SIMGRO V7.1.0

User's guide

P.E.V. van Walsum

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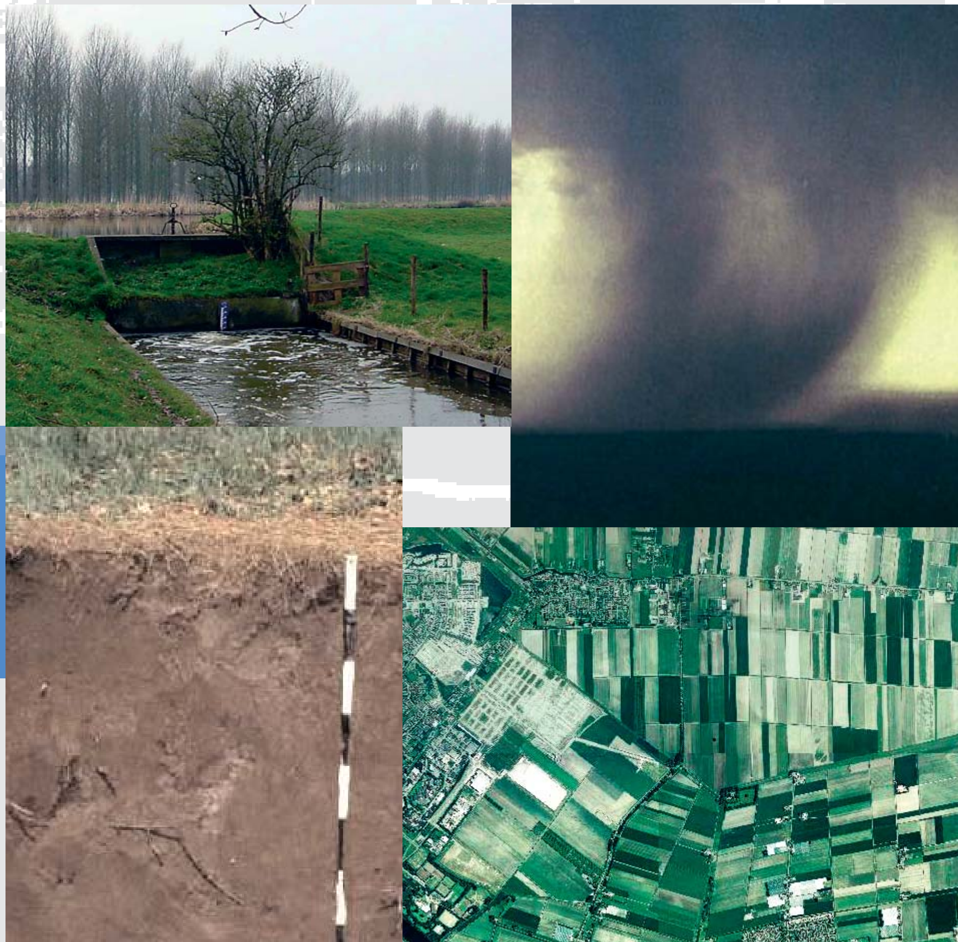

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ABSTRACT

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The regional hydrologic model SIMGRO is used for investigating various kinds of water management problems. The model implementation can include the crop growth model WOFOST, with feedback to the hydrologic parameters like root zone depth and leaf area index. SIMGRO is especially suited for modelling situations with shallow groundwater levels in relatively flat areas, like in delta regions. In such terrain the two-way interaction between groundwater and surface waters plays a crucial role. The offered modelling options include the simulation of drainage with feedback from surface water levels at the time step of the 'fast processes'. The SIMGRO package also includes a simplified model for the simulation of surface water processes. The user has furthermore the option of through-linking the surface water locations to a hydraulic model. The SIMGRO model assembly for the 'top system processes' is used in combination with MODFLOW for the groundwater. This manual contains brief information regarding the way theoretical concepts relate to practical water management issues, how to set up the model schematization, technical features of the modules, installation, program use and error handling.

Keywords: regional hydrology, simulation, water management, crop growth.

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PREFACE

In the past year the model has been made suitable for soils with deep groundwater levels; formerly the evapotranspiration of such soils was under¬estimated. The added extra ‘aggregation layer’ for the zone just below the root zone remedied that deficiency. The idea of using extra aggregation layers was first suggested by former colleague Pim Dik. This idea has now been implemented in a generalized form, involving N-layers forming a cascade of nonlinear reservoirs.

The second major enhancement of the last year was the coupling to the crop growth model WOFOST. This coupling has been implemented in a two-way fashion, including the (optional) feedback from the vegetation development to the hydrologic model. The used state variables for this feedback are the depth of the root zone, the crop height, the leaf area index, and the soil cover. For facilitating this feedback an option was included for dynamic development of the root zone layer in MetaSWAP. The coupling to WOFOST coincided with the enhancement of the SWAP-WOFOST coupling by SWAP developers Joop Kroes, Jos van Dam and the WOFOST expert Iwan Supit. They provided the information needed for realizing the coupling of WOFOST to SIMGRO.

The concept for the interception evaporation was reformulated, in collaboration with the SWAP developers. Furthermore, the SWAP-method for handling the partitioning between transpiration and soil evaporation was implemented. The Maas-Hoffman method was included for simulating the effect of salt stress on the transpiration uptake. The coupling to the TRANSOL model for simulating solute movements and processes in soils was implemented in collaboration with Joop Kroes. The program metaswap2transol also includes the temperature simulation of SWAP.

Low-cost parallel computing is now possible on multi-core pc’s with 2 to 8 cores. And high-performance pc-clusters provide a further multiplication of computing power. To make use of these opportunities the codes of MetaSWAP and SIMGRO-drainage have been parallelized via the OpenMP-protocol in combination with a state-of-art 64bit-compiler (Intel Fortran 11.1).

SIMGRO has a history that goes back to the mid-eighties. The first and second versions were developed by Erik Querner in collaboration with Jan van Bakel. In the course of time, various other persons not belonging to the current team have contributed in one way or the other: Pim Dik, Robert Smit, and Frank van der Bolt.

The realization of SIMGRO7 was financed by the National Hydrologic Instrument project, by the Centre for Water & Climate of Alterra-Wageningen UR, by the Alterra funds for strategic research, and by the GENESIS project of 7th EU Framework program.

Wageningen, December 2009.

1 Introduction

Integrated modelling has the attraction of including feedback mechanisms between the hydrological subsystems. However, covering a wide range of processes in a spatially distributed manner requires a large logistic effort, involving masses of data. Even the experienced modeller can easily make a fatal mistake. In the form of an ultimate safety net, there is of course no substitute for constant awareness and thorough analysis of the simulation results. However, avoiding mistakes in the first place is usually more efficient, and one of the prerequisites for doing that is to have a good overview of the model and its data. At a conceptual level, that overview is provided by the theory description in Alterra-Report 913.1. In the form of a reference manual, the formats of input and output files are described in Alterra-Report 913.3. The latter has the disadvantage that it is purely data-oriented, and not so much conceptually oriented. The aim of this guide is to document the functionalities at a technical level, following the thematic overview given in the theory description. It is hopefully of help in quickly making choices with respect to the modelling options and in maintaining an overview of a study.

1.1 Modules and options for links

Three modules are distinguished (Figure 1.1):

- SVAT-module (‘Soil Vegetation Atmosphere Transfer’), including plant/soil-atmosphere interactions;
- groundwater module;
- surface water module.

We do not follow the principle that a module ‘owns’ a certain part of the domain. Instead, we follow the principle that a module owns a certain *process*. For instance, the evaporation of surface water is simulated by an inundated MetaSWAP column; the surface water module is then informed about the involved water use.

For both soil water (MetaSWAP) and groundwater (MODFLOW) there is just one simulation option. For surface water, there are three available options:

- SurfW module, using a simplified approach of linked reservoirs;
- SOBEK-CF, using the 1D Saint Venant equation in the full form;
- SWQN, using the 1D Saint Venant equation in a simplified form.

The simplified SurfW module (that comes along with the SIMGRO package) is especially useful for efficiently modelling upland parts of a catchment: it uses stage-discharge relationships that have been obtained in a pre-processing phase. The module has been heavily simplified, but it does contain many options for water management, including supply and weir management. This ‘meta’ concept is less suitable for lower parts of a catchment with a small hydraulic gradient. For these parts, the use of a more sophisticated hydraulic model is more appropriate. It is possible to use such a hydraulic model (SWQN or SOBEK-CF) in combination with the SIMGRO surface water module. So there are currently three options for simulating surface water flow; the choice is specified by the parameter *surfacewater_mdl* (in file PARA_SIM.INP).

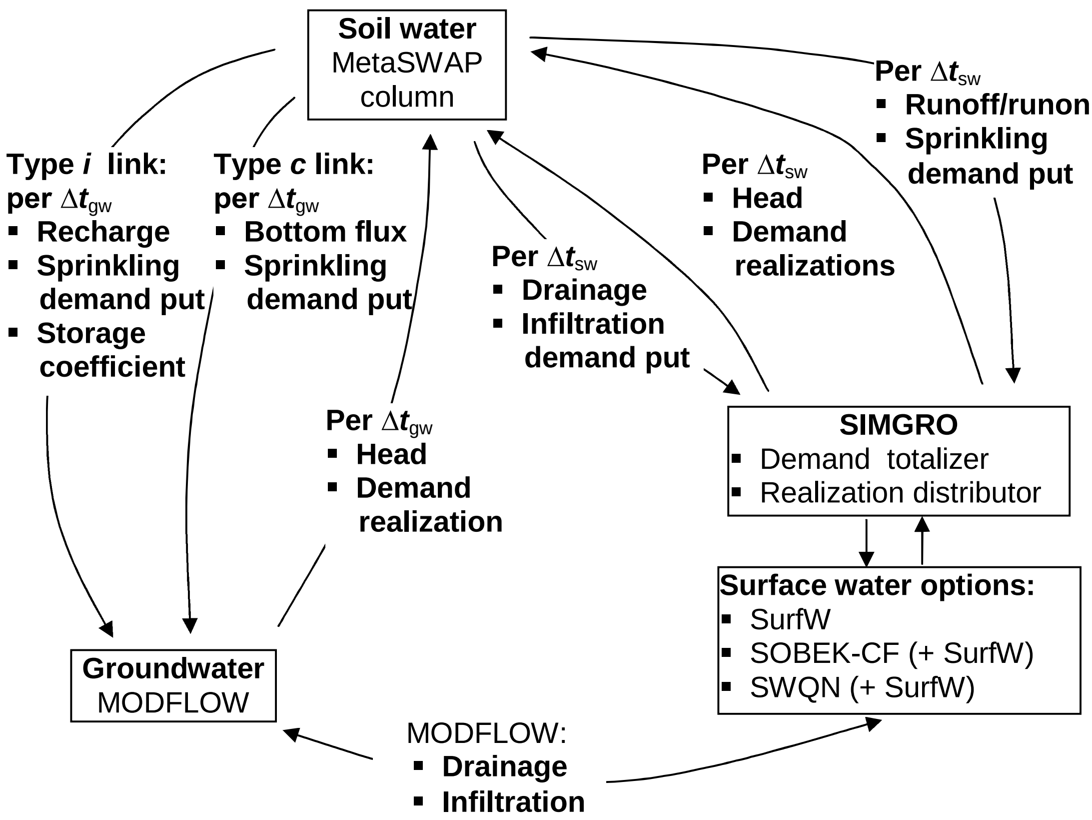

Figure 1.1 Modules with relationships and options. MetaSWAP is the "SVAT" (Soil-Vegetation-Atmosphere Transfer) module of SIMGRO. The SurfW model is a simplified approach for simulating surface water with a network of reservoirs. It can be used in combination with the hydraulic model SOBEK-CF or SWQN. The links involve the 'putting' of demands and the reply in the form of a 'demand realization'. The left half of the scheme has a time step of the groundwater model, Δt_{gw}*, the right half of the 'fast processes',* Δt_{sw}

There are several options available for modelling the interaction between subsystems; Figure 1 contains an overview. A general principle is that when a process involves the transfer of water from one subsystem to the other, this transfer is first 'put' as a water *demand*. The affected module that should deliver the water then returns how much of the demand can be fulfilled, the so-called demand *realization*. In the case of a demand from groundwater we assume that the realization is always 100%.

There are two options for the link between MetaSWAP and MODFLOW:

– *i*-link, which is a resistance-free link, meaning that the groundwater level of the SVAT unit and the head in MODFLOW cell are kept equal;
– *c*-link, which is a resistance link, involving a head difference.

The *i*-link is the most used type; the model uses *c*-link if the following two conditions are met:

- groundwater head above soil surface;
- presence of resistances *ctop_down* and *ctop_up* in the file INFI_SVAT.INP.

The layer 1 of a SVAT can be coupled to any layer of the MODFLOW model. This feature can be used for modelling surface water that occupies a significant areal percentage and that has a different level than the surrounding groundwater. If such an inundated SVAT is linked to a surface water location − via the mapping table in SVAT2SWNR.INP − the inundation water acts as a resistance-free surface water link. The combination of a *c*-link and a connection to a surface water location in SVAT2SWNR.INP is the SIMGRO method for modelling surface water interactions with deeper layers of MODFLOW, with feedback per *dtsw*.

For the relationship between a MetaSWAP column and a surface water location, we distinguish the following two hydrologic pathways:

- over the soil surface, i.e. via runoff/runon;
- through the shallow subsoil, i.e. via drainage/infiltration.

For the runoff/runon, we use an integrated concept, in which the water on the soil surface is present in the soil column model *and* in the surface water model. Both modules ‘do’ something with this water.

There are two options for simulating phreatic drainage flow:

- the SIMGRO drainage module, with the time step of the *surface* water model;
- the drain and river packages of MODFLOW, with the time step of the *ground*water model.

The advantage of the SIMGRO drainage option is that the feedback from the surface water level is at the time levels of the surface water model. Especially in highly dynamic situations with rising water levels, this gives a more realistic result than the MODFLOW option. The drawback of the SIMGRO method is that ‘explicit’ use is made of information about the groundwater level, by using the level at the beginning of the groundwater time step. This can lead to numerically instable behaviour. However, several measures have been taken in the SIMGRO code for reducing the danger of instability by first estimating the amount of groundwater that is drainable. That estimate includes the percolation water that is ‘underway’, the prevailing flow from the MODFLOW model, and the drainable water that is in storage above the drainage base. The latter cannot simply be estimated from the storage coefficient that was last passed to MODFLOW by the MetaSWAP model.

1.2 Overview of this document

Chapter 2 describes the functionalities and their definition in the SIMGRO-input files. Per subsection we give:

- the organization of files involved in defining a certain functionality;
- a short description of the functionality;
- a specification of the input files.

The specifications are given as formatted tables of the involved parameters and the key variables (e.g. the SVAT unit) that are used for accessing them.

In Chapter 3 we describe how to obtain output from the model. In Chapter 4 we give information about running the model.

2 Input files and model use

2.1 Data flow and overview of input files

For each application, the model requires a set of input data files. An overview of the data flow is given in Figure 2.1.

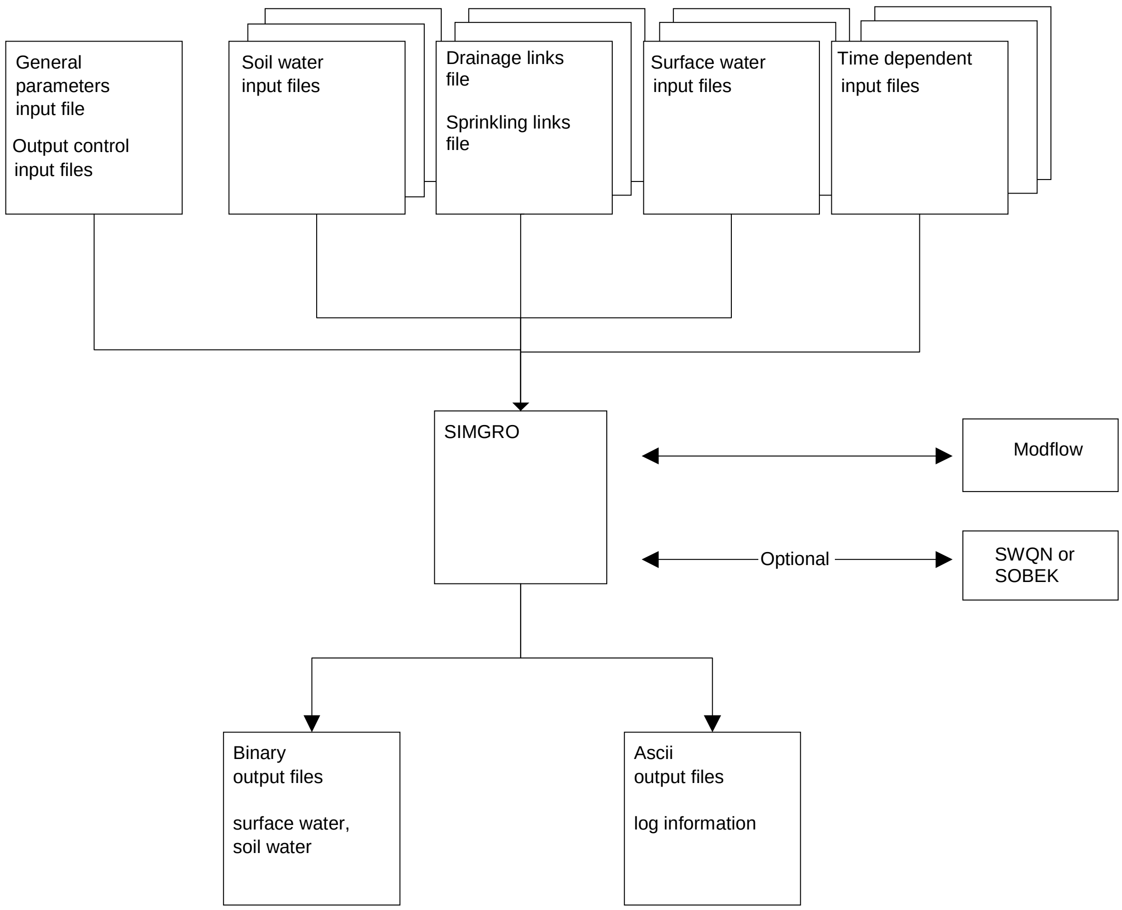

Figure 2.1 Data flow in SIMGRO

In Table 2.1 an overview of the input files is given. Various files are optional. A more extensive description of the input files is given in the document ‘SIMGRO Description of input and output files’ (Alterra-Report 913.3).

Table 2.1 Input files for SIMGRO. SVAT refers to the MetaSWAP model, SurfW to the simplified reservoir model that comes along with the SIMGRO package

Input file	Required/ optional	Module	Description
PARA_SIM.INP	req	parameter	general input file, including options
TIOP_SIM.INP	req	output, time	time-related control commands
SEL_KEY_SVAT_PER.INP	opt	output	SVAT key vars for period bda output
SEL_KEY_SVAT_DTGW.INP	opt	output	SVAT key vars for dtgw bda output
SEL_SVAT_BDA.INP	opt	output	specification of SVATs for bda output
SEL_SVAT_CSV.INP	opt	output	specification of SVATs for csv output
SEL_SWNR.INP	opt	output	specification of SWNRs for output to csv files
MOD2SVAT.INP	req	coupling	linking of SVAT units to MODFLOW
SVAT2SWNR_ROFF.INP	opt	coupling	runoff routing of SVAT units to SIMGRO surface water locations
SVAT2SWNR_DRNG.INP	opt	coupling	drainage parameters of SIMGRO drainage links
SWNR2SWQN.INP	opt	coupling	through-linking of SIMGRO surface water locations to SWQN nodes
AREA_SVAT.INP	req	SVAT	area, soil surface elevation , soil unit, land use, thickness root zone, meteo station
INFI_SVAT.INP	req	SVAT	infiltration parameters of soil surface
LUSE_SVAT.INP	req	SVAT	set of land use options and their characteristics
FACT_SVAT.INP	req	SVAT	values of vegetation factors, interception characteristics
UNSA_SVAT.BDA THSAT_SVAT.INP	req	SVAT	database with steady states of soil moisture profiles, file with saturated water contents of SWAP profile compartments
BETA2_SVAT.INP	req	SVAT	Boesten parameters of bare soil evaporation, per soil
FCWP_SVAT.INP GXG_GG_SVAT.INP	opt	SVAT	field capacity FC and wilting WP (pF's) groundwater levels for determining FC and WP
INIT_SVAT.INP	opt	SVAT	initial conditions of soil water
SCAP_SVAT.INP	opt	SVAT/coupling	capacities of sprinkling links between SVAT units and SW and/or GW
FXSP_SVAT.INP	opt	SVAT	fixed sprinkling rates per time period
METE_STAT.INP METE_SVAT.INP	req	SVAT	meteo-station parameters precipitation and evapotranspiration
SWNR_SIM.INP	opt	surface water	list of SIMGRO surface water locations
MANA_RES.INP	opt	SurfW	water management per sw location
GOTO_RES.INP	opt	SurfW	links of network structure
DISH_RES.INP	opt	SurfW	discharge capacity per sw-location
DISU_RES.INP	opt	SurfW	discharge capacity per trajectory (summer value) of SurfW model
RESV_RES.INP	opt	SurfW	supply links within SurfW model
TACL_RES.INP	opt	SurfW	target level lowering schemes of SurfW
TISW_RES.INP	opt	SurfW	time dependent water levels and discharges of SurfW model
INIT_RES.INP	opt	SurfW	initial conditions surface water

2.2 Setting up the schematization

2.2.1 Coupling in space

The schematisations of the modules can be constructed as shown in Figure 2.2. The bottom layer consists of combined land-use and soil units (which can be obtained from an overlay procedure of land-use and soil maps). A second layer with cells of the groundwater model follows this bottom layer, and the third layer is formed by the subcatchments of the surface water model. In the top layer the schematisations are combined. These are the so-called SVAT-units (Soil Vegetation Atmosphere Transfer) which are used for the top-system modelling.

Surface water is modelled as a network of 'surface water locations'. Depending on the way the model has been implemented, this can involve even the smallest of watercourses.

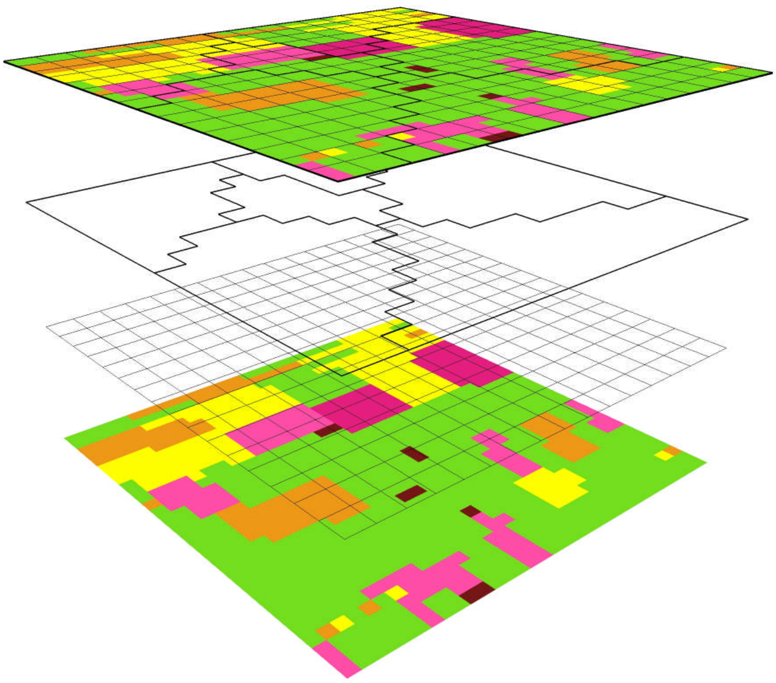

Figure 2.2 Example of how the spatial schematisations of the integrated model can be constructed. The bottom layer involves the units obtained from an overlay of the land use and soil maps. The next layer represents the cells of the groundwater model, followed by the subcatchments of the surface water model in the next layer. The top layer shows how the schematisations have been combined to form the so-called SVAT-units (Soil Vegetation Atmosphere Transfer)

Table 2.2 Related input files for model schematization

Input file	Description
MODFLOW.BAS	defines list of existing MODFLOW cell numbers, including numbers for cells in deeper layers of subsoil
AREA_SVAT.INP	defines list of existing SVATs (and other parameters)
MOD2SVAT.INP	links between SVAT units and MODFLOW cells
SVAT2SWNR_ROFF.INP*	runoff routing from SVAT units to SIMGRO surface water locations *swnr*
SVAT2SWNR_DRNG.INP*	drainage links between SVAT units and surface water locations *swnr*
SWNR2SBK*	mapping from SIMGRO locations SWNR to SOBEK locations (configuration file in SOBEK format)
SWNR2SWQN*	mapping from SIMGRO locations SWNR to SWQN locations
MANA_RES.INP*	defines list of SIMGRO surface water location identifiers that are modelled with the simplified SurfW model that comes along with the SIMGRO package (and other management parameters)
SWNR_SIM.INP*	list of SIMGRO surface water location identifiers SWNR

** optional*

The relationships between the modelling layers are coded in the form of mapping tables. These tables and the related files are listed above.

All MetaSWAP id's (SVAT-units) should be specified in AREA_SVAT.INP, as an ordered index with step 1.

At the start of setting up the SIMGRO model, it is assumed that a MODFLOW groundwater model is available. In that case, there is a file with extension .BAS that defines the groundwater-modelling grid. The mapping of SVAT-units to the MODFLOW model is done with the list MOD2SVAT.INP. There can be more than one SVAT-unit coupled to a specific MODFLOW cell. The areas of the SVAT's should add up to the MODFLOW cell they are coupled to.

If the SIMGRO model involves groundwater extractions for sprinkling, then the mapping should include entries for SVAT/layer combinations coupled to the specific MODFLOW cell identifier. If the extraction is from the phreatic layer, then no extra entry is needed. If the extraction is from a deeper layer, then the MODFLOW cell will have an identifier that is greater than NROW*NCELL of the MODFLOW model.

For each SVAT there should at least be a link of its top layer (*ly*=1) to the MODFLOW model. It should be realized that this layer indicator only has a meaning within the SIMGRO model schematisation. In the case of a deeper link (e.g. *ly*=3) for mapping the groundwater extraction to a MODFLOW cell, the *ly*-value does not have to have to correspond with the numbering of layers within the MODFLOW model. (Though of course it is usually convenient to make it correspond.) The only thing that really counts is that the layer specification of the sprinkling extraction in file SCAP_SVAT.INP has a value that is present in the mapping list. Otherwise the extraction for sprinkling is not passed to the MODFLOW model. The SIMGRO code checks for the presence of the link.

If it is desired to model surface water, the SIMGRO model schematization should start by defining the SIMGRO surface water locations SWNR. These are listed in SWNR_SIM.INP. The file can be left out if no surface water simulation is wanted. By default the model contains a SWNR=0 location.

If a mapping to surface water locations is desired, then these should be given in file SVAT2SWNR.INP. The used SWNR-references should be present in the list given by SWNR_SIM.INP. The file does not have to contain records for all of the SVATs that have been defined in AREA_SVAT.INP. For the SVATs that are not listed the model assumes a default mapping to SWNR=0. The SVAT2SWNR.INP file can be left out altogether; in that case the model assumes a mapping of all SVATS to SWNR =0.

The use of the SurfW model for simplified surface water simulation is optional. In that case the file MANA_RES.INP is present, plus the other SurfW files. The list of SWNR-identifiers in the first column of MANA_RES.INP defines which of the SIMGRO surface water locations are modelled by the SurfW model. There can only be one SurfW unit per SWNR-identifier.

When the SWQN/Surface water model is used for simulating the surface water dynamics, the file SWNR2SWQN.INP has to be specified. This file relates the identifiers of the SIMGRO surface water locations to the identifiers of the SWQN model. For coupling to the SOBEK model the path and name of the so-called configuration file has to be specified in PARA_SIM.INP. There can be *more* than one SWNR-identifier coupled to a specific location of an external surface water model.

For the SVATS's that are coupled to surface water locations that are *not* modelled by SurfW or by SWQN/SOBEK the model model operates in the following manner:
- unrestricted runoff (except for the impediment due to the so-called micro-storage capacity *vxmu*, see file AREA_SVAT.INP); no runon;
- drainage and infiltration simulation using the default water levels provided in SVAT2SWNR_DRNG.INP; if no level is provided in SVAT2SWNR_DRNG.INP and the surface water location is not coupled, then no infiltration is possible;
- unlimited supply for sprinkling from surface water.

2.2.2 Coupling in time

In the file, PARA_SIM.INP the groundwater time step (SIMGRO) should be made equal to the length of the stress period of MODFLOW. Therefore the *bas*-file of the MODFLOW-model should have for the following parameters fixed values:

- PERLEN = *dtgw* (usually 1 d);
- NSTP = 1;
- TSMULT = 1.

Usually a time step of 1 day is used.

MODFLOW time refers to the length of the time period from the start of the calculation. SIMGRO uses a time in days (with *t* =0 at the beginning of a year at 00:00:00) and a Gregorian year. The model user has to be aware of this and has to synchronise both time indications.

2.3 Plant/Soil-Atmosphere interactions

Organization

Table 2.3 Related input files

Input file	Description
General	
PARA_SIM.INP	several general parameters, including the choice of evapotranspiration model *etmdl*
METE_STAT.INP	meteo-station parameters, for Penman-Monteith method
METE_SVAT.INP	meteo-data
LUSE_SVAT.INP	sprinkling data, evaporation reduction factors, vegetation type
FACT_SVAT.INP	vegetation evapotranspiration factors
VG2CRP_SVAT.INP	coupling of vg-index to crops of WOFOST model
SVAT unit-specific	
AREA_SVAT.INP	land use characteristics, meteorological region number
INFI_SVAT.INP	infiltration parameters
SCAP_SVAT.INP	sprinkling characteristics
FXSP_SVAT.INP	fixed sprinkling demands

2.3.1 Precipitation

Description

For the simulation period, the time series information of the meteorological conditions should be available in the form of a ***step-function.*** This entails that the value of the time variable is for the ***start of a new intensity***. Especially if a file contains values per day the novel user can easily misinterpret the given time as the 'index' of a certain day, which can lead to the presumption that the model simulation contains an errant time shift. The given time values do not necessarily have to contain values for the beginning of a specific day. In fact, most rainfall data are obtained by gauges that are read early in the morning, e.g. at 8 AM. In that case the time values should be at 1/3 of a day, i.e. at 0.333, 1.333, and so on.

There can be any number of time steps per day. During the simulation, the meteo-data will vary per *dtsw* that is the time step for calculation of the fast processes. For doing this the model uses time-averaged meteo-values for the *dtsw*-steps, obtained by integrating the step functions over time.

The AREA_SVAT file contains a field with the number of the meteorological region. The model then makes the connection with the number in the file containing the meteorological data, METE_SVAT.INP. This field can be left blank if use is made of grids, and so that file METE_SVAT.INP does not need to be present. For input via grids see the IO-manual Section 2.3.10.

Specification

Table 2.4 Input files and related parameters for precipitation

Input file	Parameter	Unit	Description
PARA_SIM.INP	dtsw	d	time step for fast processes
METE_SVAT.INP	**td**	**d**	**time for start of new value meteo-variable**
	iy	**-**	**year number**
	pr	mm	precipitation
AREA_SVAT.INP	**svat**	**-**	**SVAT unit**
	nmmend	-	meteorological region number

- For using the meteorological data in the top-system modelling, the time step for the fast processes is used, *dtsw* (PARA_SIM.INP)
- The meteorological data are specified in METE_SVAT.INP. Meteorological data should be specified from the start to the end of the model run. The data in this file should be in chronological order. For each time step, the meteo stations should be in the same order. For each time step, data for all the meteo-stations should be available.
- The time step can be smaller than 1 day. When the user wants to use relatively short meteo time steps, the groundwater and surface water time steps should be chosen accordingly (see PARA_SIM.INP).
- The meteorological region number specifies the meteorological station. See METE_SVAT.INP and AREA_SVAT.INP.

2.3.2 Sprinkling

Description

The ‘natural’ precipitation can be augmented by sprinkling. During the growing season, precipitation deficits are likely to occur regularly. If, in severe cases, the pressure head in the root zone is lowered beyond the reduction point, crop growth will be reduced. To avoid this in many parts of the world crops are irrigated.

The SIMGRO sprinkling module contains two steps for the sprinkling simulation:
- determining the demand;
- determining the ‘realization’ by trying to match the demand with the available supply.

Sprinkling can be triggered by the pressure head in the rootzone or can be prescribed in a file. When enough supply is available, the demand will be realized as a sprinkling gift. The source for the sprinkling water has to be specified; it can be surface water, groundwater or a combination. If sprinkling from both groundwater and surface water is enabled, sprinkling from surface water has priority. But when in that case the surface water does not have enough capacity to fulfil the demand the remainder will be supplied from groundwater.

Sprinkling triggered by pressure head

Automatic sprinkling requirements are specified per land use type in LUSE_SVAT.INP. For determining the moment to start sprinkling (and to stop) use is made of the pressure head in the root zone. Sprinkling is triggered when the pressure head in the root zone has fallen below a crop-related ‘start’ value. The user has to specify a sprinkling gift, gift duration and the length of the rotational period. For instance:

- The sprinkling gift equals 25 mm;
- The gift duration is 0.5 d;
- The rotational period is 10 days;
- The pressure head in the rootzone is below the pressure head to begin sprinkling

Then the sprinkling demand equals 50.0 mm d^{-1} during half a day and a new demand will not be calculated within 10 days since the start of the sprinkling. Notice that it concerns a demand. Even if this demand cannot be realised due to the low availability of water, the model will wait the *full* length of the rotational period before checking the sprinkler demand-trigger again.

Prescribed sprinkling demand

For each time a new demand can be specified in the FXSP_SVAT.INP. When the demand:

- is set to value greater than zero, it is interpreted as a fixed sprinkling demand;
- is set to zero, it is interpreted as ‘no sprinkling’;
- is given a negative value, sprinkling will be calculated depending on the rootzone pressure head (automatic sprinkling).

We use an example to explain how it works:

time	year	SVAT unit	sprinkling demand (mm d^{-1})
0.00	1990	1	0.00
100.00	1990	1	200.00
100.50	1990	1	0.00
150.00	1990	1	-1.00

At time 0.0/1990 a fixed flux of 0.0 mm d^{-1} is specified for SVAT unit 1; so from this moment on the automatic sprinkling is switched off. This ‘no sprinkling’ condition lasts until the next time value (i.e. time 100.0). At time 100.0/1990 a demand is prescribed of 200 mm d^{-1} ; it lasts half a day. From then on the demand equals 0.00 mm d^{-1} again. At time 150.0/1990 the fixed-demand sprinkling is switched off and the automatic sprinkling is enabled. As this example shows, it is possible to specify the period of automatic sprinkling for each SVAT unit individually. This then over-rules the values given LUSE_SVAT.INP.

Demand realization

The demand is read by the model per *dtgw*-interval, but applied per *dtsw*-interval. The demand realization can be less than 100% if one of the following conditions is limiting:

- the pump capacities given in file SCAP_SVAT.INP;
- the availability of water at the linked surface water locations specified in SCAP_SVAT.INP;

It is assumed that there always is enough groundwater for sprinkling.

The pump capacities should be set at realistic values, to avoid excessively high application rates during the the *dtsw*-intervals, leading to runoff.

Sprinkling evaporation

It is well known that quite a relevant part of the sprinkling water evaporates. This can be specified using the 'fraction evaporated sprinkling water' (*frevsplu*) in LUSE_SVAT.INP.

Specification

Table 2.5 Input files and related parameters for sprinkling

Input file	Parameter	Unit	Description
PARA_SIM.INP	dtsw	d	time step for fast processes
LUSE_SVAT.INP	**lu**	**-**	**land use type**
	pbgsplu	m	pressure head begin sprinkling
	frevsplu	-	fraction evaporated sprinkling water
	gisplu	mm	gift in rotational period
	tigisplu	d	duration gift
	rpsplu	d	rotational period
	dybgsplu	d	beginning of sprinkling period, in days from beginning of year at 00:00:00
	dyedsplu	d	end of sprinkling period
SCAP_SVAT.INP	**svat**	**-**	**SVAT unit**
	fmmxabgw	mm d^{-1}	maximum abstraction from groundwater
	fmmxabsw	mm d^{-1}	maximum abstraction from surface water
	fxabgw	m^3 d^{-1}	maximum abstraction from groundwater
	fxabsw	m^3 d^{-1}	maximum abstraction from surface water
	svatab	-	SVAT unit from which groundwater is abstracted
	lyab	-	layer number for abstraction
	swnrab	-	subcatchment from which surface water is abstracted
FXSP_SVAT.INP	**td**	**d**	**time from beginning of year at 00:00:00**
	iy	**-**	**year number**
	nnex	**-**	**SVAT unit**
	fxspi	mm d^{-1}	intensity sprinkling demand

- For sprinkling simulation, the time step for the fast processes is used *dtsw* (PARA_SIM.INP).
- The trigger for automatic sprinkling is the pressure head *pbgsplu* in LUSE_SVAT.INP, which is specified per land use type.
- In SCAP_SVAT.INP several characteristics are defined: the layer for groundwater sprinkling, the abstraction SVAT unit, the watercourse and the maximum capacities from groundwater and surface water.
- If for both surface water and groundwater capacities are specified, sprinkling from surface water has priority, and is reduced if the supply to the subcatchment (see MANA_RES.INP for when the water is from the SurfW model) is insufficient. Supply from groundwater will then compensate the low availability from surface water.
- If both *fmmxabgw* and *fxabgw* are specified, the abstraction of *fxabgw* is used (so when *fmmxabgw* = 1 and *fxabgw* not specified the abstraction equals 1 mm/d and with *fxmmabgw* = 1 and *fxabgw* = 0 the abstraction will be zero). The same applies for surface water.
- If a sprinkling demand is prescribed then this demand is used independent of the state of the unsaturated soil.

2.3.3 Interception and interception evaporation

Description
Incoming precipitation and sprinkling water can fall directly on the ground surface as free throughfall or can be intercepted by the vegetation canopy. Due to interception the evaporation will be enhanced.

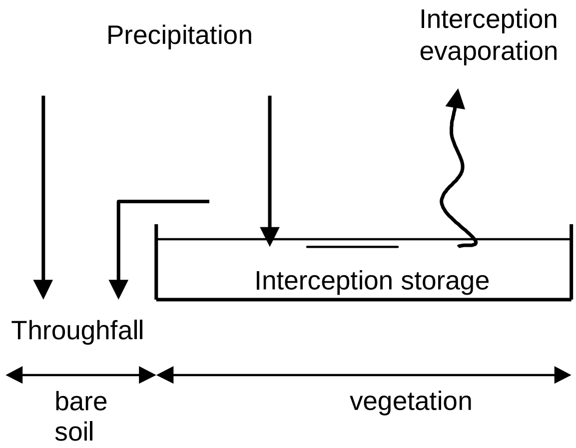

Figure 2.2 Schematic representation of interception process

The storage on canopy and trunks is modelled using an interception reservoir (Figure 2.2). This reservoir has a maximum storage capacity that is strongly related to the leaf area and therefore depends on the season (e.g. in the case of deciduous forest), which is specified in the file FACT_SVAT.INP. In the same file the evaporation factor for the interception reservoir has to be given if the reference crop method is used for the evapotranspiration.

In the case that the meteorological data have been obtained with a time sampling at short intervals of say 15 minutes, the filling and emptying of the reservoir can be adequately modelled. However, if the meteorological data are based on a sampling interval of for instance 1 d, then one should take into account that the precipitation will be spread out over the whole day, resulting in too high computed interception evaporation.

In the standard FACT_SVAT.INP interception is parameterised for deciduous and pine forest. The evapotranspiration factor is only needed if the reference vegetation method is used for the evapotranspiration, see Section 2.3.4.

Example
Assuming a soil cover (*csvg*) of 0.7 (m^2/ m^2) and an interception capacity (*vxicvg*) of 0.010 $m^3/m^2$the maximum storage per SVAT unit will be 0.007 m^3/m^2. In that case, the direct throughfall will be 30%.

Specification

Table 2.6 Input files and related parameters for interception

Input file	Parameter	Unit	Description
PARA_SIM.INP	dtsw	d	time step for fast processes
METE_SVAT.INP	**td**	**d**	**time from beginning of year at 00:00:00**
	iy	**-**	**year number**
	pr	mm	precipitation
	evgr	mm d^{-1}	intensity reference evapotranspiration
AREA_SVAT.INP	**svat**	**-**	**SVAT unit**
	lu	-	land use type
	nm	-	meteorological region number
LUSE_SVAT.INP	**lu**	**-**	**land use type**
	vglu	-	vegetation type
FACT_SVAT.INP	**vg**	**-**	**vegetation type**
	dy	**-**	**day number**
	csvg	m^2 m^{-2}	soil cover
	vxicvg	m^3 m^{-2}	interception capacity
	faeivg	-	factor for interception evaporation

- For simulation of the interception the time step for the fast processes is used *dtsw* (PARA_SIM.INP)
- The land use type is specified in AREA_SVAT.INP
- A vegetation type is connected to a land use type
- The parameters for simulating the interception process type are specified in FACT_SVAT.INP. All the parameters have to be specified per day
- The interception capacity has to be specified per unit of area vegetation
- The factor for interception evaporation is not needed if a referenece evapotranspiration method is used (*evapotranspiration_mdl*=1 or 2 in PARA_SIM.INP)

2.3.4 Evapotranspiration

Description

There are three methods available for the evapotranspiration; the choice is specified with parameter *etmdl* in PARA_SIM.INP:

1. reference crop method, using ‘Makkink’;
2. reference crop method, using ‘Penman-Monteith’ with standard crop parameters;
3. Penman-Monteith with specific crop parameters.

Below we describe what is needed for the Makkink-method,. For the Penman-Monteith method the reader is referred to the IO-manual and the theory document.

With the Makkink method, the evapotranspiration of vegetated soil is computed in three steps by:

- determining the reference crop evapotranspiration;
- applying a vegetation factor to obtain the potential evapotranspiration;

– reducing the potential evapotranspiration to the actual evapotranspiration based on the soil moisture content.

The implementation of the ‘Feddes’ function for the reduction of evapotranspiration **differs** from the implementation used in **SWAP**. In the implementation of the Feddes function in **SIMGRO**, the pressure head values for the reduction of ET due to **wet** conditions apply to the **pressure head at the soil surface**, not in the root zone itself. In effect, the reduction is based on the groundwater level, which determines the pressure head at the soil surface under wet conditions. The computed reduction factor is applied to the root extraction in the **whole** root zone. To disable the reduction function for rice, for instance, values of *p1* and *p2* should be used that are higher than the maximum inundation depth in a paddy.

For calculating the reduction due to **dry** conditions, the model first downscales the pressure head in the root zone to separate values for equal fractions (‘slices’) of it. The reduction function is then applied to the separate fractions, and then averaged for the root zone as a whole.

Typically, for agricultural crops, the factors are only available for the growing season. When the factors are used in the model, the assumption is made that the factors have been calibrated based on field experiments, involving the *total* evapotranspiration, including that of bare soil. Therefore the value of the soil cover is taken to be 1.0 in the part of the year for which a vegetation factor is available, and 0.0 for the remaining part. So for the vegetated part of the year no separate calculation for bare soil evaporation is made.

For natural vegetations (and for agricultural grassland) it is assumed that a vegetation factor is available all the year round.

Evaporation from bare soil will be calculated for the days that the soil cover is less than 1.0.

For forests the interception evaporation is of great importance. Therefore, one should preferably not use “all-inclusive” vegetation factors (i.e. inclusive interception).

Urban areas are partly vegetated and partly paved. Simulating urban area should be done by using separate SVAT’s for the vegetated and the paved parts. The built-up area should be given a zero or small infiltration capacity (AREA_SVAT.INP) and a small micro storage capacity from which water can evaporate. It is important to use (near) zero crop factors, to simulate realistic (near) zero evaporation.

The vegetated part in built-up area is simulated using standard crop factors (for instance grass).

Specification

Table 2.7 Input files and related parameters for evaporation

Input file	Parameter	Unit	Description
PARA_SIM.INP	dtsw	d	time step for fast processes
METE_SVAT.INP	**td**	**d**	**time from beginning of year at 00:00:00**
	iy	**-**	**year number**
	pr	mm	precipitation
	evgr	mm/d	intensity reference evapotranspiration
LUSE_SVAT.INP	**lu**	**-**	**land use type**
	luna	-	name of land use type
	vglu	-	vegetation type
	p1fd	m	p1 Feddes function
	p2fd	m	p2 Feddes function
	p3hfd	m	p3h Feddes function
	p3lfd	m	p3l Feddes function
	p4fd	m	p4 Feddes function
	t3hfd	m	t3 Feddes function
	t3lfd	m	t3 Feddes function
FACT_SVAT.INP	**vg**	**-**	**vegetation type**
	dy	**-**	**day number**
	faevvg	-	crop factor
AREA_SVAT.INP	**svat**	**-**	**SVAT unit**
	ar	m2	area
	lu	-	land use type
	dprz	m	thickness of root zone
	nm	-	meteorological region number

- For simulation of the evapotranspiration the time step for the fast processes is used *dtsw* (PARA_SIM.INP).
- Evapotranspiration
  The crop factor numbers are referred to in LUSE_SVAT.INP by the pointer to the vegetation factors (*vglu*). See FACT_SVAT.INP*.*
- Root water uptake function
  Per land-use type the characteristic storages are given of the root water uptake function. See LUSE_SVAT.INP
- Evaporation of surface water
  The vegetation factor for the surface water is defined in FACT_ SVAT.INP

2.3.5 Crop growth simulation

Simulation of crop growth is enabled by setting *vegetation_mdl*=2 (without feedback to the hydrological parameters) or 3 (*with* feedback) in file PARA_SIM.INP, and by supplying in file VG2CRP_SVAT.INP the link between the *vg*-index and the crops of WOFOST. Not all of the *vg*-index values listed in LUSE_SIM.INP need to be linked, that is flexible. The crop input file format is described in the SWAP documentation. Some changes have been made, including the conversion from cm's to m's. The feedback from WOFOST to the crop factors (if used) is done via the leaf area index. the user is referred to the *.crp files in the T-model example provided supplied with SIMGRO.

2.4 Soil water

Organization

Table 2.8 Related input files

Input file	Description
General information	
PARA_SIM.INP	time step *dtgw*
UNSA_SVAT.KEY/BDA	soil physical characteristics (metadata-file)
SPTU_SVAT.INP	soil physical parameters for numerical calculation
SVAT unit-specific	
AREA_SVAT.INP	soil physical unit , thickness of root zone
INFI_SVAT.INP	infiltration parameters of soil surface
INIT_SVAT.INP	initial condition root zone

2.4.1 Surface runoff

Description

Surface runoff can occur when the precipitation cannot infiltrate quickly enough into the soil, or even cannot infiltrate at all (urban areas or fully saturated soil profiles). In these extreme cases all of the rainfall remains on the soil surface, where it gathers in pools that can start to overflow if the rain persists for a long enough time. Only when it finds its way to the surface water system does it actually become runoff. In the conceptualization of the runoff process, a distinction is made between:

- runoff that is generated due to a limiting infiltration capacity and storage capacity on the soil surface itself (i.e. the soil physical properties and conditions);
- runoff that is generated due to the full saturation of the soil column.

In the input file AREA_SVAT.INP the micro storage on the soil surface itself are specified, in file INFI_SVAT.INP the infiltration capacity. The actual infiltration capacity firstly depends on the soil properties as defined in UNSA_SVAT.BDA. The maximum infiltration capacity as defined in AREA_SVAT.INP is an *extra* restriction for the infiltration capacity. This parameter gives the user a means to take into account non-modelled processes like crust forming at the soil surface. The capacity can also be made dependent on the depth of water on the soil surface (*Spd*), via the parameter *ctop_down*. The extra capacity is then given by *Spd/ctop_down*.

The actual infiltration rate is not only determined by the capacity, but of course also by the availability of water on the soil surface, by the available storage space in the subsoil, and – in the case that the soil becomes fully saturated – by the vertical groundwater flow rate.

'Micro storage' is formed by small depressions in the soil surface at sub-grid scale. When the micro storage is filled completely, the remainder will become runoff. The runoff is routed to the connected surface water location (SVAT2SWNR.INP). The micro storage capacity (parameter *vxmu*) acts as a *sill* for the runoff process. If it is set to zero, water can freely flow to surface water over the soil surface; if it is set to a high value (e.g. 10 m), then runoff is disabled (Extremely high values should be avoided because they cause extra memory use for the building of storage tables.). If a certain SVAT is not coupled to any surface water unit (like is the case when only the MetaSWAP module of SIMGRO is used in combination with MODFLOW), then the surface water level is set to -9999. and thus does not obstruct the runoff process in any manner. If the runoff is modelled in MODFLOW itself, then the MetaSWAP runoff should be disabled.

Specification

Table 2.9 Input files and related parameters for runoff

Input file	Parameter	Unit	Description
PARA_SIM.INP	dtsw	d	time step for fast processes
SVAT2SWNR_ROFF.INP	**svat**	**-**	**SVAT-unit**
	vxmu	m	micro storage capacity
	crun	d	runoff resistance
AREA_SVAT.INP	qinfmaxi	m/d	infiltration capacity

– For simulation of the runoff the time step for the fast processes is used *dtsw* (PARA_SIM.INP).

2.4.2 Unsaturated flow

Description

For each SVAT-unit a soil physical unit has to be specified (see AREA_SVAT.INP). This soil physical unit is a standard soil type with specific characteristics specified in UNSA_SVAT.BDA. This file contains the meta-data for the storage and flux characteristics. The data for these standard types are assembled using the model SWAP (Wesseling, 1991). A ready-to-use database is available for the standard soil types of the Netherlands. For other soil types a standard procedure is available using Van Genuchten parameters for a steady-state version of the SWAP model (Groenendijk, 2006).
Root zone depths are specified per SVAT-unit and are assumed not to vary in time.

Specification

Table 2.10 Input files and related parameters for unsaturated flow

Input file	*Parameter*	Unit	Description
PARA_SIM.INP	dtsw	d	time step for fast processes
UNSA_SVAT.BDA	**sl**	**-**	**soil number**
	rz	**-**	**rootzone number**
	dprztb	**m**	**thickness rootzone**
	ig	**-**	**index groundwater level**
	ip	**-**	**index percolation**
	srtb	-	storage rootzone (table)
	s2tb	-	storage box 2 (table)
	qmrtb	-	flux bottom rootzone (table)
	p2tb	-	pressure head box 2 (table)
	prztb	-	pressure head rootzone (table)
BETA2_SVAT.INP	beta2	-	Boesten parameter of bare soil eavporation
INIT_SVAT.INP	**svat**	**-**	**SVAT unit**
	Sic	m	storage interception reservoir
	Spd	m	storage ponding reservoir
	Spl	m	storage precipitation lens
	przav	m	pressure head root zone
	prz2	m	pressure head box 2
	qsat	m/d	bottom flow (+=up)
AREA_SVAT.INP	nnex	-	SVAT unit
	sl	-	soil physical unit number
	dprz	m	thickness of root zone

- For simulation of the unsaturated flow the time step for the fast processes is used *dtsw* (PARA_SIM.INP).
- The Boesten parameter in BETA2_SVAT.INP should be specified for each soil profile that is defined in UNSA_SVAT.BDA.
- The indexes *ig* and *ip* in the file UNSA_SVAT.BDA are related to a hard coded groundwater depth and percolation flux.
- The initial conditions are defined in INIT_SVAT.INP. At the end of a SIMGRO-run a file INIT_SVAT.OUT is generated, which can be used as an input file for the next run.

2.5 Drainage

Description

Drainage can be simulated in two ways:

- Using standard MODFLOW functionalities (drainage and river records)
  This is described in detail in the MODFLOW documentation;
- Using the SIMGRO functionality (using the file SVAT2SWNR_DRNG.INP)
  In this case, the fluxes are connected to watercourses for which a water balance is calculated.

The SIMGRO drainage option can be used in combination with any of the options for surface water simulation, including the hydraulic models.

The assignment of the drainage fluxes is specified in the file SVAT2SWNR_DRNG.INP. Note that *not* all of the drainage fluxes from a certain SVAT unit have to be assigned to the same location that is specified in SVAT2SWNR.INP: in SVAT2SWNR_DRNG.INP the assignment of a drainage record to a surface water location is specified *explicitly*, and thus can deviate from that in SVAT2SWNR.INP. The assignment to a watercourse not only determines where the water goes to, but also the water level that is used in the drainage flux calculation itself.

The dimensions of the watercourses and drainage systems (from SVAT2SWNR_DRNG.INP) are used to calculate the volume-stage relationships, which are used for the surface water simulations. The dimensions are also used for the calculations of drainage fluxes. The surface water location to which the drainage device is connected to is also specified in SVAT2SWNR_DRNG.INP.

It is also possible to use the MODFLOW packages (DRN/RIV/GLS). But in that case the fluxes are not anymore coupled to the SIMGRO surface water locations. This does not have to be a problem if the drainage involves interaction with a large canal that is anyhow not modelled within the scope of SIMGRO package.

Specification

Table 2.11 Input files and related variables for regional watercourses

Input file	Parameter	Unit	Description
SVAT2SWNR_DRNG.INP	**svat**	**-**	**SVAT unit**
	sy	**-**	**system index**
	dpsw	m	drain depth (soil surface in AREA_SVAT.INP)
	wisw	m	drain width at bottom
	adsw	-	cotangent of slope
	ddsw	m	drain spacing
	lesw	m	length of drainage system
	redr	d	drainage resistance
	reen	d	entry resistance
	rein	d	infiltration resistance
	reex	d	exit resistance
	swnr	**-**	**surface water location of drainage link**
SVAT2SWNR.INP	**svat**	**-**	**SVAT unit**
	swnr	-	surface water location

2.6 Surface water

Organization

Table 2.12 Related input files for surface water

Input file	Description
General information	
PARA_SIM.INP	- several general parameters - selection of surface water model - path and name of SOBEK-CF configuration file for coupling of SIMGRO *swnr* locations to SOBEK locations
Coupling of modules	
SWNR_SIM.INP	SIMGRO surface water locations
SWNR2SWQN.INP	mapping of SIMGRO locations to SWQN locations
SVAT unit or surface water specific information	
SVAT2SWNR_DRNG.INP	- dimensions of watercourses and drains - drainage levels and resistances - connection to watercourse
MANA_RES.INP	- option for target or weir level control - target levels - target level control options
GOTO_RES.INP	- surface water network - weir levels - weir control options - backflow option
DISH_RES /DISU_RES.INP	Q(h)-relationships
TACL_RES.INP	weir level control specifications
RESV_RES.INP	surface water supply definition through special links
INIT_RES.INP	initial surface water levels
TISW_RES.INP	time dependent boundary conditions

2.6.1 Watercourses of the regional system

Description

For the surface water the users has to choose between 3 model options by specifying the parameter *surfacewater_mdl*:

1. SIMGRO surface water model SurfW;
2. SOBEK-CF surface water model, plus upstream SurfW model (optional);
5. SWQN surface water model, plus upstream SurfW model (optional);

For using an external hydraulic model (*surfacewater_mdl* ≥ 2) a mapping table should be made available. In the case of coupling to SWQN the table is contained in file SWNR2SWQN.INP. The table contains SIMGRO-identifiers in the first column, and identifiers of the external model in the second column. These SIMGRO-identifiers are then available for referencing by SIMGRO interaction modules. The identifiers of the external model are not used by SIMGRO itself. For coupling to SOBEK-CF a so-called configuration file is needed, as described in the SOBEK-CF documentation. The path and name of this file are given in PARA_SIM.INP.

Setting up the SurfW model

The use of an external hydraulic model can be combined with the simplified SurfW model that is contained in SIMGRO. The SurfW model should be upstream of the external model. The use of the simplified SurfW-concept can be adequate for relatively steep upstream areas without hydraulic backwater effects. Simplified modelling of urban areas is another main field of application. In this paragraph the use of the SurfW surface water model is described.

For practical purposes the following classification into classes of watercourses is used:

1. primary watercourses, involving canals that traverse the region, but the level is determined at a supra-regional scale;
2. secondary watercourses, forming the main arteries of the regional system;
3. tertiary watercourses, usually the ditches;
4. field drains;
5. furrows/gulleys.

The first and secondary 'main' watercourses are usually modelled explicitly by a surface water model. The rest are modelled as 'additional storage'. The main watercourses are described by:

1. Definition of the existence of SurfW-trajectories (list of unique identifiers) and main management parameters (MANA_RES.INP)
2. Definition of the connections between the trajectories (GOTO_RES.INP); there can be connections from SurfW locations to locations of an external hydraulic model (if used), but not vice versa;
3. The discharge as a function of the water level is defined for each of the trajectories (DISH_SIM.INP and DISU_RES.INP);
4. The dimensions of the trajectory-sections per SVAT unit (SVAT2SWNR_DRNG.INP).

During the schematization of the watercourses into trajectories, it is recommended to make them neither too long nor too short. Too long trajectories may cause too much levelling out of surface water levels and too short trajectories may cause numerical problems. As a guideline, a minimum length of 25 m is recommended and a maximum of 500 m, but this depends off course on the discharges per trajectory and the cross-sectional dimensions. High discharges require greater lengths and/or smaller time steps.

Initial water levels can be set by using the file INIT_RES.INP. For initialization of levels in locations modelled by an external model, the reader is referred to the relevant manuals.

The simplified SurfW-concept for surface water flow assumes that the main flow direction is known beforehand. In order to avoid situations with downstream levels that are higher than upstream levels, the user can implement the 'stop-flow' option (*iofwbk*=1). If this option is used, part (or all, if necessary) of the flow is used to fill the upstream trajectory to the level of the downstream one; only the amount that remains (if any) can flow through. For the calculation of flow in the reverse direction (e.g. during summer when the conduits are used for water supply) a number of so-called ‘backflow’ options are available (*iofwbk=2,3 and 4*). The backflow option has to be specified per watercourse in the file GOTO_RES.INP.

In the top half of Figure 2 the ‘Common backflow’ option is visualized: via a water-balance calculation a level equalization is performed if the downstream level is higher than the upstream one. This option is especially useful for situations that due to a water management measure (raised downstream weir level) a series of trajectories together form a large lake.

In the lower half of Figure 2.2 the ‘strong’ backflow option (*iofwbk*=3) is visualized. In the case of ‘mega’ backflow (*iofwbk*=4) also the water level in the compartment 3 (not shown) will be checked and the water will be used for reverse flow, if necessary for the upstream fill-up. It should be realized that in the case of backflow option 3 and 4 the weirs become backwards permeable, so both backflow options should not be used for normal weirs and pumps! But these options *can* be used for weirs that have ‘flap gates’ in the reverse direction.

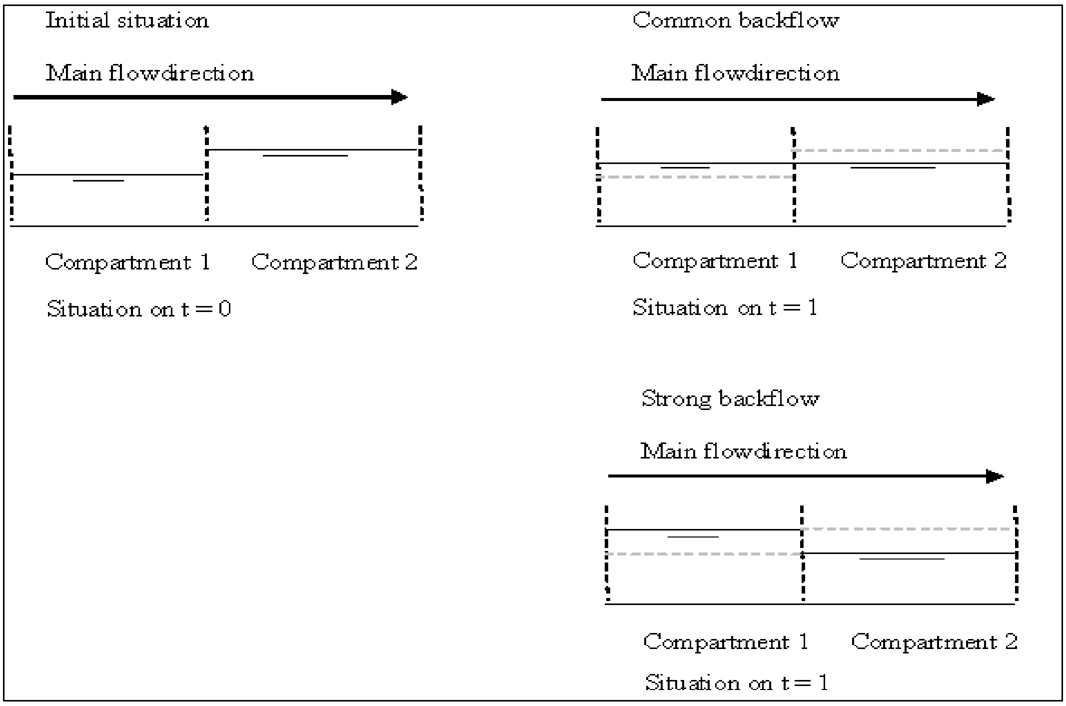

Figure 2.2 Backflow simulation options.

The user should verify whether a back flow option is performing adequately under the data-specific conditions. Situations can occur with the water flowing in the direction of a slight ‘uphill gradient’. That is due to the ‘explicit’ up-to-downstream calculation sequence. If this kind of anomaly is found objectionable then the user should employ an externally coupled hydraulic model instead.

There is also a variation on these backflow options, these are the stabilised backflow options (-4, -3, -2, and -1). These backflow options are used when numerical stabilisation of the calculations is needed. The negative backflow options can be used when the calculations in a certain compartment are not stable. The minus sign causes the algorithm to ‘wait one time step’ before rising from below the threshold of the *Q*(*h*)-relationship (in the case of a weir that is the crest) to above it. This option was devised for suppressing the premature spilling of water over a weir crest just downstream of a bifurcation.

There are several other ways of stabilizing the surface water calculations. The first is to reduce the time step *dtsw*. A second option is to change the parameter *dhmxsw*. This parameter defines the maximum allowed change in surface water level over *dtsw*. If the model wants to exceed this change, then some of the inflow is temporarily ‘parked’; it is subsequently added to the flow during the next time step. Using the recommended values of 0.20 m for *dhmxsw* and 1 hr for *dtsw,* the water level can (theoretically) change by 24*0.2 = 4.80 m/d. That is enough to accommodate any realistic fluctuations for medium sized water courses.

Specification

Table 2.13 Input files and related variables for setting up the SurfW model

Input file	Parameter	Unit	Description
PARA_SIM.INP	tdbgsm	d	time of transition from “winter” to “summer”, in days from beginning of year at 00:00:00
	tdedsm	d	time of transition from summer to winter
	dtgw	d	time step for slow processes
	dtsw	d	time step for fast processes
	dhmxsw	-	maximum change in surface water level over dtsw
SVAT2SWNR_DRNG.INP	**svat**	**-**	**SVAT unit**
	sy	**-**	**system index**
	dpsw	m	drain depth
	wisw	m	drain width at bottom
	adsw	-	cotangent of slope
	ddsw	m	drain spacing
	lesw	m	length of drainage system
	swnr	**-**	**surface water location of drainage link**
GOTO_RES.INP	**swnr**	**-**	**number water course**
	swnrgo	**-**	**watercourse water is conducted to**
	lvwrsm	m+MSL	summer weir level (ioma = 2 or 4)
	lvwrwt	m+MSL	winter weir level (ioma = 1 or 2)
	lvwrlw	m+MSL	lowest possible weir level
	iofwbk	-	option for backflow
	glnr	m+MSL	soil surface elevation next to weir
	lvcv	m+MSL	elevation of culvert
	alfa	$m^{(3-beta)}/s$	coefficient of discharge relationship
	beta	-	exponent of discharge relationship
MANA_RES.INP	**swnr**	**-**	**surface water location**
	ioma	-	option for weir/target in summer/winter
	lvtasm	m+MSL	summer target level (ioma = 1 or 3)
	lvtawt	m+MSL	winter target level (ioma = 3 or 4)
DISH_RES.INP or DISU_RES.INP	**swnr**	**-**	**surface water location**
	dhwr	**m**	**energy head above weir crest**
	fmwr	l/s/ha	discharge capacity of weir
	fswr	m3/s	discharge capacity of weir
	swnrgo	**-**	**“goto” sw location**
TISW_RES.INP	**td**	**d**	**time from beginning of year at 00:00:00**
	iy	**-**	**year**
	nrex	**-**	**surface water location**
	hhwrnw	see iolv	new weir/target level
	flswnw	m3/d	new surface water inflow rate
	swrgo	-	goto subcatchment in case of a new weir/target level
INIT_RES.INP	**nrex**	**-**	**surface water location**
	hhsw	m	initial surface water level
	fliw	m3	surface water inflow
	flow	m3	surface water outflow
	Vmpa	m3	temporarily stored volume (stabilisation)

Table 2.14 General values for numerical approximation

Name	General value	Unit	Description
dhmxsw	0.20	m	Maximum change in sw-level per *dtsw*

- Summer or winter period
  This period is specified in PARA_SIM.INP. The period between *idbgsm* and *idedsm* is the summer period, which has the following characteristics:
  - o the summer weir or target levels are valid;
  - o the dynamic water level control for the summer is active (when specified), see GOTO_RES.INP and MANA_RES.INP;

  The winter period has the following characteristics:
  - o the winter weir or target levels are valid;
  - o the dynamic water level control for the winter is active (when specified), see GOTO_RES.INP and MANA_RES.INP
- Time step for surface water module
  In PARA_SIM.INP the time step for the surface water module, *dtsw*, is specified. The time steps for groundwater and surface water calculations usually have a value of respectively 0.25 and 0.05 days. Of course, this depends on the goal of the study and the system modelled. In highly dynamic systems, it is advisable to reduce the time step for surface water to for instance 0.01 day;
- Parameters for numerical approximation
  The parameter *dhmxsw* has to be specified in PARA_SIM.INP. Usually standard values are used.
  In Table 2.15 the general value for *dhmxsw* is given.
- Surface water structure
  The surface water structure is defined in GOTO_RES.INP. In the surface water structure, no closed loops are allowed; but supply via closed loops can be specified via RESV_RES.INP (see Section 2.6.3);
  The file includes the specification of optional Q-Δh relationships, which are used for water retention simulations (see IO-manual)
- Q(h)-relationships
  See DISH_RES.INP and DISU_RES.INP.
  It is not allowed to decrease the discharge capacity of a weir with increasing energy head above the weir crest.
  DISU_RES.INP specifies the Q(h)-relationship for summer situations.
- Upstream flow
  The default backflow (*iofwbk*) option is set in PARA_SIM.INP. The backflow option can be specified per watercourse in the file GOTO_RES.INP. The latter will overrule the default value.
- Initial surface water conditions
  The initial conditions are defined in INIT_RES.INP.
  At the end of a SIMGRO-run a file INIT_RES.OUT is generated, which can be used as an input file for the next run (after renaming).
- Boundary conditions
  Time dependent weir levels and inflow fluxes can be chosen as a boundary condition (TISW_RES.INP).
- Dimensions of the watercourses
  See SVAT2SWNR_DRNG.INP.

2.6.2 Weirs and pumps

Description

When weirs are implemented in the model, not only the weir levels or target level should be assigned (GOTO_RES.INP and MANA_RES.INP), but also the relationship between water level and discharge should be specified (DISH_SIM.INP).

Water level control with a weir can be done either *indirectly* by manipulating the weir crest or *directly* by manipulating the target water level.

When in the model definition the target level is activated, the model itself will calculate the optimal weir crest. The weir crest will in that case be adjusted in such a way that the water level upstream equals the target level (if there is enough water for that). The weir crest cannot, however, become lower than the lowest possible weir level (as defined in GOTO_RES.INP)!

The SIMGRO-code also has the possibility of letting the weir/target levels be determined by groundwater level (or surface water level or soil water content). In that case a water level control scheme must be specified in the form of a table, with per record:

- a groundwater level in the monitoring SVAT unit *i*;
- a lowering of the target/weir level in trajectory *n.*

The records must form a consistent set, with decreasing groundwater level (starting from 0 at the soil surface) and decreasing lowering of the target/weir level. The principle being 'the higher the groundwater level, the lower the weir/target level should be', in order to counteract the negative effects of too wet conditions. The model interpolates to get the corresponding lowering of the weir or target level. If the current groundwater level is deeper than the deepest groundwater level in the table, the lowering for the deepest groundwater level is taken.

Specification

Table 2.15 Input files and related variables for weirs and pumps

Input file	Parameter	Unit	Description
PARA_SIM.INP	tdbgsm	d	time of transition from “winter” to “summer”
	tdedsm	d	time of transition from summer to winter
GOTO_RES.INP	**swnr**	**-**	**surface water location**
	swnrgo	**-**	**surface water location downstream**
	lvwrsm	m+MSL	summer weir level (ioma = 2 or 4)
	lvwrwt	m+MSL	winter weir level (ioma = 1 or 2)
	lvwrlw	m+MSL	lowest possible weir level
	ndwr	-	SVAT unit for weir level control on ground water level (ioma = 1, 2 or 4)
	iowrsmnd	-	index weir level control on summer ground water level (ioma = 2 or 4)
	iowrwtnd	-	index weir level control on winter ground water level (ioma = 1 or 2)
	nrwr	-	water course for weir level control on surface water level (ioma = 1, 2 or 4)
	iowrsmsb	-	index weir level control on summer surface water level (ioma = 2 or 4)
	iowrwtsb	-	index weir level control on winter surface water level (ioma = 1 or 2)
MANA_RES.INP	**swnr**	**-**	**surface water location**
	ioma	-	option for weir/target in summer/winter
	lvtasm	m+MSL	summer target level (ioma = 1 or 3)
	lvtawt	m+MSL	winter target level (ioma = 3 or 4)
	svatta	-	SVAT unit for target level control on ground water level (ioma = 1, 3 or 4)
	iotasmnd	-	index target level control on summer ground water level (ioma = 1 or 3)
	iotawtnd	-	index target level control on winter ground water level (ioma = 3 or 4)
	swnrta	-	subcatchment for target level control on surface water level (ioma = 1, 3 or 4)
	iotasmsb	-	index target level control on summer surface water level (ioma = 1 or 3)
	iotawtsb	-	index target level control on winter surface water level (ioma = 3 or 4)
TACL_RES.INP	**iota**	**-**	**index for level control**
	dpgwlw	m	groundwater depth below soil surface or surface water level below reference level
	lwta	m	lowering target/weir level
DISH_RES.INP /	**swnr**	**-**	**surface water location**
DISU_RES.INP	**dhwr**	**m**	**energy head above weir crest**
	fmwr	l/s/ha	discharge capacity of weir
	fswr	m3/s	discharge capacity of weir
	swnrgo	**-**	**“goto” surface water location**
TISW_RES.INP	**td**	**d**	**time from beginning of year at 00:00:00**
	iy	**-**	**year**
	swnr	**-**	**surface water location number**
	iolv	-	option code for level reference
	hhwrnw	see iolv	new weir/target level

– Summer or winter period
  This period is specified in PARA_SIM.INP. The period between *idbgsm* and *idedsm* is the summer period, which has the following characteristics:
    - The summer weir or target levels are valid;
    - The dynamic water level control for the summer is active (when specified), see GOTO_RES.INP and MANA_RES.INP;

  The winter period has the following characteristics:
    - The winter weir or target levels are valid;
    - The dynamic water level control for the winter is active (when specified), see GOTO_RES.INP and MANA_RES.INP

– Target levels and weir levels (summer and winter)
  Both target and weir levels can be specified. MANA_RES.INP specifies the target levels and GOTO_RES.INP the weir levels. The parameter *ioma* in MANA_RES.INP determines the use of target or weir level in the model.
  Weir and target levels can be specified as time dependent levels, see TISW_RES.INP.

– Q(h)-relationships
  See DISH_RES.INP and DISU_RES.INP.
  It is not allowed to decrease the discharge capacity of a weir with increasing energy head above the weir crest.
  DISU_RES.INP specifies the Q(h)-relationship for summer situations.

– Dynamic target or weir level control on surface water levels, groundwater levels. The control on root zone saturation is not implemented.
  See MANA_RES.INP and GOTO_RES.INP in combination with TACL_RES.INP
  The indexes *iowrsmnd, iowrwtnd, iowrsmsb, iowrwtsb, iowrsmfr, iowrwtfr* refer to the indexes in the file TACL_RES.INP.
  When because of the implementation of more control levels several target levels are calculated, the lowest target level will be used.

2.6.3 Surface water supply

Description

During summer, many regions receive surface water supply. The reason for supplying the water can be diverse. In the higher parts of the Netherlands, the reason is usually to supply water for sprinkling and sub-irrigation. In the lower parts (which are below sea level), the supply is mainly used for maintaining water quality at an acceptable level. In the *SurfW* model, there are two ways of implementing water supply:

1. ‘out of nowhere’, from outside the model region;
2. through special links that involve the transfer from one location to the next.

Per location with water supply, only one type of water source can be used.

Supply from outside the model region

The supply is specified in the file MANA_SIM.INP using the parameters *fxsuswsb* for the supply capacity *and dptasu* for defining the water level drop that triggers the actual supply. The latter takes place when the water level in a location drops below the weir/target level by more than *dptasu*.

Supply from one location to another

By specifying a supply link in file RESV_SIM.INP it is possible to use an ‘extraction location’ *n* as a supply source (see Fig. 2.3). This type of link can also be from outside the model domain; in that case, the extraction location should be one of the locations in file SWNR_SIM.INP that has not been coupled to *SurfW* or to an external model. Such a link works differently from the option provided by MANA_SIM.INP. The latter simply fills up (exactly) to the target level, and there is no ‘spillage’. The RESV_SIM.INP option involves dynamic flow regulation that does not exactly have to be on target all the time; there can be some fluctuation. This option has the advantage that it is possible to force an *outflow* from the *m*-location to where the water is supplied to. This is effectuated by setting the depth below target level for supply (*dptasu*, which is given in MANA_SIM.INP, also when the RESV_SIM.INP option is used) at a *negative* value. Such a negative value of *dptasu* is usually combined with the option provided by RESV_SIM.INP to specify a target flow at a remote location *k* (which can also be the same as *m*).

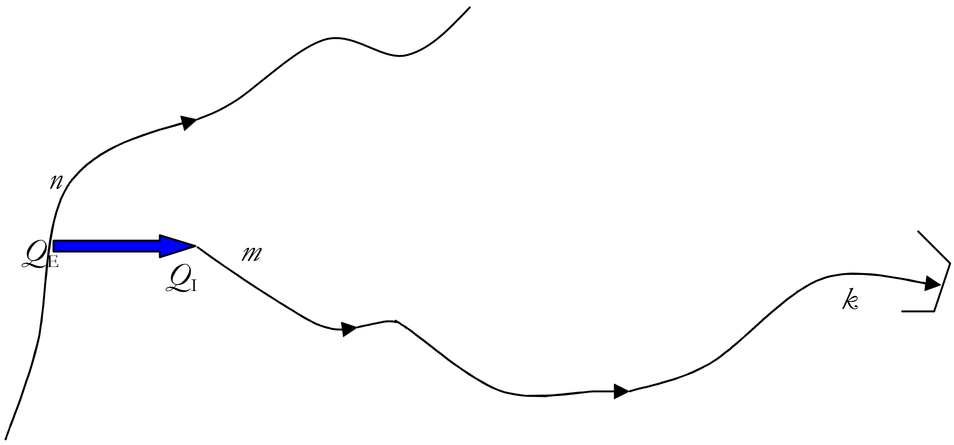

Figure 2.3 Surface water supply link. Water is transferred from location n to m. Supply control is based on the water levels in n and m, and the target flow at the location at k.

The flow regulation (Figure 2.3) is based upon stepwise adjustment of the supply rate, at each time step (*dtsw*) of the surface water model. The used increments and decrements are [*dtsw*/*dtgw*] ·[supply capacity]. Thus the full supply capacity can be reached at the end of the first groundwater time step (*dtgw*). The flow rate is *decremented* if one (or more) of the following conditions are present:

- the water level in the extraction trajectory *n* has become lower than the allowed depletion level;
- the water level in the supply trajectory *m* has exceeded the maximum allowed level;
- the flow rate at the flow control trajectory *k* is higher than the target flow.

The flow rate is *incremented* if *none* of the above conditions and one (or more) of the following conditions are present:

- the water level in the supply trajectory *m* is lower than the maximum allowed level;
- the flow rate at the flow control trajectory *k* is lower than the target flow.

The flow rate is not allowed to exceed the specified capacity.

It is possible to use a single extraction location for supplying multiple locations. However, the model cannot handle supply to one target trajectory from different extraction locations. Neither can this form of supply be combined with the supply option of MANA_RES.INP.

The criterium for the depletion level of the extraction trajectory is purely based on the available water in storage at the beginning of the time step. Therefore, the algorithm does not take into account that there can be inflow to the extraction trajectory from e.g. an upstream trajectory. The amount of water that can be supplied in this manner is limited by the storage characteristics, the weir/target level and the allowed level of depletion in the extraction trajectory. This storage-related amount can be supplied at each time step of the surface water. So the realized supply flow rate can be increased by either increasing the storage capacity or by making the time step smaller.

Because the supply capacity is used for determining the flow increment/decrement, it is important to specify a realistic value; otherwise the flow regulation will cause undesired spillage situations.

Specification

Table 2.16 Input files and related variables for surface water supply

Input file	Parameter	Unit	Description
MANA_RES.INP	***swnr***	**-**	**surface water location**
	dptasu	m	depth below target level for supply
	fxsuswsb	$m^3\ d^{-1}$	maximum supply surface water
RESV_RES.INP	**swnrrviw**	**-**	**sw location that receives supply (in)**
	swnrrvow	-	sw location of extraction reservoir (out)
	dptarv	m	allowed depletion depth below weir/target level in extraction reservoir
	fltarv	$m^3\ d^{-1}$	target flow at subcatchment nrsbow for supply
	flcprv	$m^3\ d^{-1}$	supply capacity
	swnrsbow	-	sw location used for control
	icsmrv	**-**	season for which the link should be active (icsm=1 for summer, 2 for winter)

2.7 Time dependency

Organization

Table 2.17 Related input files

Input file	Description
General information	
PARA_SIM.INP	several general parameters
LUSE_SVAT.INP	time parameters for sprinkling, summer and winter definition for weirs and pumps
METE_ SVAT.INP	meteo-data
Dynamical input	
TISW_RES.INP	time dependent boundary conditions for surface water
TIOP_SIM.INP	specification periods for output, change of water management period (summer/winter)

Description

The most important driving force for a hydrologic model is the meteorologic time series, which is specified in the file METE_ SVAT.INP.

In the file TIOP_SIM.INP is the specification of the periods for periodical water balance output. The boundary conditions for the surface water system have to be specified in the file TISW_RES.INP.

Specification

Table 2.18 Input files and related variables for time dependent variables

Input file	Parameter	Unit	Description
PARA_SIM.INP	tdbg	d	time to start calculation, in days from beginning of year at 00:00:00
	iybg	-	year number to start calculation
METE_ SVAT.INP	**td**	**d**	**time from beginning of year at 00:00:00**
	iy	**-**	**year**
	pr	mm/d	precipitation intensity
	evgr	mm/d	intensity reference evapotranspiration
TISW_RES.INP	**td**	**d**	**time from beginning of year at 00:00:00**
	iy	**-**	**year**
	nrex	**-**	**subcatchment number**
	hhswnw	see iolv	new surface water level
	hhwrnw	see iolv	new weir/target level
	flswnw	$m^3\ d^{-1}$	new surface water inflow rate
	swnrgo	-	goto subcatchment in case of new weir/target level
TIOP_SIM.INP	**td**	**d**	**time from beginning of year at 00:00:00**
	iy	**-**	**year**
	io	**-**	**option (1/7)**
	ip	-	parameter (1/2)

- Simulation period
  The length of the simulation run is controlled by MODFLOW using information from the *bas* file. The start time is needed in PARA_SIM.INP in order to know where to start with the reading of the meteorological data, and to know when to switch to summer/winter regimes.
- Meteo-data
  The meteorologic data are specified in METE_ SVAT.INP. Meteorologic data should be specified from the time to start the model run until the time to stop. The data in this file should be in chronological order.
  The time step can also be smaller than 1 day. When the user wants to use relatively short meteo time steps, the appropriate groundwater and surface water time step (see PARA_SIM.INP) should be used
- Surface water levels, weir levels, inflow flux
  Time dependent weir levels and inflow flux boundaries can be chosen.
  See file TISW_RES.INP
- Change of water management period, using *io*=1 in TIOP_SIM.INP. The change of season is ' forced' by setting the option parameter to *ip*=1 for change to summer, 2 for change to winter. This overrules the parameters *idbgsm* and *idedsm* that are given in PARA_SIM.INP. Once a specification of *io*=1 has been given, the season will only change through a subsequent season specification.
- Periods for output, using *io*=7 in TIOP_SIM.INP
  This triggers the writing to periodical water balance output files (*_PER.*)

3 Output files

3.1 ASCII-output files

ASCII files are only used for the run log and for writing the end states. The files are listed in the table below.

Table 3.1 Output files, description and options

File	Module	Output if	Description
INIT_SVAT.OUT	SVAT	always	end state of soil moisture
INIT_SVATVG.OUT	SVAT	vegetation_mdl ≥2	end state of vegetation
INIT_RES.OUT	SurfW	always	end state of surface water

3.2 Binary output files

Description
Writing to a binary file is an efficient way to store data. The output options can be specified in PARA_SIM.INP.

To extract information from the binary output files two help files have to be used. So each binary output consists of three files:
– the key information is written to .key-files,
– the timer information to .tim-files (both in ASCII);
– the actual output is written to .bda-files, using a binary ‘format’.

Table 3.2 Output files, description and options. Option parameter values are set in PARA_SIM.INP

File	Option par =1	Description
SVAT_GT	*svat_gt*	ground water level per 14 days
SVAT_PER #	*svat_per*	water balances of SVAT units per water balance period
SVAT_DTGW *,+	*svat_dtgw*	water balances of SVAT units per gr. water time step
SVAT2GW_DTGW*	*svat2gw_dtgw*	water balances for groundwater as a system volume
DRNG_PER	*drng_per*	drainage of SIMGRO drainage links, per period
SW_PER @	*sw_per*	water balances of surface water locations
SW_DTGW %	*sw_dtgw*	water balances of surface water locations
SW_HQ_DTGW	*sw_hq_dtgw*	sw flows and water levels for plotting purposes
SW_DTSW	*sw_dtsw*	water balances of surface water locations
SW_HQ_DTSW	*sw_hq_dtsw*	sw flows and levels for plotting purposes

* *only for units specified in SEL_SVAT_BDA.INP*
\# *also available in the form of csv-files for selected units, if svat_per_csv=1*
\+ *also available in the form of csv-files for selected units, if svat_dtgw_csv=1*
@ *also available in the form of csv-files for selected swnr locations, if sw_per_csv=1*
% *also available in the form of csv-files for selected swnr locations, if sw_dtgw_csv=1*

Files with totals for a certain part of the domain can be obtained by setting one or more of the following parameters to 2:
- *svat_per*
- *svat_dtgw*
- *sw_per*
- *sw_dtgw*

Separate files are created with totals for:
- the *svat*’s that are not linked a surface water model;
- the *svat*’s that are linked to SurfW;
- the *svat*’s that are linked to SOBEK;
- the *svat*’s that are linked to SWQN.

3.3 Extracting data from binary files

Several post-processing programs have been developed to read the binary output and to convert it to the desired format. The binary files have the extension ‘bda’, which stands for **b**inary **d**irect **a**ccess. Each of the binary files is accompanied by a ‘. key’ file containing information about the content of the database, and a ‘. tim’ file containing information about the simulation times for which data are available. Unfortunately, binary files produced by Fortran do not have a standardized format. Thus it is crucial that the used postprocessing programs have been compiled with the ***same compiler version*** as the used version of MODFLOW-SIMGRO! For that reason the names of all executables include the used compiler version.

Determining statistics of the phreatic regime

The programme *bda2gt.exe* generates a text file with the mean lowest, the mean highest, the spring and the mean groundwater level (in Dutch abbreviated to GLG, GHG, GVG and GG). These statistics of the groundwater levels are calculated for all the SVAT units. The groundwater levels should be available at bimonthly intervals (i.e. the levels on the 14th and 28th day of the month) for a period of at least two years. The files are obtained by setting *svat_gt*=1 in PARA_SIM.INP. The data are written to the pair of database-files files *svat_gt.key* and *svat_gt.bda.* The so-called key-file *svat_gt.key* (in ASCII format, thus viewable in a text-editing programme) defines the content of the binary file *svat_gt.bda* that contains the actual data. Apart from the mentioned files the user should have available the file *SVAT.asc*, which is an ASCII grid-file of the SVAT-polygons. The polygons should first have been converted to a grid (using a GIS-system), with the smallest of the SVAT-polygons as the gridding unit. The gridding should be done for the ‘id’ of the SVAT-units. The grid-file can be exported with the ‘Export data source’ functonality, using the option ‘ASCII raster’.

The programme is called with 10 arguments; the command line for using the programme is:

- `bda2gt.exe < log-file> <key-file> <item> <gt.csv> <SVAT.asc> <glg.asc> <ghg.asc> <gvg.asc> <gg.asc> <gt.asc>`

All file references should include the full directory path. The columns of the csv-file represent:

- SVAT unit
- glg, the mean lowest groundwater level
- ghg, the mean highest groundwater level
- gvg, the spring groundwater level
- gg, mean groundwater level
- gt-group1 (new group)
- gt-group2
- gt-group3

The units are transformed from m+MSL to ***centimetres*** below soil surface.

The output for glg, ghg, gvg, gg and gt (ranging from 1 to 8) is also written to ASCII-grid files (integer-format), using SVAT.asc for mapping.

Extracting time series

The programme *BDA2TIME.EXE* can be used for extracting a time series from a binary file. It has to be called with 4 arguments:

- BDA2TIME.EXE <log-file> <key-file> <item> <SVAT/SWNR>

All file references should include the full directory path.

It is not possible to specify more than one SVATunit/SWNR in a single call of bda2time.

An example of a query for a time series of the groundwater levels in SVAT unit 30433:

- bda2time.exe d:\logs\svat.log d:\data\svat_dtgw.key Hgw 30433

The generated text-file is written to the directory location of the key-file and the name of the csv-file (in ASCII format) is composed as follows:

- <item>_<SVAT/SWNR>.csv

The columns of the csv-file represent:

- ‘yyyy-mm-dd; hr:mn:ss’
- value of item, ***with the length unit as given in the key-file, in m***

A ‘model time’ of for instance ‘0.0 1989’ is converted to: '1988-31-12;23:59:59'.

Extracting model area series

The programme *BDA2GRID.EXE* has to be called with at least 5 arguments. When no day-year combination is specified, all the periods of the tim-file are selected and the long-term average of the time series is computed for each spatial unit:

- BDA2GRID.EXE <log-file> <key-file> <item> <SVAT.asc> <output.asc> (<<day> <year>, .. >)^{n}

All file references should include the full directory path. Several day-year combinations can be specified. Apart from the database files (key-file and bda-file) the user should have available the file *SVAT.asc*, which is an ASCII grid-file of the SVAT-polygons. The polygons should first have been converted to a grid (using a GIS-system), with the smallest of the SVAT-polygons as the gridding unit. The gridding should be done for the ‘id’ of the SVAT-units. The grid-file can be exported with the ‘Export data source’ functonality, using the option ‘ASCII raster’.

For example, for every SVAT unit the mean root zone pressure head for day 273 and 274 of 1996 is obtained with:

- BDA2GRID.EXE d:\logs\svat.log d:\data\svat_dtgw.key phrz01 d:\tmp\SVAT.asc d:\tmp\phrz01.asc 273.0 1996 274.0 1996.

This programme generates a csv-file with the item information for the specified periods.

The generated text-file is written to the path directory <path> and the name of the csv-file is composed as follows:

- <item>.csv

The columns of the csv-file (in ASCII format) represent:

- SVAT unit/subcatchment
- value of item, ***with the length unit in mm***

The average for the item over the period(s) is presented in case of flux and storage terms. In case of levels, the values ***at the end*** of the specified periods are averaged.

If the input file SVAT.asc exists, the output is also written to an ASCII-grid file (floating-format), using SVAT.asc for mapping.

4 Programme execution

4.1 Hardware requirements

To run SIMGRO you are advised to use at least the following system configuration:
- IBM compatible PC with a pentium processor (≥ 2 GHz);
- 1 Gb RAM;
- CD drive for installation of SIMGRO;
- hard disk with at least 10 Gb free;
- Windows XP - Windows 7.

Especially if use is made of an external disk via the USB connection, the user should make sure that it has been formatted under the NTFS system, and not under the FAT32 system that the disks usually have as the off-the-shelf format. If the format is left at FAT32, then the output files will not be able to become bigger than about 4 Gb.

4.2 Executables

In the name of the executable the length of the reserved X-array of MODFLOW will be apparent (e.g. "_LENX250M" = a LENX dimension of 250 million). This is the only hard-coded array dimension. All SIMGRO arrays are dimensioned dynamically in the initial phase of programme running. The following information about the specific programe build is contained in the name of the executable::
- the MODFLOW version tag, e.g. "_V16R1_1_1_0";
- the SIMGRO-version number, e.g. V7_0_0;
- the SVN-version number of the build, which is the unique key to the version;
- whether or not the programme has been compiled with checks of the array bounds; this is indicated by the code "Release" for no check of bounds and "Debug" for the version that includes this check (and other ones);
- whether or not the code-parallellization has been enabled; the version with parallellized SIMGRO and MetaSWAP routines is recognizable from the text string **_pll_** in the name of the executable, the sequential version by the string **_seq_** in the name;
- the compiler used for the compilation; this information is important because the used utilities BDA2TIME.EXE and BDA2GRID.EXE should have been generated with the same compiler (Intel/other), otherwise the reading of the binary output files can be erroneous.

An example of a programme name is (programme compiled with Intel Fortran 11.1) "MODFLOW_V16R1_1_1_0-SIMGRO_V7_0_0_SVN150_RELEASE_PLL_IFORT110.EXE".
We strongly recommend that with each major change of input data the user first makes a short run with "Debug" version, to check whether array bounds are being violated. Such violations can occur due to user-errors in data files.

4.3 MODFLOW-SIMGRO solution scheme parameters

The MODFLOW-SIMGRO solution scheme follows the standard MODFLOW pattern of:

- an outer loop for setting of head-sensitive parameters, like the phreatic storage coefficient;
- an inner loop for solving the the set of equations for the groundwater model.

The iteration scheme for the convergence between MetaSWAP and MODFLOW would continue indefinitely if not some sort of smoothing operation is performed between the outer-loop iterations; the latter are indexed by the variable *iter*. The iteration would never stop because – especially in a large model – there will always be a situation where the saturated flux is very sensitive to the specified storage coefficient of the phreatic layer. In order to use the computational resources efficiently we use the following smoothing scheme:

$$sc1(iter) = sc1new, \qquad \text{for} \qquad iter \leq iterur1$$
$$sc1(iter) = sc1new * \omega + sc1(iter - 1)*(1- \omega), \quad \text{for} \quad iterur1+1 \leq iter \leq iterur2\text{-}1$$
$$sc1(iter) = sc1(iter - 1) \qquad \text{for} \quad iterur2 \leq iter$$

where *sc1new* is the new storage coefficient based on the latest information from MODFLOW and MetaSWAP, and ω is the under-relaxation factor defined as:

$$\omega = 1.0 - (iter - iterur1))/(iterur2 - iterur1)$$

The parameters *iterur*1 and *iterur*2 are specified in file PARA_SIM.INP. The default values are respectively 5 and 7.

The MODFLOW file with extension “pcg” contains the parameters that control the MODFLOW part of the scheme. We recommend the following settings, with the names of variables as used in the MODFLOW2005 manual:

- MXITER=*iterur*2+2, for the maximum number of outer-loop iterations;
- ITER1=20, for the maximum number of inner-loop iterations;
- NPCOND=1;
- HCLOSE=0.005 m, for the stopping criterium of the head change;
- RCLOSE=1000.
- RELAX=0.98
- NBPOL, IPRPCG, DAMP = 0

During execution the programme sends information about the convergence between MODFLOW and MetaSWAP to the screen, and also to file INFO_SIM.OUT. The maximum deviation (+ and -) is reported. A maximum deviation of a few decimeters often occurs. That does not necessaraily harm the accuracy of the model, because no water balance errors are made. The error made is simply that the MODFLOW fluxes are not computed with the same head as that of MetaSWAP; the latter is always consistent with the saturated flux of MODFLOW. The user should evaluate the accuracy of the model for the goal of the application. Often it will suffice to compare the long-term statistics of the groundwater regime, as computed from the MetaSWAP levels and the MODFLOW ones. For convenience of the user the output file SVAT_GT.BDA contains information about the levels in both models.

4.4 Problems during execution

A user may encounter problems during execution of the model. To determine the cause of these problems the following steps should be taken:

- check the amount of free memory (RAM), paging file, and hard disk space;
- run the "Debug" version of the executable if that has not been done recently;
- inspect the reported errors in the files INFO_TIM.OUT, INFO_SIM.OUT and INFO_SVAT.OUT*.* Open these files, read the (last) lines in the file and try to determine if there is a mistake in the input file. The log-files are:
    - INFO_SIM.OUT: This file contains the SIMGRO-log of running MODFLOW-SIMGRO.EXE. It is recommended to always consult this file. Several checks will be done while reading the input-files. Warnings and errors are written. These warnings will not cause the programme to stop, but can be of help in preventing wrong input.
    - INFO_SVAT.OUT: This files contains the error messages of the soil moisture module.
- check if there are **tabs** in the input files or check the positions in the input file. Check if there are empty lines at the end of your input file.

It is important to check that SIMGRO has ended due to the end-call of MODFLOW, and not due to a crash. The latter can for instance happen if the file with meteorological data does not continue to the next day after the end time of the run.

Literature

Van Walsum, P.E.V., A.A. Veldhuizen, P.J.T. van Bakel, F.J.E. van der Bolt, P.E. Dik, P. Groenendijk, E.P. Querner, M.F.R. Smit, 2010. *SIMGRO 7.0; Description of theory and model implementation.* Wageningen, Alterra, Alterra-rapport 913.1.

Van Walsum, P.E.V, 2010. *SIMGRO Input and output reference manual.*. Wageningen, Alterra, Alterra-rapport 913.3.

Appendix A PreMetaSWAP

1 Program use

PreMetaSWAP is a program that processes soil physical parameters and generates files necessary for running MetaSWAP. The program consists of a single executable, PreMetaSWAP.exe. The processing is done in a three major of steps:

1. Conversion of input files to intermediate file PreMetaSWAP.key.
2. Steady-state simulations for various soil types, root zone depths, and boundary condtions.
3. Construction of the metafunctions needed for running MetaSWAP.

The steps are performed after each other without any intervention of the user needed.

For running the program the following subdirectories of the work directory should be available:

- **bat**, containing the command file
- **exe**, containbing the executable
- **inp**, containing the input files
- **csv**, containing results of steady state simulations, for inspection by the user
- **out**, containing the output files for use by MetaSWAP
- **log**, containing the log files

This subdirectory structure is already present in the zip-file of the program and example files.

To run the program the files listed in Table 1 should be available. The contents of the files are explained along with the format in chapter 2. The bat-file in the bat-subdirectory can be double-clicked.

Table 1.1. List of input files

Name fo file	Description
COMP_SWAP.CSV	List of compartment thicknesses in vertical profile
FEDDES_SWAP.CSV	parameters of transpiration reduction function
TAUFUNC_SWAP.CSV	function for the distribrution of the root extraction over the root zone depth
HZN_SWAP.CSV	soil horizons used as building blocks of soil physical units
SPU_SWAP.CSV	definitions of soil physical units
BOX_SWAP.CSV	definitions of aggregation boxes
ROOTD_SWAP.CSV	root depths for simulations
GWL_SWAP.CSV	groundwater levels for simulations
QTOP_SWAP.CSV	infiltration fluxes for simulations
TPOT_SWAP.CSV	potential transpiraiton rates for simulations

The program produces the output files listed in Table 2. The output files are documented in chapter 3.

Table 1.2. List of output files

Name fo file	Description
\LOG\PREMETASWAP.LOG	over-all log ile
\LOG\SWAPSS.CSV	log of SWAPsteady simulations
\LOG\PREMETASWAP.KEY	intermediate key file containing overview of input data
\CSV\PRHEAD_SPU00001 - \CSV\PRHEAD_SPU<NUMSPU>	series of files with pressure head profiles for a certain soil physical unit
\CSV\WATCON_SPU00001 \CSV\WATCON_SPU<NUMSPU>	series of files with water content profiles for a certain soil physical unit
\OUT\UNSA_SOIL.INP \OUT\UNSA_SOIL.BDA	saturated water contents, used by MetaSWAP in determining output for groundwater as a system volume
\OUT\UNSA_SVAT.INP \OUT\UNSA_SVAT.BDA	database of metafunctions, ASCII format and binary direct acces format, for use by MetaSWAP
\OUT\UNSA_POST.INP \OUT\UNSA_POST.BDA	database of metafunctions, ASCII format and binary direct acces format, for use by PostMetaSWAP

2 Input file descriptions

The specification for the input file descriptions is tabulated below. In the subsequent sections the files are described and in all cases examples are included. If necessary, descriptions are clarified through additional remarks.

Table 2.1 Input item characteristics

Item	Description
Name	name of the parameter or variable
Format	input format
Unit	unit of the input parameter or variable
Description	brief description of the parameter or variable
Min.	minimum value allowed
Max.	maximum value allowed

2.1 COMP_SWAP.CSV

Variable format and description

name	Format	unit	description
cp	I	-	compartment index
thickns	F	m	thickness of compartment

Variable characteristics

name	min	max
cp	1	-
thickns	0.010	10.00

Example

cp	thickns
1	0.010
2	0.010
3	0.010
4	0.010
5	0.010
6	0.025
7	0.025
8	0.025
9	0.025
...	...

Remarks

The sum of the compartment thicknesses should be exactly equal to 100 m. (For other depths of the profile please consult Alterra). Any number of compartments can be used.

2.2 FEDDES_SWAP.CSV

Variable format and description

name	Format	unit	description
hlim1	F	cm	no water extraction at higher pressure heads
hlim2u	F	cm	h below which optimum water uptake starts for top layer
hlim2l	F	cm	h below which optimum water uptake starts for sub layer
hlim3h	F	cm	h below which water uptake reduction starts at high Tpot
hlim3l	F	cm	h below which water uptake reduction starts at low Tpot
hlim4	F	cm	wilting point, no water uptake at lower pressure heads
adcrh	F	$cm\ d^{-1}$	level of high atmospheric demand
adcrl	F	$cm\ d^{-1}$	level of low atmospheric demand

Example

vert_nod	th_vert_nod
200	hlim1
200	hlim2u
200	hlim2l
-800	hlim3h
-1000	hlim3l
-17000	hlim4
0.50	adcrh
0.10	adcrl

Remarks

The given values should cover the full range of possible values for different crops; for these the user is referred to the SWAP documentation. It is advised to **not change** the values that come along with the example files.

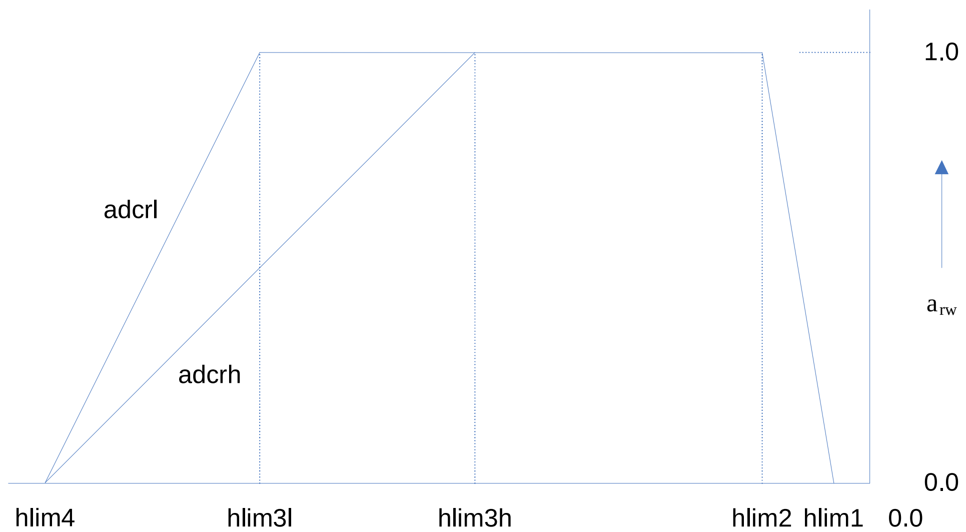

Figure 2: Reduction coefficient for root water uptake α, as function of soil water pressure head *h* and potential transpiration rate Tpot (after Feddes et al, 1978).

2.3 TAUFUNC_SWAP.CSV

Variable format and description

name	Format	unit	description
i	I	-	index of function value
d/rootd	F	-	relative depth within the root zone
τ*rootd/Tpot	F	-	relative extraction intensity

Variable characteristics

name	min	max
i	2	-
d/rootd	0.0	1.0
τ*rootd/Tpot	0.0	1.0

Example

pair	d/rootd	τ*rootd/Tpot
1	1.00	1.00
2	0.50	0.50
3	0.00	0.00

Remarks

The τ-function specifies the manner in which the root extraction is distributed over the depth. Any number of function values can be given; the value of [d/rootd] should increase with [i]. Only the relative values are important. The normalization is done by the program.

2.4 HZN_SWAP.CSV

Variable format and description

name	Format	unit	description
soilhzn	A	-	id of soil horizont
omac	F	$cm^3\ cm^{-3}$	macro-porosity in the form of added storage
ores	F	$cm^3\ cm^{-3}$	residual water content
osat	F	$cm^3\ cm^{-3}$	saturated water content
ksat	F	$cm\ d^{-1}$	saturated hydraulic conductivity
alfa	F	cm^{-1}	shape parameter of main drying curve
npar	F	-	shape parameter of main drying curve and main wetting curve
lexp	F	-	exponent hydraulic conductivity function
psand	F	%	sand weight percentage
psilt	F	%	silt weight percentage
pclay	F	%	clay weight percentage
orgmat	F	%	organic matter weight percentage

Example

soilid	omac	ores	osat	ksat	alfa	npar	lexp
B1	0.0000	0.0200	0.4300	23.4100	0.0234	1.8010	0.0000
O1	0.0000	0.0100	0.3600	15.2200	0.0224	2.2860	0.0000

Remarks

HZN_SWAP.CSV is used to define characteristics for each horizon. Translation to MetaSwapKey is in combination with input file SPU_SWAP.CSV.

The weight fractions are converted to volumetric fractions by premetaswap.

In the current model version the macro-porosity only serves to increase the storage capacity; it does not have any flow function. This porosity is only filled with water below the groundwater level.

2.5 SPU_SWAP.CSV

Variable format and description

name	Format	unit	description
spu	I9	-	id of soil physical unit
ly	I9	-	number of layer
dp_ly	F9.2	m b.s.s.	depth of new layer
soilhzn	A4	-	id of soil horizont

Variable characteristics

name	min	max
spu	1	-
ly	1	-
dp_ly	0	-

* depending on thickness of SWAP compartments (COMP_SWAP.CSV)

Example

spu	ly	dp_ly	soilhzn
1	1	0.35	B18
1	2	110.00	O17
2	1	0.20	B2
2	2	0.70	O16
2	3	110.00	O2

2.5 BOX_SWAP.CSV

Variable format and description

name	Format	unit	description
spu	I	-	id of soil physical unit
thickness_box2	F	m	thickness of box 2
hbot_box3	F	m b.s.s.	bottom of box 3
..	F		
hbot_box*N*	F	m b.s.s.	bottom of box *N*

Variable characteristics

name	min	max
spu	1	-
thickness_box2	0.05	-
hbot_box*N*	5	100

* depending on thickness of SWAP compartments (COMP_SWAP.CSV)

The bottom of box 3 should be at least one SWAP-compartment lower than the maximum root zone thickness plus the thickness of box 2. The latter should be determined via calibration on the SWAP model, for which a special test suite exists.

2.6 ROOTD_SWAP.CSV

Variable format and description

name	Format	unit	description
ird	I	-	index of rootzone thickness
rootd	F	m	thickness of rootzone

Variable characteristics

name	min	max
ird	1	-
rootd	0.05	-

Example

ird	rootd
1	0.05
2	0.10
3	0.15
4	0.20
5	0.25
6	0.30
7	0.35
8	0.40
9	0.45
10	0.50
11	0.60
12	0.70

2.7 GWL_SWAP.CSV

Variable format and description

name	Format	unit	description
i	I	-	index of groundwater level
gwl	F	m	groundwaterlevel (zero = soil surface)

Variable characteristics

name	min	max
i	1	-
gwl	-100.	-0.02

Remarks
This input file is not yet open to modification by the user; it should contain the 52 levels that are supplied along with the example.

2.8 QTOP_SWAP.CSV

Variable format and description

name	Format	unit	description
i	I	-	index
qtop	F	mm/d	potential infiltration at soil surface

Variable characteristics

name	min	max
i	1	-
qtop	-500	0.0000

Example

i	qtop
1	-500
2	-460
3	-420
4	-380
5	-340
6	-300
7	-280
8	-260
9	-240
10	-220
..	..
50	0

Remarks

The value of zero should be included as the last value.

2.9 TPOT_SWAP.CSV

Variable format and description

name	Format	unit	description
i	I	-	index
Tpot	F	mm/d	potential evapotranspiraiton

Variable characteristics

name	min	max
i	1	-
Tpot	0.00	-

Example

i	Tpot
1	0.000
2	0.005
3	0.010
4	0.020
5	0.030
6	0.040
7	0.050
8	0.060
9	0.070
10	0.080
11	0.090
12	0.100

Remarks

The first value should be zero.

3 Output files

The output files UNSA*.* are documented in the IO-manual. An example is available via the ftp-site of Alterra.

The binary files (*.BDA) are the preferred option to use in combination with the model, because the access is much faster. However, the SIMGRO program should be compiled with the same Fortran compiler as the PreMetaSWAP, otherwise incompatibility can occur. In that case the ASCII files (*.INP) can be used instead. These files are also useful for inspecting the data. If the file is too large for loading in memory, then the head of the file should be transferred to a .TMP file by shortly running the type command in a dos-box, and redirecting the output with ‘>’.

The CSV-files contain the simulated profiles.

Appendix B PostMetaSWAP

1 Program use

PostMetaSWAP2TRANSOL is a program that disaggregates the output of MODFLOW-SIMGRO. The default output consists of a series of SWATRE*.UNF files that can be used in water quality simulations.

To run the program the files listed in Table 1 should be available.

Table 1.1. List of input files

Name fo file	Description
UNSA_POST.BDA	extended database produced by PreMetaSWAP
SVAT_PER.UNF	database file produced by MODFLOW-SIMGRO by setting the *svat_per_unf* parameter to 1 in PARA_SIM.INP (undocumented file)
COMP_POST.CSV	list of desired compartment thicknesses in vertical profile (see Section 2.1 of this Appendix)
SEL_SVAT.INP	selection of SVAT's that should actually be processed (see Section 2.2 of this Appendix)
SEL_SVAT_CSV.INP	selection of SVAT's for which extra output will be supplied in the form of csv files of head, moisture content, and temperature
WRITECONTROL.INP	file for control of programme action (example given below)

The program produces by default the output files listed in Table 2. An example of the WRITECONTROL.INP file:

```
-----------------------------------------------------------------------------------------------------------
 .true.     ! write2file   : optional output to SWATRE.* files
 .false.    ! dotransol  : optional simulation of transport of solutes
 .true.     ! dotemp     : optional simulation of temperature
  " "        ! unsa_path : path of soil database;  " " = work dir;   end path with "\"
-----------------------------------------------------------------------------------------------------------
```

Table 1.2. List of output files

Name fo file	Description
SWATRE_*.UNF	unformatted files per MetaSWAP columns, with disgaggregated moistire profiles
SWATRE_*.OUT	ascii version of files

The running of the programme is done automatically in the T-Model example (Appendix C).

2 Input file descriptions

The specification for the input file descriptions is tabulated below. In the subsequent sections the files are described and in all cases examples are included. If necessary, descriptions are clarified through additional remarks.

Table 2.1 Input item characteristics

Item	Description
Name	name of the parameter or variable
Format	input format
Unit	unit of the input parameter or variable
Description	brief description of the parameter or variable
Min.	minimum value allowed
Max.	maximum value allowed

2.1 COMP_POST.CSV

Variable format and description

name	Format	unit	description
cp	I	-	compartment index
thickns	F	m	thickness of compartment

Variable characteristics

name	min	max
cp	1	-
thickns	0.010	10.00

Example

cp	thickns
1	0.010
2	0.010
3	0.010
4	0.010
5	0.010
6	0.025
7	0.025
8	0.025
9	0.025
...	...

Remarks

The thicknesses should comply with two requirements:

- the sum of the compartment thicknesses should be exactly equal to 100 m;
- the compartments should be an aggregation of the compartments used in the pre-processing.

A maximum of 100 compartments can be used.

2.2 SEL_SVAT.INP

The file SEL_SVAT.INP selects the SVATs for which output is actually processed.

Variable format and description

col	format	name	unit	description
1-10	I10	svat	-	SVAT unit for which data are processed

Remarks

If the file SEL_SVAT.INP is not present *none* of the SVATs are selected.

3 Output files

The format of the SWATRE*.* output files is described in the ANIMO manual, included in the docs-subdirectory of SIMGRO and the T-Model-Basic example.

Appendix C Demonstration dataset

1 T-model_Basic

The so-called T-model_Basic has a rectangular model area, involving 110 SVAT units as numbered in Figure 1. The SVATs are mapped to surface water locations 1-21. But these locations are not coupled to a surface water model in this basic example. That means that if there is demand of sprinkling from one of these locations, the supply is assumed to always be available.

The data of the demo-set have been structured with the following subrdirectories (alphabetical order):
- **apr**, with the ArcView project file;
- **bat**, with the command files; the model can be run by simply double-clicking on the **modflow-simgro.bat** file;
- **cov**, with the shape files and grids;
- **exe**, with the executables
- **inp_modflow** and **inp_simgro**, with the input files
- **log,** with the log files;
- **out_modflow** and **out_simgro** with the output files

The out_simgro subdirectory has four subdirectories:
- **asc**, with the grids that can be imported;
- **bda**, with the output database files;
- **csv**, with the output csv-files;
- **unf,** with the disaggregated soil moistire profiles for use by water quality models

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100
101	102	103	104	105	106	107	108	109	110

Figure 1. SVAT units

The MODFLOW model has a single layer aquifer that is simulated with the BCF-package. The initial groundwater level is set at 10 m. The head boundary condition is also set at 10 m. The model contains just one phreatic layer, with its bottom at a level of -100 m. The conductivity is set at 1 m/d, so the *kD*-value is around 110 m2/d.

The surface elevation of the SVAT's varies as shown in Figure 2. Three of the SVAT's have been given a spinkling capacity:

- 45, with a sprinkling capacity from surface water; the sprinkling is triggered by the file FXSP_SVAT.INP;
- 95, with a sprinkling capacity from surface water, the sprinkling is triggered by the pressure head;
- 105, with a sprinkling capacity from groundwater, the sprinkling is triggered by the pressure head.

In the case of SVAT number 95 the triggered sprinkling is applied during two days, as can be seen in the output file svat_dtgw_0000000095.csv. The reason for not applying it in a single day is that the model has first to 'ask' the surface water location if the water is available. The water can then only be really applied during the next dtsw-time step of the 'fast' model cycle, so there is a delay in the demand realization. A single dtgw-step of 1 day consists of 4 dtsw steps of 0.25 day. So the demand of the fourth dtsw-step is realized the next dtgw, involving a quarter of the 25 mm that is specified in the file luse_svat.inp as the sprinkling amount, with an application duration of 1 d.

Examples of model output are displayed in the ArcView project that is supplied with the demo-data.

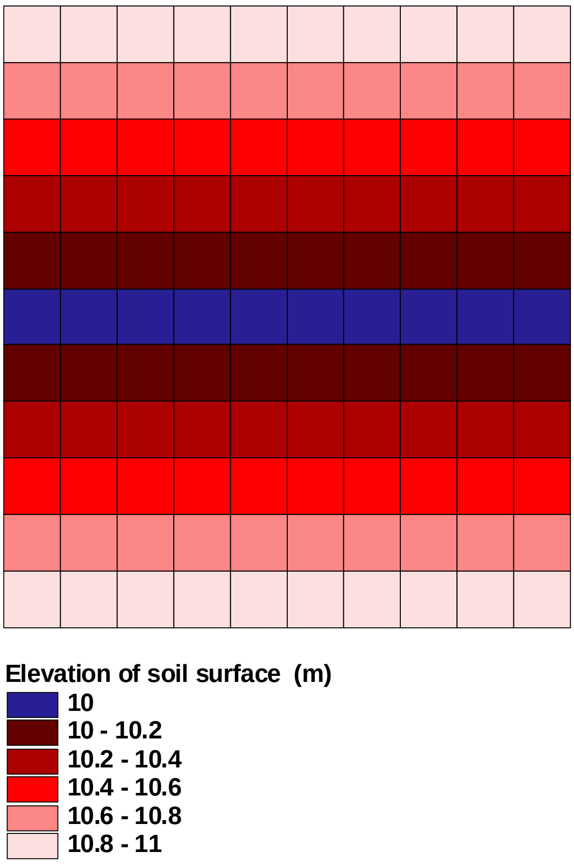

Figure 2. Soil surface elevation