Land routines

This section explains the computations in the land routines of HYPE. If you want an interactive overview of how the routines simulates runoff please have a look at the HYPE Runoff Explorer.

Basic assumptions

A subbasin in HYPE is divided into classes depending on land use, soil type etc. The classes are called SLC:s which stands for Soil type Land use Combination. This division can be compared to hydrological response units. Lakes and river is also classes, but this section consider only land classes.

HYPE model soil routine contains (up to) three soil layers. The number of soil layers and their respective lower limits (*soillayerdepth* in meters, figure 1) are listed by class in GeoClass.txt. It is possible to have a different number of layers and depth of these different classes.

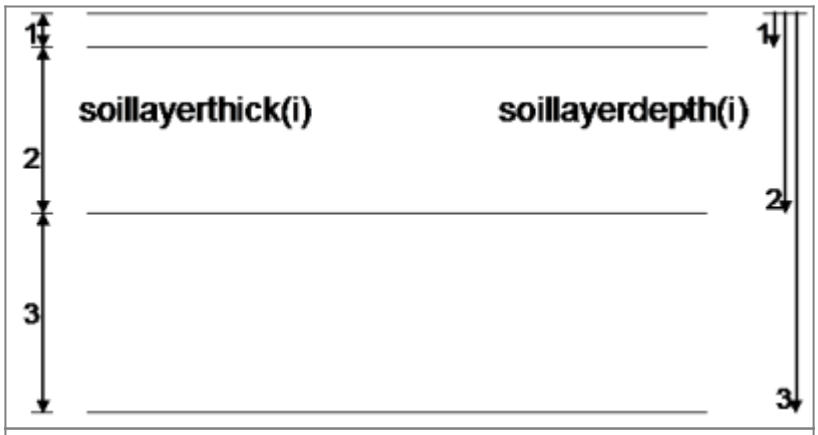


Figure 1: Soil layer with depth variables (m)

The parameters of water retention in the soil are wilting point (*wcwp*), field capacity (*wcfc*) and effective porosity (*wcep*). These are exclusive and are specified in units of depth (figure 2). The model allocates the water retention capacity evenly between soil layers, depending on their thickness, if only one value set. It is also possible to specify one value per parameter and layer. The model uses water holding capacity in mm for the layers. These are represented in the model code and this document (figure 3) as *wp(i)*, *fc(i)* and *ep(i)*. The model parameters for the water storage capacity *wcfc*, *wcwp*, *wcep* (and layer depending alternative *wcwp1*, *wcwp2*, *wcwp3*, *wcfc1*, *wcfc2*, *wcfc3*, *wcep1*, *wcep2*, *wcep3*) depend on soil type.

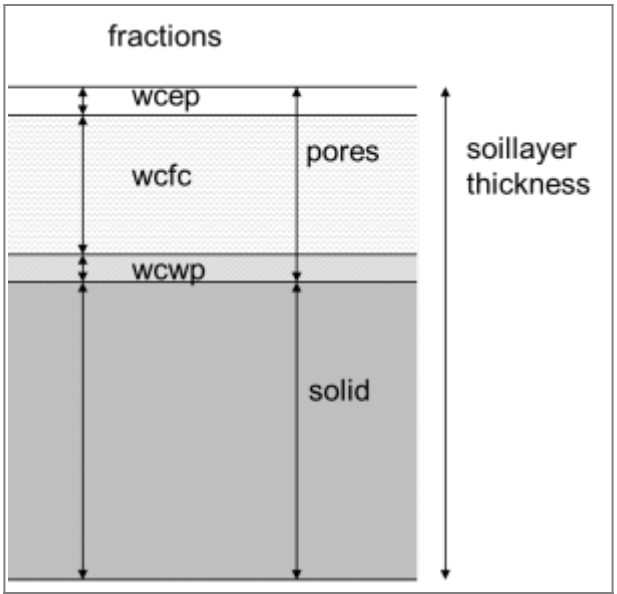


Figure 2: Water retention parameters.

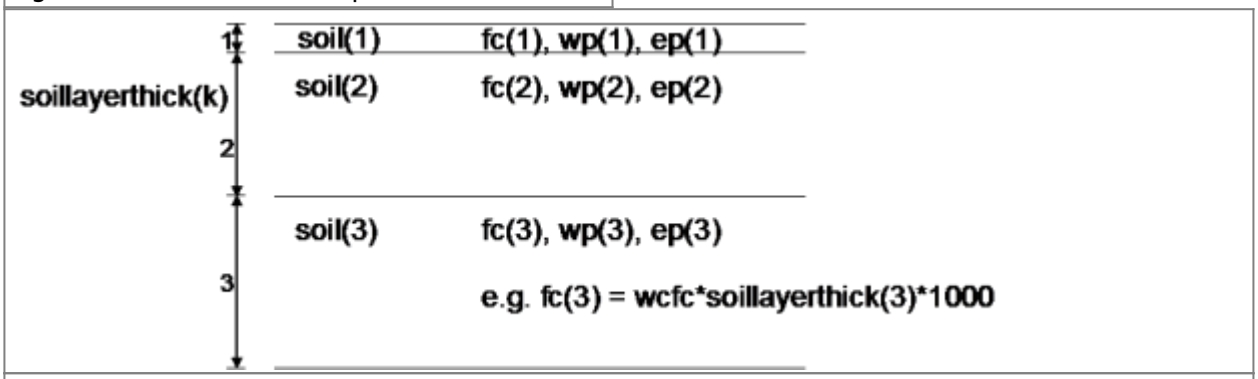


Figure 3: Soil layers water content (mm) and parameters of the water storage capacity (mm).

The soil layer water content (mm) is represented in the document as *soil(i)*, where i = layer, but the value also depends on the subbasin and class (figure 3). The initial value of soil water is set to *wp* + *fc*. Optionally the initial value may be set to saturation (*wp* + *fc* + *ep*). The upper soil layer can hold more water than the porevolume. Standing water is not treated as a separate pool.

Tile drainage can be placed in any soil layer (figure 4). The depth of the drainage pipe in meters (*tiledepth*) is specified in GeoClass.txt for each class. A depth of 0 m is interpreted as drainage pipes are missing.

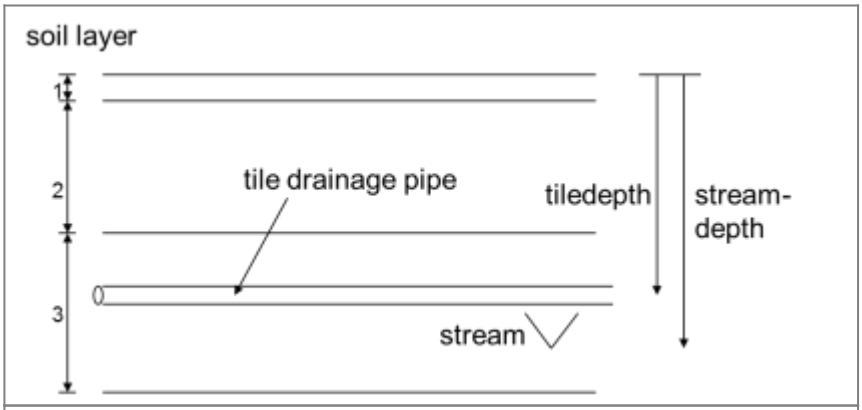


Figure 4: Drainage pipe and creek bottom in the third soil layer.

Another depth (*streamdepth*) is specified in GeoClass.txt; this is the maximum depth of the drainage to stream (or ditch). Soil water below this level does not contribute to the local runoff. Note that all

land runoff goes through the local river (and possibly local lake) and then the main river before it reaches the outlet lake. There is no direct runoff to lakes.

Overview of flow paths

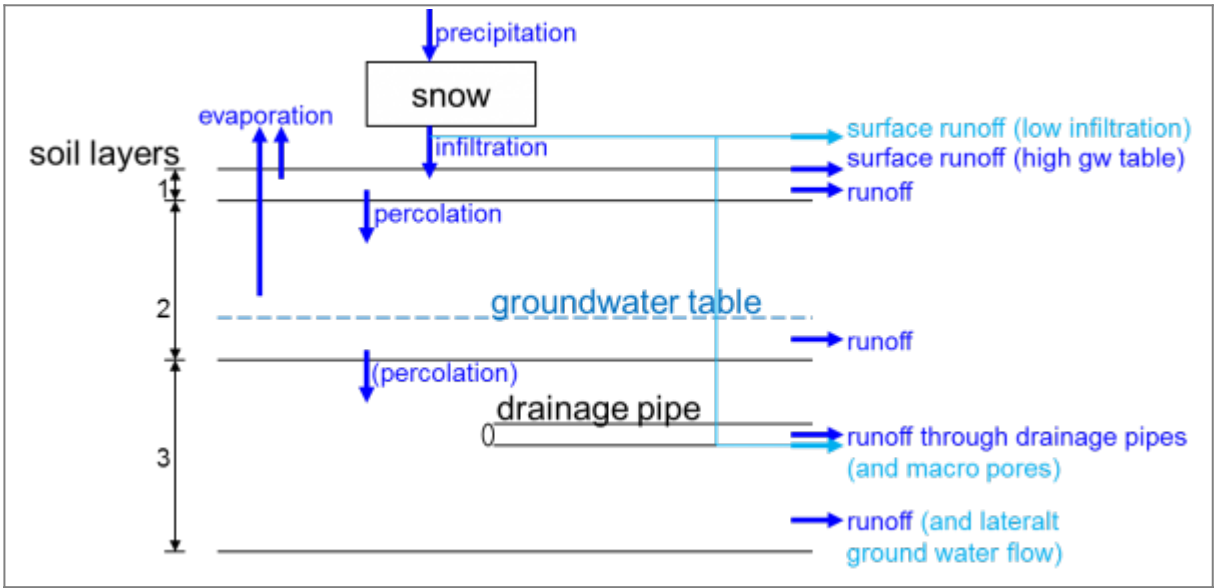


Figure 5: Illustration of flowpaths in the soil in the HYPE model.

Diagnostic variables

Some additional output variables are calculated from the soil state variables.

Groundwater level

The groundwater level is measured negative from surface (0m) to bottom of the soil layers. A positive groundwater level means that the soil surface is below water. If the ground water table reaches above the surface, the water is calculated with 100% porosity.

The water table is found in the lowest soil layer that is not completely filled with water. Soil layers above this layer may have water in its effective porosity, but that is not included in the groundwater level output variable. The water table for a soil layer is calculated linearly from the proportion of water-filled pores of effective porosity part of the soil pore volume. If the soil moisture of a soil layer is at field capacity (or below), the groundwater level of that soil layer is at the bottom of the layer. If the pore volume is filled, the groundwater level of that soil layer is at the top of the layer.

Soil moisture deficit

Soil moisture deficit (*smdf*) is calculated for the root zone, i.e. the upper two soil layers. It is the water (in *mm*) needed to fill the soil (*soil*) to field capacity (*wp+fc*).

$$smdf = \sum_{k=1}^{2} MAX\left\{ fc_k + wp_k - soil_k,\ 0 \right\}$$

Frost depth

Ground frost depth (which is only calculated if the soil temperature is less than zero) depends on soil temperature (*soiltemp*), but also on soil water content (*soil*), field capacity (*fc*), wilting point (*wp*) and two parameters *frost* and *sfrost*.

$$frostdepth = \frac{frost \times sfrost \times soiltemp \times \left(fc + wp \right)}{soil}$$

There are two parameters in order to be able to choose if you want the frost depth to be land use dependent or soil dependent. The not used parameter is set to one.

Links to file reference

Section	Symbol	Parameter/Data	File
Basic assumptions		*soillayerdepth, tiledepth, streamdepth*	GeoClass.txt
	soillayerthick	calculated from *soillayerdepth*	
	wp, fc, ep	calculated from *wcwp,wcfc,wcep,wcwp1-3,wcfc1-3,wcep1-3*	par.txt
Diagnostic variables		*frost,sfrost*	
	soiltemp	see needed data in Links for soil temperature	

Links to relevant procedures in the code

Modules (file)	Procedures	Section
soil_processes (soil_proc.f90)	initiate_soil_water_state	basic assumptions
	initiate_soil_water	
	calculate_groundwater_table	ground water level
	calculate_soil_moisture_deficit	soil moisture deficit
	calculate_frostdepth	frost depth

Soil water

Groundwater runoff

Runoff depends on the water table in relation to the drainage level. Runoff occurs when soil water reaches above field capacity in the soil layers. Runoff depends on soil water in the effective porosity (also used to calculate the groundwater table) and a recession coefficient (*rc*). If the soil is not saturated, runoff from the soil layer depends only on the water of that soil layer. Runoff occurs from all three soil layers (*runoff(k), k=1-3*) down to the drainage level, which is the depth of the stream (streamdepth).

$$runoff\left(k\right)=\begin{cases} rc\left(k\right)\times\left(soil\left(k\right)-wp\left(k\right)-fc\left(k\right)\right) & wp\left(k\right)+fc\left(k\right)<soil\left(k\right)<wp\left(k\right)+fc\left(k\right)+ep\left(k\right) \\ 0 & soil\left(k\right)<wp\left(k\right)+fc\left(k\right) \end{cases}$$

For the soillayer at drainage level, e.g. in the third layer of figure 6, and if the soil layer is not saturated, the runoff depends on the water level above the stream depth and the following equation replaces the one above.

$$runoff\left(k\right)=\begin{cases} rc\left(k\right)\times\dfrac{deltah\times ep\left(k\right)}{soillayerthick\left(k\right)} & deltah>0 \\ 0 & deltah<0 \end{cases}$$

where

$$deltah=\frac{\left(soil\left(k\right)-wp\left(k\right)-fc\left(k\right)\right)}{ep\left(k\right)}\times soillayerthick\left(k\right)-\left(soillayerdepth\left(k\right)-streamdepth\right)$$

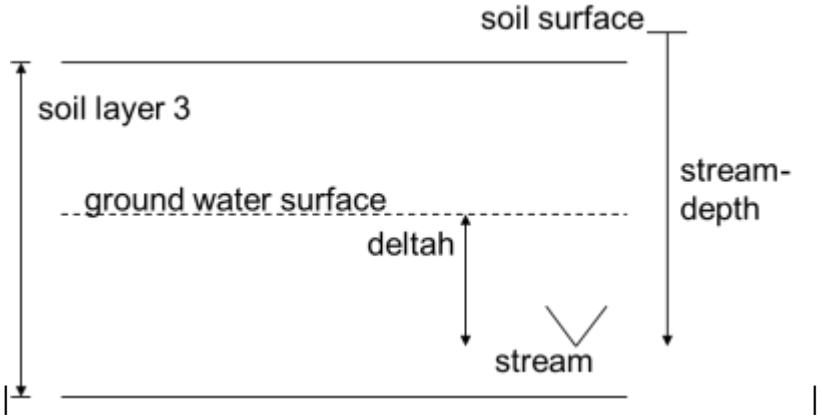


Figure 6: Runoff from the third soil layer with a stream.

Soil layers that lye entirely below the stream depth have no groundwater runoff.

If a soil layer is saturated, i.e. *soil*>=*fc*+*wp*+*ep*, the runoff of the soil layer depends also on the water in the soil layer(s) above. For example if the drainage is in soil layer 3 and both soil layer 2 and 3 are saturated, the groundwater table in soil layer 1 determines the runoff of soil layer 3. The runoff is limited to the water above field capacity in the third layer though.

$$runoff\left(3\right)=MIN\left(soil\left(3\right)-wp\left(3\right)-fc\left(3\right),rc\left(3\right)\times\frac{deltah}{soillayerthick\left(3\right)}\times ep\left(3\right)\right)$$

$$deltah = \frac{\left(soil\left(3\right) - wp\left(3\right) - fc\left(3\right)\right) \times soillayerthick\left(3\right)}{ep\left(3\right)} - \left(soildepth\left(3\right) - streamdepth\right) + \frac{\left(soil\left(2\right) - wp\left(2\right) - fc\left(2\right)\right) \times soillayerthick\left(2\right)}{ep\left(2\right)} + \frac{\left(soil\left(1\right) - wp\left(1\right) - fc\left(1\right)\right) \times soillayerthick\left(1\right)}{ep\left(1\right)}$$

If the stream depth is below the bottom of the lowest soil layer. The extra distance will act as a level to increase *deltah* and the runoff from the lowest soillayer.

Recession coefficient of groundwater runoff

The recession coefficient is calculated from two parameters, *rrcs1* and *rrcs2* which depend on soil type and a parameter that is general *rrcs3*. The recession coefficient is assumed to decrease with depth and the parameters indicate the coefficient value in the topmost layer (*rrcs1*) and in the bottom layer (*rrcs2*). If *rrcs2* is not specified it is assumed to be similar to the recession in the topmost layer. The third parameter adjusts the upper layer recession due to the subbasin gradient (*slope*).

$$rrcs1 = rrcs1 \times \left(1 + rrcscorr\right) + rrcs3 \times slope$$

$$rrcs2 = rrcs2 \times \left(1 + rrcscorr\right)$$

The correction factor corrects *rrcscorr* parameters *rrcs1* and *rrcs2* for different parameter regions (*parreg*). It is defined as an increase. Note that the recession is limited to one. The recession is assumed to diminish exponentially and values of *rrcs1* and *rrcs2* applies to the midpoint of each layer (d_k).

$$rc\left(k\right) = rrcs \times e^{-b \times d_k}$$

The variable *b* is an auxiliary variable.

$$b = \frac{\log\left(\frac{rrcs1}{rrcs2}\right)}{\left(soillayerdepth\left(3\right) - \frac{soillayerthick\left(3\right)}{2}\right) - \frac{soillayerthick\left(1\right)}{2}}$$

The result is:

$$rc\left(1\right) = rrcs1$$

$$rc\left(2\right) = rrcs1 \times \exp\left(-b \times \left(\frac{soillayerthick\left(1\right)}{2} + \frac{soillayerthick\left(2\right)}{2}\right)\right)$$

$$rc\left(3\right)=rrcs2$$

Runoff through drainage pipes

Runoff in the drainage pipes occurs when the water table (the percentage of filled pores of the effective porosity) rises above the pipe's depth (figure 7). Runoff depends on the groundwater surface elevation over the pipe (*deltah*, m), and a recession coefficient *trrcs*. Recession parameter *trrcs* depends on soil type, while drainage pipe level depends on the class. The recession parameter is adjusted with the correction parameter *rrcscorr* for different parameter regions (*parreg*). It is defined as an increase.

$$trrcs=trrcs\times\left(1+rrcscorr\right)$$

Depending on which soil layer drainage pipe is in, the runoff will be calculated for water in that soil layer. For the soil layer *k* (*soil(k)* is the water content in soil layer *k*) runoff is calculated as the parameter *trrcs* times the water found in the effective porosity of the layer and of the overlying soil layers if it is full.

```
deltah = (soil(k)-wp(k)-fc(k))/ep(k) * soillayerthick(k) -
         (soillayerdepth(k) - tiledepth)
IF(soil(k)-wp(k)-fc(k)-ep(k)>=0.) deltah= deltah + (soil(k-1)-wp(k-1)-
                                fc(k-1))/ep(k-1) * soillayerthick(k-1)
IF(deltah>0.)
  runoffd = trrcs * deltah / soillayerthick(k) * ep(k)
```

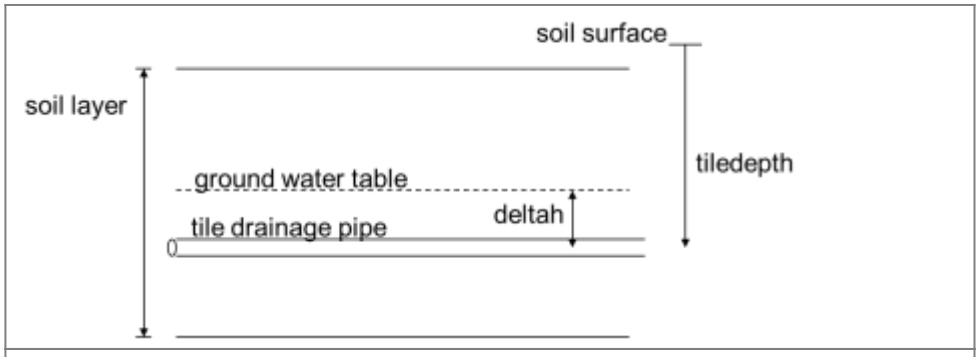


Figure 7: Illustration for calculation of runoff through the drainage pipes.

Infiltration

Infiltration is calculated from the sum of rain and snowmelt (*infilt0*, mm/time step) .

$$infilt0=rainfall+melt$$

Part of the available water for infiltration (*infilt0*) may not infiltrate into the soil, due to limitations by the soil's infiltration capacity and other properties of the soil. The calculation of actual infiltration will consider effects of surface runoff, macropore flow and frozen soil. If the finally calculated infiltration is greater than zero, it is added to the upper layer soil water. This is done regardless of whether there is space in the soil pores there or not. If the water exceeds the water pore volume it is assumed to lie on the ground, but it still belongs to the upper soil layer, is totally mixed and thus has the same concentrations.

HYPE has an option for alternative calculation order of soil processes during a timestep. As default it calculates and add infiltration (and let the soil water percolate) before runoff and evaporation is calculated and removed from the soil water. Alternatively runoff and evapotranspiration is calculated before infiltration and percolation to slow the response of soil runoff. These options is tested during development of the soil routine.

Diversion of surface runoff and macropore flow

Surface runoff due to excess infiltration and macropore flow are calculated from the sum of snow melt and rainfall; the water available for infiltration (*infilt0*).

If the current infiltration rate is greater than a threshold (*mactrinf*, mm/timestep) then macropore flow (*macroflow*) and surface runoff (*infoverflow*) may occur. In addition, the water in the upper soil layer needs to be larger than another threshold (*mactrsm*) for surface runoff and macropore flow to occur. The two flows are calculated as a percentage (*macrate* respective *srrate*) of the infiltration above the first threshold;

$$macroflow = macrate \times \left(infilt0 - mactrinf \right)$$

$$infoverflow = srrate \times \left(infilt0 - mactrinf \right)$$

All the four aforementioned parameters are soil type dependent. If *macrate* and *srrate* together are greater than one, they are weighted so that their sum is one prior to calculation of the surface runoff and macropore flow;

$$macroflow = \left(\frac{macrate}{macrate + srrate} \right) \times \left(infilt0 - mactrinf \right)$$

$$infoverflow = \left(\frac{srrate}{macrate + srrate} \right) \times \left(infilt0 - mactrinf \right)$$

The actual infiltration is calculated by subtracting the macropore flow and surface runoff from the sum of snow melt and rain.

$$infilt = infilt0 - macroflow - infoverflow$$

Additional infiltration limitation by frozen soil

An optional model for infiltration limitation and diversion of flow considers the effect of frozen soil. It is developed based on Zhao and Gray (1999). This model redirects all or part of the remaining infiltration, after calculating the diversion of surface runoff and macropore flow as described above.

If the minimum daily temperature is less than 10 degrees and the infiltration is larger than 5mm/d an ice lens is created in the soil. In this case, and as long as the maximum daily temperature is below zero, the ice lens redirect all infiltration to surface runoff and macropore flow.

$$redirect = infilt$$

If there is no ice lens, but the soil temperature of the upper soil layer (*soiltemp*) is below zero the infiltration is restricted but not blocked. The infiltration is restriced by a potential infiltration adapted from Zhao and Gray (1999). The potential infiltration (*potinfilt*) depends on a model parameter (*bfroznsoil*) that is soil type dependent. It also depend on the “opportunity time” (*t0*), which is an estimate of the time with possible infiltration in hours;

$$potinfilt = \begin{cases} 0 & for\ soil \geqslant pw \\ \dfrac{bfroznsoil \times 0.99^{2.92} \times \left(1 - \frac{soil}{pw}\right)^{1.64} \times \left(\frac{0 - soiltemp}{273.15}\right)^{-0.45} \times to^{0.44}}{\frac{to}{24}} & for\ soil < pw \end{cases}$$

$$to = \begin{cases} 1 & for\ 0.65 \times snow < 6 \\ 0.65 \times snow - 5 & for\ 0.65 \times snow > 6 \end{cases}$$

Here *soil* is soil water of the upper soil layer (mm), *pw* is pore volume of the upper soil layer (mm) and calculated from the model parameters for water holding capacity (*wcwp*, *wcfc* and *wcep*), and *snow* is snow water equivalent (mm).

If the actual infiltration is greater than the potential infiltration then the overshoot is redirected to surface runoff and macropore flow.

$$redirect = infilt - potinfilt$$

The here redirected infiltration is added to the macropore flow and overland flow of the basic model proportionally to their respective model parameters (*macrate* and *srrate*).

$$macroflow = macroflow + \left(\frac{macrate}{macrate + srrate}\right) \times redirect$$

$$infoverflow = infoverflow + \left(\frac{srrate}{macrate + srrate}\right) \times redirect$$

Percolation

The flow of water downward through the soil layers is only done by water over field capacity (water in the effective porosity). A maximum percolation (mm/d) limits the flow between soil layers. For the upper soil layer it is *mperc1*, and for the second soil layer it is *mperc2*. These parameters are soil type dependent. Flow is also limited by how much water the lower layer can receive.

Drainage from soil layer 1 to soil layer 2 is

$$perc1x = MIN\left(\left(soil\left(1\right) - wp\left(1\right) - fc\left(1\right) \right), mperc1 \right)$$

but if there is not enough capacity in soil layer 2 the drainage is instead

$$perc1 = wp\left(2\right) + fc\left(2\right) + ep\left(2\right) - soil\left(2\right) + perc2$$

and fills the second soil layer.

Drainage from soil layer 2 to soil layer 3 can be at most

$$perc2x = MIN\left(wp\left(3\right) + fc\left(3\right) + ep\left(3\right) - soil\left(3\right), mperc2 \right)$$

for that is what the soil layer 3 can receive. If soil layer 2 does not reach field capacity with *perc1x* added

$$perc2 = 0$$

but if soil layer 2 with *perc1x* added exceeds field capacity

$$perc2 = MIN\left(soil\left(2\right) + perc1 - wp\left(2\right) - fc\left(2\right), perc2x \right)$$

Regional groundwater flow is created by additional percolation from soil (see Section on Regional groundwater flow).

Upwelling

Flow may enter the lowest soil layer, i.e. regional groundwater flow. Upwelling to soil layers above may occur if the soil layer is filled.

Saturated surface runoff

Surface runoff due to a high ground water table (q, mm/time step) occurs when the water table in the upper soil layer reaches above the surface. It depends on a parameter *srrcs* which is dependent on land use. The recession parameter is corrected with the correction factor *rrcscorr* for different parameter regions (parreg). It is defined as an increase.

$$srrcs = srrcs \times \left(1 + rrcscorr\right)$$

$$q = MAX\left(srrcs \times \left(soil\left(1\right) - wp\left(1\right) - fc\left(1\right) - ep\left(1\right) \right), 0. \right)$$

Runoff is removed from the uppermost soil layer. The total surface runoff (due to high ground water table and low infiltration capacity) is calculated and printed.

Macropore flow

Macropore flow occurs when the potential infiltration and water in the upper soil layer is large (see Diversion of surface runoff and macropore flow above). It is caused by a limited infiltration capacity of the soil. Macropore flow (*macroflow*) is added to the layer in which the water table is located (see Diagnostic variables above). The water is added to this layer only until it is full and the excess is trapped in the layer above.

Thus water does not flow up into the layer above when macropore flow is larger than the empty space in the soil layer with the water table, as in the case of groundwater inflow. Instead the excess flow stays in the soil layer above before reaching the soil layer of the water table. This distinction is important for the substances following the macropore flow.

References

Zhao, L., and D.M. Gray 1999. Estimating snowmelt infiltration into frozen soils, Hydrological Processes, 13:1827-1842.

Links to file reference

Section	Symbol	Parameter/Data	File
Groundwater runoff	*wp, fc, ep*	calculated from *wcwp,wcfc,wcep,wcwp1-3,wcfc1-3,wcep1-3*	par.txt
		rrcs1, rrcs2, rrcs3, rrcscorr	
		soillayerdepth, streamdepth, tiledepth	GeoClass.txt
	soillayerthick	calculated from *soillayerdepth*	
	slope	*slope_mean*	GeoData.txt
		parreg	
Runoff through drainage pipes		*trrcs*	par.txt
Infiltration		*mactrinf, mactrsm, macrate, srrate, bfroznsoil*	par.txt
	pw	calculated from *wc+fc+wp*	
Percolation		*mperc1, mperc2*	par.txt
Saturated surface runoff		*srrcs*	par.txt

Links to relevant procedures in the code

Modules (file)	Procedures	Section
soil_processes (soil_proc.f90)	initiate_soil_water	groundwater runoff
	calculate_soil_runoff	
	calculate_tile_drainage	runoff thorugh drainage pipes
	infiltration	diversion of surface runoff and macropore flow, infiltration
	percolation	percolation
	add_macropore_flow	macropore flow
general_water_concentration (general_wc.f90)	inflow_lowest_soillayer	upwelling

Snow routines

Snow melt

As default, snow melting occurs when the temperature is greater than the threshold temperature. The amount of snow (in mm) that melts (*melt*) depends on the snowmelt parameter *cmlt*, threshold temperature parameter *ttmp* and air temperature (*temp*).

$$melt = MIN\left(cmlt \times \left(temp - ttmp \right), snow \right)$$

The parameters *cmlt* and *ttmp* are related to land use.

Snow melt models

Alternative snowmelt models exist, but are not fully described here yet.

Model 0 (default)

Temperature index model, without snow cover scaling

$$melt = MIN\left(cmlt \times \left(temp - ttmp \right), snow \right)$$

Model 1

Temperature index model, with snow cover scaling

$$melt = MIN\left(cmlt \times \left(temp - ttmp \right), snow \right) \times snowcover$$

Model 2

Temperature and radiation index model, with snow cover scaling

Snow cover

Normally snow is assumed to cover the whole class if present. Alternatively if parameters are given, snow cover fraction (*fsc*) within a class is calculated based on snow water equivalent (*snow*). The formulation is based on Samuelsson et al. (2006). During snow build up the snow cover increase as a function of snow water equivalent until a maximum value (general parameter *fscmax*) is reached.

$$fsc = fscmax \times \tanh\left(0.1 \times snow\right)$$

It is also possible to specify a minimum snow cover (general parameter *fscmin*). As soon as the fractional snow cover area reaches above a certain threshold (*fscmax-fsclim*), the snow cover area is determined by another relation that represents the redistribution of snow during winter. In this case snow cover is dependent on maximum snow pack during the winter (*snowmax*) and a snow cover redistribution factor that is dependent on variation in elevation (*stdelev*, the standard deviation of elevation within the subbasin) and land use.

$$fsc = \frac{snow}{snowmax \times fscdist}$$

$$fscdist = fscdist_0 + fscdist_1 \times stdelev$$

The snow distribution factor (*fscdist*) is determined by three land use dependent parameters; *fscdist0* and *fscdist1* in the linear equation and a maximum value (*fscdistmax*). Also in this case the snowcover is limited by the maximum and minimum value parameters. When the end of the snow season approaches (defined by general parameter *fsck1*) the *snowmax* variable is gradually decreased in order to be reset before next winter season:

$$snowmax = snowmax - \frac{\left(fsck_1 \times snowmax - snow\right) \times 1 - e^{-fsckexp \times ts}}{fsck_1}$$

$$\frac{snow}{snowmax} < fsck_1$$

The equation depends on two general parameters, *fsck1* and *fsckexp*, where *fsckexp* depend on time (*ts* is seconds per timestep of simulation).

For winters when the snow pack not reach the definition of large snow pack, the first equation is used during the whole season.

Soil temperature and snow depth

Soil layer temperature (*soiltemp*) is calculated as a balance of three temperatures; previous time step soil layer temperature, soil temperature at deep depth (*deeptemp*) and air temperature (*T*). The weight of the deep soil is constant (0.001), while the weight of the air temperature (*weightair*)

depends on snow depth (*snowdepth*) and parameters. The soil memory (*soilmem*) depends on depth and land use, with parameters *surfmem* and *depthrel*. The memory of deep soil temperature is a general parameter (*deepmem*).

$$soilmem = \begin{cases} deepmem & for\ deeptemp \\ surfmem \times e^{-depthrel \times depth\left(k\right)} & for\ soil\ layer\ k \end{cases}$$

$$weigth_{air} = \frac{1}{soilmem + 10 \times snowdepth}$$

$$deeptemp = weight_{air} \times T + \left(1 - weight_{air}\right) \times deeptemp$$

$$soiltemp = weight_{air} \times T + \left(1 - weight_{air} - weight_{deep}\right) \times soiltemp + weight_{deep} \times deeptemp$$

In the default snow depth model, snow density (*snowdens*) depends on the snow's age in days (*snowage*). Snow density for fresh snow (*sdnsnew*) and the increase of density with snow age (*snowdensdt*) are general parameters (~ 0.1 and ~0.002). The snow's age increases by one every time step, but are weighted with age (0) for any new snow.

$$snowage = \frac{\left(snowage + 1\right) \times oldsnow}{\left(oldsnow + snowfall\right)}$$

$$snowdens = sdnsnew + snowdensdt \times snowage$$

$$snowdepth = \frac{0.1 \times snow}{snowdens}$$

In the alternative snow depth model, snow density is calculated by a compacting factor. Snow density for fresh snow (*sdnsnew*), maximum snow density (*sdnsmax*), compactation rate for low temperatures (*sdnsrate*) and additional compactation for high temperature (*sdnsradd*) are all general parameters. The change in snowdensity (*densdt*) due to compactation each time step is calculated as:

$$densdt = sdnsrate \times \left(sdnsmax - snowdens\right)$$

for cold days (temperature is below threshold temperature parameter *ttmp*), and

$$densdt = \left(sdnsrate + sdnsradd\right) \times \left(sdnsmax - snowdens\right)$$

for warm days.

Links to file reference

Section	Symbol	Parameter/Data	File
Snow melt	*cmlt, ttmp*	*cmlt, ttmp*	par.txt
	T	calculated from	Tobs.txt
Snow cover	*stdelev*	*elev_std*	GeoData.txt
	fscmax, fscdist0, fscdist1, fsck1, fsckexp	*fscmax, fscdist0, fscdist1, fsck1, fsckexp*	par.txt
		fscmin,fsclim,fscdistmax	
Soil temperature and snow depth	*deeptemp*	*init2*	par.txt
		deepmem, surfmem, depthrel, sdnsnew, snowdensdt, sdnsmax, sdnsrate, sdnsradd, ttmp	

Links to relevant procedures in the code

Modules (file)	Procedures	Section
soil_processes (soil_proc.f90)	calculate_snow	snow melt
	calculate_snowmelt	
	snowalbedo_function	
	calculate_fractional_snowcover	snow cover
	calculate_snowdepth	soil temperature and snow depth
	calculate_soiltemp	
	calculate_weigthed_temperature	

Glaciers

The glacial class' area ($class_{area}$) is divided into snowfield and glacier ($glac_{area}$). The division may vary with simulation time, but the glacier cannot be larger than the slc class' area. At simulation start the area is considered to be all glacier, unless specific information on which year the class area is valid is given. The initial glacier volume is calculated based on glacier area or set for each glacier. If the initial year is given the initial volume is valid for that date. In this case, year of the area and/or volume and the average annual change in massbalans (*annmb* in m/yr) is given as input data or model parameters. The initial glacier volume is then adjusted according to the difference in years (*yeardiff*) between simulations start and glacier area data.

The glacier volume - area relationship:

$$glac_{vol} = coef \times glac_{area}^{\exp}$$

$$coef = coef0 \times e^{c}$$

The initial glacier volume if calculated from class area:

$$glac_{vol} = coef \times class_{area}^{\exp} + yeardiff \times \frac{annmb \times class_{area}}{glacdens \times 1000}$$

The glacier area is correspondingly calculated from the glacier ice volume, but is limited by the class area. The relation is:

$$glac_{area} = \left(glac_{vol} \times \frac{1}{coef} \right)^{\frac{1}{exp}}$$

The equation coefficients *coef* and *exp* can have different values for specific glaciers. The first coefficient coef is calculated as the product of *EXP(c)*, where *c* is a glacier volume correction, and a general parameter (*glacvcoef/glacvcoef1*) depending on glacier type. The second coefficient, *exp* is a general parameter (*glacvexp/glacvexp1*) depending on glacier type. Glacier density (*glacdens*) is a general model parameter (m^3 water / m^3 ice).

Glaciers are divided into four types. The default type is mountain glacier, the alternatives are ice cap, ice sheet and infinite glacier. Glacier type is given as input, or determined by the glacier area (a threshold (*glac2arlim*, a general parameter). The glacier area is used to determine the glacier type if it is not given as input and the threshold parameter is set. The glaciers will then be divided into mountain glaciers and ice caps.

The default glacier and the ice cap glacier type differ by having different parameter values for the volume-area relationship. The default values for the volume-area relationship are based on Radic and Hock (2010).

The ice sheet glacier do not simulate an snow field, and the glacier will have a constant area. The ice sheet glacier type is thus not depending on the volume-area relationship, except for initial volume if that is not given. In that case the initial volume of the ice sheet glacier will used the ice cap parameter values.

The infinite glacier type is independent on glacier volume, because the glacier melting is not limited by the glacier volume. It has a constant area (the class area) and do not simulate an snow field.

For snowfields, all soil processes are calculated as for the common land classes. Snow pack is only calculated for the snowfield, i.e. snow depth is assumed zero on glaciers. For glaciers, all precipitation is added to the glacier ice. Glacier melting is calculated as:

$$melt = cmlt \times \left(T - ttmp \right)$$

where *cmlt* is the general parameter *glaccmlt* and *ttmp* the general parameter *glacttmp*.

An alternative glacier melting model exist, which depend on class' temperature (*T*) and radiation (*swrad*) and has a refreezing component (goverened by general parameter *crefr*). The radiation component depend on the albedo of the glacier, which in turn depends on if the glacier is snow covered (*snowcov*) or not, and general parameters for rate (*cmrad*) and glacier ice albedo (*glacalb*). The refreezing component is limited to the glacier melt.

$$melt = \begin{cases} cmrad \times swrad \times \left(1 - albedo_{glacier} \right) + cmlt \times \left(T - ttmp \right) & for\ T \geqslant ttmp \\ cmrad \times swrad \times \left(1 - albedo_{glacier} \right) - crefr \times cmlt \times \left(ttmp - T \right) & for\ T < ttmp \end{cases}$$

$$albedo_{glacier} = albedo_{snow} \times snowcov + glacalb \times \left(1 - snowcov \right)$$

Glacier evaporation is optional and set by an model option (`snowevaporation`). The evaporation is determined as a fraction of the potential evaporation by the general model parameter *fepotglac*.

Glacier melting, snow melting on snowfield and/or rain are added to the soil. Thus the soil represents the whole glacier class area. The concentrations in the glacial melt water are zero. This means that any atmospheric deposition of nutrients is lost on the glacier.

Links to file reference

Symbol	Parameter/Data	File
$class_{area}$	*slc_nn, area*	GeoData.txt
annmb	*annualmb*	GlacierData.txt
	or *glacannmb*	par.txt
yeardiff	calculated from *slcdate*	GlacierData.txt or par.txt
	and *bdate*	info.txt
c	*logvolcorr*	GlacierData.txt
	glactype	
T	see needed data in Links for temperature	
swrad	calculated or from	SWobs.txt
coef0	*glacvcoef* or *glacvcoef1*	par.txt
exp	*glacvexp* or *glacvexp1*	
cmlt, ttmp	*glaccmlt, glacttmp*	
$albedo_{snow}$	calculated from *snalbmin, snalbmax, snalbkexp*	
	glacalb, glacdens, glac2arlim, crefr, cmrad, fepotglac	

Links to relevant procedures in the code

Modules (file)	Procedures
glacier_soilmodel (glacier_soilmodel.f90)	soilmodel_3
	initiate_glacier
	initiate_glacier_state
	calculate_glacier_area
	get_glacier_parameters

References

Samuelsson, P., S. Gollvik, and A. Ullerstig, 2006. The land-surface scheme of the Rossby Centre regional atmospheric climate model (RCA3), SMHI Report Meteorologi Nr 122, 25 pp.

Radic, V. and Hock, R., 2010. Regional and global volumes of glaciers derived from statisti-cal upscaling of glacier inventory data, J. Geophys. Res., 115, F01010, doi:10.1029/2009JF001373.