5 Soil water – groundwater interaction

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5.1 Introduction

In the unsaturated zone water flow and solute transport occur mainly in the vertical direction. Once in the saturated zone, water starts to move in a three dimensional pattern, following the prevailing pressure gradients. The bottom boundary of the one-dimensional SWAP is either in the unsaturated zone or in the upper part of the saturated zone where the transition takes place to three-dimensional groundwater flow.

At the lower boundary we can define three types of conditions:
- Dirichlet condition, the pressure head h is specified;
- Neumann condition, the flux q is specified;
- Cauchy condition, the flux depends on the groundwater level.

The *Dirichlet* condition is a predescribed pressure head, often as a recorded phreatic surface of a present groundwater table.
The *Neumann* condition is usually applied when a no-flow boundary (e.g. an impermeable layer) can be identified, or in case of a deep groundwater table, resulting in free drainage.
The *Cauchy* condition is used when unsaturated flow models are combined with models for regional groundwater flow or when effects of surface water management are to be simulated. The relation between flux and groundwater level can be obtained from drainage formulae (see Par. 4.2.2) and/or from regional groundwater flow models (e.g. Van Bakel, 1986).

SWAP offers eight options to prescribe the lower boundary condition (Table 3), which each have their typical scale of application.

Table 3. Eight options for the lower boundary condition

Lower boundary condition (input switch SwBotb)	Description	Type of condition	Typical scale of application
1	Prescribe groundwater level	Dirichlet	field
2	Prescribe bottom flux (q_{bot})	Neumann	region
3	Calculate bottom flux from hydraulic head of deep aquifer	Cauchy	region
4	Calculate bottom flux as function of groundwater level	Cauchy	region
5	Prescribe soil water pressure head of bottom compartment	Cauchy	field
6	Bottom flux equals zero	Neumann	field
7	Free drainage of soil profile	Neumann	field
8	Free outflow at soil-air interface	Neumann	field

In case of options 1, 2, 3, 5 and 6, in addition to the bottom flux *(q_{bot})*, a drainage flux *(q_{drain})* can be defined (Par. 4.2). In case of option 4 the lower boundary includes drainage to local ditches or drains so q_{drain} should not be defined separately. In case of options 7 and 8, the simulated soil profile is unsaturated, so lateral drainage will not occur.

5.2 Field scale

When the model is applied at field scale with locally known/measured data, the following 5 options are commonly applied:

- Prescribe groundwater level (SwBotB = 1)
- Prescribe soil water pressure head of bottom compartment (SwBotB = 5)
- Bottom flux equals zero (SwBotB = 6)
- Free drainage of soil profile (SwBotB = 7)
- Free outflow at soil-air interface (SwBotB = 8)

Prescribed water levels (ϕ_{avg}) are given as a function of time. This groundwater level respresents a field average groundwater level. For days with unknown values a linear interpolation occurs between the days with known values. The main advantage of this boundary condition is the easy recording of the phreatic surface in case of a present groundwater table. A drawback is that at shallow groundwater tables the simulated phreatic surface fluctuations are very sensitive to the soil hydraulic functions. This condition may result in strong fluctuations of the water fluxes across the lower boundary, which may not be desirable. Especially when the output of the Swap model is used as input in water quality calculations, it is is generally recommended to use another type of lower boundary condition.

Model input

Variable	*Code*	*Description*	*Default*
ϕ_{avg}	*GWLEVEL*	Groundwater level as function of time (cm below soil surface)	-

Prescribed soil water pressure heads of bottom compartment (h_n) are input to the model and. The soil water pressure head is assigned to the lowest compartment. For days with unknown values a linear interpolation occurs between the days with known values.

Model input

Variable	*Code*	*Description*	*Default*
h_n	HOBTS	Soil water pressure head of bottom compartment as function of time (cm)	-

A *bottom flux (q_{bot}) of zero* may be applied when an impervious layer exists at the bottom of the profile. This option is implemented with a simple switch, which forces q_{bot} to zero.

In case of *free drainage of a soil profile*, unit gradient is assumed at the bottom boundary and the bottom flux depends directly from the hydraulic conductivity of the lowest compartment:

$$\frac{\partial H}{\partial z} = 1 \qquad \text{thus:} \quad q_{\text{bot}} = -K_n \tag{5.1}$$

In case of *free outflow at soil-air interface*, drainage will only occur if the pressure head in the bottom compartment (h_n) increases until above zero. During drainage and after a drainage event, h_n is set equal to zero and q_{bot} is calculated by solving the Richards' equation. This option is commonly applied for lysimeters, where outflow only occurs when the lowest part of the lysimeter becomes saturated.

5.3 Regional scale

At regional scale the lower condition will generally be used describe the interaction with a regional groundwater system. In these cases 3 options are common:

- Prescribe bottom flux (SwBotB = 2)
- Calculate bottom flux from hydraulic head of deep aquifer (SwBotB = 3)
- Calculate bottom flux as function of groundwater level (SwBotB = 4)

Prescribed bottom flux

In this case the bottom flux (q_{bot}) is input to the model and should be given as a function of time. For days with unknown values a linear interpolation occurs between the days with known values. This option has a similar disadvantage as previously described option with the prescribed groundwater level. When a mismatch occurs between boundary conditions and soil physical properties the result may be a continuously declining or increasing groundwater level. Especially when the output of the Swap model is used as input in water quality calculations, it is is generally recommended to use another type of lower boundary condition.

Model input

Variable	*Code*	*Description*	*Default*
	SW2	Switch for kind of input: as sinus or as table	
When SW2=1:			
	SINAVE	Average value of bottom flux (cm d^{-1})	-
	SINAMP	Amplitude of bottom flux (cm d^{-1})	-
	SINMAX	Time of the year with maximum value of bottom flux (daynr from Jan 1)	-
When SW2=2 then enter a table:			
q_{bot}	*QBOT2*	Average value of bottom flux (cm d^{-1})	-

Calculate bottom flux from hydraulic head of deep aquifer

This Par. discusses how a Cauchy condition may be applied to determine the bottom boundary flux q_{bot}, starting from a given hydraulic head of a deep aquifer.

To illustrate this option Figure 26 shows a soil profile which is drained by ditches and which receives a seepage flux from a semi-confined aquifer. SWAP makes a distinction between the local drainage flux to ditches and drains q_{drain}, as calculated according to chapter 4, and the bottom flux due to regional groundwater flow, q_{bot}.

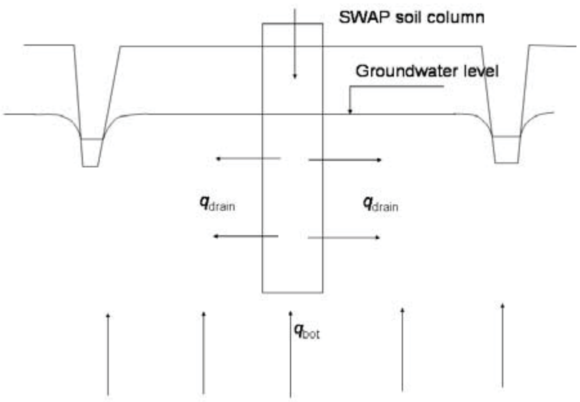

Figure 26 Pseudo two-dimensional Cauchy lower boundary conditions, in case of drainage to ditches and seepage from a deep aquifer

The bottom flux q_{bot} depends on the average groundwater level, the hydraulic head in the semi-confined aquifer, and the resistance of the semi-confining layer. The bottom flux q_{bot} is calculated by:

$$q_{\text{bot}} = \frac{\phi_{\text{aquif}} - \phi_{\text{avg}}}{c_{\text{conf}}} \tag{5.2}$$

where ϕ_{aquif} is the hydraulic head in the semi-confined aquifer (cm), ϕ_{avg} is the average groundwater level, and c_{conf} is the semi-confining layer resistance (d).
The hydraulic head in the aquifer may be prescribed using a sinusoidal wave:

$$\phi_{\text{aquif}} = \phi_{\text{aquif,m}} + \phi_{\text{aquif,a}} \cos\left(\frac{2\pi}{\phi_{\text{aquif,p}}}\left(t - t_{\max}\right)\right) \tag{5.3}$$

where $\phi_{\text{aquif,m}}$, $\phi_{\text{aquif,a}}$, and $\phi_{\text{aquif,p}}$ are the mean (cm), amplitude (cm) and period (d) of the hydraulic head sinus wave in the semi-confined aquifer, and $t_{\max}$ is a time (d) at which ϕ_{aquif} reaches its maximum.

The average phreatic head, ϕ_{avg} (cm), is calculated as:

$$\phi_{\text{avg}} = \phi_{\text{drain}} + \beta_{\text{gwl}}\left(\phi_{\text{gwl}} - \phi_{\text{drain}}\right) \tag{5.4}$$

with ϕ_{drain} is the hydraulic head of the drain (cm) and β_{gwl} the groundwater shape factor (-). Possible values for β_{gwl} are 0.66 (parabolic), 0.64 (sinusoidal), 0.79 (elliptic) and 1.00 (no drains).

Model input

Variable	*Code*	*Description*	*Default*
β_{gwl}	*SHAPE*	Shape factor to derive average groundwater level (-)	1.0
ϕ_{drain}	*HDRAIN*	Mean drain base to correct for average groundwater level (cm)	-
c_{conf}	*RIMLAY*	Vertical resistance of aquitard (d)	-
-	*SW3*	Switch for kind of input: as sinus or as table	-
When SW3=1 then enter a sinus wave:			
$\phi_{\mathrm{aquif,m}}$	*AQAVE*	Average value of hydraulic head in underlaying aquifer (cm)	-
$\phi_{\mathrm{aquif,a}}$	*AQAMP*	Amplitude of hydraulic head sinus wave (cm)	-
t_{max}	*AQTMAX*	First time of the year with maximum hydraulic head (daynr from Jan 1)	-
$\phi_{\mathrm{aquif,p}}$	*AQPER*	Period hydraulic head sinus wave (d)	-
When SW3=2 then enter a table:			
ϕ_{aquif}	*HAQUIF*	Average value of hydraulic head in underlaying aquifer (cm)	-

Calculate bottom flux as function of groundwater level

Calculate q_{bot} from an exponential flux - average groundwater relationship, which is valid for deep sandy areas:

$$q_{\mathrm{bot}} = a_{\mathrm{qbot}}\ \mathrm{e}^{b_{\mathrm{qbot}}\left|\phi_{\mathrm{avg}}\right|} \tag{5.5}$$

where a_{qbot} (cm d^{-1}) and b_{qbot} (cm^{-1}) are empirical coefficients. For additional data of q_{bot} - ϕ_{avg} relationships, see Massop and De Wit (1994).

Model input

Variable	*Code*	*Description*	*Default*
a_{qbot}	*COFQHA*	Coefficient A (cm d^{-1})	-
b_{qbot}	*COFQHB*	Coefficient B (cm^{-1})	-