the atmosphere, and precipitates on the land or the oceans. From there, it will eventually reach the seas via different processes known as infiltration, percolation, and groundwater flow. This cycle of processes is known as the *hydrologic cycle*.

Basically, SOBEK Rainfall Runoff focuses on the following transport processes:

- ◇ precipitation
- ◇ evapo(transpi)ration
- ◇ surface runoff
- ◇ infiltration
- ◇ (Drainage) outflow
- ◇ Seepage
- ◇ Percolation

In SOBEK RR, the user can choose from many different ways to model the flows of water over and under the ground surface, depending on the area type. The following area types are available:

- ◇ paved area
- ◇ unpaved area
- ◇ greenhouse area
- ◇ open water
- ◇ industrial area

Please refer to the corresponding sections for more information about the way the water transport and storage processes are modelled.

1.1.1.12 Improved separated sewer

The sewer type of a paved area node can be one of the following types:

- ◇ mixed sewer
- ◇ separated sewer
- ◇ improved separated sewer

A separated sewer system has separate sewer systems for rainfall and dry weather flow. The improved separated system is designed to reduce the sewer overflows of a separated system. Although overflows from the rainfall sewer system do not contain waste loads originating from DWF, they do contain waste loads from street surfaces, and thus can have negative impacts on water quality of the receiving water (the so-called ‘first flush’)

The improved separated sewer system has a connection between the rainfall sewer and the DWF sewer. This connection is used to store overflows from the rainfall sewer in the DWF sewer, if storage in the DWF sewer is available and no overflow of the DWF sewer is caused. If storage in the DWF sewer is not enough to store the overflow of the rainfall sewer system, the rainfall sewer will still spill into open water (but less than in case of a normal separated system).

1.1.1.13 Infiltration

Infiltration is the process by which water infiltrates from the surface of the ground into the *root zone* (subsoil), and is thus a part of the so-called *Hydrologic Cycle*. The infiltration capacity is influenced by many factors, like the condition of the soil surface and its vegetative cover, the soil properties and the current moisture content of the soil.

In SOBEK-RR, the infiltration capacity of the unpaved areas is considered to have a constant value in time, and can be entered in either mm/hour or mm/day.

1.1.1.14 Infiltration from open water

In dry periods the groundwater level can decrease. When the groundwater level is lower than the open water level, infiltration from the open water occurs. The infiltration rate depends on 1 the difference between open water level and groundwater level and 2 the resistance of the channel

In SOBEK-RR, this process is described by the modified De Zeeuw-Hellinga equation.

Therefore, the user must define a specific reaction factor, α. The difference between the open water level and groundwater level is computed by SOBEK-RR.

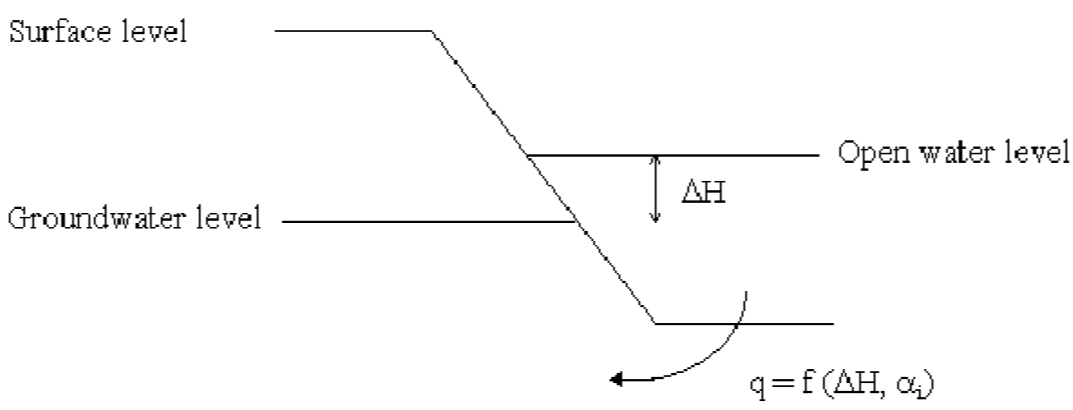


Figure 1.7: *Infiltration from open water*

1.1.1.15 Krayenhoff van de Leur drainage formula

One of the options of modelling the runoff for unpaved area is the Krayenhoff van de Leur formulation. Another available option is the de Hellinga-de Zeeuw formulation.

The following figure illustrates the principles of the Krayenhoff van de Leur method.

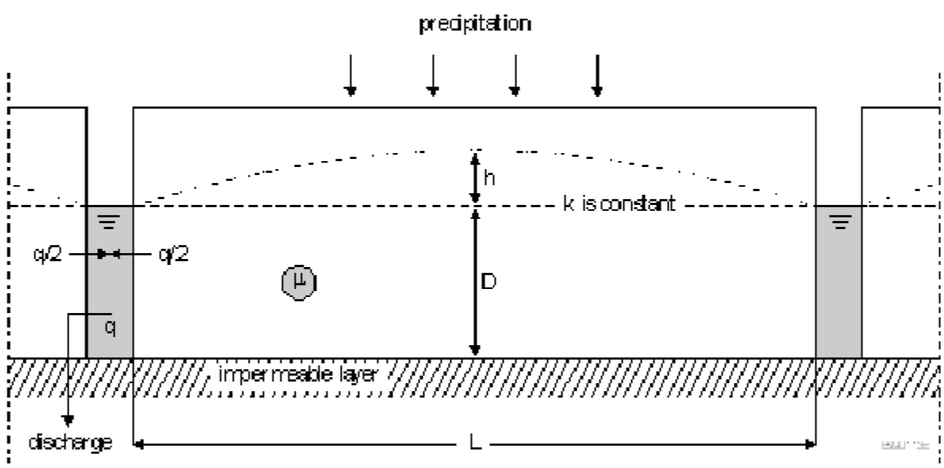


Figure 1.8: *Drainage according to Krayenhoff van de Leur*

The reservoir coefficient j is either specified directly, or calculated as:

$$j = \frac{\mu L^2}{\pi^2 k_D} \tag{1.30}$$

The (cumulative) drainage flow q is computed as:

$$q = \frac{8P}{\pi^2} \sum_{n=1,3,5,...}^{n\to\infty} \frac{1}{n^2}(1 - e^{-n^2 \frac{t}{j}}) \tag{1.31}$$

and the (cumulative) highest groundwater level between the ditches as computed as:

$$h = \frac{\pi^2 P}{8\mu} j \left(1 - \frac{32}{\pi^3} \sum_{n=1,3,5,...}^{n\to\infty} \frac{1}{n^3} e^{-n^2 \frac{t}{j}}\right) \tag{1.32}$$

where:

j	reservoir coefficient [d]
m	storage coefficient (specific yield) [$-$]
L	distance between drainage ditches [m]
k_D	soil transmissibility (transmissivity) [m^2/d]

k_D can be derived from:

k	soil permeability [m/d]
D	thickness of permeable layer [m]
P	precipitation [m]
q	(cumulative) drainage flow [m/d]
h	difference between highest groundwater level and ditch level [m]
t	time [d]

Given the area A [m^2], precipitation and drainage flow can be converted to [m^3/s]

1.1.1.16 Minimum filling percentage for greenhouse storage basin

When the water level in the greenhouse storage basins becomes equal/lower than this minimum filling percentage, the withdrawal of water out of the basins will be stopped.

Default: 10 %

1.1.1.17 Mixed sewer

The sewer type of a paved area node can be one of the following types:

- ◇ mixed sewer
- ◇ separated sewer
- ◇ improved separated sewer

A mixed sewer system means that there is only one system for the discharge of both rainfall water and dry weather flow (return flow from domestic water use, e.g. showers, toilets, etc.)

Spilling from the sewer system after heavy rainfall thus contains a mix of rainfall water and domestic return flow. Spilling from a mixed sewer system therefore in general has a negative effect on the water quality of the receiving open water.

1.1.1.18 Paved area node

General

The paved area node is used to simulate the rainfall-runoff process on paved or impervious areas.

A paved area is characterized by:

- area $[ha]$
- maximum storage on street $[mm]$
- maximum storage in sewer $[mm]$
- sewer pump capacity $[m^3/s]$
- sewer type (mixed, separated, or improved separated system)
- DWF (dry weather flow)

Important processes are surface runoff or sewer overflow, occurring when the storage on land or storage in the sewer exceeds its maximum and rapid runoff occurs.

1.1.1.19 Paved node surface runoff

When the amount of water on the RR-paved surface exceeds the maximum storage, surface runoff will occur. The surface runoff can be implemented using either

- no delay,
- using a runoff delay coefficient, or
- using a QH-relation.

The first option, no delay, means all surface runoff reaches the outflow point in the same timestep. Surface runoff can be blocked however if the open water level at the connecting node exceeds the surface level of the paved node. But when using the 'no delay' option the surface storage will immediately runoff as soon as the water level drops below the paved surface level. This may lead to very spiky discharges from the paved node to the RR-open water or RR-Boundary node.

The second option, using a runoff delay coefficient, is similar to the RR-Urban runoff model.

(See also the description of delay of runoff in the RR-Urban documentation, **??**. This is formulating the surface runoff using the rational method ($q = ch$). The runoff delay coefficient c is specified as a number between zero and one (1/min). A coefficient of one means all runoff occurs in 1 minute, while a coefficient of 0.1 means only 10 % of the excess volume will reach the open water in 1 minute.

The impact of the runoff delay coefficient on the runoff pattern is shown in the following graph. The graph shows the rainfall time-series used, and the runoff using runoff delay coefficients of 0.1, 0.2 and 0.5. It is assumed that there is no infiltration or sewer, and that the maximum storage on the street is zero.

Note: The example Figure 1.9 is actually taken from a simulation of the RR-Urban inflow model, but the behaviour for the RR-Paved node is the same.

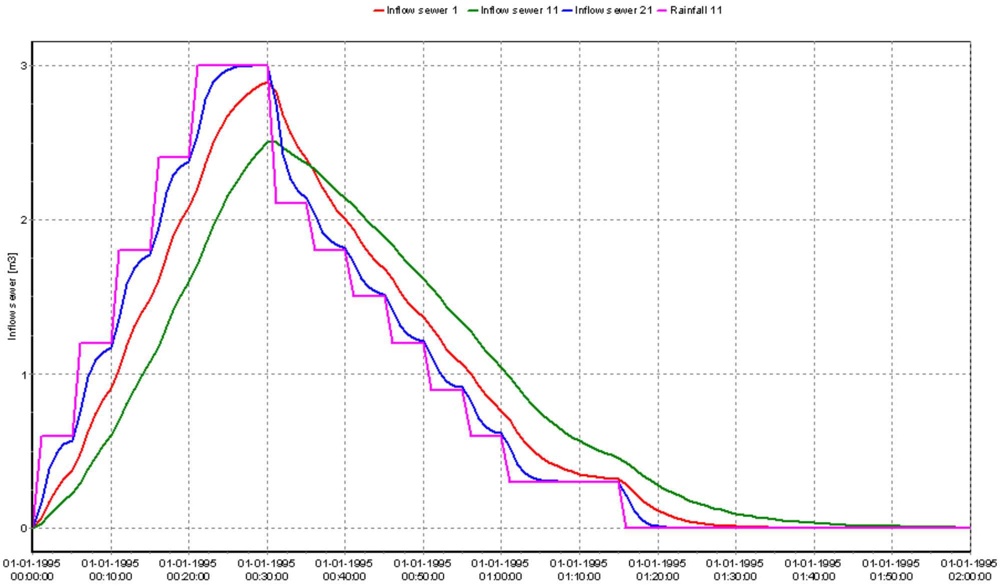


Figure 1.9: *Impact of delay coefficient on runoff pattern*

The third option, using a QH-relation, allows limiting of the Q based on the water level h. Based on the interpolation table defined by the user a maximum Q is determined with which the overflowing discharge is limited.

The used h is the water level of the open water node or RR-CF-connection node downstream of the paved node, where the overflowing discharge of the RR-paved node is discharged to. See the following two examples:

1 Figure 1.10 shows the result of water overflowing from two paved nodes to open water nodes without delay of discharge from the paved nodes.
2 Figure 1.11 shows the discharges after using a QH-relation.

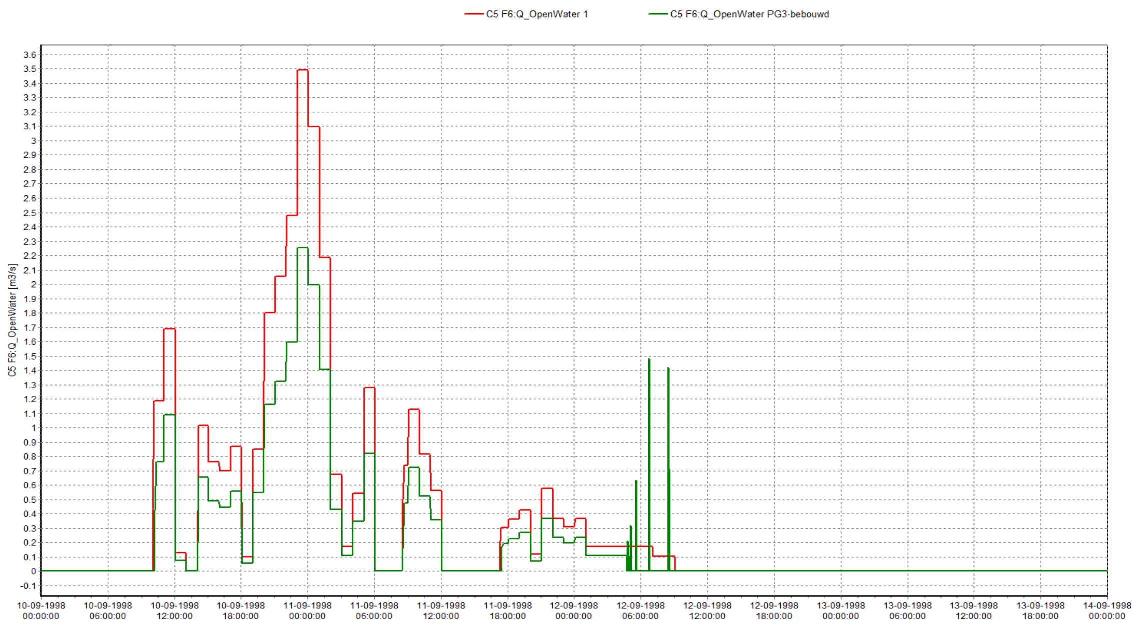


Figure 1.10: *Discharge from Paved to Open Water without delay*

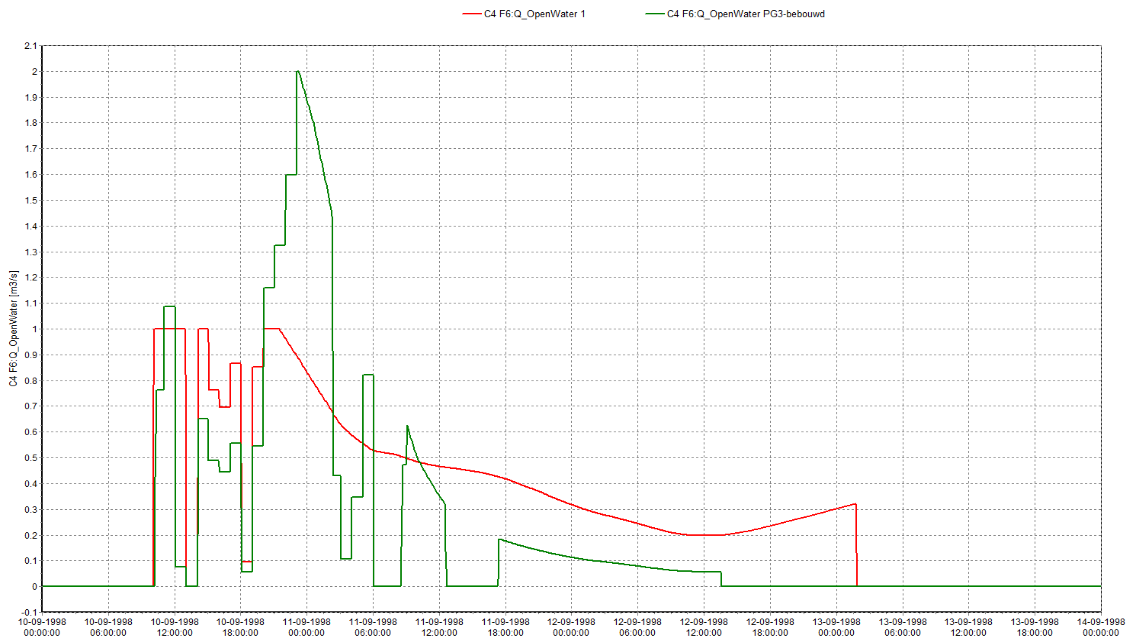


Figure 1.11: *Discharge from Paved to Open Water using QH-relation*

1.1.1.20 Percolation

If the moisture storage in the root zone exceeds the equilibrium content, percolation occurs from root zone to groundwater:

$$q_p = \frac{V_{eq} - (V(t - \Delta t) + \Delta V)}{\Delta t} \tag{1.33}$$

q_p	Percolation $[m/d]$
V	Soil moisture storage in the root zone $[m]$

V_{eq}	Equilibrium moisture storage in the root zone $[m]$
Δt	Time step $[d]$

If percolation occurs, it is assumed that the percolating water reaches the groundwater table within the current time step of the groundwater.

The equilibrium moisture storage in the root zone is defined as the amount of moisture corresponding with a steady-state simulation with no-flow conditions to or from the root zone.

1.1.1.21 Root zone

The root zone for which the water balance is considered has a thickness which is a function of the land use type and the soil physical unit:

$$d_r = f(j, s) \tag{1.34}$$

where:

d_r	root zone thickness
j	land use type (1,. . . ,16)
s	soil physical unit (1,. . . ,21)

The thickness of the root zone is assumed to be constant, regardless of season and year. The moisture storage of the root zone at equilibrium condition is calculated with the function:

$$V_{eq} = f(s, d_r, dg) \tag{1.35}$$

where:

V_{eq}	the moisture storage of the root zone at equilibrium condition $[m]$
s	soil physical unit $[-]$
d_r	thickness of root zone $[m]$
d_g	depth of the groundwater level $[m]$

Initial storage in the root zone

The initial storage in the root zone can be defined by one of the three following options:

- ◇ the equilibrium root zone storage for the given crop-soil combination and specified initial groundwater level;
- ◇ the root zone storage at pF= 2;
- ◇ the root zone storage at pF= 3.

Root zone thickness defining more than one crop

When the user defines more than one crop per unpaved node SOBEK calculated the overall root zone by weighted averaging. So, the area of the individual crops is also taken into account.

For calculating the evaporation SOBEK uses the crop with the largest sub-areal.

1.1.1.22 Separated sewer

The sewer type of a paved area node can be one of the following types:

- ◇ mixed sewer
- ◇ separated sewer

◇ improved separated sewer

A separated sewer has separate sewer systems for rainfall and dry weather flow. This system is designed to reduce water quality impacts of sewer overflows on the receiving open water. In a mixed sewer system spilling contains DWF water (domestic return flows). In a separated sewer system however, sewer overflows usually only originate from the rainfall sewer system and not from the DWF sewer system. Therefore, the sewer overflows do not contain the waste loads from the domestic return flows.

1.1.1.23 Silo capacity/Pump capacity

Apart from storage in rainfall basins in some greenhouse areas there is also storage of water in silo's. These silo's, usual capacity approximately 200 m^3/ha, function as a temporary storage before pumping the water into the soil (subsoil storage). The pump capacity for subsoil storage usually is about 15 m^3/h.

1.1.1.24 Storage coefficient

The storage coefficient m represents the percentage of soil-volume which is available for storage of water. Once the storage coefficient is known, the total storage capacity can be calculated:

$$V = \mu d \tag{1.36}$$

V	storage capacity [mm]
μ	storage coefficient [m/m]
d	depth to groundwater table [mm]

With the storage coefficient, the change of the groundwater level can be calculated.

Option 'Unsaturated zone = none'

Calculating groundwater level

For calculating the groundwater level the average storage coefficient is used during the simulation period (Table 1.3). This average storage coefficient depends on the drainage basis, i.e. the distance between the surface level and the initial groundwater level. These coefficients are provided by the Winand Staring Centre -DLO.

The soil types are:

1 loamy, humous fine sand,
2 peat,
3 heavy clay,
4 humous clay and peat,
5 light loamy sand, medium coarse sand,
6 loamy silt,
7 humous clay and peat with silty top layer,
8 clay and light clay,
9 loamless, medium coarse and coarse sand,
10 silt,
11 very light clay,
12 sand with a silty top layer.

Table 1.3: *Average storage coefficients depending on soil type and dranaige basis.*

Drainage basis [m]	Soil type											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
0.1	0.0074	0.0077	0.0094	0.0063	0.0046	0.0049	0.0049	0.0048	0.0027	0.0029	0.0025	0.0013
0.2	0.0183	0.0153	0.0166	0.0134	0.0124	0.0103	0.0118	0.0092	0.0098	0.0066	0.0052	0.0032
0.3	0.0302	0.0226	0.0226	0.0206	0.0220	0.0158	0.0181	0.0132	0.0162	0.0105	0.0079	0.0052
0.4	0.0419	0.0305	0.0278	0.0279	0.0323	0.0211	0.0237	0.0171	0.0228	0.0145	0.0107	0.0074
0.5	0.0532	0.0387	0.0323	0.0350	0.0427	0.0262	0.0289	0.0206	0.0294	0.0186	0.0134	0.0096
0.6	0.0664	0.0467	0.0363	0.0420	0.0528	0.0310	0.0339	0.0240	0.0359	0.0226	0.0160	0.0120
0.7	0.0805	0.0545	0.0399	0.0486	0.0625	0.0364	0.0386	0.0271	0.0422	0.0265	0.0185	0.0143
0.8	0.0938	0.0621	0.0431	0.0551	0.0715	0.0416	0.0430	0.0300	0.0484	0.0303	0.0210	0.0167
0.9	0.1061	0.0702	0.0461	0.0613	0.0801	0.0466	0.0472	0.0328	0.0542	0.0341	0.0235	0.0191
1.0	0.1173	0.0784	0.0489	0.0673	0.0880	0.0514	0.0512	0.0355	0.0598	0.0377	0.0258	0.0214
1.2	0.1372	0.0939	0.0538	0.0786	0.1024	0.0605	0.0586	0.0404	0.0704	0.0446	0.0303	0.0261
1.5	0.1614	0.1158	0.0600	0.0941	0.1208	0.0729	0.0685	0.0470	0.0845	0.0541	0.0366	0.0329

<u>Calculating drainage flux</u>

For calculating the drainage flux according to De Zeeuw- Hellinga a constant storage coefficient is used. This storage coefficient, which is the same as for calculation the changes in groundwater level, is the storage coefficient corresponding with the initial groundwater level.

Option 'Unsaturated zone = CAPSIM'

<u>Groundwater level</u>

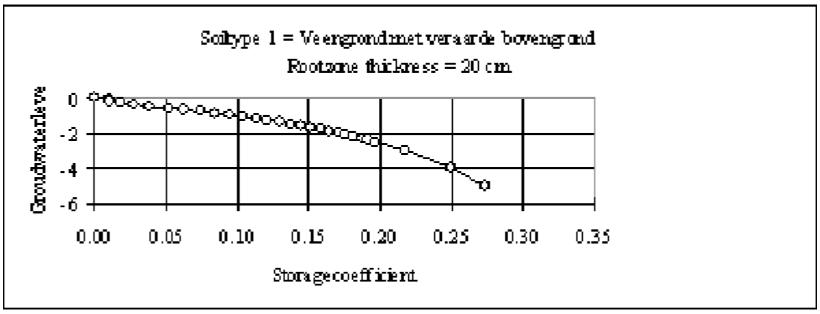
For calculating the groundwater level a storage coefficient is used depending on the actual groundwater level during the simulation period.

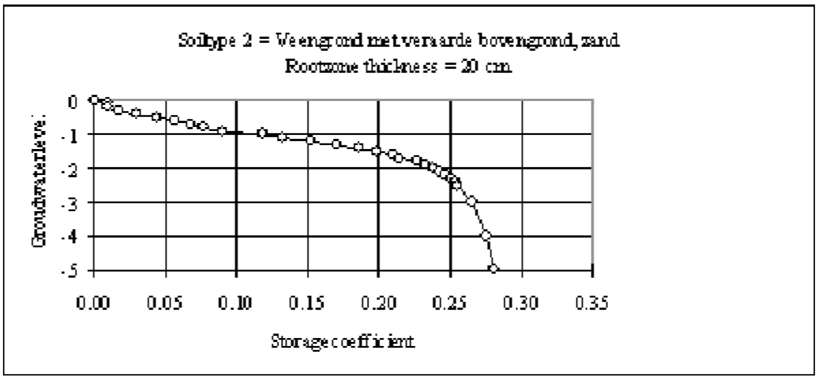
<u>Drainage flux</u>

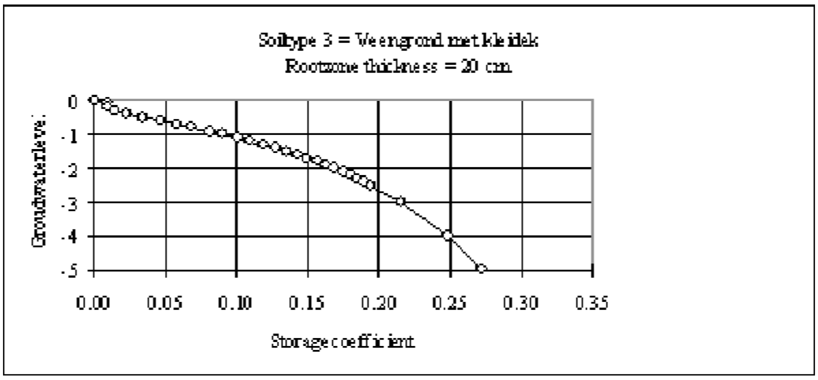
The storage coefficient is calculated by averaging all coefficients within in the domain of the groundwater level and the open water level. Since the groundwater level and the open water level may change during the simulation period, the average storage coefficient may change.

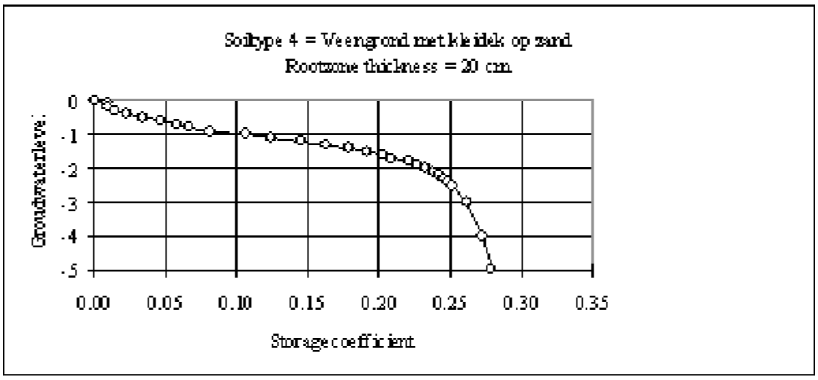
The coefficients for calculating the groundwater level and the drainage flux are tabulated in in SOBEK. These storage coefficients depend on the soil type, the root zone thickness end the groundwater level. Below the storage coefficients are depicted for a root zone thickness of 20 cm. SOBEK also takes into account storage coefficient for root zone thicknesses of 10 cm, 50 cm, 100 cm and 200 cm.

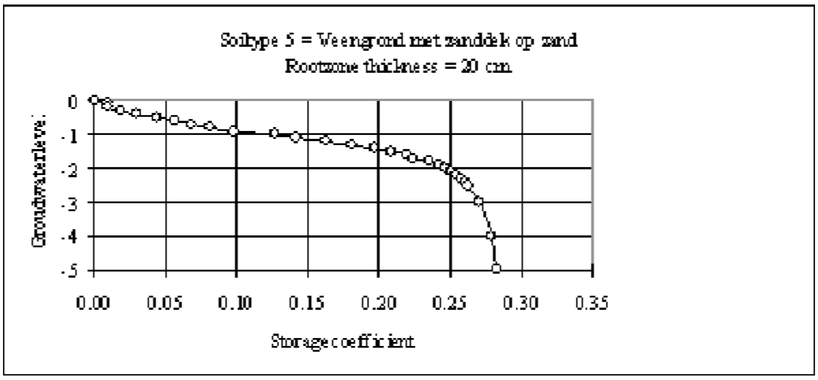
All coefficients are provided by Alterra.

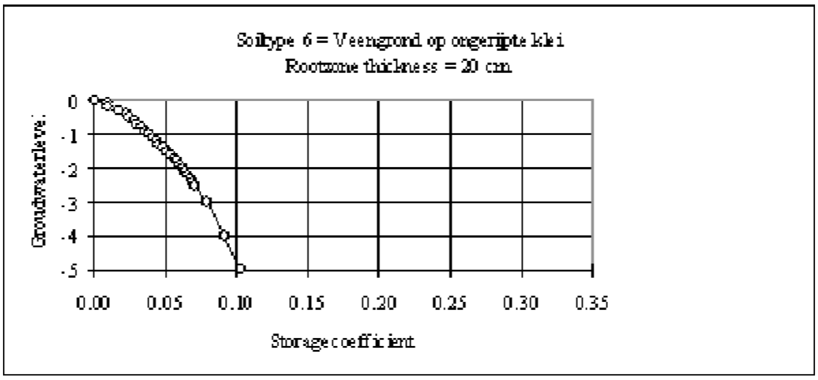


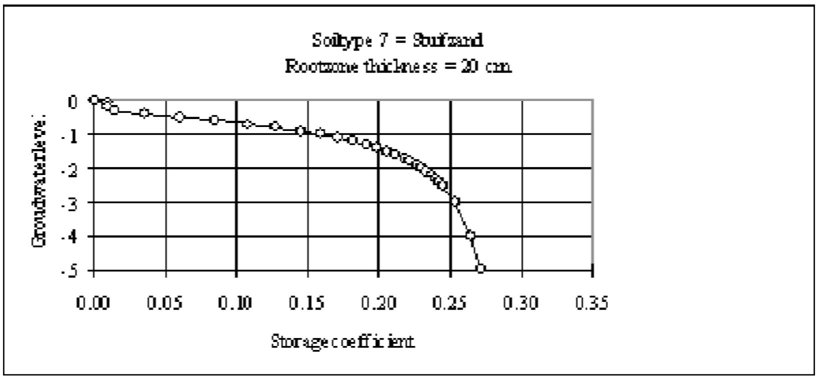

Soiltype 2 = Veengrond met veraarde bovengrond, zand
Rootzone thickness = 20 cm
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

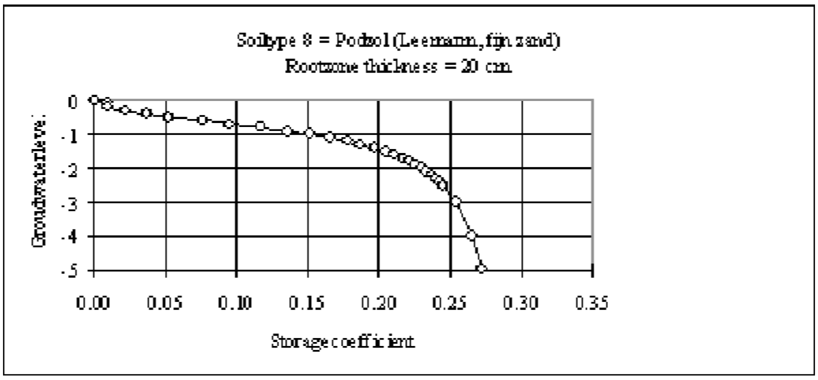

Soiltype 3 = Veengrond met kleidek
Rootzone thickness = 20 cm
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

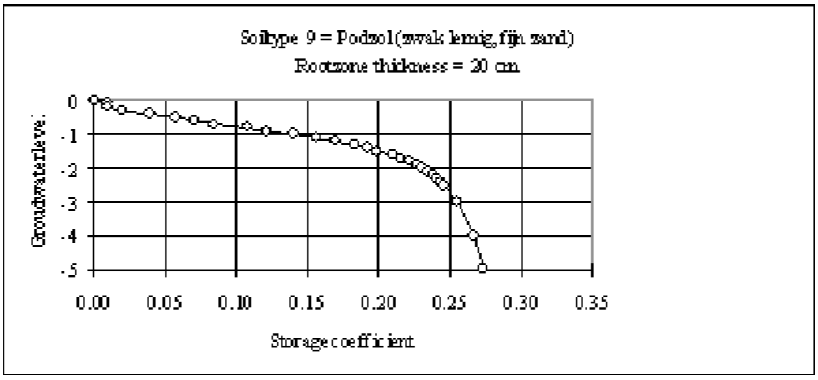

Soiltype 4 = Veengrond met kleidek op zand
Rootzone thickness = 20 cm
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

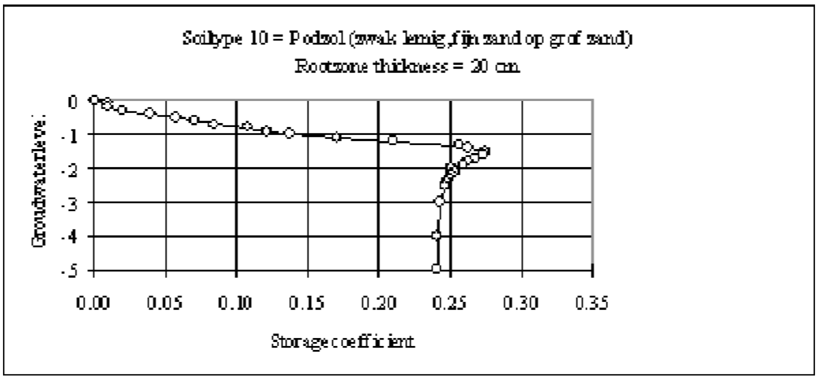

Soiltype 5 = Veengrond met zanddek op zand
Rootzone thickness = 20 cm
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

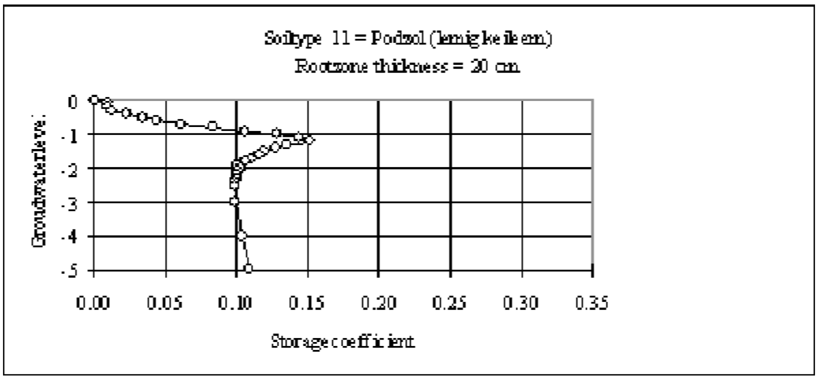

Soiltype 6 = Veengrond op ongerijpte klei
Rootzone thickness = 20 cm
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

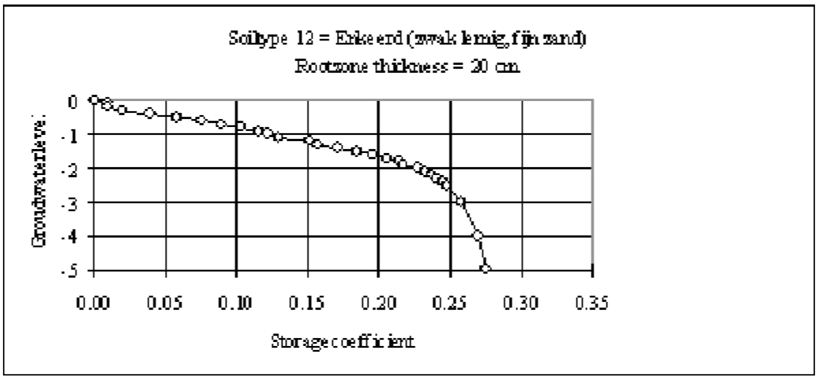

Soiltype 7 = Stuifzand
Rootzone thickness = 20 cm
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

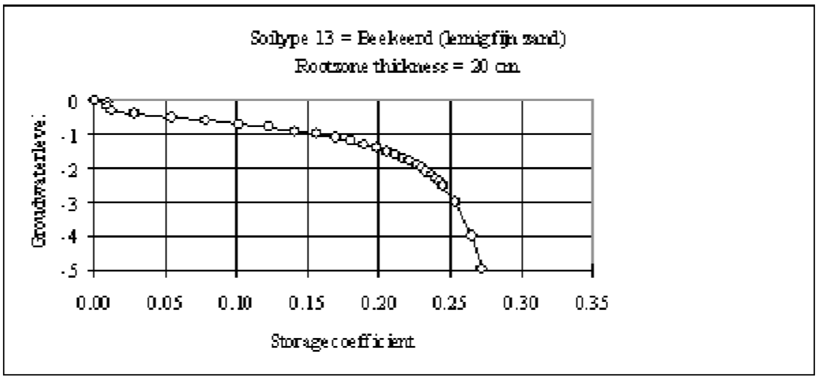

Soiltype 8 = Podzol (Leemarm, fijn zand)
Rootzone thickness = 20 cm
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

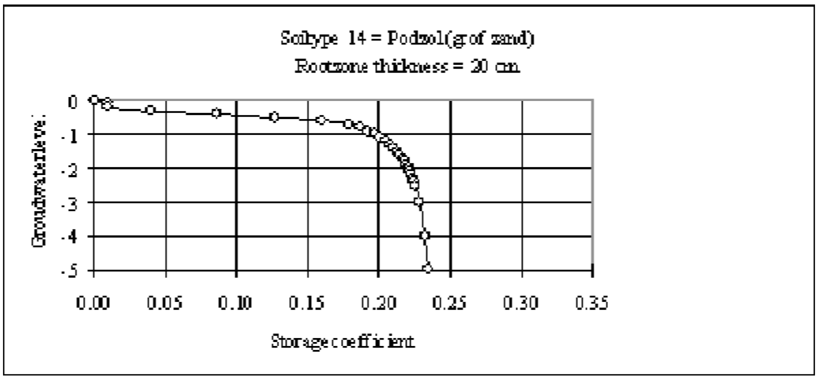

Soiltype 9 = Podzol (zwak lemig, fijn zand)
Rootzone thickness = 20 cm
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

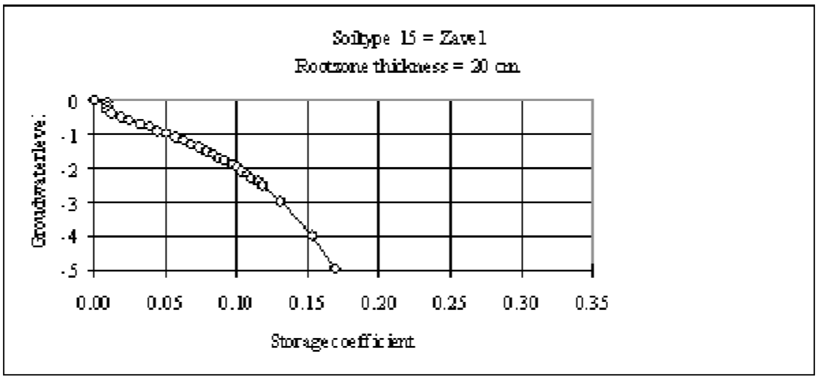

Soiltype 10 = Podzol (zwak lemig, fijn zand op grof zand)
Rootzone thickness = 20 cm.
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

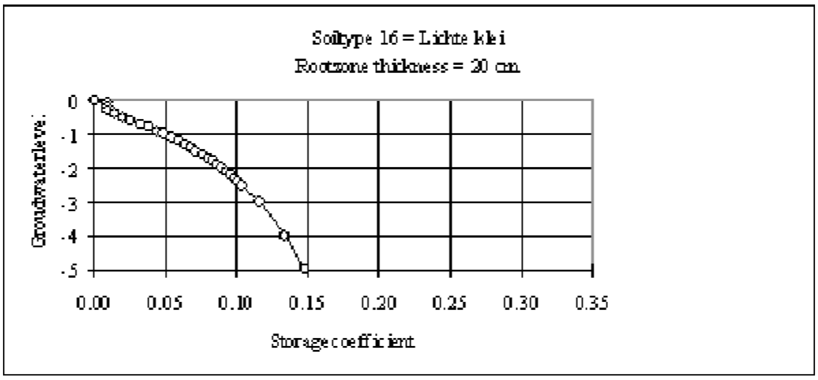

Soiltype 11 = Podzol (lemig keileem)
Rootzone thickness = 20 cm.
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

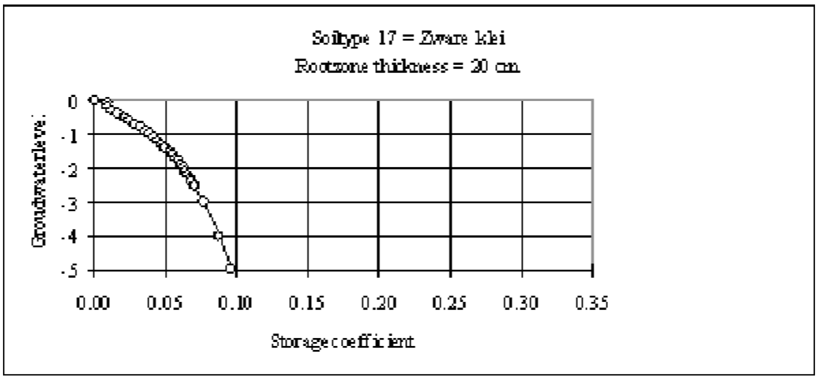

Soiltype 12 = Enkeerd (zwak lemig, fijn zand)
Rootzone thickness = 20 cm.
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

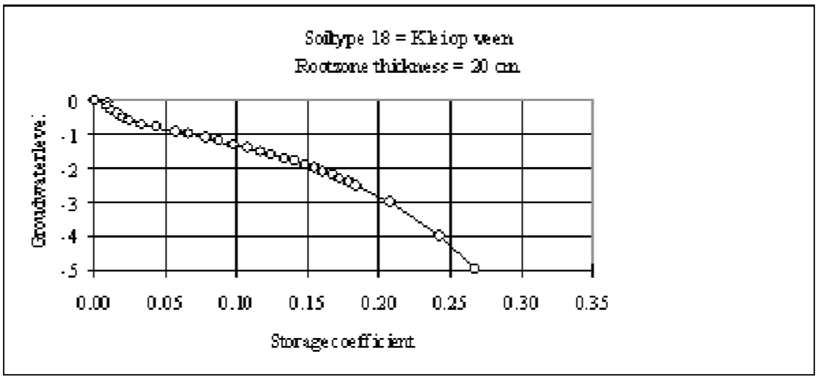

Soiltype 13 = Beekeerd (lemig fijn zand)
Rootzone thickness = 20 cm.
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

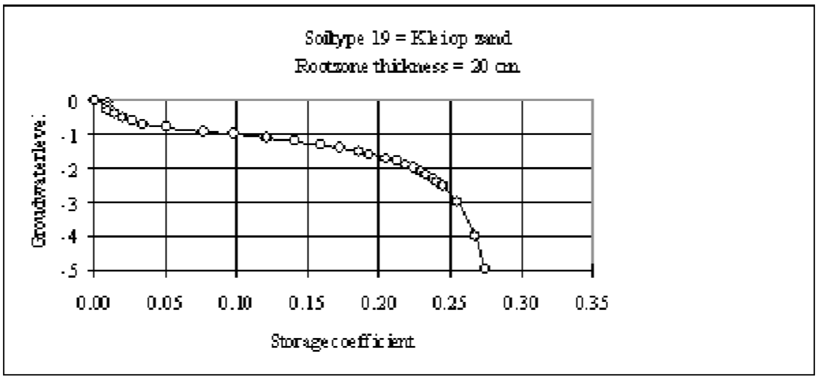

Soiltype 14 = Podzol(grof zand)
Rootzone thickness = 20 cm
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

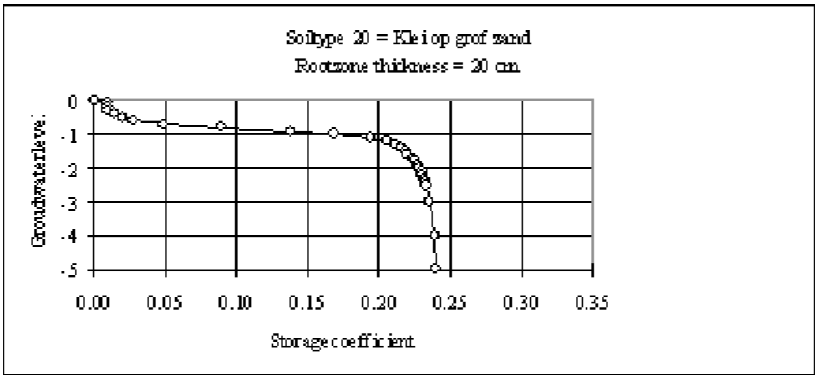

Soiltype 15 = Zavel
Rootzone thickness = 20 cm
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient

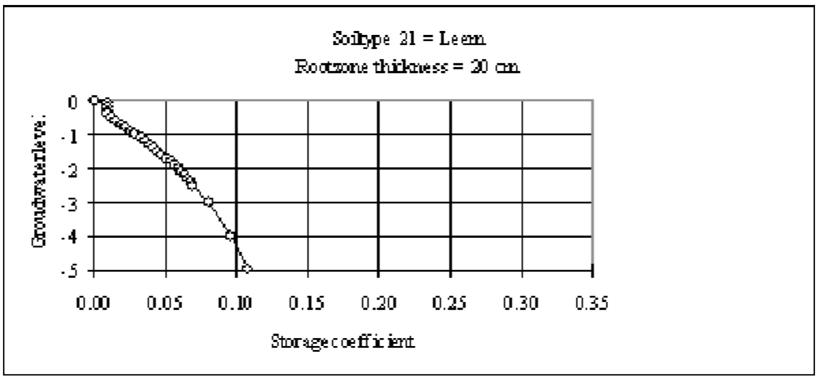

Soiltype 16 = Lichte klei
Rootzone thickness = 20 cm
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient


Soiltype 17 = Zware klei
Rootzone thickness = 20 cm
Groundwaterlevel
0
-1
-2
-3
-4
-5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Storage coefficient









1.1.1.25 Surface runoff

Surface runoff in paved areas

In paved areas surface runoff occurs when the ‘storage on street’ reservoir is completely filled.

Surface runoff in unpaved areas

In unpaved nodes surface runoff to open water can occur in two cases:

1 when the ‘storage on land’ reservoir is filled by the precipitation (minus evaporation and infiltration into the soil).
2 when the groundwater level has reached the soil surface level. In this case, the storage on land has not been taken into account, so surface runoff will immediately take place when the groundwater level has reached the surface level.

In both cases the runoff process is simulated by means of the de Zeeuw-Hellinga equation. Therefore, the user must define a specific surface runoff reaction factor.

Notice that when the soil surface is defined as a constant level, the total area defined in the unpaved node is part of the surface runoff process. Often this causes very large discharges to the open water.

When the soil surface is defined as a variable level, only the inundated part of the soil surface is part of the surface runoff process.

1.1.1.26 Time step output

By default the time step of the results is equal to the time step of the computation. Especially when a small time step is chosen, this results in a very large amount of output values. Then the user can choose an other option in the Settings task in order to reduce the number of output values.

Output reduction options in Settings:

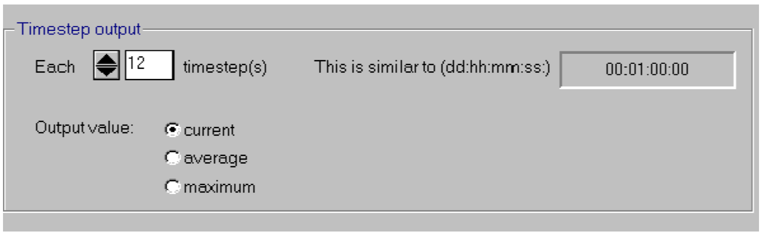


Figure 1.12: *Output reductions in Settings*

In this case each 12th computed value is shown in the results graphs. The user can define any interval he wants.

Other options;

- ◇ Current: each nth computed value is written to the output file;
- ◇ Average: the average value of n computed values is written to the output file;
- ◇ Maximum: the maximum value of n computed values is written to the output file.

Note: the user should realise that the chosen options are of great importance to the shape of the output graph, see this example:

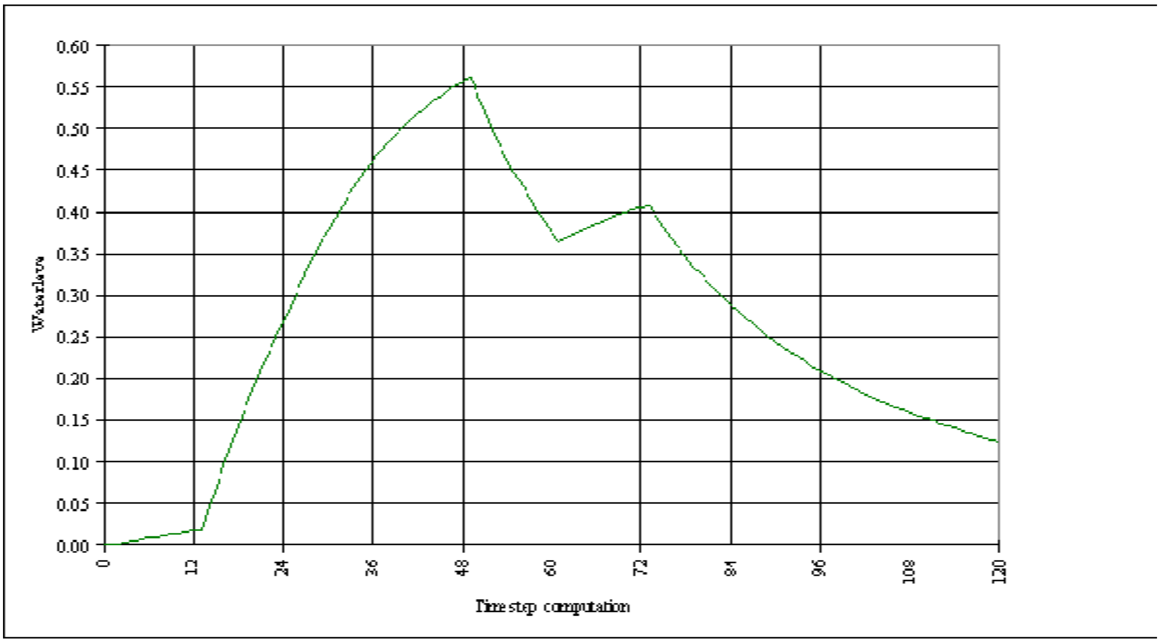


Figure 1.13: *Time step computation*

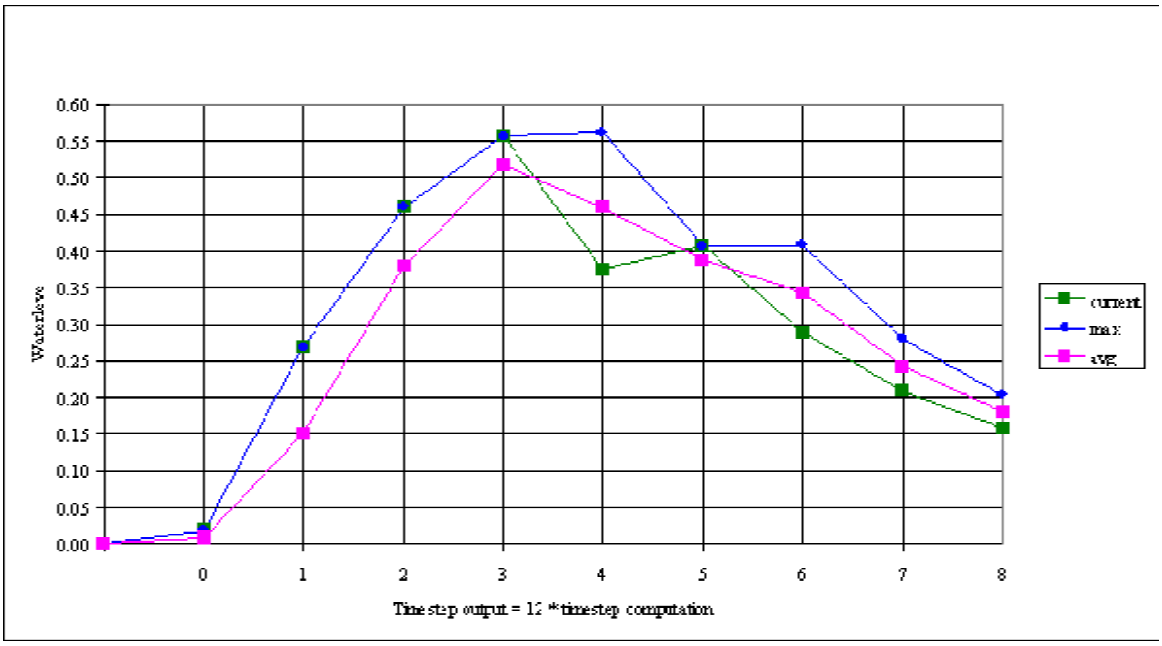


Figure 1.14: *Time step output = 12 $*$ time step computation*

When SOBEK is used to compute series of precipitation events, then the maximum realised level is written to the output file, based on all computed values. The options current, average and maximum are not relevant anymore.

1.1.1.27 Unpaved area node

General

The unpaved area node is used to simulate the rainfall-runoff process on unpaved areas.

An unpaved area is characterized by:

- total unpaved area (sum of crop areas)
- groundwater area
- area per crop
- soil surface level
- soil type
- storage coefficient
- root zone
- saturated zone
- evaporation
- capillary rise/percolation from root zone to groundwater
- storage on land
- infiltration capacity
- drainage resistance value / reaction factor (dependent on the chosen method)
- seepage/percolation (constant, variable in time or calculated from a defined groundwater head in the lower confined aquifer and the resistance value of the confining layer)
- surface runoff

The unpaved area is modeled using boxes representing storage on land, storage in the unsaturated zone, and the saturated zone. The unsaturated zone is optional. The surface area is divided into area for different crops. The sum of the crop area is the total unpaved area. This area is used for the surface storage and unsaturated zone computations. The saturated zone computations use the groundwater area. This area is by default equal to the total unpaved area, but can be defined separately by the user.

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