

# Deep processes

There are two model options for processes deep below ground; regional groundwater flow and aquifers. The regional groundwater flow model simulates groundwater flow between subbasins, but no explicit storage of deep groundwater. The aquifer model simulates aquifer storage and delay before regional groundwater reaches the destination.

## Regional groundwater flow

### Soil regional groundwater flow creation

Regional groundwater flow from a subbasin is calculated before the subbasin and class loops. This water is added to the downstream subbasin (in the class-loop part of the code) and/or to the outlet lake of the present subbasin (in the routing calculation part of the code). A subbasin dependent variable (*grwtolake*) governs the allocation between them. The outflow from a subbasin is calculated as a percentage of the water-retention capacity with a recession coefficient (*rcgrw*) e.g. for the lowest soil layer (*k*) the groundwater outflow for a class becomes:

$$q_{grw}(t) = rcgrw \times \left( soil(k) - wp(k) - fc(k) \right) \quad soil(k) > fc(k) + wp(k)$$

Groundwater flows are summarized for all classes in proportion to their areas and converted to volume flow out of the subbasin.

### Soil addition of regional groundwater flow

The groundwater flow to be added to the bottom layer (and mixed) is added in the class loop portion of the code. If the layer then becomes full of water, it will be pressed into the layer above and mixed, etc. Please note that if downstream subbasin is much smaller than the upstream subbasin, groundwater inflows can become large.

### Regional groundwater to outlet lake

With an input variable in GeoData.txt, an outlet lake may be flagged to receive inflow from the regional groundwater. The coefficient (*grwtolake*) specifies the portion of the produced regional groundwater flow which is led to the subbasins outlet lake. The part of the groundwater flow that is to go to the outlet lake is added to the lake volume in the routing part of the code.

### Links to file reference

Section	Symbol	Parameter/Data	File
Soil regional groundwater flow creation		<i>grwolake, grwdown</i>	<a href="#">GeoData.txt</a>
	<i>rcgrw</i>	<i>rcgrw</i>	<a href="#">par.txt</a>
	<i>wp(k)</i>	<i>wcwp, wcwp1, wcwp2, wcwp3</i>	
	<i>fc(k)</i>	<i>wcfc, wcfc1, wcfc2, wcfc3</i>	

Links to relevant procedures in the code

Modules (file)	Procedures	Sections
<a href="#">regional_groundwater_module</a> ( <a href="#">regional_groundwater.f90</a> )	<code>calculate_regional_groundwater_flow</code>	soil regional groundwater flow creation
	<code>calculate_soillayer_groundwaterflow_removal</code>	soil regional groundwater flow creation
	<code>add_regional_groundwater_flow_to_soil</code>	soil addition of regional groundwater flow
	<code>add_regional_groundwater_flow_to_olake</code>	regional groundwater to outlet lake

Aquifers

Aquifers are large water bodies covering several subbasins and located below the soillayers simulated by HYPE. They recieve water by percolation from land and river classes, and they return flow to a river (Figure 1). They can also be used as a water source for abstraction. The aquifer is a large water body that can have a passive volume partaking in mixing but not return flow (Figure 2).



Figure 1 Water flows of aquifer.

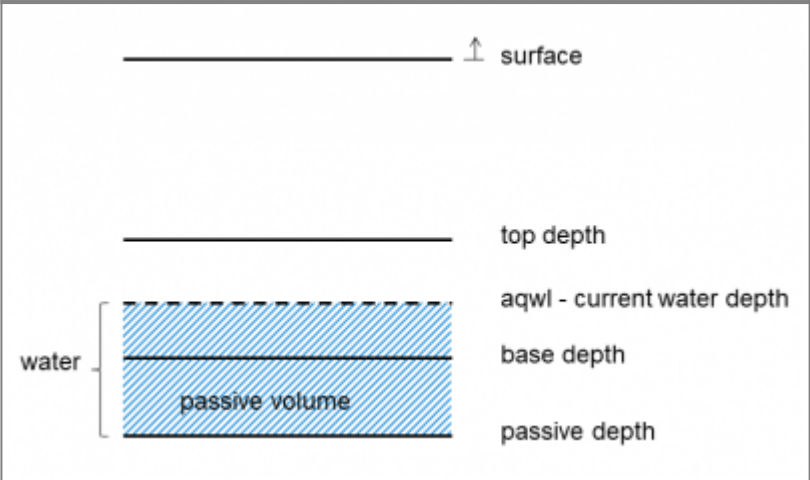


Figure 2 Structure of an aquifer.

Deep percolation

Deep percolation is determined by a recession coefficient ( $rc_{grw}$ ). The recession coefficient is set based on the recession parameter ( $rcgrwst$ ) which is soil type dependent, but if it is not set the general parameter ( $rcgrw$ ) is used instead. The recession coefficient can also be regionally adjusted by the correction parameter ( $aqpercorr$ ).

$$rc_{grw} = rcgrw \left( \text{or } rcgrwst \right) \times \left( 1 + aqpercorr \right)$$

Deep percolation from lowest soil layer in model is determined by the recession coefficient and the available water for runoff in the soil layer ( $qperc$  (mm/timestep)).

$$q_{perc}(t) = rc_{grw} \times (sm - fc - wp) \quad sm > fc + wp$$

Deep percolation from main river in model is determined by the recession coefficient and the water in the river ( $qperc$  (m3/timestep)).

$$q_{perc}(t) = rc_{grw} \times (waterdepth)$$

The water is removed from river water and the queue in proportion to their relative volumes.

## Deep percolation delay and aquifer recharge

Deep percolation from soil and rivers in all recharge subbasins of an aquifer is added together. This total deep percolation ( $q_{perc}$ ) is delayed before it recharges the aquifer ( $q_{rech}$ ).

$$q_{rech}(t) = (1 - coeff) \times q_{perc}(t) + coeff \times q_{rech}(t-1)$$

$$coeff = e^{-\frac{1}{delayts}}$$

The delay property ( $delayts$ , in timesteps per day) is specified for each aquifer ( $delay$  in days). It can be adjusted by the parameter region dependent model parameter  $aqdelcor$ .

## Return flow from aquifer

Outflow from the aquifer depends on the water in the aquifer ( $vol$ ) (not including passive volume) and a rate. The rate is determined by a aquifer property ( $retrate$ ) and a regional adjustment parameter ( $aqretcor$ , parameter region dependent).

$$q_{out} = retrate \times (1 + aqretcor) \times vol$$

The outflow may be divided between several receiving subbasins ( $retfrac$ ). The receiving subbasins may or may not be different from the subbasin recharging the aquifer. The specified fraction of outflow is added to the inflow to the main river of these subbasins.

It is possible to simulate that (part of) the aquifer's outflow leads to outside of the modelled domain (sum of  $retfrac$  less than 1). It is possible to simulate addition of water (from aquifers) from outside

the model domain to the model as aquifer recharge by upscaling the recharge calculated for an aquifer in the model set-up (sum of retfrac larger than one).

Nutrient processes related to aquifers

For most models the organic nitrogen, particulate phosphorus, and organic carbon in water percolating from soil and river stay in the soil/river, while temperature, inorganic nitrogen and SRP follow the water to the aquifer. In the case of a model using the simplified soil model based on travel time through soil and half life of pollutants (i.e. using load as input to HYPE) all substances follow the water to the aquifer.

Inorganic nitrogen is subjected to denitrification in the aquifer (see Chapter [Nitrogen and phosphorus in land routines - Denitrification](#)). For other substances an exponential decay can be applied in the aquifer. The process is goverened by the model parameter *decay* (e.g. ppdecaq), which denote the half life of the substance in days. The decay will decrease the concentration (*conc*) of the substance in the aquifer.

$$conc = conc \times 2^{-\frac{ts}{decay}}$$

where *ts* is length of time step in days.

Abstraction from aquifers

Aquifers can be used for abstraction of water. The abstraction is defined through PointSourceData for a subbasin. The water is removed from the aquifer below that subbasin. Water is taken from the aquifer water volume. This means that also water from the passive volume can be removed.

Links to file reference

Section	Symbol	Parameter/Data	File
Aquifers		<i>aquid, subid, parreg</i>	<a href="#">AquiferData.txt</a>
		<i>basedepth, passivedep, inidepth, porosity, area</i>	
Deep percolation	<i>rc<sub>grw</sub></i> calculated from	<i>rcgrw, rcgrwst, aqpercorr</i>	<a href="#">par.txt</a>
	<i>wp</i>	<i>wcwp, wcwp1, wcwp2, wcwp3</i>	
	<i>fc</i>	<i>wcfc, wcfc1, wcfc2, wcfc3</i>	
Deep percolation delay and aquifer recharge		<i>recharge</i>	<a href="#">AquiferData.txt</a>
	<i>delay</i>	<i>delay</i>	<a href="#">par.txt</a>
	<i>aqdelcorr</i>	<i>aqdelcorr</i>	
Return flow from aquifer	<i>retrate, retfrac</i>	<i>retrate, retfrac</i>	<a href="#">AquiferData.txt</a>
	<i>aqretcorr</i>	<i>aqretcorr</i>	<a href="#">par.txt</a>
Nutrient processes related to aquifers		<i>topdepth, temp, conc_IN, conc_SP</i>	<a href="#">AquiferData.txt</a>
		<i>denitaq, hsatINs, wcep, wcfc, wcwp</i>	<a href="#">par.txt</a>
	<i>decay</i>	<i>ondecaq, spdecaq, ppdecaq, ocdecaq, ssdecaq, aedecaq, t1decaq</i>	<a href="#">par.txt</a>

## Links to relevant procedures in the code

Modules (file)	Procedures	Sections
<a href="#">regional_groundwater_module</a> <a href="#">(regional_groundwater.f90)</a>	calculate_aquifer	
	calculate_regional_groundwater_flow	
	calculate_soillayer_groundwaterflow_removal	deep percolation
	calculate_river_groundwaterflow_removal	
	calculate_aquifer_percolation	
	calculate_percolation_delay	deep percolation delay and aquifer recharge
	calculate_delayed_water	
	calculate_aquifer_outflow	return flow from aquifer
	add_aquifer_flow_to_river	
	calculate_current_flow_from_aquifer	return flow from aquifer nutrient processes related to aquifers
	set_percolation_concentration	nutrient processes related to aquifers
<a href="#">npc_soil_processes</a> <a href="#">(npc_soil_proc.f90)</a>	soil_denitrification	nutrient processes related to aquifers
<a href="#">general_functions</a> <a href="#">(general_func.f90)</a>	exponential_decay	