SWAP 1993 - Input instructions manual

Work Group SWAP

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INTRODUCTION

The model **SWAP 1993** preceeds the final SWAP version to appear later on in 1994.

This **SWAP 1993** manual replaces the SWATRE INSTRUCTIONS FOR INPUT manual by J.G. Wesseling, J.A. Elbers, P. Kabat and B.J. van den Broek (december 1991).

The main changes with respect to the SWATRE 1991 version are :

- The discretization and solution scheme of the Richards' equation is improved. The water balance error due to the non-linearity of the capacity term is reduced according to the approach of Celia et al. (1990). The user may choose between an iterative and non-iterative solution of the Richards' equation.

- The mixing cell numerical scheme of the solute transport is replaced by an efficient explicit, central difference scheme of the convection-dispersion equation. This approach is flexible in describing the physical dispersion.

- The solute processes were extended with adsorption and decomposition as described by Boesten and Van der Linden (1991).

- Hysteresis of the water retention function is implemented according to the concept of Kool and Parker (1987).

- A concept of water and solute transport in soils with stagnant or immobile parts is included (Van Dam et al., 1990).

Other changes concern :

- calculation of drainage fluxes
- boundary conditions at the top during infiltration
- calculation of the soil hydraulic functions by means of the Van Genuchten parameters
- effect of osmotic head on root water extraction

The program, including its source code, is distributed among researchers belonging to or closely affiliated with the participating institutes. It should be noted that, although various tests were performed, at present no guarantee of the absence of bugs can be given.

Please, inform the authors about your experience with the program !

SETUP OF *INPUT INSTRUCTIONS MANUAL*

The model SWAP 1993 supports various hydrological options. Each option requires different input data with corresponding format. The input instructions given below describe how to make the required input files depending on your choice of options.

This *INPUT INSTRUCTIONS MANUAL* is made up of 6 separate SECTIONS each representing one datafile. Each of these SECTIONS is made up of GROUPS. The group nummering includes SECTION number and a letter of the alphabet, eg. GROUP 1.M (SECTION 1 with GROUP M). Some GROUPS are made up of a number of SUB-GROUPS which are separated by a grey line.

INPUT and OUTPUT FILES

INPUT files:

- FILE 1 : described in SECTION 1	(general input data)	**default**
- FILE 2 : described in SECTION 2	(top boundary data)	"
- FILE 3 : described in SECTION 3	(crop data)	"
- FILE 4 : described in SECTION 4	(soil physical data)	"
- FILE 5 : described in SECTION 5	(bottom boundary data)	"
- FILE 6 : described in SECTION 6	(drainage data)	**optional**

* Please note: FILE 1 containing the general input data as described in SECTION 1 of this *INPUT INSTRUCTIONS MANUAL*, **must at all times be named SWAP93.INP**
* There are two choices to enter data: either as separate files (with **user-definable names to be specified in FILE 1**) or the input data of files 2 through 6 may also be entered directly in the general input file **SWAP93.INP**

OUPUT files:

default
File with echo of the input and the terms of the waterbalance on a daily basis (GROUP 1.B)

optional
File with specific profile data on a daily basis for each nodal point (GROUP 1.C)
File with cropgrowth and cropproduction terms on a daily basis (GROUP 1.O)
File with solute transport output on a daily basis (GROUP 1.V)
File with water and solute transport data on a daily basis at each nodal point (GROUP 1.X)
5 files with data for the graphical package BALANCE (GROUP 1.Y)

All OUTPUT file names are user definable, except those for the graphical package BALANCE. Please use the **advised file name extensions** (given in the respective GROUPS) when naming your OUTPUT files.

Example GROUP 1.M as listed in this *INPUT INSTRUCTIONS MANUAL*

GROUP 1.M	**used only if SWTOPB = 2 or 4**	**(see GROUP 1.H)**
LABEL ">excons:"	**use 1 line**	
	Constants used for calculating evapotranspiration.	
	Use this line if SWTOPB = 2 :	
R ALPHA	empirical constant in Priestly and Taylor eq'n, (1.35 ± 0.10)	
	Use this line if SWTOPB = 4 :	
R RSMIN	minimum canopy resistance ($s \cdot m^{-1}$) in Monteith-Rijtema eq'n	
R RSMAX	maximum canopy resistance ($s \cdot m^{-1}$) in Monteith-Rijtema eq'n	

Explanation of GROUP 1.M

GROUP 1.M is made up of : i) **group heading**
ii) **group text**

The **group heading** (shaded) indicates:

- the group number	1.M
- when a group should be used	used only if ....
- the unique group label (max. 8 characters)	" >excons: "
- the amount of lines to use for input	use 1 line

The **group text** indicates :

- occasional explanatory text	Constants used for calculating evapotranspiration.
- variable name	ALPHA if SWTOPB = 2 and RSMIN and RSMAX if SWTOPB = 4
- type of variable	Real
- description of variables	empirical constant... or minimum canopy...

HOW TO CREATE AN INPUT DATA FILE

In each INPUT data file, there are default and optional lines:

default lines are:	- **a label line** containing the unique group label
	- **data line(s)** containing the value(s) of the variables
optional lines are:	- **comment lines**

Label line :
The first 8 characters of a label line should contain the label as given in the group heading. In the example this is: " >excons: " Any characters to the right of this label are not significant and may be used as comment. The label indicates that the next line **must be** a data line.

Data lines :
A data line **always** follows a label line. Data on one line must be separated by one or more blanks. The line should end with a <cr/lf> (carriage return/line feed).

Comment lines :
These may be used *before a label line* or *after a data line* (or group of data lines). They are not significant to the program. Their purpose is purely explanatory.

Example of GROUP 1.M as listed in the main input file *SWAP93.INP*

```
extra constants for calculating evapotranspiration      ← comment line
>excons:                                                ← label line
1.35                                                    ← data line
alpha for Priestly and Taylor equation                  ← comment line
```

Additional information when using this MANUAL:

* Variable names correspond with those used in the source code. Variable names are either REAL (R), INTEGER (I) or STRING (S) as indicated before each variable name.
  Please note: **STRING data should be quoted using single quotes (' ')**

* Special attention should be given to explanatory notes with a ☞ .

* For all equations, figures and page numbers you find in the **group text** please refer to the following publication, unless stated otherwise:

* Feddes, R.A., Kowalik, P.J., and Zaradny, H., (1978): "Simulation of field water use and crop yield", Simulation Monographs, Pudoc, Wageningen.

* More background literature is listed in the **References**.

SECTION 1. File describing general input data (SWAP93.INP)

GROUP 1.A **use 1 line**
LABEL ">genhdr:"

S HEADER — Desired heading to be printed. Will be printed in the output file (see GROUP 1.B) Use max. 40 characters

☞ reminder: string data, e.g. HEADER, should be quoted using a single quote.

GROUP 1.B **use 1 line**
LABEL ">output:"

I SWSTAG — = 0 : the stage of computation is not shown during calculations

= 1 : the stage of computation is shown as: a bar on the screen showing % of computed days (advised for interactive systems)

= 2 : the stage of computation is shown as: 'year', 'time' and '% mass balance error' (advised for batch processing)

I OUTIVL — interval between output written to all output files (d)

S OUTPUTFL — give name of general output file containing:
i) the echo of the input and ii) terms of the water balance.
Use max. 40 characters (Advised filename = ********.BAL)

GROUP 1.C **if SWEXFL = 0 use 1 line**
LABEL ">exfile:" **if SWEXFL = 1 use 3 lines**
if SWEXFL = 2 use 2 lines
if SWEXFL = 3 use 3 lines

Choice for additional output file containing supplementary data.

I SWEXFL — = 0 : no additional output file

= 1 : additional output file created containing soil-profile data

= 2 : additional **unformatted** output file created as input file for the water-quality model ANIMO

= 3 : Two additional output files created as input files for the water-quality model ANIMO:
i) **unformatted** ouput file created as input file.
ii) **formatted** (readable) output file created as input file.

Use this line if SWEXFL = 1, 2 or 3:

S OUTFILE1

If SWEXFL = 1; give name of additional output file containing soil profile data, (*Advised filename* = ********.**PRF**)
(see below for choice of soil profile data)
If SWEXFL = 2 or 3; give name of additional **unformatted** output file containing input data for ANIMO model,
(*Advised filename* = ********.**UNF**)
(see next page for type of output data)

Use max. 40 characters

Use this line **only** if SWEXFL = 3 :

S OUTFILE2

give name of additional **formatted** output file containing input data for ANIMO model, (*Advised filename* = ********.**FMT**)
(see next page for type of output data)
Use max. 40 characters

Use this line **only** if SWEXFL = 1 :

Make a choice of soil profile data to be written to the filename given in OUTFILE1 above.

Output per nodal point with interval OUTIVL (see GROUP 1.B) of :

I SWOUTP(1)

= 0 : no output
= 1 : output of the **volumetric soil moisture content** of the profile at the end of the interval

I SWOUTP(2)

as above, for the **pressure head** in the profile at the end of the interval

I SWOUTP(3)

as above, for the **hydraulic conductivity** of the profile at the end of the interval

I SWOUTP(4)

as above, for the **flux** through the compartments cumulated during the interval

I SWOUTP(5)

as above, for the **extracted volume** by the roots cumulated during the interval

I SWOUTP(6)

as above, for the **drainage fluxes** to each drainage medium cumulated during the interval

Note: **ponding** thickness, **groundwater level** and **perched water level** are always given

If **SWEXFL = 2** or **3**; then the following parameters are output to the ANIMO file(s):

Initial values :

**	YEAR	year when simulation starts (-)
**	YEAR	year when simulation ends (-)
	DAYSTA	day when simulation starts (d)
	DAYEND	day when simulation ends (d)
	OUTIVL	length of output interval (d)
**	NUMNOD	number of compartments (-)
	NUMLAY	number of different types of soil layers (-)
	NRLEVS	number of drainage levels (-)
**	BOTCOM()	bottom compartment of layer 1 to NUMLAY (-)
**	THETSN()	saturat. soil moisture fr. layer 1 to NUMLAY ($m^3 \cdot m^{-3}$)
**	THETPFF()	soil moisture cont. at pF 2.0 layer 1 to NUMLAY (-)
**	THETPFW()	soil moisture cont. at pF 4.2 layer 1 to NUMLAY (-)
**	DZ()	height of compartment 1 to NUMNOD (m)
**	THETA()	soil moisture cont. of compart. 1 to NUMNOD ($m^3 \cdot m^{-3}$)
**	GWL(3)	groundwater table (m below soil surface, positive)
	POND	initial ponding level (m)

At each interval :

**	T	day number of output (d)
	IPREC	average precipitation during interval ($m \cdot d^{-1}$)
	IINTC	average interception during interval ($m \cdot d^{-1}$)
	IEVAP	average evaporation during interval ($m \cdot d^{-1}$)
	IEPND	average ponding evap. during interval ($m \cdot d^{-1}$)
	IPEVA	aver. pot. evaporation during interval ($m \cdot d^{-1}$)
	IPTRA	aver. pot. transpiration during interval ($m \cdot d^{-1}$)
	IRUNO	average runoff during interval ($m \cdot d^{-1}$)
	GWL(3)	groundwater table at end of interval (m)
	POND	ponding level at end of interval (m)
**	H()	pressure head 1 to NUMNOD at end of interval (m), (negative when unsaturated)
**	THETA()	soil moisture cont. 1 to NUMNOD at end of interval (-)
**	INQROT()	average root extraction flux 1 to NUMNOD ($m \cdot d^{-1}$)
**	INQ()	average flux at the top of compartments 1 to NUMNOD+1 ($m \cdot d^{-1}$, positive = downwards). INQ(NUMNOD+1) represents seepage/drainage
**	INQDRA(1)	average flux of 1st drain level from compartment 1 to NUMNOD ($m \cdot d^{-1}$)
		vrepeatv
**	INQDRA(nrlevs)	average flux of level NRLEVS from compartment 1 to NUMNOD ($m \cdot d^{-1}$)

**indicates a new record (unformatted output). Formatted output uses the same order of data but more records.

Units and signs used for this output are **not** the same as units and signs used in SWAP 1993. Drainage fluxes are given for levels 1 to NRLEVS, if NRLEVS = 0 no fluxes are given. If there is no groundwater or perched water table a dummy value of -9.99 is given.

GROUP 1.D **use 2 lines**
LABEL ">fimeva:"

Describes the calculation period and size of time step.

I YEARST	starting year of calculations (-)
I YEAREN	finishing year of calculations (-)
I DAYSTA	starting day of calculations (Julian day number, January 1st = 1)
I DAYEND	finishing day of calculations (d)
R DTMIN	minimum value of time step allowed (d), this value may range from 1.0E-8 to 1.0E-5, we advise 1.0E-6
R DTMAX	maximum value of time step allowed (d), this value may range from 0.01 to 0.5, we advise 0.2
I SWNUMS	1 = implicit scheme with 1 (one) iteration 2 = implicit scheme with iteration till convergence is reached

---

Use this line if SWNUMS = 1 :

$$\Delta h_{tmax} = RELTOL\ |h| + ABSTOL$$

where: Δh_{tmax} = maximum pressure head change per timestep

R RELTOL	relative tolerance (-) to calculate Δh_{tmax}
R ABSTOL	absolute tolerance to calculate Δh_{tmax} (cm)

☞ Indicative values: RELTOL = 1.0E-2 and ABSTOL = 1.0

Use this line if SWNUMS = 2 :

$$\Delta h_{tmax} = RELTOL\ |h| + ABSTOL$$

where: Δh_{imax} = maximum pressure head change per iteration

R RELTOL	relative tolerance (-) to calculate Δh_{imax}
R ABSTOL	absolute tolerance to calculate Δh_{imax} (cm)

☞ Indicative values: RELTOL = 1.0E-3 and ABSTOL = 0.2

GROUP 1.E **use 1 line**
LABEL ">redeva:"

Choice of reduction of potential soil evaporation.

I SWREDU = 0 : no reduction

= 1 : reduction is calculated using the Black (1969) model

= 2 : reduction is calculated using the Boesten (1986) model

= 3 : reduction is calculated using an adapted Boesten model taking into account the actual moisture condition of soil surface

R COFRED coefficient α (Black, $cm \cdot d^{-1/2}$) or β (Boesten, $cm^{1/2}$)

- for α we advise to use 0.35 ± 0.15
  for β we advise to use 0.63 (range 0.54 - 0.95)
- if SWREDU = 0, a dummy value should be given for COFRED

GROUP 1.F **if SWIRRI = 0 use 1 line**
LABEL ">irriva:" **if SWIRRI = 1 use 2 lines**
if SWIRRI = 2 use 1 + 1 + NIRRIG lines

I SWIRRI = 0 : irrigation is not simulated

= 1 : time of irrigation is simulated

= 2 : time and amount of irrigation is given at prescribed days

---

Use this line if SWIRRI = 1 :

R IRRAMT(0) amount of each irrigation water application (cm)

R IRRCON(0) concentration of irrigation water ($mg \cdot cm^{-3}$)

I TLAGIR minimum time-lag between two successive applications (d)

R HCRIT critical pressure head value below which irrigation is applied (cm), (the irrigation criterium)

I NCRIT nodal point number where HCRIT applies (-), (see GROUP 1.P)

Use these lines if SWIRRI = 2 :

I NIRRIG — number of days that irrigation takes place

I IRRDAY(1) — first day at which irrigation takes place
R IRRAMT(1) — amount of irrigation water applied on this first day (cm)
R IRRCON(1) — concentration of irrigation water on this first day ($mg \cdot cm^{-3}$)

---

vrepeatv for each irrigation day (one data-pair per line)

I IRRDAY(NIRRIG) — last day at which irrigation takes place
R IRRAMT(NIRRIG) — amount of irrigation water applied on this last day (cm)
R IRRCON(NIRRIG) — concentration of irrigation water on this last day ($mg \cdot cm^{-3}$)

GROUP 1.G use 1 line
LABEL ">methdr:"

S HEADER — Description of the meteorological conditions. Will be printed in the output file (see GROUP 1.B) Use max. 40 characters

GROUP 1.H use 1 line
LABEL ">topbnd:"

Describes the upper boundary conditions.

I SWTOPB

= 0 : pot. evapotranspiration ($cm \cdot d^{-1}$) is entered as pot. soil evaporation and pot. transpiration (see Group 2.B)

= 1 : pot. evapotranspiration ($cm \cdot d^{-1}$) is entered as REFEVA (reference evapotranspiration) and then multiplied by a crop factor (see GROUP 3.H)
(for choice of REFEVA as E_{OPEN} or E_{MAK}, see GROUP 2.B)

= 2 : pot. evapotranspiration ($cm \cdot d^{-1}$) is calculated with the Priestly and Taylor equation (see GROUP 2.B)

= 3 : pot. evapotranspiration ($cm \cdot d^{-1}$) is calculated with the Penman equation (eq'n. 3.26) as E_{OPEN} (see GROUP 2.B) and then multiplied by a crop factor (see GROUP 3.H)

= 4 : pot. evapotranspiration ($cm \cdot d^{-1}$) is calculated with the Monteith-Rijtema equation (eq'n. 3.33) (see GROUP 2.B) Internal canopy resistance r_s is calculated from RSMIN, RSMAX and Ewet. (for RSMIN and RSMAX values see GROUP 1.M)

= 5 : pot. evapotranspiration ($cm \cdot d^{-1}$) is calculated with the Makkink equation as E_{MAK} (see GROUP 2.B) and then multiplied by a crop factor (see GROUP 3.H)

If SWTOPB = 2, 3, 4 or 5: potential soil evaporation is calculated with eq'n. 35 [Belmans et al. (1983)] and the minimum allowed pressure head at the soil surface is calculated according to eq'n. 4.11

☞ **To calculate crop production, SWTOPB should be 2, 3, 4 or 5.**

I SWTBVA = 0 : upper boundary condition is constant with time

= 1 : upper boundary condition is varying with time

GROUP 1.I use YEARST - YEAREN + 1 lines
LABEL ">metfil:"

SWAP 1993 gives the option to calculate for several successive years.
Give name(s) of the input file(s) containing the meteorological data.
See SECTION 2 for the input description of these files.
For each simulation year, give yearnumber and matching filename.

I yearst first year of calculation (see GROUP 1.D)

S METEOFL(yearst) give name of the input file containing the parameters describing the boundary conditions at the top of the soil profile (meteo data) for year YEARST. Use max. 40 characters

vrepeatv for each year of calculation

I yearen last year of calculation (see GROUP 1.D)

S METEOFL(yearen) give name of the input file containing the parameters describing the boundary conditions at the top of the soil profile for year YEAREN

☞ If 'SWAP93.INP' is given as file name, then the corresponding meteo input data can be added to the file SWAP93.INP

GROUP 1.J use 1 line
LABEL ">crphdr:"

S HEADER Description of the crop input data. Will be printed in the output file (see GROUP 1.B) Use max. 40 characters

GROUP 1.K **if SWUPFU = 0 use 1 line**
LABEL ">sinkva:" **if SWUPFU = 1 use 2 lines**
if SWUPFU = 2 use 1 line

Description of sink term and root extraction pattern.

I SWSINK
= 0 : sink term according to Feddes
See fig. 1 (appendix 1) and Feddes et al. (1978)
= 1 : sink term according to Hoogland
See fig. 2 (appendix 1) and Feddes et al. (1988b)

I SWHYPR
= 0 : linear relationship between the points HLIM3 and HLIM4 of the sink term. See fig. 3 (appendix 1)
= 1 : hyperbolic relationship between the points HLIM3 and HLIM4 of the sink term. See fig. 4 (appendix 1)

For values of HLIM3 and HLIM4 see GROUP 3.A

I SWUPFU
= 0 : water uptake function according to Feddes
See fig. 5 (appendix 1) and Feddes et al. (1988b)
= 1 : water uptake function according to Hoogland
See fig. 6 (appendix 1)
= 2 : water uptake function according to Prasad (1988)
See fig. 7 (appendix 1)

Use this line if SWUPFU = 1 :

R COFSZA intercept 'a' of eq'n. $S_{max} = a - b \cdot |z|$ [Feddes et al. 1988a]

R COFSZB slope 'b' of eq'n. $S_{max} = a - b \cdot |z|$ [Feddes et al. 1988a]

where: z = depth below soil surface (cm)

GROUP 1.L **use 1 line**
LABEL ">rootac:"

Nonactive layer of roots at the top of the profile.

R ZRONAM maximum thickness (cm, absolute value) of the nonactive layer during the period t > TRONAE

R TRONAB point of time (d) at which the nonactive layer starts, (drought damage or morphological reasons)

R TRONAE point of time (d) at which the nonactive layer reaches its maximum thickness

$$t \leq TRONAB \quad : ZRONA = 0$$
$$TRONAB < t \geq TRONAE \quad : ZRONA = ZRONAM * \frac{t - TRONAB}{TRONAE - TRONAB}$$
$$t > TRONAE \quad : ZRONA = ZRONAM$$

where: t = time (d)
ZRONA = actual thickness of the non-active layer (cm)

☞ to cancel this option: set ZRONAM = 0.0 and give dummy values for TRONAB and TRONAE

GROUP 1.M **used only if SWTOPB = 2 or 4** **(see GROUP 1.H)**
LABEL ">excons:" **use 1 line**

Constants used for calculating evapotranspiration.

Use this line if SWTOPB = 2 :

R ALPHA — empirical constant in Priestly and Taylor eq'n, (1.35 ± 0.10)

Use this line if SWTOPB = 4 :

R RSMIN — minimum canopy resistance ($s \cdot m^{-1}$) in Monteith-Rijtema eq'n

R RSMAX — maximum canopy resistance ($s \cdot m^{-1}$) in Monteith-Rijtema eq'n

GROUP 1.N **use YEARST - YEAREN + 1 lines**
LABEL ">crpfil:"

SWAP 1993 gives the option to calculate for several successive years.
Give name(s) of the input file(s) containing the crop data.
See SECTION 3 for the input description of these file(s).
For each simulation year, give yearnumber and matching filename.

I yearst — first year of calculation (see GROUP 1.D)

S CRPINPFL(yearst) — give name of the input file containing the crop data for year YEARST, Use max. 40 characters

vrepeatv for each year of calculation

I yearen — last year of calculation (see GROUP 1.D)

S CRPINPFL(yearen) — give name of the input file containing the crop data for year YEAREN

☞ If 'SWAP93.INP' is given as file name, then the corresponding crop input data can be added to the file SWAP93.INP

GROUP 1.O **if SWPROD = 0 use 1 line**
LABEL ">crppro:" **if SWPROD = 1 use 2 lines**

I SWPROD	= 0 : crop yield is not simulated = 1 : crop yield is simulated
	☛ To calculate crop yield SWTOPB should be 2, 3, 4 or 5 (see GROUP 1.H)

Use this line if SWPROD = 1 :

S CRPOUTFL	give name of the output file containing crop production terms, (*Advised filename* = ********.CRP) Use max. 40 characters

GROUP 1.P **use 1 line + max. 4 lines (assume 10 values/line)**
LABEL ">profil:"

Describes the geometry of the soil profile.

I NUMLAY	number of different types of soil layers (-) The maximum is 5
I NUMNOD	number of soil compartments (-) The maximum is 40
I BOTCOM(1)	compartment number at bottom of 1st soil layer (-)
	▽repeat▽ for each compartment
I BOTCOM(NUMLAY-1)	compartment number at bottom of soil layer NUMLAY-1 (-)
	☛ BOTCOM(NUMLAY) equals NUMNOD

Distribution of compartments over the soil profile.

R DZ(1)	thickness of 1st (top) compartment (cm)
	▽repeat▽ for each compartment
R DZ(NUMNOD)	thickness of deepest compartment (NUMNOD) (cm)
	☛ We advise to limit compartment thickness to a maximum of 25 cm (for unsaturated compartments)

GROUP 1.Q **use max. NUMLAY - lines**
LABEL ">soilfl:"

Input filename(s) containing the soil physical parameters.
See SECTION 4 for the input description of these files.

S SOILFL(1) give name of the file containing the soil physical parameters of the 1st soil layer, Use max. 40 characters.

vrepeatv for each soil layer

S SOILFL(NUMLAY) give name of the file containing the soil physical parameters of the deepest soil layer (NUMLAY)

☛ If 'SWAP93.INP' is given as file name, then the corresponding soil input data can be added to the file SWAP93.INP

GROUP 1.R **use 1 line**
LABEL ">pondmx:"

R PONDMX maximum thickness of ponding water layer on the soil surface (cm)

GROUP 1.S **if SWINCO = 0 use 1 + max. 4 lines (assume 10 values/line)**
LABEL ">incond:" **if SWINCO = 1 use 1 + max. 4 lines (assume 10 values/line)**
if SWINCO = 2 use 2 lines

Initial 'theta' or 'pressure head' condition for first day of calculation.

I SWINCO = 0 : volumetric soil moisture content ($cm^3 \cdot cm^{-3}$) at each nodal point input

= 1 : pressure head (cm) at each nodal point is input, (**unsaturated** = negative value)

= 2 : pressure head at each nodal point is calculated as equilibrium with the initial groundwater table depth

Use these lines if SWINCO = 0 :

Input of initial volum. soil moisture content profile (t = DAYSTA)

R THETA(1) initial volum. soil moisture content ($cm^3 \cdot cm^{-3}$) of 1st compartment (top compartment at the soil surface)

vrepeatv for each compartment

R THETA(NUMNOD) initial volum. soil moisture content of the NUMNODth compartment (deepest compartment at the bottom of the soil profile)

Use these lines if SWINCO = 1 :

Input of initial pressure-head profile (t = DAYSTA)

R H(1) initial pressure head (cm) of 1st compartment

vrepeatv for each compartment

R H(NUMNOD) initial pressure head of NUMNODth compartment

☛ pressure heads are negative in the unsaturated zone while in the saturated zone these values are positive and equal to the depth below groundwater level

---

Use this line if SWINCO = 2 :

Input of initial groundwater table depth. Absolute value may be given (soil surface is used as reference level)

R GWL initial groundwater table depth (cm)

☛ if SWBOTB = 0 (see GROUP 5.B) this line may be skipped

GROUP 1.T use 1 line
LABEL ">bbdfil:"

S BBOUNDFL Give name of the input file containing the parameters describing the boundary conditions at the bottom of the soil profile.
See SECTION 5 for the input description of this file.
Use max. 40 characters.

☛ If 'SWAP93.INP' is given as file name, then the corresponding bottom boundary input data can be added to the file SWAP93.INP

GROUP 1.U **if SWDRNS = 0 use 1 line**
LABEL ">drains:" **if SWDRNS = 1 use 2 lines**

I SWDRNS = 0 : no drainage or subsurface irrigation simulated
= 1 : drainage and/or subsurface irrigation simulated

Use this line if SWDRNS = 1 :

S DRAINFL Give name of the input file containing the parameters describing the boundary conditions at the lateral side of the soil profile: drainage.
See SECTION 6 for the input description of this file.
Use max. 40 characters.

☛ If 'SWAP93.INP' is given as file name, then the corresponding lateral boundary input data can be added to the file SWAP93.INP

GROUP 1.V **if SWSOLU = 0 use 1 line**
LABEL ">solute:" **if SWSOLU = 1 see ☛ note below**

I SWSOLU = 0 : no solute transport simulated
= 1 : solute transport is simulated

Use these lines if SWSOLU = 1:

S SOLUTEFL give name of general output file for solute transport
(*Advised filename* = ********.SLT)

R CPRE solute concentration in precipitation ($mg \cdot cm^{-3}$)

R CGRO solute concentration in groundwater ($mg \cdot cm^{-3}$)

R CML(1) initial solute concentration in 1st compartment ($mg \cdot cm^{-3}$)

vrepeatv for each compartment

R CML(NUMNOD) initial solute concentration in NUMNODth compartment ($mg \cdot cm^{-3}$)

☛ Comment lines should be placed between each variable sub-group These should contain the symbol names.

$$h_{osm} = OSMOTA + OSMOTB * CML$$

where: h_{osm} = osmotic head (cm)
CML = solute concentration of soil water in mobile volume ($mg \cdot cm^{-3}$)

R OSMOTA regression coefficient (cm)

R OSMOTB regression coefficient ($cm^4 \cdot mg^{-1}$)

$$H_t = h + REDOSM * h_{osm}$$

where: H_t = total head (cm) used to derive α reduction factor (see GROUP 1.K and figures 1 - 4 of appendix 1)

R REDOSM factor accounting for plant sensitivity to salinity

$$D_{dis+dif} = DDIF + LDIS * |v|$$

where: $D_{dis + dif}$ = dispersion coefficient ($cm^2 \cdot d^{-1}$)
$|v|$ = pore water velocity ($cm \cdot d^{-1}$)

R DDIF diffusion coefficient ($cm^2 \cdot d^{-1}$)

R LDIS dispersion length (cm)

$$Ru = TSCF * S * CML$$

where: Ru = solute uptake by plant roots ($mg \cdot cm^{-3} \cdot d^{-1}$)
S = root water extraction (d^{-1})

R TSCF root uptake concentration factor (-)

$$amount\ adsorbed = KF * C^{FREXP}$$

where: C = solute concentration of soil water ($mg \cdot cm^{-3}$)
C may be either mobile (CML) of immobile (CIL) volume

R KF Freundlich coefficient ($cm^{3/FREXP}\ mg^{-1/FREXP}$)

R FREXP Freundlich exponent (-)

R BDENS dry soil bulk density ($g \cdot cm^{-3}$)

R RER convergence criterium non-linear Freundlich adsorption (default 0.001)

$$FLUX_{mobile \Longrightarrow immobile} = KMOBIL * (CML - CIL)$$

where: CIL = solute concentration of soil water in immobile volume ($mg \cdot cm^{-3}$)

R KMOBIL exchange rate between mobile-immobile parts (d^{-1})

R DECPOT 1st order transform. rate (d^{-1}) in ploughlayer @ 20 °C and h = -100 cm

$$RED_{temp} = e^{(GAMPAR * (T_{soil} - 20))}$$

where: T_{soil} = soil temperature (°C)

R GAMPAR transformation reduction factor ($°C^{-1}$)

$$RED_{water} = \min[1, (\theta / RTHETA)^{BEXP}]$$

R RTHETA volumetric soil moisture content below which transformation rate is reduced ($cm^3 \cdot cm^{-3}$)

R BEXP exponent(-)

$$T_{soil} = TMEAN + TAMPLI\,[\sin(2\pi/365 * (t - TIMREF) - z/DDAMP)] * e^{(z/DDAMP)}$$

R TAMPLI amplitude of annual soil surface temperature wave (°C)

R TMEAN mean annual temperature (°C)

R DDAMP damping depth (cm)

R TIMREF starting time of temperature wave (d)

$$RED_{depth} = FDEPTH(LAY)$$

R FDEPTH(1) transformation reduction factor in 1st soil layer (-)

vrepeatv for each soil layer

R FDEPTH(NUMLAY) transformation reduction factor in deepest soil layer (NUMLAY)

☞ Actual transformation rate (d^{-1}) is calculated as :

$$DECACT = RED_{temp} * RED_{water} * RED_{depth} * DECPOT$$

GROUP 1.W **used only if SWPHYS = 1** **(see GROUP 4.B)**
LABEL ">mobile:" **if SWMOBL = 0 use 1 line**
if SWMOBL = 1 use 3 lines

Preferential paths for water and solute transport.

I SWMOBL = 0 : no preferential paths are assumed
= 1 : the soil profile contains preferential paths

Use this (these) line(s) if SWMOBL = 1 :

R FMOBIL(1) volume fraction of preferential paths in the 1st soil layer

vrepeatv for each soil layer

R FMOBIL(NUMLAY) volume fraction of preferential paths in the deepest soil layer (NUMLAY) (see GROUP 1.P)

Use this (these) line(s) if SWMOBL = 1 :

R THETIM(1) constant volumetric soil moisture content ($cm^3 \cdot cm^{-3}$) in immobile parts in the 1st soil layer

vrepeatv for each soil layer

R THETIM(NUMLAY) constant volumetric soil moisture content in immobile parts in the deepest soil layer (NUMLAY) (see GROUP 1.P)

GROUP 1.X **if SWANFL = 0 use 1 line**
LABEL ">anafil:" **if SWANFL = 1 use 2 lines**

Choice for additional output file containing water and solute data.

I SWANFL = 0 : no additional output file
= 1 : additional output file made

Use this line if SWANFL = 1:

S OUTFILE3 — give name of additional output file containing values at each nodal point (*Advised filename* = ********.OUT)

Information per nodal point:

theta	volumetric soil moisture content	($cm^3 \cdot cm^{-3}$)
h	pressure head	(cm)
cmsy	total conc. (solved and adsorbed) of mobile vol.	($mg \cdot cm^{-3}$)
cisy	total conc. (solved and adsorbed) of immobile vol.	($mg \cdot cm^{-3}$)
cml	solute conc. of soil water in mobile volume	($mg \cdot cm^{-3}$)
cil	solute conc. of soil water in immobile volume	($mg \cdot cm^{-3}$)
cl	average conc. of **cml** and **cil** weighted to **theta**	($mg \cdot cm^{-3}$)

use max. 40 characters.

GROUP 1.Y — if SWGRFL = 0 use 1 line
LABEL ">balance:" — if SWGRFL = 1 use 2 lines

Choice for additional output files for graphical package BALANCE

I SWGRFL
= 0 : no additional output files
= 1 : 5 additional output files generated for graphical package

---

Use this line if SWGRFL = 1 :

S REFERID — give an identificationstring which will be printed in each of the 5 additional BALANCE files generated by the model.
Use max. 40 characters.

The name given to these 5 files is: 'BALANCE' with the respective extensions: .GEN .MOI .RTS .SOL and .WB

☛ **if SWGRFL = 1 then OUTIVL must be 1 (see GROUP 1.B)**

SECTION 2. File describing input data for the upper boundary.

The name of this file should be specified in GROUP 1.I of file SWAP93.INP

In the labels of this section the simulation year (minus 1900) should be given instead of the question marks, e.g. for 1993 the label of GROUP 2.A becomes " >radi93: "

GROUP 2.A **used only if SWTOPB = 2, 3, 4 or 5** **(see GROUP 1.H)**
LABEL ">radi??:" **use 1 or 2 lines**

Determines: type of radiation as given in your input file (GROUP 1.I) and transformation factors needed to change type of radiation (if necessary)

I SWRADS
= 0 : type of radiation in your input file is global
= 1 : type of radiation in your input file is net

Use this line : if SWRADS = 0 and SWTOPB = 2 (GROUP 1.H)
or
if SWRADS = 0 and SWTOPB = 4 (GROUP 1.H)

Transformation factors to change global radiation (as given in your input file) to net radiation as requested (when SWTOPB = 2 or 4)

$$R_{NET} = (A * R_{GLOBAL}) + B \qquad (global \rightarrow net)$$

R COFNGA
coefficient A in above equation, $(1-\alpha)$
where: α = surface reflection coefficient (albedo) of short wave radiation (-)

R COFNGB
coefficient B in above equation, (R_t)
where: R_t = flux of net outgoing thermal or long wave radiation $(W \cdot m^{-2})$

☛ these factors vary for each crop.
☛ in case of **potatoes** we advise : COFNGA = 0.54
COFNGB = -4.0

NOTE ☛ if SWRADS = 0 and SWTOPB = 3 (GROUP 1.H):
the global to net transformation takes place within the Penman equation itself.

Use this line : if SWRADS = 1 and SWTOPB = 5 (GROUP 1.H)
or
if SWRADS = 1 and SWPROD = 1 (GROUP 1.O)

Transformation factors to change net radiation (as given in your input file) to global radiation.

$$R_{GLOBAL} = \frac{R_{NET} - B}{A} \qquad (net \blacktriangleright global)$$

R COFNGA — coefficient A in above equation, $(1-\alpha)$
where: α = surface reflection coefficient (albedo) of short wave radiation (-)

R COFNGB — coefficient B in above equation, (R_t)
where: R_t = flux of net outgoing thermal or long wave radiation $(W \cdot m^{-2})$

☛ these factors vary for each crop.
☛ in case of **potatoes** we advise : COFNGA = 0.54
COFNGB = -4.0

GROUP 2.B use 1 or max. 366 lines
LABEL ">metd??:"

Input of meteorological data to calculate potential evapotranspiration.

if SWTBVA = 0 (GROUP 1.H): 1 line required for **1st day of input**, the value of daynr is not significant

if SWTBVA = 1 (GROUP 1.H): 1 line required for **each day of input**, [DAYEND-DAYSTA + 1] lines

☛ first daynr ≤ DAYSTA and last daynr ≥ DAYEND
(see GROUP 1.D)

Use these lines if SWTOPB = 0 : (see GROUP 1.H)

Pot. evapotranspiration rate is entered as pot. soil evaporation and pot. transpiration.

I daynr	Julian day number (January 1st = 1)
R PREC(daynr)	precipitation ($cm \cdot d^{-1}$)
R PEVA(daynr)	potential soil evaporation rate ($cm \cdot d^{-1}$)
R PTRA(daynr)	potential transpiration rate ($cm \cdot d^{-1}$)

Use these lines if SWTOPB = 1 : (see GROUP 1.H)

Potential evapotranspiration rate ($cm \cdot d^{-1}$) entered as REFEVA (reference evapotranspiration) to be multiplied by crop factors. REFEVA may be entered as E_{OPEN} (Penman, open water evaporation) or as E_{MAK} (Makkink, reference crop evapotranspiration). Depending on choice of REFEVA you must choose the right crop factors as asked for in GROUP 3.H

I daynr	Julian day number (January 1st = 1)
R PREC(daynr)	precipitation ($cm \cdot d^{-1}$)
R REFEVA(daynr)	reference evapotranspiration rate ($cm \cdot d^{-1}$)

Use these lines if SWTOPB = 2 : (see GROUP 1.H)

Potential evapotranspiration rate ($cm \cdot d^{-1}$) calculated with the Priestly and Taylor equation.

I daynr	Julian day number (January 1st = 1)
R PREC(daynr)	precipitation ($cm \cdot d^{-1}$)
R RADIA(daynr)	net radiation flux ($W \cdot m^{-2}$) (see GROUP 2.A)
R TEM(daynr)	mean daily air temperature (°C)
R RH(daynr)	mean daily air humidity (-)

Use these lines if SWTOPB = 3 : (see GROUP 1.H)

Potential evapotranspiration rate ($cm \cdot d^{-1}$) calculated with the Penman equation as E_{OPEN} (open water evaporation) and to be multiplied by the crop factors you will choose in GROUP 3.H

I daynr — Julian day number (January 1st = 1)

R PREC(daynr) — precipitation ($cm \cdot d^{-1}$)

R RADIA(daynr) — net radiation flux ($W \cdot m^{-2}$) (see GROUP 2.A)

R TEM(daynr) — mean daily air temperature (°C)

R RH(daynr) — mean daily air humidity (-)

R U(daynr) — mean daily wind velocity at 2 m height ($m \cdot s^{-1}$)

R DEGCLD(daynr) — degree of cloudiness (-)

☞ if net radiation is given instead of global radiation (default) degree of cloudiness can be omitted.

Use these lines if SWTOPB = 4 : (see GROUP 1.H)

Potential evapotranspiration rate ($cm \cdot d^{-1}$) calculated with the Monteith-Rijtema equation.

I daynr — Julian day number (January 1st = 1)

R PREC(daynr) — precipitation ($cm \cdot d^{-1}$)

R RADIA(daynr) — net radiation flux ($W \cdot m^{-2}$) (see GROUP 2.A)

R TEM(daynr) — mean daily air temperature (°C)

R RH(daynr) — mean daily air humidity (-)

R U(daynr) — mean daily wind velocity at 2 m height ($m \cdot s^{-1}$)

	Use these lines if SWTOPB = 5 : (see GROUP 1.H)
	Potential evapotranspiration rate ($cm \cdot d^{-1}$) calculated with the Makkink equation as E_{MAK} (reference-crop evapotranspiration) and to be multiplied by the crop factors you will choose in GROUP 3.H
I daynr	Julian day number (January 1^{st} = 1)
R PREC(daynr)	precipitation ($cm \cdot d^{-1}$)
R RADIA(daynr)	global radiation flux ($W \cdot m^{-2}$) (see GROUP 2.A)
R TEM(daynr)	mean daily air temperature (°C)
R RH(daynr)	mean daily air humidity (-)

SECTION 3. File describing input data for crop parameters.

The name of this file should be specified in GROUP 1.N of file SWAP93.INP

In the labels of this section the simulation year (minus 1900) should be given instead of the question marks, e.g. for 1993 the label of GROUP 3.A becomes ">sink93:".

GROUP 3.A use 1 line
LABEL ">sink??:"

Limiting pressure head (matrix potential) values.

☛ if SWSINK = 0, (see GROUP 1.K and figure 1 (appendix)):
all values below must be given **except HLIM3** (give dummy)
☛ if SWSINK = 1, (see GROUP 1.K and figure 2 (appendix)):
all values below must be given **except HLIM3H and HLIM3L** (give dummy values)

R HLIM1 — pressure head value (cm) below which roots start to extract water from the soil (starting point)

R HLIM2U — pressure head value (cm) below which roots start to extract water **optimally** from the top soil layer

R HLIM2L — as above, but for all sub soil layers

R HLIM3H — pressure head value (cm) below which roots cannot extract water optimally any more, for a High pot. transpiration rate equal to 0.5 $cm \cdot d^{-1}$ (limiting point)

R HLIM3L — as above, but for Low pot. transpiration rate equal to 0.1 $cm \cdot d^{-1}$

R HLIM3 — pressure head value (cm) below which the roots cannot extract water optimally any more (limiting point)

R HLIM4 — pressure head value (cm) below which no water uptake by roots is possible (wilting point)

☛ If FWSINK = 0, an **intermediate** value $HLIM3^{inter}$ is calculated between HLIM3H and HLIM3L under following 3 conditions:

- if $0.1 \leq PTRAN \leq 0.5$ then $HLIM3^{inter}$ is calculated from linear interpolation between HLIM3H and HLIM3L, according to :

$$HLIM3^{inter} = HLIM3H + \frac{(0.5 - PTRAN)}{(0.5 - 0.1)} (HLIM3L - HLIM3H)$$

- if PTRAN < 0.1 $cm \cdot d^{-1}$ then $HLIM3^{inter}$ = HLIM3L
- if PTRAN > 0.5 $cm \cdot d^{-1}$ then $HLIM3^{inter}$ = HLIM3H

where: PTRAN = potential transpiration rate ($cm \cdot d^{-1}$)

GROUP 3.B **use 1 + max. 37 lines (10 data-pairs/line)**
LABEL "*root??:"

Describes the rooting depth.

I NUMLIN	number of lines containing the data-pair values. (a data-pair consists of: daynr - rooting depth)

I firstd	first day of calculation (DAYSTA) (see GROUP 1.D)
R DROOTZ(firstd)	depth of root zone (cm) at firstd
	vrepeatv
I lastd	last day of calculation (DAYEND) (see GROUP 1.D)
R DROOTZ(lastd)	depth of root zone (cm) at lastd

The data-pairs (daynr - rooting depth) may be given using intervals of one or more days.
If intervals of more than one day are used the values of DROOTZ for the intermediate days will be calculated by the program via linear interpolation.
If the value of DROOTZ is identical for two data-pairs, the rooting depth is constant for the intermediate days.
One line of data should contain at least 1 data-pair and a maximum of 10 data-pairs.

☛ **Every data-pair line must end with a slash (/)**

EXAMPLE:

```
1                                  ← no. of lines with data-pairs
120 10.  150 30.  250 30./         ← 3 data-pairs on one line
```

```
  ↑
data-pair
```

DROOTZ at daynr 120 is 10.0 cm	linear interpolation between day 120 and 150.
DROOTZ at daynr 150 is 30.0 cm	linear interpolation between day 150 and 250 (in this case a constant DROOTZ of 30.0 cm)
DROOTZ at daynr 250 is 30.0 cm	

☛ firstd ≤ DAYSTA and lastd ≥ DAYEND (see GROUP 1.D)

GROUP 3.C used only if SWTOPB = 4 (see GROUP 1H)
LABEL ">chwi??:" if SWCHFU = 0 use 1 line
if SWCHFU = 1 use 2 lines

Describes the coefficients of the crop height-wind function FUNCCH; used to calculate the aerodynamic resistance of a crop.

$$FUNCCH = COFCHA * CH^{COFCHB} \quad for\ CH \geq COFCHX$$
$$FUNCCH = COFCHC * CH^{COFCHD} \quad for\ CH < COFCHX$$
$$FUNCCH_{MAX} = COFCHM$$

where: CH = crop height

I SWCHFU

= 0 : 6 coefficients of the FUNCCH-function don't need to be given. They are the same as in fig. 30 and given here:

COFCHA	= 0.37E-7	COFCHB	= 0.238
COFCHC	= 0.164E-7	COFCHD	= 0.59
COFCHM	= 1.3E-7	COFCHX	= 20.0

= 1 : 6 coefficients of the FUNCCH-function must be prescribed in this GROUP.

Use this line if SWCHFU = 1 :

R COFCHA
R COFCHB
R COFCHC
R COFCHD
R COFCHM
R COFCHX

coefficients of the FUNCCH-function used to estimate potential evapotranspiration flux (see eqn's. 8.3 to 8.5)

GROUP 3.D used only if SWTOPB = 1, 2, 3, 4 or 5 (see GROUP 1H)
LABEL ">lasc??:" use 1 line

Describes the coefficients for the Leaf-Area-Index - Soil Cover function named: LAI(SC).

$$LAI = COFLSA * SC + COFLSB * SC^2 + COFLSC * SC^3$$

R COFLSA
R COFLSB
R COFLSC

coefficients of the leaf area index-soil cover function, for more detail see fig. 31 and equation 8.6

☛ this very important equation affects the partitioning of potential evapotranspiration into soil evaporation and plant transpiration. **The equation varies greatly for different crops.**

GROUP 3.E **used only if SWTOPB = 1, 2, 3, 4 or 5 (see GROUP 1.H)**
LABEL ">prin??:" **if SWPRFU = 0 use 1 line**
if SWPRFU = 1 use 2 lines

Describes coefficients for the precipitation - interception function INTC; where: SC = soil cover (-) and PREC = precip. ($cm \cdot d^{-1}$)

$$INTC = SC * COFIPA + PREC^{(COFIPB - COFIPC * (PREC - COFIPD))} \quad for \prec\preceq COFIPX$$
$$INTC = SC * COFIPE \quad for \prec\succ COFIPX$$

I SWPRFU
= 0 : 6 coefficients of the INTCEP-function are the same as in fig. 32 but transformed to $cm \cdot d^{-1}$:
COFIPA = 0.169; COFIPB = 0.516; COFIPC = 0.1787;
COFIPD = 0.0593; COFIPE = 0.19; COFIPX = 2.0

= 1 : 6 coefficients of the INTCEP-function must be prescribed below.

Use this line if SWPRFU = 1 :

R COFIPA
R COFIPB
R COFIPC
R COFIPD
R COFIPE
R COFIPX

coefficients of the INTCEP-function describing reduction in precipitation rate as caused by interception (see eqn's. 8.7 to 8.9)

GROUP 3.F **used only if SWPROD = 0 (see GROUP 1.O) and**
LABEL ">soco??:" **SWTOPB = 1, 2, 3, 4 or 5 (see GROUP 1.H)**
use 1 + max. 37 lines (10 data-pairs/line)

Describes the soil cover.

I NUMLIN
number of lines containing the data-pair values
(a data-pair consists of: daynr - soil cover)

I firstd
first day of calculation (DAYSTA)

R SC(firstd)
soil cover at firstd (-)
▽repeat▽

I lastd
last day of calculation (DAYEND)

R SC(lastd)
soil cover at lastd (-)

For explanation of the input format see GROUP 3.B
☛ Every data-pair line must end with a slash (/)
☛ firstd ≤ DAYSTA and lastd ≥ DAYEND (see GROUP 1.D)

GROUP 3.G **used only if SWTOPB = 4** **(see GROUP 1.H)**
LABEL ">crhe??:" **use 1 + max. 37 lines (10 data-pairs/line)**

Describes the crop height.

I NUMLIN — number of lines containing the data-pair values,
(a data-pair consists of: daynr - crop height)

I firstd — first day of calculation (DAYSTA)

R CROPHT(firstd) — crop height at firstd (cm)

vrepeat v

I lastd — last day of calculation (DAYEND)

R CROPHT(lastd) — crop height at lastd (cm)

For explanation of the input format see GROUP 3.B

- Every data-pair line must end with a slash (/)
- firstd ≤ DAYSTA and lastd ≥ DAYEND (see GROUP 1.D)

GROUP 3.H **used only if SWTOPB = 1, 3 or 5** **(see GROUP 1.H)**
LABEL ">crfa??:" **use 1 + max. 37 lines (10 data-pairs/line)**

Describes the crop factors used.

I NUMLIN — number of lines containing the data-pair values,
(a data-pair consists of: daynr - crop factor)

I firstd — first day of calculation (DAYSTA)

R CRPFAC(firstd) — crop factor (-) at firstd

vrepeat v

I lastd — last day of calculation (DAYEND)

R CRPFAC(lastd) — crop factor (-) at lastd

If SWTOPB = 1 (GROUP 1.H) and REFEVA = E_{OPEN} (GROUP 2.B) use Penman crop factors.
If SWTOPB = 1 (GROUP 1.H) and REFEVA = E_{MAK} (GROUP 2.B) use Makkink crop factors.
If SWTOPB = 3 (GROUP 1.H and 2.B) use Penman crop factors
If SWTOPB = 5 (GROUP 1.H and 2.B) use Makkink crop factors

For explanation of the input format see Group 3.B

- Every data-pair line must end with a slash (/)
- firstd ≤ DAYSTA and lastd ≥ DAYEND (see Group 1.D)

GROUP 3.1 used only if SWPROD = 1 (see GROUP LO)
LABEL ">grow??:" use 1 line

R	TCROPS	time (d) at which crop starts growing (emergence date or after)
R	TCROPE	time (d) at which crop stops growing (harvest date)
R	PINIT	dry matter weight of crop ($kg \cdot ha^{-1}$) at TCROPS

GROUP 3.J used only if SWPROD = 1 (see GROUP LO)
LABEL ">grfu??:" use 4 lines

Description of: i) SC - development stage function and ii) partitioning to tubers - development stage function. These two function are only valid for tubercrops (potatoes, beets). See [Feddes et al. (1988a)].

R	FSX(1)	1st	values of DEVELOPMENT STAGE in SC(DVS) function
R	FSX(2)	2nd	(values must range between 0.0 and 1.0 in
R	FSX(3)	3rd	ascending order)
R	FSX(4)	4th	first value must be 0.0, last value must be 1.0
R	FSX(5)	5th	
R	FSX(6)	6th	

R	FSY(1)	1st	values of SOIL COVER in SC(DVS) function
R	FSY(2)	2nd	corresponding to the FSX-values (see above)
R	FSY(3)	3rd	Values must range between 0.0 and 1.0
R	FSY(4)	4th	
R	FSY(5)	5th	
R	FSY(6)	6th	

R	FTX(1)	1st	values of DEVELOPMENT STAGE in FTUBER(DVS)
R	FTX(2)	2nd	function
R	FTX(3)	3rd	Values must range between 0.0 and 1.0 in ascending order
R	FTX(4)	4th	First value must be 0.0, last value must be 1.0
R	FTX(5)	5th	
R	FTX(6)	6th	

R	FTY(1)	1st	values of FTUBER (fraction of production going to
R	FTY(2)	2nd	tuber) in FTUBER(DVS) function corresponding to
R	FTY(3)	3rd	the FTX-values (see above)
R	FTY(4)	4th	Values must range between 0.0 and 1.0
R	FTY(5)	5th	
R	FTY(6)	6th	

☞ Intermediate SOIL COVER (FSY) and FTUBER (FTY) -values will be interpolated

GROUP 3.K **used only if SWPROD = 1** **(see GROUP 1.O)**
LABEL ">grco??:" **use 1 line**

R	WUSEFF	maximum water use efficiency ($kg \cdot mbar \cdot ha^{-1} \cdot cm$)
R	CONFAC	conversion factor (sugars into starch) to account for growth respiration (-)
R	MATHFL	mathematical flexibility factor (eq'n. 5.18) We advise a value of 0.01

For more details see [Feddes et al. (1988a)]

SECTION 4. File(s) describing input data for soil physical parameters.

The name(s) of the file(s) should be specified in GROUP 1.Q of file SWAP93.INP

In the labels of this section the number of the soil layer should be given instead of the question mark, e.g. for layer 1 the label becomes ">solhd1:".

GROUP 4.A **use 1 line**
LABEL ">solhd?:"

S HEADER — Description of soil type. Will be printed in the output file (see GROUP 1.B) Use max. 40 characters.

GROUP 4.B **use 1 line**
LABEL ">metho?:"

Selects which method is applied to describe the soil-physical relationships of the soil layer(s)

I SWPHYS — = 0 : the h(θ) and K(h) relation is described in **table format**

= 1 : the h(θ) and K(h) relation is described as **Van Genuchten parameters** [see Van Genuchten, 1980]

GROUP 4.C **if SWPHYS = 0 use 1 + max. 100 lines** **(see GROUP 4.B)**
LABEL ">soild?:" **if SWPHYS = 1 use 1 line**

Use this line if SWPHYS = 0 :

R THETHI — saturated volumetric soil moisture content, θ_s ($cm^3 \cdot cm^{-3}$)

Use these lines if SWPHYS = 0 :

R thet — volumetric soil moisture content value ($cm^3 \cdot cm^{-3}$)

R HTABLE(thet) — pressure head corresponding to **thet** (cm, **negative**)

R KTABLE(thet) — hydraulic conductivity corresponding to **thet** ($cm \cdot d^{-1}$)

☞ **This line should be repeated starting from a low value of thet up to saturation (THETHI) with increments of 0.01.** The lowest starting value of **thet** allowed is 0.01 while the highest value of **thet** should equal THETHI.

☞ Value of pressure head (**corresponding to lowest thet**) must be between -1.0E8 and -1.0E6 for the top layer. Highest value of pressure head (**corresponding to THETHI**) = 0

Use this line if SWPHYS = 1 :

Input of soil moisture retention curve and the hydraulic conductivity as described by Van Genuchten.

R COFGEN(1) residual volumetric soil moisture content, θ_r ($cm^3 \cdot cm^{-3}$)

R COFGEN(2) saturated volumetric soil moisture content, θ_s ($cm^3 \cdot cm^{-3}$)

R COFGEN(3) saturated hydraulic conductivity, K_s ($cm \cdot d^{-1}$)

R COFGEN(4) fitting parameter α_d (**drying** curve) (cm^{-1})

R COFGEN(5) fitting parameter L (-)

R COFGEN(6) fitting parameter n (-)

R COFGEN(7) fitting parameter α_w (**wetting** curve) (cm^{-1})

☛ **if no hysteresis is considered: set COFGEN(7) = 0**

GROUP 4.D used only if COFGEN(7) is greater than 0 (see GROUP 4.C)
LABEL ">hyster:" if SWCURV = -1 use 2 lines
if SWCURV = 1 use 2 lines

Hysteresis in the retention function.

I SWCURV = -1 hysteresis is considered at the initial stage, equilibrium with the **main drying curve** is assumed

= 1 hysteresis is considered at the initial stage, equilibrium with the **main wetting curve** is assumed

R TAU minimal change of pressure head (h) during a timestep which triggers a reversal in the hysteresis scanning curves (cm); default TAU = 0.2 cm

SECTION 5. File describing input data for the lower boundary.

The name of this file should be specified in GROUP 1.T of file SWAP93.INP

GROUP 5.A use 1 line
LABEL ">bothdr:"

S HEADER — Description of the bottom boundary conditions. Will be printed in the output file (see GROUP 1.B) Use max. 40 characters.

GROUP 5.B use 1 line
LABEL ">swbotb:"

Choosing type of lower boundary conditions.

I SWBOTB

= 0 : daily groundwater tabel depth (cm) is input (see GROUP 5.C)

= 1 : flux ($cm \cdot d^{-1}$) from saturated zone is input (see GROUP 5.D)

= 2 : flux ($cm \cdot d^{-1}$) from deep aquifer is calculated (see GROUP 5.E)

= 3 : flux ($cm \cdot d^{-1}$) from the saturated zone is calculated as a function of groundwater table depth (see GROUP 5.F)

= 4 : press. head (cm) at bottom compart. is input (see GROUP 5.G)

= 5 : zero flux at the bottom of the profile

= 6 : free drainage at the bottom of the profile, flux ($cm \cdot d^{-1}$) equals hydraulic conductivity of bottom compartment

GROUP 5.C **used only if SWBOTB = 0** **(see GROUP 5.B)**
LABEL ">daygwl:" **use 1 + max. 37 lines (10 data-pairs/line)**

Input of daily groundwater tabel depth.

I NUMLIN — number of lines containing the data-pair values,
(a data-pair consists of: daynr - groundwater level)

I firstd — first day of calculation (DAYSTA)

R GW(firstd) — groundwater level (cm, negative, absolute value may be given) at the beginning of firstd

vrepeatv

I lastd — last day of calculation (DAYEND)

R GW(lastd) — groundwater level (cm, negative) at the beginning of lastd

For explanation of the input format see GROUP 3.B

- ☛ Every data-pair line must end with a slash (/)
- ☛ firstd ≤ DAYSTA and lastd ≥ DAYEND (see GROUP 1.D)

GROUP 5.D **used only if SWBOTB = 1** **(see GROUP 5.B)**
LABEL ">dayflx:" **use 1 + max. 37 lines (10 data-pairs/line)**

Input of daily flux values from the saturated zone
(positive = upwards, $cm \cdot d^{-1}$)

I NUMLIN — number of lines containing the data-pair values.
(a data-pair consists of: daynr - flux)

I firstd — first day of calculation (DAYSTA)

R QBOTOM(firstd) — flux from the saturated zone (cm) at the beginning of firstd

vrepeatv

I lastd — last day of calculation (DAYEND)

R QBOTOM(lastd) — flux from the saturated zone (cm) at the beginning of lastd

For explanation of the input format see GROUP 3.B

- ☛ Every data-pair line must end with a slash (/)
- ☛ firstd ≤ DAYSTA and lastd ≥ DAYEND (see GROUP 1.D)

GROUP 5.E **used only if SWBOTB = 2** **(see GROUP 5.B)**
LABEL ">semipl:" **use 2 lines**

Describes infiltration to / seepage from the deep aquifer (the soil surface is **always** used as reference level for water table and pressure-head values).

R SHAPE — shape factor of groundwater table (reduction coefficient)

SHAPE: the shape of the groundwater table in between the drains. Possible values are :
0.66 (parabolic); 0.64 (sinusoidal);
0.79 (elliptic); 1.00 (no drains present, see GROUP 1.U)

R RIMLAY — vertical resistance of semi-permeable layer (d)

R AQAVE — average distance between water level in piezometer (located in deep aquifer) and soil surface (negative when water level is below the soil surface) (cm)

R AQAMP — amplitude of sine function (cm)
(= maximum deviation from the average water level)

R AQTAMX — first time the water level reaches its highest position (d)

R AQPER — nr. of days between highest positions (period of sine-function) (d)

☞ If the water level of the deep aquifer remains constant at AQAVE cm, the latter 3 variables of this line should be set to zero

GROUP 5.F **used only if SWBOTB = 3** **(see GROUP 5.B)**
LABEL ">flgwfu:" **use 1 line**

Describes the flux - groundwater table relationship according to :

$$q = COFQHA * e^{(COFQHB * |\phi|)}$$

R COFQHA — value of COFQHA in above equation

R COFQHB — value of COFQHB in above equation

where:
q = basic discharge ($cm \cdot d^{-1}$)
$|\phi|$ = the groundwater level (cm, absolute value)
COFQHA and COFQHB are parameters to be determined from fig. 8 on appendix 1 or to be derived from measurements.

GROUP 5.G **used only if SWBOTB = 4** **(see GROUP 5.B)**
LABEL ">dayprh:" **use 1 + max. 37 lines (10 data-pairs/line)**

Input of daily values of pressure head at bottom compartment.

I NUMLIN	number of lines containing the data-pair values, (a data-pair consists of: daynr - pressure head)

I firstd	first day of calculation (DAYSTA)
R HGIVEN(firstd)	pressure head at bottom compartment (cm) at the beginning of firstd
	vrepeatv
I lastd	last day of calculation (DAYEND)
R HGIVEN(lastd)	pressure head at bottom compartment (cm) at the beginning of lastd

For explanation of the input format see GROUP 3.B

- ☛ Every data-pair line must end with a slash (/)
- ☛ firstd ≤ DAYSTA and lastd ≥ DAYEND (see GROUP 1.D)

SECTION 6. File describing input data for drainage/subirrigation.

This section can be skipped if SWDRNS = 0 (see GROUP 1.U)
The name of this file should be specified in GROUP 1.U of file SWAP93.INP

WARNING: *Please note that although the model offers the option to choose more than one (1) drainage level, the manner in which drainage is currently described needs to be verified and further tested.*
We strongly advise you to use 1 drainage level only.

GROUP 6.A use 1 line
LABEL ">lathdr:"

S HEADER — Description of the lateral boundary conditions. Will be printed in the output file (see GROUP 1.B) Use max. 40 characters.

GROUP 6.B use 2 lines
LABEL ">dgener:"

I NRLEVS — number of drainage levels to be considered.

☛ the maximum of NRLEVS is 4; 1st order : channel
2nd order : ditch
3rd order : trench/drain
4th order : trench/drain

R BASEGW(1) — depth of semi-impermeable layer (m) (negative)

☛ This layer is located **below** the defined profile (base of the aquifer)

R COFANI(1) — an-isotropic factor for 1st soil layer; horizontal saturated conductivity divided by vertical saturated conductivity; k_h/k_v

vrepeatv for each soil layer

R COFANI(NUMLAY) — an-isotropic factor for the deepest soil layer (NUMLAY) (GROUP 1.P)

Common values for this factor are between 3 and 10
If COFANI is unknown use a value of 1. (layer is isotropic)

GROUP 6.C use NRLEVS lines (see GROUP 6.B)
LABEL '>drchar:'

Specifies parameters for the drainage calculation.
Repeat this GROUP for all drainage levels NRLEVS.

I level — drainage level

R L(level) — spacing between drainage mediums (channel / ditch / trench / pipe drain) (m)

R ZBOTDR(level) — depth of bottom of drainage medium (cm) (negative)

R WETPER(level) — wet perimeter of the drainage medium (cm)
The wet perimeter u should be calculated according to:

$$u = b + 2y\sqrt{s^2+1} \qquad \textit{for channel, ditch, trench}$$
$$u = b + 2R_o \qquad \textit{for pipe drain}$$

where: b = bottom width of drainage medium or width of drain trench (cm)
y = average water depth in channel (cm)
s = side slope of channel; $\Delta h/\Delta v$ (-)
R_o = outer radius of the pipe drain (cm)

☛ If the water depth in the channel = 0 use u = b.

I SWDTYP(level)
= 0 : drainage medium is either channel/ditch/trench
= 1 : drainage medium is pipe drain only

I SWALLO(level)
= 0 : drainage and infiltration both allowed
= 1 : drainage not allowed
= 2 : infiltration not allowed

GROUP 6.D **if SWWLEV(level) = 0 use 2 + max. 37 lines (assume 10 values/line)**
LABEL ">level?:" **if SWWLEV(level) = 1 use 2 lines**

Open water level in the drainage mediums (channel/ditch/trench);
open water level is taken at ZBOTDR(level) (GROUP 6.C)

☛ **Repeat this GROUP for all drainage levels NRLEVS except if SWDTYP(level) = 1 (GROUP 6.C); then skip this GROUP**

I SWWLEV(level) = 0 : open water level in channel/ditch/trench is input
= 1 : open water level in channel/ditch/trench calc. as sinusoidal funct.

Use this line if SWWLEV(level) = 0 :

I NUMLIN number of lines containing the data-pair values,
(a data-pair consists of: daynr - open water level)

Use these lines if SWWLEV(level) = 0 :

I firstd first day of calculation (DAYSTA)

R DRAIN(firstd,level) open water level on 1st day of input (cm)
(below the top of the soil profile)

vrepeatv

I lastd last day of calculation (DAYEND)

R DRAIN(lastd,level) open water level on last day of input (cm)

For explanation of the input format see GROUP 3.B

☛ Every data-pair line must end with a slash (/)
☛ water levels may be given as absolute value
☛ firstd ≤ DAYSTA and lastd ≥ DAYEND (see GROUP 1.D)

Use this line if SWWLEV(level) = 1 :

R AVELEV(level) average water level in the channel/ditch/trench (cm) (negative)

R DRNAMP(level) amplitude of sine function (cm)
(= maximum deviation from the average level)

R TAMMAX(level) 1st time water level in drainage medium reaches highest position (d)

R PERIOD(level) nr. of days between highest positions (period of sine-function) (d)

References.

Belmans, C., J.G. Wesseling and R.A. Feddes, 1983. *Simulation model of the water balance of a cropped soil: SWATRE.* Journal of Hydrology, 63 (1983) 3/4: 271-286.

Black, T.A., W.R. Gardner and G.W. Thurtell, 1969. *The prediction of evaporation, drainage, and soil water storage for a bare soil.* Soil Science Society of America Journal 33: 655-660.

Boesten, J.J.T.I. and L. Stroosnijder, 1986. *Simple model for daily evaporation from fallow tilled soil under spring conditions in a temperate climate.* Netherlands Journal of Agricultural Science 34: 75-90.

Boesten, J.J.T.I. and A.M.A. van der Linden, 1991. *Modeling the influence of sorption and trans -formation on pesticide leaching and persistence.* Journal of Environmental Quality 20: 425-435.

Celia, M.A., E.T. Bouloutas and R.L. Zarba, 1990. *A general mass conservative solution for the unsaturated flow equation.* Water Resources Research 26: 1483-1496.

De Jong, R. and P. Kabat, 1990. *Modeling water balance and grass production.* Soil Science Society of America Journal 54: 1725-1732.

Feddes, R.A., P.J. Kowalik and H. Zaradny, 1978. *Simulation of field water use and crop yield.* Simulation Monographs, 189 pp, PUDOC, Wageningen, The Netherlands, isbn 90-220-067-x.

Feddes, R.A., M. de Graaf, J. Bouma, and C.D. van Loon, 1988a. *Simulation of water use and production of potatoes as affected by soil compaction.* Potato Research 31: 225-239.

Feddes, R.A., P. Kabat, P.J.T. van Bakel, J.J.B. Bronswijk and J. Halbertsma, 1988b. *Modelling soil water dynamics in the unsaturated zone - state of the art.* Journal of Hydrology, 100 (1988): 69-111.

Kabat, P., B.J. van den Broek and R.A. Feddes, 1992. *SWACROP: a water management and crop production simulation model.* In: (L.S. Pereira, A. Perrier, M. Ait Kadi and P. Kabat (Eds.) Special issue on Crop-Water Models. ICID Bulletin 41 (2): 61-84.

Kool, J.B. and J.C. Parker, 1987. *Development and evaluation of closed form expressions for hysteretic soil hydraulic properties.* Water Resources Research 23: 105-114.

Penman, H.L., 1948. *Natural evaporation from open water, bare soil and grass.* Proc. Roy. Soc. London A 193: 120-145.

Prasad, R., 1988. *A linear root water uptake model.* Journal of Hydrology 99: 297-306.

Ragab, R., F. Beese and W. Ehlers, 1990a. *A soil water balance and dry matter production model: I. Soil water balance of oat.* Agronomy Journal 82: 152-156.

Ragab, R., F. Beese and W. Ehlers, 1990b. *A soil water balance and dry matter production model: II. Dry matter production of oat.* Agronomy Journal 82: 157-161.

Van Dam, J.C., J.M.H. Hendrickx, H.C. van Ommen, M.H. Bannink, M.Th. van Genuchten and L.W. Dekker, 1990. *Water and solute movement in a coarse-textured water-repellent field soil.* Journal of Hydrology 120: 359-379.

Van Genuchten, M.Th. and D.R. Nielsen, 1985. *On describing and predicting the hydraulic properties of unsaturated soils.* Annales Geophysicae 3(5): 615-628.

Wesseling, J.G., J.A. Elbers, P. Kabat and B.J. van den Broek, 1991. SWATRE december 1991. *Instructions for input.* Internal note, Winand Staring Centre, Wageningen, The Netherlands.

Zepp, H. and A. Beltz, 1992. *Sensitivity and problems in modelling soil moisture conditions.* Journal of Hydrology 131: 227-238.

Appendix 1. Figures.

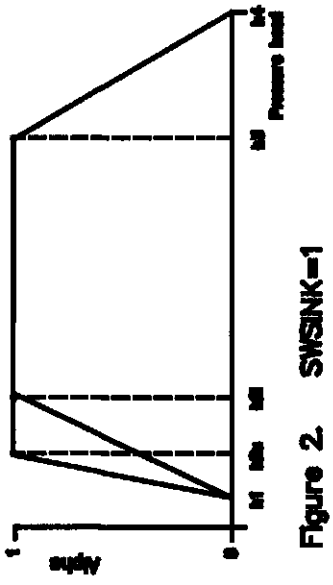

Figure 2. SWSINK=1

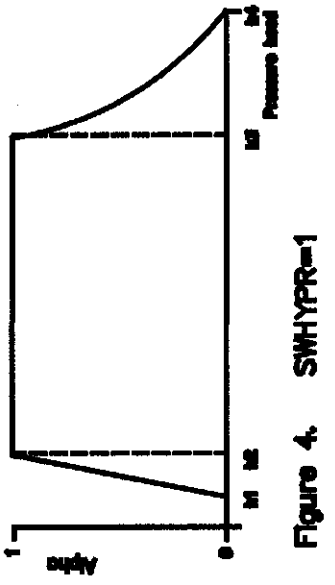

Figure 4. SWHYPR=1

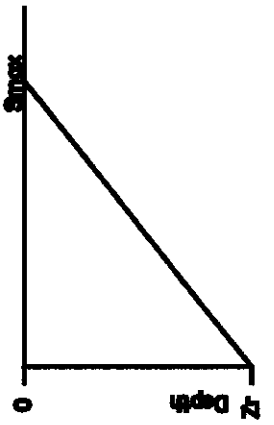

Figure 7. SWUPFU=2

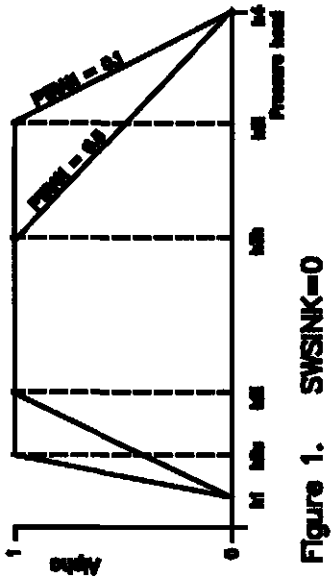

Figure 1. SWSINK=0

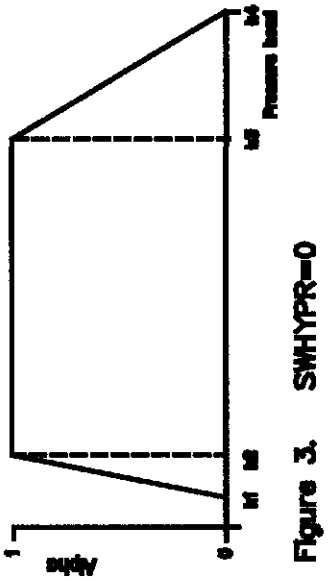

Figure 3. SWHYPR=0

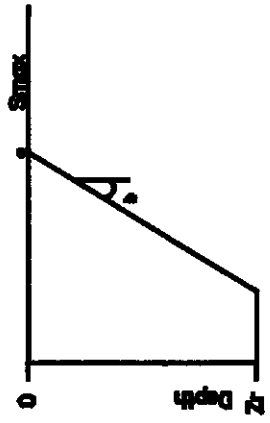

Figure 6. SWUPFU=1

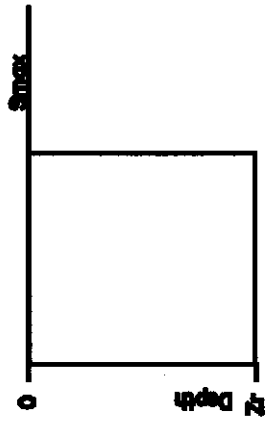

Figure 5. SWUPFU=0

Appendix 2. Alphabetical list of labels and corresponding groups.

label	group
>anafil:	1.X
>balance:	1.Y
>bbdfil:	1.T
>bothdr:	5.A
>chwi??:	3.C
>crhe??:	3.G
>crfa??:	3.H
>crpfil:	1.N
>crphdr:	1.J
>crppro:	1.O
>dayflx:	5.D
>daygwl:	5.C
>dayprh:	5.G
>dgener:	6.B
>drains:	1.U
>drchar:	6.C
>excons:	1.M
>exfile:	1.C
>flgwfu:	5.F
>genhdr:	1.A
>grco??:	3.K
>grow??:	3.I
>grfu??:	3.J
>hyster:	4.D
>incond:	1.S
>irriva:	1.F
>lasc??:	3.D
>lathdr:	6.A
>level?:	6.D
>metd??:	2.B
>metfil:	1.I
>methdr:	1.G
>metho?:	4.B
>mobile:	1.W
>output:	1.B
>pondmx:	1.R
>prin??:	3.E
>profil:	1.P

label	group
>radi??:	2.A
>redeva:	1.E
>rootac:	1.L
>root??:	3.B
>semipl:	5.E
>sink??:	3.A
>sinkva:	1.K
>soco??:	3.F
>soild?:	4.C
>soilfl:	1.Q
>solhd?:	4.A
>solute:	1.V
>swbotb:	5.B
>timeva:	1.D
>topbnd:	1.H

Appendix 3. Alphabetical list of variable names and description.

variable	description	type	units
A			
ALPHA	empirical constant of Priestly-Taylor equation	R	-
AQAMP	amplitude of piezometric level in deep aquifer	R	cm
AQAVE	average piezometric level in deep aquifer	R	-
AQOMEG	periodic frequency of level in deep aquifer	R	$rad \cdot d^{-1}$
AQPER	period of sinusoidal piezometric level in aquifer	R	d
AQTAMX	first day with piezometric level in aquifer at a max.	R	d
ATMPOT	potential evapotranspiration (atmospheric demand)	R	$cm \cdot d^{-1}$
AVELEV[5]	average water level of each drainage system	R	cm
B			
BASEGW[2]	depth of base of (perched) water table	R	cm
BDENS	dry soil bulk density	R	$g \cdot cm^{-3}$
BELL	ASCII character 7	S	-
BEXP	exponent in reduction transformation due to dryness	R	-
BOTCOM[5]	bottom compartment of each layer	I	-
C			
CEPND	cumulative evaporation of ponding layer	R	cm
CEVAP	cumulative actual soil evaporation	R	cm
CGRO	solute concentration in groundwater	R	$mg \cdot cm^{-3}$
CIL[40]	solute conc. in soil water in immobile volume	R	$mg \cdot cm^{-3}$
CINTC	cumulative actual interception by leaves	R	cm
CISY[40]	total conc. (solved + adsorbed) in immobile volume	R	$mg \cdot cm^{-3}$
CL[40]	average conc. of 'CML' and 'CIL' weighted to THETA	R	$mg \cdot cm^{-3}$
CML[40]	solute conc. in soil water in mobile volume	R	$mg \cdot cm^{-3}$
CMSY[40]	total conc. (solved + adsorbed) in mobile volume	R	$mg \cdot cm^{-3}$
COBPPL	compartment at bottom of poorly permeable layer	I	-
COFANI[5]	an-isotropic factor for each soil layer	R	-
COFCHA	coeff. a of crop-height function 'FUNCCH'	R	-
COFCHB	coeff. b of crop-height function 'FUNCCH'	R	-
COFCHC	coeff. c of crop-height function 'FUNCCH'	R	-
COFCHD	coeff. d of crop-height function 'FUNCCH'	R	-
COFCHM	maximum value of 'FUNCCH'	R	-
COFCHX	breakpoint of 'FUNCCH'	R	-
COFGEN[7,5]	i_{th} coefficient (i=1-7) of Van Genuchten equation for layer j (j=1-5)	R	-

COFIPA	coefficient a of INTCEP('PREC') function	R	-
COFIPB	coefficient b of INTCEP('PREC') function	R	-
COFIPC	coefficient c of INTCEP('PREC') function	R	-
COFIPD	coefficient d of INTCEP('PREC') function	R	-
COFIPE	coefficient e of INTCEP('PREC') function	R	-
COFIPX	breakpoint of INTCEP('PREC') function	R	-
COFLSA	coefficient a of 'LAI'('SC') function	R	-
COFLSB	coefficient b of 'LAI'('SC') function	R	-
COFLSC	coefficient c of 'LAI'('SC') function	R	-
COFNGA	coefficient a for transformation of radiation	R	-
COFNGB	coefficient b for transformation of radiation	R	-
COFPCA	coeff. a of gross photosynthetic funct. on a clear day	R	-
COFPCB	coeff. b of gross photosynthetic funct. on a clear day	R	-
COFPCC	coeff. c of gross photosynthetic funct. on a clear day	R	-
COFPOA	coeff. a of gross photosynthetic funct. on overcast day	R	-
COFPOB	coeff. b of gross photosynthetic funct. on overcast day	R	-
COFPOC	coeff. c of gross photosynthetic funct. on overcast day	R	-
COFQHA	coefficient a of q(h)-relation	R	$cm \cdot d^{-1}$
COFQHB	coefficient b of q(h)-relation	R	-
COFRCA	coefficient a of solar radiation flux for photosynthesis	R	-
COFRCB	coefficient b of solar radiation flux for photosynthesis	R	-
COFRCC	coefficient c of solar radiation flux for photosynthesis	R	-
COFRED	coefficient α or β used in reduction of soil evaporation	R	$cm \cdot d^{-½}$ or $cm^{½}$
COFSZA	coefficient a of S(z)-relation (Hoogland)	R	$cm \cdot d^{-1}$
COFSZB	coefficient b of S(z)-relation (Hoogland)	R	d^{-1}
CONFAC	conversion factor (sugars into starch)	R	-
COTPPL	compartment at top of poorly permeable layer	I	-
CPEVA	cumulative potential soil evaporation	R	cm
CPRE	solute concentration in precipitation	R	$mg \cdot cm^{-3}$
CPREC	cumulative precipitation	R	cm
CPTRA	cumulative potential transpiration	R	cm
CQBOT	cumulative flux through bottom of profile	R	cm
CQDRA	cumulative total drainage flux	R	cm
CQROT	cumulative root water uptake	R	cm
CQTOP	cumulative flux through top of profile	R	cm
CROPHT[366]	crop height for each day	R	cm
CRPFAC[366]	crop factor for each day	R	-
CRUNO	cumulative surface runoff	R	cm

D

DAYIRL	day at which last irrigation took place	R	d
DAYNR	day on which calculations are performed	R	d
DAYSTA	first day of calculation	I	d
DAYEND	last day of calculation	I	d
DDAMP	damping depth of soil temperature wave	R	cm
DDIF	diffusion coefficient	R	$cm^2 \cdot d^{-1}$
DECPOT	potential transformation rate in plough layer	R	d^{-1}
DEEPGW	calculated water level in deep aquifer	R	cm
DEGCLD	degree of cloudiness (Penman)	R	-
DMCC[5,99]	C-values of C(h) table (max. 5 layers)	R	cm^{-1}
DMCH[5,99]	'H '-values of C(h) table (max. 5 layers)	R	cm
DIMOCA[40]	differential moisture capacity at node	R	cm^{-1}
DISNOD[41]	distance between two nodes	R	cm
DOMEGA[5]	radial frequency of each drainage level	R	$rad \cdot d^{-1}$
DPTRA	incrementing daily potential transpiration	R	cm
DQROT	incrementing daily root extraction	R	cm
DRAIN[366,5]	daily water level in each drainage system	R	cm
DRNAMP[5]	amplitude of each drainage level	R	cm
DROOTZ[366]	depth of root zone for each day	R	cm
DRZ	depth of root zone	R	cm
DSOILP	depth of soil profile	R	cm
DT	time step	R	d
DTM1	previous time step	R	d
DTMAX	maximum time step	R	d
DTMIN	minimum time step	R	d
DVS	development stage	R	-
DZ[40]	compartment size	R	cm

E

EWET	maximum possible evaporation of a cropped surface (Monteith-Rijtema)	R	$cm \cdot d^{-1}$
EWETHI	'EWET' at upper limit of 'RS'	R	$cm \cdot d^{-1}$
EWETLO	'EWET' at lower limit of 'RS'	R	$cm \cdot d^{-1}$

F

FACLAI	reduction coefficient for 'LAI'	R	-
FDEPTH[5]	transformation reduction factor due to soil layer	R	-
FLENDD	indicates if time is at end-of-day	L	-
FLEQUA	indicates if input data on first and last day of calculation are of equal value	L	-

FLGENU[5]	indicates if soil characteristics are according to van Genuchten or from table	L	-
FLGIFT[366]	indicates whether irrigation gift is applied	L	-
FLGROW	indicates if crop growth should be simulated	L	-
FLIOUT	indicates if intermediate output should be given	L	-
FLLAST	indicates last time step of day	L	-
FLOUTP[10]	indicates type of output	L	-
FLPPLA	indicates presence of poorly permeable layer	L	-
FLREAD	indicates if meteo. data are to be read	L	-
FLREDY	indicates if end of calculations is reached	L	-
FMOBIL[5]	volume fraction of preferential paths in a soil layer	R	-
FREXP	Freundlich exponent	R	-
FSX[6]	development stage in SC(DVS) relationship	R	-
FSY[6]	soil cover in SC(DVS) relationship	R	-
FTX[6]	development stage in FTUBER(DVS) relationship	R	-
FTY[6]	tuber partitioning in FTUBER(DVS) relationship	R	-
FUNCCH	function of crop-height	R	-

G

GAMMA	time fraction that sky is overcast	R	-
GAMPAR	transformation reduction factor due to temperature	R	$^{\circ}C^{-1}$
GW[366]	given ground-water level for each day	R	cm
GWL[2]	water level (ground water and perched water)	R	cm

H

H[40]	pressure head at nodal point	R	cm
HATM	minimum allowed 'h ' at soil surf. for present time step	R	cm
HATMD	minimum allowed 'h ' at soil surface obtained or calculated from meteorological data	R	cm
HCRIT	critical 'h ' below which irrigation is required	R	cm
HGIVEN[366]	given 'h ' at bottom node for each day	R	cm
HLIM1	'h' below which roots start to extract water (O_2 defic.)	R	cm
HLIM2U	'h' below which root extraction is optimal for upper soil layer	R	cm
HLIM2L	'h ' below which root extraction is optimal for the lower layers	R	cm
HLIM3	'h ' below which water can not be optimally extracted (reduction point)	R	cm
HLIM3H	'h ' below which water can not be optimally extracted at a high evaporative demand	R	cm
HLIM3L	'h ' below which water can not be optimally extracted at a low evaporative demand	R	cm

HLIM4	'h ' below which roots cannot extract water (wilt. point)	R	cm
HM1[40]	'h ' at previous time step	R	cm
HM2[40]	'h ' at second last time step	R	cm
HTABLE[5,99]	table containing 'h ' - values	R	cm

I

IEPND	intermediate cumulative ponding evaporation	R	cm
IEVAP	intermediate cumulative soil evaporation	R	cm
IINTC	intermediate cumulative interception	R	cm
INQ[41]	intermediate cumulative flux between compartments	R	cm
INQDRA[4,40]	intermediate cumulative drainage per level per node	R	cm
INQROT[40]	intermediate cumulative root extr. volume per node	R	cm
INTC	interception flux	R	$cm \cdot d^{-1}$
IPEVA	intermediate cumulative potential evaporation	R	cm
IPREC	intermediate cumulative precipitation	R	cm
IPTRA	intermediate cumulative potential transpiration	R	cm
IQDRA	intermediate cumulative drainage flux	R	cm
IQROT	intermediate cumulative root extraction	R	cm
IRRAMT[50]	amount of irrigation at certain application	R	cm
IRRAPL	amount of irrigation at current day	R	cm
IRRCON[50]	solute concentration of irrigation water	R	$mg \cdot cm^{-3}$
IRRDAY[50]	day at which is irrigated	R	day
IRUNO	intermediate cumulative runoff	R	cm

K

K[41]	hydraulic conductivity at nodal point	R	$cm \cdot d^{-1}$
KF	Freundlich coefficient	R	
KGEOM[41]	hydraulic conduc. between two nodes (geometric mean)	R	$cm \cdot d^{-1}$
KMOBIL	exchange rate between mobile and immobile volumes	R	d^{-1}
KSURF	'K ' between top node and soil surface	R	$cm \cdot d^{-1}$
KTABLE[5,99]	table containing 'K '- values	R	$cm \cdot d^{-1}$

L

L	distance between two channels	R	m
LAI	leaf area index	R	$m^2 \cdot m^{-2}$
LASTD	last day of calculations	I	d
LAYER[40]	soil layer in which node is situated	I	-
LDIS	dispersion length for solute transport	R	cm
LDWET	last day it rained and/or irrigation took place	I	d
LUNBAL	logical unit number for water balance output	I	-
LUNCON	logical unit number for screen output	I	-
LUNCRP	logical unit number for crop production output	I	-

LUNERR	logical unit number for error messages	I	-
LUNEXA	logical unit number for supplementary output	I	-
LUNEXB	logical unit number for supplementary output	I	-
LUNIN	logical unit number for input	I	-
LUNSAL	logical unit number for solute data output	I	-

M

MAINTA	maintenance respiration for actual production	R	$kg \cdot ha^{-1} \cdot d^{-1}$
MAINTP	maintenance respiration for potential production	R	$kg \cdot ha^{-1} \cdot d^{-1}$
MATHFL	mathematical flexibility factor	R	-
MAXITR	maximum allowed number of iterations	I	-
MAXTIT	maximum allowed number of decrements of 'DT' in iteration procedure	I	-

N

NCRIT	critical node where 'HCRIT' is checked	I	-
NDYEAR	number of days in year	I	d
NIRRIG	number of irrigation	I	-
NODDRZ	bottom node of root zone	I	-
NRLEVS	number of drainage levels	I	-
NUMLAY	number of soil layers	I	-
NUMNOD	number of nodes	I	-

O

OSMOTA	regression coefficient to derive osmotic head	R	cm
OSMOTB	regression coefficient to derive osmotic head	R	$cm^4 \cdot mg^{-1}$
OUTIVL	interval between intermediate outputs	I	d

P

PARAM	decision parameter for subroutine INTERPOL	I	-
PASYMA	actual asymptotic daily production	R	$kg \cdot ha^{-1} \cdot d^{-1}$
PASYMP	potential asymptotic daily production	R	$kg \cdot ha^{-1} \cdot d^{-1}$
PC	gross photosyn. rate of standard canopy on clear day	R	$kg \cdot ha^{-1} \cdot d^{-1}$
PDA	daily actual production	R	$kg \cdot ha^{-1} \cdot d^{-1}$
PDAPRT	daily actual production of productive parts	R	$kg \cdot ha^{-1} \cdot d^{-1}$
PDP	daily potential production	R	$kg \cdot ha^{-1} \cdot d^{-1}$
PDPPRT	daily potential production of productive parts	R	$kg \cdot ha^{-1} \cdot d^{-1}$
PEVA	potential evaporation flux	R	$cm \cdot d^{-1}$
PI	pi	R	-
PINIT	initial dry matter weight of crop	R	$kg \cdot ha^{-1}$
PO	gross photosyn. rate of standard canopy on overcast day	R	$kg \cdot ha^{-1} \cdot d^{-1}$
POND	thickness of ponding water layer	R	cm

PONDMX	maximum allowed 'POND'	R	cm
PREC	precipitation	R	cm
PST	gross photosynthesis of standard canopy	R	$kg \cdot ha^{-1} \cdot d^{-1}$
PTA	total actual production	R	$kg \cdot ha^{-1}$
PTAPRT	total actual production of productive parts	R	$kg \cdot ha^{-1}$
PTP	total potential production	R	$kg \cdot ha^{-1}$
PTPPRT	total potential production of productive parts	R	$kg \cdot ha^{-1}$
PTRA	potential daily transpiration	R	$cm \cdot d^{-1}$

Q

QBOT	flux through bottom of soil profile	R	$cm \cdot d^{-1}$
QBOTOM[366]	given flux through bottom of profile	R	$cm \cdot d^{-1}$
QDRA[4,40]	flux per node to/from each drainage system	R	$cm \cdot d^{-1}$
QROT[40]	root extraction flux per node	R	$cm \cdot d^{-1}$
QTOP	flux through top of soil profile (demand)	R	$cm \cdot d^{-1}$

R

RA	aerodynamic diffusion resistance	R	$s \cdot m^{-1}$
RC	part of solar radiation flux involved in photosynthesis	R	$W \cdot m^{-2}$
REDOSM	factor accounting for plant sensitivity to salinity	R	-
RER	convergence criterium non-linear adsorption	R	-
REVA	reduced potential soil evaporation	R	$cm \cdot d^{-1}$
RGLOB	global radiation	R	$W \cdot m^{-2}$
RH	mean daily relative humidity	R	-
RIMLAY	vertical resistance of poorly permeable layer	R	d
RNET	net radiation	R	$W \cdot m^{-2}$
RTHETA	volumetric soil moisture content below which transformation rate is reduced	R	$cm^3 \cdot cm^{-3}$
RS	internal canopy resistance	R	$s \cdot m^{-1}$
RSMAX	maximum internal canopy resistance	R	$s \cdot m^{-1}$
RSMIN	minimum internal canopy resistance	R	$s \cdot m^{-1}$

S

SATVAP	saturation vapour pressure	R	mbar
SC[366]	soil cover for each day	R	-
SHAPE	shape factor of the ground-water level	R	-
SINFAC	proportionality factor for sink term	R	-
SLOPE	slope of 'SATVAP' - curve	R	$mbar \cdot K^{-1}$
SOLIVL	interval between output of solute data	I	d
SWALLO[4]	switch for allowance of drainage/infiltration	I	-
SWANFL	switch for extra output file with water and solute data	I	-
SWGRFL	switch for output files for graphical package	I	-

SWBOTB	switch for bottom boundary conditions	I	-
SWCHFU	switch selecting 'FUNCCH'-variables	I	-
SWCURV	switch for initial drying or wetting condition	I	-
SWDCAS[4]	switch indicating which drainage formula to use	I	-
SWDRNS	switch indicating drainage should be simulated	I	-
SWDTYP[4]	switch for type of drainage medium	I	-
SWEROR	switch to direct error messages	I	-
SWEXFL	switch for extra output file with supplementary data	I	-
SWHYPR	switch for linear/hyperbolic shape of sink term between 'HLIM3' and 'HLIM4'	I	-
SWINCO	switch indicating type of initial conditions	I	-
SWIRRI	switch for irrigation option	I	-
SWMOBL	switch for occurence of immobile soil volumes	I	-
SWNUMS	switch numerical discretization Richards' equation	I	-
SWOUTP[6]	switch selecting of data written to extra file	I	-
SWPHYS	switch describing soil-physical relation	I	-
SWPRFU	switch for reading of INTCEP - variables	I	-
SWPROD	switch for production option	I	-
SWRADS	switch for type of given radiation	I	-
SWREDU	switch for reduction of soil evaporation	I	-
SWSALT	switch for solute transport	I	-
SWSINK	switch of sink term (Feddes, Hoogland or Prasad)	I	-
SWSOLU	switch whether transport of solutes is simulated	I	-
SWSTAG	switch for showing the computing stage	I	-
SWTBVA	switch for varying bottom boundary conditions	I	-
SWTOPB	switch for the top boundary conditions	I	-
SWUPFU	switch for root water uptake function	I	-
SWWLEV[5]	switch specifying 'DRAIN'	I	-

T

T	time of calculation	R	d
TAMMAX[4]	day of highest water level in drain	R	-
TAMPLI	amplitude of annual soil surface temperature wave	R	°C
TAU	minimal dh which triggers change of scanning curve	R	cm
TCROP	time at which crop starts growing (emergence date)	R	d
TEM	mean daily air temperature	R	°C
THETA[40]	volumetric soil moisture content of each compartment	R	$cm^3 \cdot cm^{-3}$
THETHI[5]	position highest 'THETA' in array for each layer	I	-
THETLO[5]	position lowest 'THETA' in array for each layer	I	-
THETM1[40]	'THETA' of previous time-step	R	$cm^3 \cdot cm^{-3}$
THETSL[5]	saturated 'THETA' of each soil layer	R	$cm^3 \cdot cm^{-3}$
THETSN[40]	saturated 'THETA' of each compartment	R	$cm^3 \cdot cm^{-3}$

TIMREF	day at which temperature wave starts	R	d
TLAGIR	minimum time-lag between 2 irrigation gifts	R	d
TMEAN	mean annual temperature	R	°C
TM1	previous time of calculation	R	d
TRONAB	time at which roots become inactive at depth 'ZRONA'	R	d
TRONAE	time at which maximum depth of inactivity is reached	R	d
TSCF	root uptake concentration factor	R	-
TVPD	ratio between TRAN and 'SATDEF'	R	-
U			
U	mean daily wind speed at 2 m height	R	$m \cdot s^{-1}$
V			
VOLACT	total volume of water in the profile	R	cm
VOLBD	volume of water at beginning of day	R	cm
VOLINI	initial volume of water in the profile	R	cm
VOLM1	volume of water at previous time step	R	cm
VPD	vapour pressure deficit	R	
W			
WUSEFF	water use efficiency	R	$kg \cdot mbar \cdot ha^{-1} \cdot cm$
Y			
YEARST	first year of calculation	I	-
YEAREN	last year of calculation	I	-
Z			
Z[40]	position of nodal point	R	cm
ZBOTDR[4]	depth of bottom of drainage medium	R	cm
ZRONA	depth above which roots are non-active	R	cm
ZRONAM	maximum allowed value of 'ZRONA'	R	cm

Appendix 4. List of subroutines used in SWAP 1993.

Routine	Function
SWAP	main program
BLOCK	initialisation of parameters and variables
BOCOBOT	calculation of lower boundary conditions
BOCODRA	calculation of drainage conditions
BOCOTOP	calculation of top boundary conditions
CALCGWL	search for groundwater levels in the profile
COMSTAGE	screen output showing stage of computation
CHECKDBL	check value of double precision variable
CHECKINT	check value of integer variable
CHECKREA	check value of real variable
DMCNODE	calculation of differential moisture capacity
ERRREAD	message of input errors
EVAPOTRA	calculation of potential transpiration and evaporation
FINDADR	search for label in input file
FLUXES	calculation of fluxes between the compartments
FOOTERS	output of foot text to files
GETCROPD	input of crop data
GETMETEO	input of meteorological data
HEADCALC	calculation of pressure heads after the time step
HEADERS	output of header text to files
HCONODE	calculation of unsaturated hydraulic conductivity
INITBOT	input and echo of specified conditions at lower boundary
INITDRA	input and echo of drainage data
INITIAL	input and echo of general data
INITPLA	input and echo of crop parameters
INITSOL	input and echo of soil hydraulic functions
INITTOP	input and echo of specified conditions at top boundary
INTEGRAL	calculation of intermediate and cumulative water fluxes
INTERPOL	interpolation between values of input table
IRRIG	calculation of time of irrigation
OPENFILE	opening of input or output file
OUTDAT	output of soil profile data (anafil)
OUTGENER	output of water balance and crop data
OUTSOL	output of solute balance and concentrations
OUTSUPP	output of soil profile data (exfile)
POTATO	calculation of potato growth
PRHNODE	calculation of pressure heads
REDUCEVA	calculation of actual soil evaporation

ROOTEX	calculation of water extraction by roots
SOLBAL	calculation of solute balance
SOLUTE	calculation of solute concentrations after the time step
THENODE	calculation of volumetric soil moisture content
TIMESTEP	calculation of length time step
UPDATE	check hysteretic reversal and update scanning curve
WATCON	calculation of water storage in soil profile
ZEROCUMU	reset cumulative values
ZEROINTR	reset intermediate values