
COUP Manual

Coupled heat and mass transfer model for soil-plant-atmosphere systems

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Introduction

How to read this document

The CoupModel is a new updated version of the previous WinSoil model (Jansson, 1998). The name “Coup” stems from the word coupled, and the model actually consists of different sub-models, which have been integrated into a system of models. The previous SOILN model (Eckersten et al, 1998, Johnsson et al., 1987) has been incorporated as an integrated part of the new CoupModel. A new approach with multiple plant canopies and also a substantially modified model for the water uptake have been introduced. The major new updates in this report correspond to the changes made to the description of water and heat flows of the system. The present report is also part of the help to the CoupModel program version 2.0.

Depending on whether the reader is a previous user of the SOIL or SOILN models or not, there are different possible strategies for reading this document. A background chapter, “Overview”, presents the basic ideas behind the model and the main purposes with using the model. This is a good start for a new potential user of the CoupModel.

The chapter “Model Structure” presents the basic structure of the model and how the different sub-models are coupled. This is useful reading before going into the chapters that describes the different processes (e.g. plant water processes or soil heat processes) considered in the model. These latter chapters i.e. the chapters on heat-, soil water-, plant water-, atmospheric and snow- and nitrogen and carbon processes are all divided into several sections that correspond to a certain tab in the model (see Edit menu). These sections all have the same layout. First a presentation of the *theory* behind the model assumptions is given. The optional approaches, *switches*, can be compared and details concerning definitions of different functions and parameter values, i.e. *parameters* and *parameter tables*, are found. At the end of each section the graphical illustrations found in the model, *viewing functions*, are included as well as a list of the output variables from the simulations, *outputs*. These chapters of the help/manual are the reference part of the guide.

Technical aspects on the use of input data and how different input outputs are specified are found in a separate chapter, “Common Characteristics”.

Experiences from use of the model and discussions on the validity of different approaches and parameter values for different examples are only briefly discussed in this report. Details on model use will instead be in the scientific literature. A bibliography on different papers where the models have been used is found in the end of this document (see “Bibliography”).

How to use the help system

There are two help systems attached to the CoupModel. First of all the Winhelp that corresponds to the standard help, normally the information you get when pressing the F1 button. This system provides help on most technical aspects of handling the program, e.g. validation files or how to use the database. The second help system is html-based and corresponds to this document. This help is accessed by pressing the help button in the edit and output menus where actual concepts of the model are described.

Terminology and conventions on denotations

There are several words that have been given a specific meaning in this manual. The knowledge of these words is useful for the complete understanding of the following text.

Auxiliary Variable

A variable that represents any variation during a simulation. The variable is normally a function of either flow or state variables. Not strictly coupled to the mass/energy balance.

Driving Variables

A forcing variable used as input to the model. Normally boundary conditions to the equations in the dynamic model.

Dynamic

A variation that is normally simulated and because of this follows a flexible type of variation by time.

Empirical

Knowledge found by experience, based on observations.

Flow

A general term used to describe a movement from one place to another, most often used for water. Apart from that the term is used almost synonymous to transfer.

Flow Variables

The Flux of energy or matter. The flow variables connect state variables or represent source/sink terms to the state variables.

Flux

The measure of the flow of some quantity per unit area per unit time, such as joule per square meter and day (heat flux).

Ground

Radiation processes including both soil and snow.

Parameter

A single input constant to the model.

Parameter Table

A table that includes one or more parameters that have a common index.

Rate

A quantity that is measured in relation to unit of time, such as meters per second (wind speed).

State Variables

A variable that represent the storage of matter or energy. The mass balance should be conservative for state variables.

Switch

A switch is a tool used to define how the model is defined for a given simulation. Switches are changed in the edit menu and recognized as options.

Transfer

A general term used to describe a movement from one place to another, used almost synonymous to flow.

Viewing functions

A function that may be visualised at time of editing values of involved parameter values

In the descriptions of nitrogen and carbon processes, the following conventions for denotations have been used:

- (1) Pools (state variables) are denoted by capital italics subscripted with name abbreviations.
- (2) Flows are denoted by capital italics subscripted with the direction of the transfer. Layer is indicated by "z" in parentheses.
- (3) Parameters are indicated by lower-case italic letters with appropriate subscripts.

These conventions are over ruled when older and commonly used denotations already exist.

The nitrogen carbon ratio in different state pools is an exception to these conventions. When the ratio is a state variable it is denoted by two letters, *CN*, subscripted with appropriate name abbreviations, and when it is given as a parameter it is also written with these two letters in lower-case italic, *cn*, with appropriate subscripts.

Availability of the model

Copies of the CoupModel can be retrieved free of charge from the following internet server:

<http://www.lwr.kth.se/vara%20datorprogram/CoupModel/index.htm>

Related documents

Previous users manuals provided for MS-DOS version of SOIL are only valid to some minor extent and consequently they are not recommended to be used in connection with the windows version of the model.

A number of tutorials are available at the help menu as separate html-based files. These files can also be found on the CoupModel home page as printable versions. The different tutorials are of different user levels. Therefore it is recommended that you do them in the following order:

- Simple run using limited of input data
Starting with this one will give you a thorough introduction in how to make an easy simulation and how you analyse your results.
- Infiltration and soil hydraulic properties tutorial
This simulation is a simulation of a one-meter deep soil profile without vegetation. The tutorial will teach you the general structure of the soil water processes and how you can use the soil database. It also gives a thorough description on how you can interpret and plot results.
- Energy balance tutorial
Continuing with this simulation will now introduce to you the concepts of surface energy balance and the connection to soil evaporation. Again the simulated system is a bare sandy soil. The "Ebal" tutorial also includes instructions on how to make validations with existing data.
- Evapotranspiration tutorial
This tutorial is a simulation of several systems with different types of vegetation. The aim with this tutorial is to show how different vegetation types affect the water balance.
- Snow piste tutorial
The aim of the snow tutorial is to give the user a glimpse of the processes concerning snow and frost. If your simulation will not include cold regions with frost and snow you can safely skip this tutorial and continue to the next one.
- Nitrogen and Carbon tutorial
This tutorial gives you an introduction to the biotic part of the

CoupModel, i.e. the fluxes of carbon and nitrogen. The tutorial shows you for example plant development and nitrogen leaching from the soil. This section is perhaps not so interesting if the biomass and the fluxes of carbon and nitrogen will not be studied in your own simulations.

- Growth

Coupling the biotic and the abiotic parts of the CoupModel enables simulation of growth. This tutorial introduces the concepts of growth and the link between the plant and its physical environment.

See the CoupModel home page for more news on documentation;
<http://www.lwr.kth.se/vara%20datorprogram/CoupModel/index.htm>

Overview

Purpose of using the model

A number of problems concerning hydrological and/or thermal processes in the soil-plant-atmosphere system can be elucidated using the model. Both applied and basic scientific problems have been solved including:

- simulation of regulating factors for biological and chemical processes in the soil
- simulation of coupled biological and abiotic processes
- simulation of coupled atmosphere and soil processes
- assessment of the importance of different factors
- identification of gaps in our present knowledge
- formulation of new hypotheses
- generalisation of results to new soils, climates and time periods
- prediction of the influence of management e.g. soil heat extraction, mulching, drainage, irrigation and plant husbandry

Basic assumptions

The model, initially developed to simulate conditions in forest soils, has recently been generalised to elucidate water and heat processes in any soil independent of plant cover. This was possible since the model is based on well-known physical equations. The fundamental nature of these physical equations allows the model to be adapted to many different types of ecosystems providing that we have quantitative knowledge of the governing properties of these systems. Recently nitrogen and carbon cycles have also been included in the model. This has enabled a dynamic interaction between the abiotic environment and the plant, and subsequently plant growth can be simulated. It is possible to include several plants that compete for water, nitrogen and radiation.

The basic structure of the model is a depth profile of the soil. Processes such as snow-melt, interception of precipitation and evapotranspiration are examples of important interfaces between soil and atmosphere. Two coupled differential equations for water and heat flow represent the central part of the model. These equations are solved with an explicit numerical method. The basic assumptions behind these equations are very simple.

- 1) The law of conservation of mass and energy

- 2) Flows occur as a result of gradients in water potential (Darcy's Law) or temperature (Fourier's law).
-

Inputs

The soil profile is divided into a number of layers, and for each layer and each boundary between layers, the two basic principles are considered. The number of layers and the thickness of each layer can be varied depending on accuracy requirements.

The calculations of water and heat flows are based on soil properties such as:

- the water retention curve
- functions for unsaturated and saturated hydraulic conductivity
- the heat capacity including the latent heat at thawing/melting
- functions for the thermal conductivity

The most important plant properties are:

- development of vertical root distributions
- the surface resistance for water flow between plant and atmosphere during periods with a non limiting water storage in the soil
- how the plants regulate water uptake from the soil and transpiration when stress occurs
- how the plant cover influences both aerodynamic conditions in the atmosphere and the radiation balance at the soil surface.
- how different plant canopies cover each other in space and therefore compete for radiation

If the nitrogen and carbon cycles are included in the model, the following soil and plant properties are of major importance:

- characteristics governing the plant life-cycle such as allocation patterns of assimilates and nitrogen
- plant activities such as assimilation, respiration and nutrient uptake
- external inputs of carbon and nitrogen to the soil
- microbial activity i.e. decomposition
- redistribution between different decomposition products such as humus or litter in the whole soil profile

All properties are represented as parameter values. Numerical values are assigned to a number of different parameters representing properties of the soil-plant-atmosphere system. For each parameter a certain range reflects differences between different types of crops, forests, soils or the range reflects a typical variation found within a certain area.

Meteorological data are the driving variables to the model, but in contrast to parameters the numerical values of driving variables vary with time.

The driving variables govern the flows at the boundaries between atmosphere and soil and between plant and atmosphere. Precipitation and air temperature are the most important driving variables, but air humidity, wind speed and cloudiness are also of great interest due to their influence on evaporation.

The required information on soil properties is large compared to what is normally available from standard field investigations. To determine these properties by independent measurements in each application with the model would be time-consuming and very labour intensive, especially since some of these properties (e.g. hydraulic conductivity) show

substantial spatial heterogeneity. The use of the database enables the user to estimate a reasonable range for such soil properties from commonly available information such as soil texture and organic matter content. Most of the material in the database originates from investigations in arable land in Sweden but the material is continuously updated with new sites including forest soils.

Outputs

Results of a simulation are obtained as time series either of variables, which represent individual layers in the soil such as:

- temperature
- content of ice
- content of unfrozen water
- water potential
- vertical and horizontal flows of heat and water
- water uptake by roots
- storage's of water and heat
- nitrogen and carbon content in different storages in the soil and the flux of matter between these storages

In addition some output variables are represented as a single variable such as:

- snow depth
- water equivalent of snow
- frost depth
- surface runoff
- drainage flow
- deep percolation to ground water
- carbon and nitrogen content in the plant
- carbon assimilation and respiration
- nitrogen uptake

It is a well-known fact that no simulation model yields better results than what can be expected from the quality of input data. Assessment of the uncertainty in the input data is therefore the first step when the model is to be used. Sometimes field measurements are available which enable a quantitative test of the model. The interpretation of discrepancies found between the measurements and the model predictions requires a lot of care and a basic knowledge of the different processes in the system. An improvement of the fit can normally be obtained after adjustments of some soil or plant properties. Nevertheless, it is not necessarily so that all input data including the physical properties of the system are correctly estimated just because a good fit is obtained when testing the model.

Note that we can always simulate a much more complete picture of both the temporal pattern and of the interaction between variables than what can be achieved by intensive field measurements. However, this should not lead us to believe more in the model predictions than in observations of the real system. Instead we have to design our field measurements to achieve an optimum test of the simulated results. We should concentrate on variables which are easy to measure and which have a strong connection to other variables in the soil-plant-atmosphere system. A typical example is soil water tension, which is easy to measure with a conventional tensiometer, but in addition reflects other factors such as soil water flow and water uptake by roots. Unsaturated water flows are very difficult to measure in field soils and in this case we must always rely on model predictions. However, tracers can be used as indicators of the actual water flow paths in the soil.

Experiences from model use

The model is helpful in elucidating how different processes and properties in the system interact. We are always constrained to investigate a limited part of the whole system with respect to both time and space. The model can be used as a tool to extend our knowledge.

The fundamental physical equations are well known and accepted but we still have to test their validity at different field scales. A general problem is that our knowledge of soil properties normally originates from small soil samples. The role of small soil units compared to larger units is not well understood and we have to find out how we can combine information, which represents different scales. Areal mean values of soil properties such as the hydraulic conductivity are hard to determine even from intensive measurement programmes and it is not certain that the use of an areal mean will be the best choice for the model simulations. The dynamical interaction between the plant and its environment is a newly developed part of the model and is thus continuously updated as new experiences are gathered.

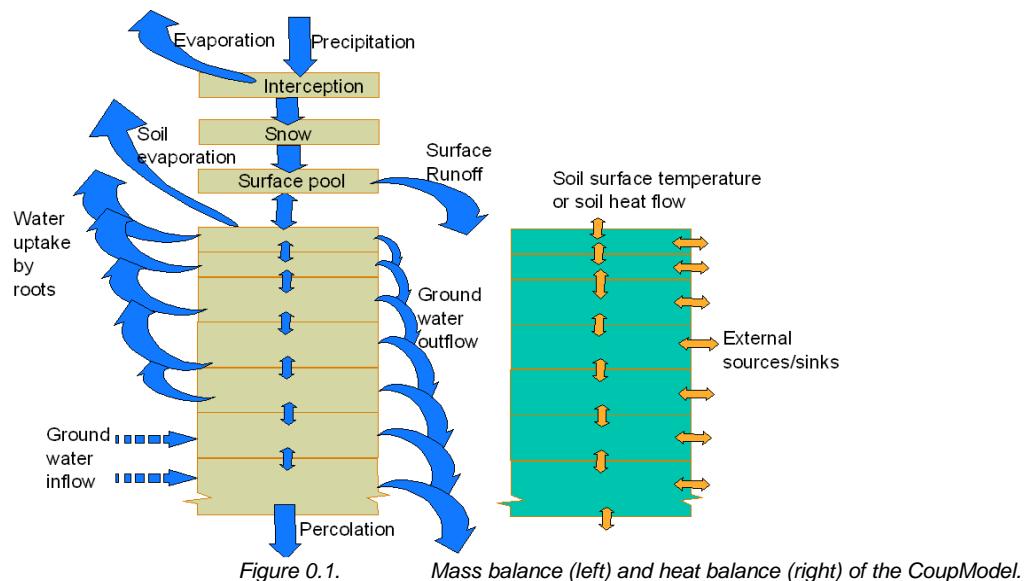
One important aspect when testing the model is that parameter values should ideally have been estimated independently of the field measurements, which are used to test the model predictions. In such a case we will learn about how the system behaves even when model predictions fail. On the other hand we will seldom learn about how nature behaves by using calibration procedures even if good agreements between simulated and observed variables are obtained. The estimated parameter values that result in a good agreement must always be compared with other independent estimates if a model application is to have scientific interest.

- 1) Do not be happy just because the model output is in agreement with observations; try instead to find out why there are no discrepancies.
- 2) Be happy when the model and the reality are different; then you have a key to new knowledge.
- 3) The model can provide you with a much better answer to an applied question than is possible with many field investigations. In many cases we cannot wait for the results from long-term field investigations.
- 4) An adviser using a good mathematical model will certainly be efficient if he/she is successful in combining the results from the model with critical thinking. The model will stimulate an examination of problems if the adviser as well as the scientist gets an opportunity to play with the model.
- 5) An adviser who believes too much in the figures from a mathematical model will be equally poor as the one who fully trusts results from field investigations.

Structure of Model

Model Structure

Components of Water and Heat Processes



The one dimensional CoupModel represents water and heat dynamics in a layered soil profile covered with vegetation. As the solution to model equations is performed with a finite difference method, the soil profile is divided into a finite number of layers. Compartments for snow, intercepted water and surface ponding are included to account for processes at the upper soil boundary. Different types of lower boundary conditions can be specified including saturated conditions and ground water flow (see switch “[GroundWaterFlow](#)”). Meteorological data are used as driving forces in the simulation and is given as measured or parameter values.

The water equation “[WaterEq](#)” and the heat flow equation “[HeatEq](#)” can be solved simultaneously or together. If only one is solved the other conditions are assumed as constants for the entire simulation periods. In such cases only initial values of these variables need to be considered.

Some options are linked to each other like the “[Evaporation](#)” and “[PlantType](#)” switches. The “[PlantType](#)” switch also differentiates between an explicitly expressed big leaf or explicitly expressed big leaves. The latter option allows the user

to simulate several plants that will compete for radiation, water and nutrients. An overview on how some of the options and parameters affect each other are given in Appendix 1.

Several options are available for the soil water processes. Runoff can be included in the simulations as governed by the switch “[LateralInput](#)”. Soil water vapour flow can also be simulated (see switch “[SoilVapour](#)”).

Snow fall will affect both water and heat processes in many ways and can optionally be included in the simulations (see switch “[SnowPack](#)”).

The water and heat equations may be coupled in a dynamic way to the plant (i.e. accounting for feedback interactions between the plant and its environment) or the plant may be specified as given by driving variables or parameter values (see section “[Abiotic driving variables](#)”). This is determined by the switch “[Nitrogen and Carbon](#)” and the processes relating to nitrogen and carbon flows are described in detail in the section below.

Irrigation may optionally be included in the simulation (see switch “[Irrigation](#)”). A salt balance can also optionally be included (see switch “[SaltTracer](#)”).

The CoupModel can be run simultaneously with the soil chemistry equilibrium model, Minteq (see switch “[Minteq](#)”). More information on Minteq can be found on: <http://www.lwr.kth.se/english/OurSoftware/Vminteq/index.htm>.

Components of Nitrogen and Carbon

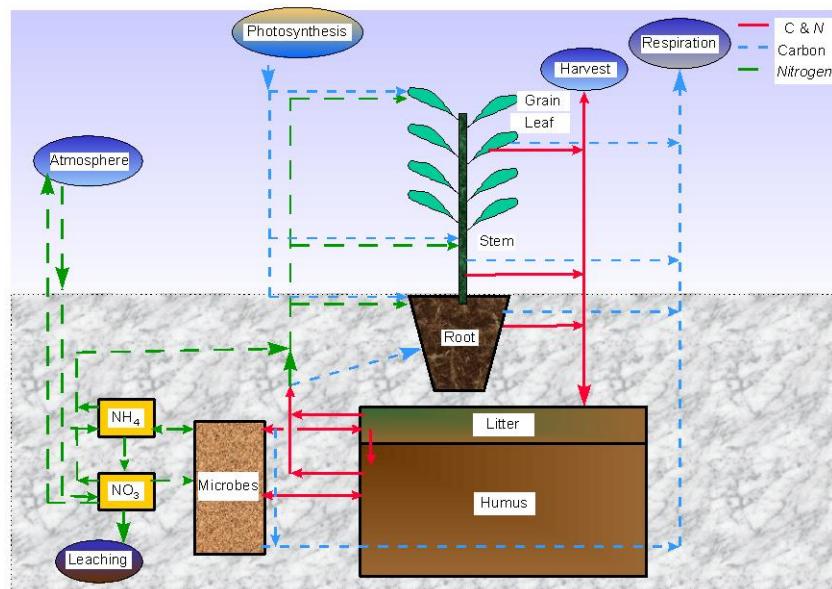


Figure 0.2. Schematic scheme of carbon, nitrogen and biomass flows (in one dimension) and storage. The soil is divided into layers and plant biomass can be divided into pools of annual and perennial tissues (Eckersten et al., 1998).

In the CoupModel the major nitrogen and carbon components of a soil-plant system can be considered (see Figure 0.2). This is accomplished by switching the “[Nitrogen and Carbon](#)” switch from off to any of the other two alternatives. Nitrogen and carbon processes may be simulated; either with the water and heat conditions as driving forces or with a dynamic interaction between abiotic and biotic components, though the latter approach is more common. In any case plant growth is simulated as carbon and nitrogen is taken up or given away from the plant i.e. the biomass in the plant is explicitly expressed.

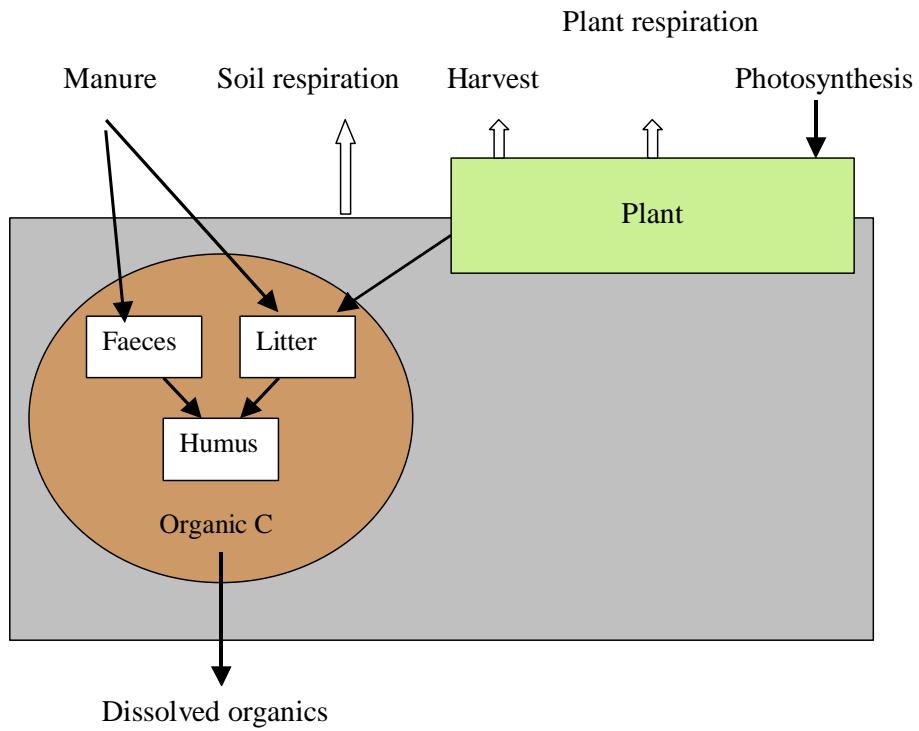


Figure 0.3. Carbon flows in the CoupModel.

Carbon and nitrogen enters the soil either as external inputs, i.e. manure, deposition and fertilisation, or from the plant as litter fall (see Figure 0.3 and Figure 0.4). The carbon and the organic nitrogen are added to two organic pools in the soil called faeces and litter, whereas the mineral nitrogen goes into the ammonium or nitrate mineral pools.

When the organic matter starts to decompose, some of the carbon and nitrogen is transferred to the third organic pool, the humus pool, and some carbon leaves the soil as soil respiration. The decomposition of carbon by microbes affects the carbon:nitrogen ratio in the organic soil. These changes are the driving force for immobilisation / mineralisation of nitrogen to or from the soil ammonium pool. Nitrogen is further transferred to the soil nitrate pool by nitrification.

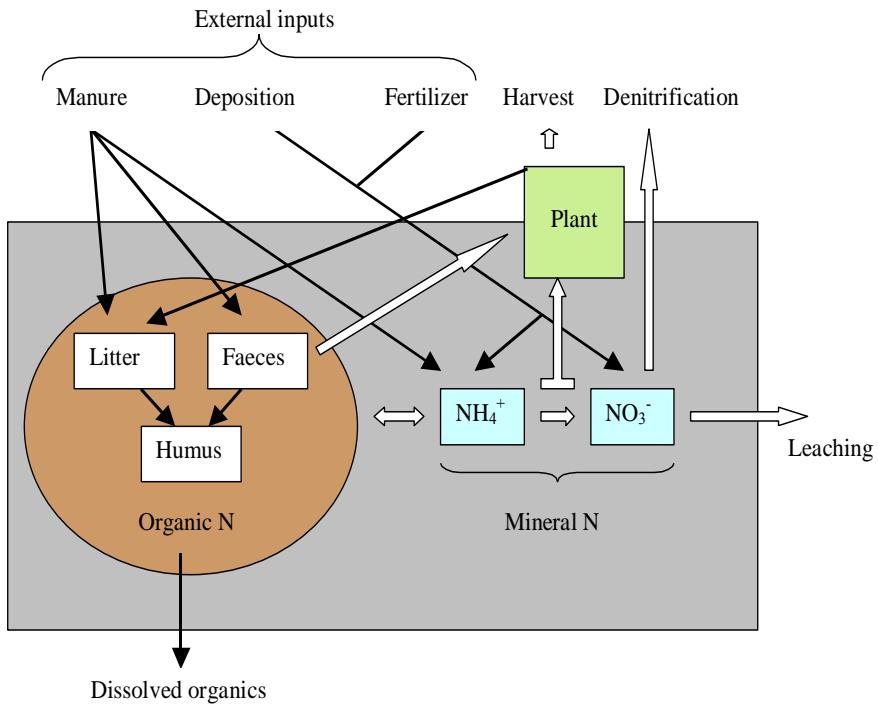


Figure 0.4. Nitrogen fluxes in the CoupModel

Plants extract nitrogen from the soil and carbon dioxide from the atmosphere during growth. Parts of this carbon dioxide is returned to the atmosphere during respiration. The plant may be harvested at the end of the growing season. This action together with denitrification processes and the leaching of nitrogen and carbon (decomposed organic matter and mineral nitrogen) removes carbon and nitrogen from the system.

Switches

Evaporation

Value	Meaning
Off	No evaporation loss to the atmosphere is considered.
Simple input style	A simple analytical equation considering only the day number of the year is used to estimate the potential evapotranspiration. Only total evapotranspiration is expressed i.e. no differentiation between transpiration and evaporation is made.
Radiation input style	A physical based equation is used accounting for both the net radiation and the transport of vapour in the atmosphere boundary layer.

GroundWaterFlow

Value	Meaning

Off	Ground water is disregarded and the whole soil profile will be assumed unsaturated.
On	Ground water will be present in the soil profile if any layer reaches saturation. The ground water level will be defined by assuming a continuous zone of saturation from the lower boundary of the soil profile to any level within the soil profile simulated.

HeatEq

Value	Meaning
Off	No heat flows will be calculated. A constant soil temperature is assumed according to selected initial conditions.
On	Heat flows between adjacent soil layers will be calculated.

Irrigation

Value	Meaning
Off	Only precipitation will be considered as input of water for infiltration.
On	Irrigation water is added to the soil in addition to precipitation.

LateralInput

Value	Meaning
No lateral input	No horizontal input of water in any driving variable files.
In driving file	A horizontal flow rate is defined as a dynamic driving variable which will be read from a PG-Bin file during the simulation.
With irrigation	Irrigation water is added directly into the soil profile at different depths.

Nitrogen and Carbon

Value	Meaning
Abiotic driving variables	All the abiotic driving variables have to be defined either as parameter values or as driving variables that must be given to the model from a separate file. The Water and Heat Equations are turned off if this option is selected
Dynamic interaction with abiotics	In this case both Water and Heat Equations must be turned on in order to supply the nitrogen and carbon models with necessary information.

Off	No nitrogen and carbon processes will be simulated.
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Minteq

Value	Meaning
Off	Coupling to the Minteq model is switched off.
On	Coupling to the Minteq model is switched on.

PlantType

Value	Meaning
No vegetation	A bare soil is assumed.
Implicit big leaf	A simple plant is defined allowing water uptake by roots from different layers in the soil but without any explicit account for soil surface evaporation and transpiration
Explicit one big leaf	A separation is made between soil evaporation and transpiration from canopy. Various options exist for definition of above ground plant characteristics. Dynamic interaction with abiotics is possible.
Explicit big leaves	A separation is made between soil evaporation and transpiration from canopy. Various options exist for definition of above ground plant characteristics. Dynamic interaction with abiotics is possible. The big leaves option implies that an array of leaves can be considered by the model but the lowest number is one.

SaltTracer

Value	Meaning
Off	No salt calculations will be made.
On	Salinity will be considered.

SnowPack

Value	Meaning
Off	No snow accumulation nor melting will be considered.
On	Snow will be simulated by a sub model for snow accumulation, melting, heat conduction and energy exchange between snow and atmosphere.

SoilVapour

Value	Meaning
off	No water vapour flows will be calculated between soil layers.
Only SoilVapourflow	Water vapour flows between adjacent soil layers will result from gradients in vapour pressure and the diffusion constant. The diffusion coefficient is adjusted because of deviations from diffusion in free air by use of the parameter " DvapTortuosity ".
Soil- and SnowVapourflow	Vapour flows are also calculated for the snow.
Only SnowVapourflow	Vapour flows are only calculated for the snow.

WaterEq

Value	Meaning
Off	No water flows will be calculated. A constant soil water content is assumed according to selected initial conditions.
On	Water flows between adjacent soil layers will be calculated.

Soil Heat Processes

Per-Erik Jansson, Manfred Stähli & Lars-Christer Lundin

Soil Heat Flow

This chapter describes heat flux in the soil. These processes are often linked to water processes, resulting in many references to other chapters. For example the boundary conditions at the surface is to a large extent described in the chapter “[Soil evaporation, snow and radiation processes](#)”. To gain full knowledge about how the CoupModel handles heat processes it is therefore recommended to look through the chapters that are referred to in the following text.

Theory

Heat flow in the soil is the sum of conduction, the first term, and convection, the last two terms:

$$q_h = -k_h \frac{\partial T}{\partial z} + C_w T q_w + L_v q_v \quad (0.1)$$

where the indices h , v and w mean heat, vapour and liquid water, q is flux, k is conductivity, T is soil temperature, C is heat capacity, L is latent heat and z is depth. The first convective term, $C_w T q_w$, may or may not be included in the solution depending on the switch “[Convection flow](#)” on page 21. Normally this convective term is important at high flow rates e.g. during heavy snow melt infiltration. The other convective term, the latent heat flow by water vapour, $L_v q_v$, is also optional (see switch “[Vapour flow](#)” on page 23).[\(1.1\)](#)

The general heat flow equation is obtained when combining eq. [\(1.1\)](#) with the law of energy conservation:

$$\frac{\partial(CT)}{\partial t} - L_f \rho \frac{\partial \theta_i}{\partial t} = \frac{\partial}{\partial z} (-q_h) - s_h$$

or

$$\frac{\partial(CT)}{\partial t} - L_f \rho \frac{\partial \theta_i}{\partial t} = \frac{\partial}{\partial z} \left(k \frac{\partial T}{\partial z} \right) - C_w T \frac{\partial q_w}{\partial z} - L_v \frac{\partial q_v}{\partial z} - s_h \quad (0.2)$$

where indices i and f mean ice and freezing respectively, t is time, ρ is density, L is latent heat, θ is the volumetric water content, [Soil Heat Pump \$s_h\$](#) is a source/sink term. The two terms on the left represent changes in sensible and latent soil

heat contents, i.e. change of heat storage in each soil layer over time. This change has to be balanced by an input or output of heat to the layer according to the law of energy conservation. The first three terms to the right (lower equation) corresponds to eq. (1.1), i.e. conductive and convective flows, and the last term to the right accounts for, e.g., the soil heat exchange of a heat pump system (see switch “[Heat pump](#)” on page 21). The change of sensible and latent heat for a partially frozen soil is described thoroughly in the section “[Soil frost](#)” on page 35. Below and above the soil freezing temperature interval the change in latent heat is by definition zero.

Upper boundary condition

Calculation of soil surface heat flow, $q_h(0)$, requires special attention. Convective heat inflow is given by precipitation throughfall and/or snow melt multiplied by the relevant surface temperature and the heat capacity of liquid water (cf. eq. . (1.1)):

$$q_h(0) = k_{ho} \frac{(T_s - T_1)}{\Delta z / 2} + C_w (T_a - \Delta T_{Pa}) q_{in} + L_v q_{vo} \quad (0.3)$$

where k_{ho} is the conductivity of the organic material at the surface, T_s is the surface temperature, T_1 is the temperature in the uppermost soil layer, ΔT_{Pa} is a parameter that represents the temperature difference between the air and the precipitation, q_{in} is the water infiltration rate, q_{vo} is the water vapour flow and L_v is the latent heat. The temperature difference, $T_a - \Delta T_{Pa}$, can optionally be exchanged to surface temperature, T_s (see switch “[PrecTemperature](#)”).

Soil surface temperature – bare soil

The surface temperature, T_s , is the upper boundary condition for the soil and can be specified in different ways (see switch “Surface temperature” in the section on soil evaporation). If soil surface temperature, T_s , is not measured, the simplest way is to assume for snow free periods that the surface temperature equals the air temperature. If soil evaporation is not accounted for, this approach has to be used.

If the interaction between aerodynamic properties, plant cover and surface evaporation is of interest, the surface temperature may also be calculated by solving the heat flow equation at the soil surface. This physical approach is described in the section on soil evaporation, and is also relevant for the boundary condition for the water flow equations.

Soil surface temperature – snow covered soil

For periods with snow cover, soil surface temperature under the snow pack, T_{ss} , is given by assuming steady state heat flow between the soil and a homogeneous snow pack, i.e. by setting the heat flow through the upper soil compartment equal to the heat flow in the snow pack (see figure below) and solving for T_{ss} :

$$T_{ss} = \frac{T_1 + aT_a}{1+a} \quad (0.4)$$

where the index 1 means the top soil layer, and the snow surface temperature is assumed to be equal to air temperature, T_a , or estimated from an energy balance approach for the snow surface (see switch “[SnowSurfTemperature](#)” in the section on snow. The weighting factor, a , is given by:

$$a = \frac{k_{snow} \left(\frac{\Delta z_1}{2} \right)}{k_h \cdot \Delta z_{snow}} \quad (0.5)$$

where Δz denotes thickness, k_{snow} is the conductivity in the snow pack and k_h is the conductivity in the uppermost soil compartment.

If the amount of liquid water in the snow pack, S_{wl} , exceeds a threshold, S_{wlmin} , (fixed parameter value) soil surface temperature under the snow, T_{ss} , is put equal to 0 °C.

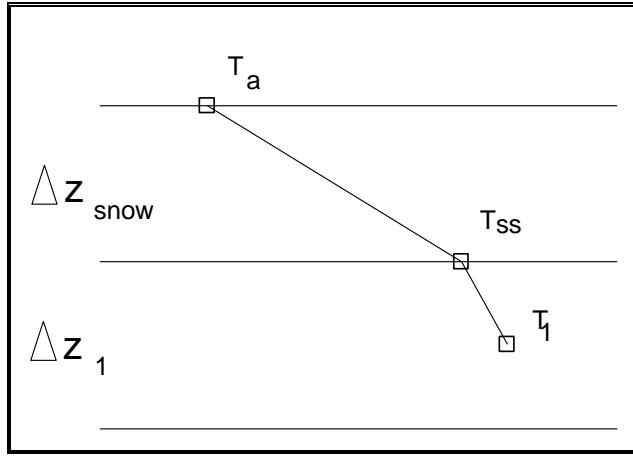


Figure 1.1 The steady state assumption of heat flow through the upper soil layer and the snow pack

The heat flow in the snow pack is calculated as:

$$q_h = k_{snow} \frac{T_a - T_{ss}}{\Delta z_{snow}} \quad (0.6)$$

and in the uppermost soil compartment as:

$$q_h = k_h \frac{T_{ss} - T_l}{\Delta z_1 / 2} \quad (0.7)$$

Soil surface temperature – soil partially covered with snow

During conditions when the snow depth is below a certain value Δz_{cov} the soil surface temperature will be calculated as a weighted sum between the calculated temperature below the snow and an estimated soil surface temperature from bare areas. The mean soil surface temperature, T_s , is then given by:

$$T_s = \left(1 - \frac{\Delta z_{snow}}{\Delta z_{cov}}\right) T_s + \frac{\Delta z_{snow}}{\Delta z_{cov}} T_{ss} \quad (0.8)$$

where Δz_{snow} is the snow depth.

Mixed composition of top layer

Since thermal properties of humus and mineral soil differ markedly (as described in detail in the next section on thermal properties), special treatment is required for a thin humus layer when numerical requirements demand that the top compartment represents a layer thicker than the humus layer, i.e. eq (1.3) has to be modified. Three special cases for heat conduction at the soil surface, $q_h(0)$, are given, depending on the depth of the insulating litter or humus layer.

For negligible depths, i.e., less than 5 mm, thermal conduction in humus is neglected:

$$q_h(0) = 2k_{hm} \frac{(T_s - T_l)}{\Delta z_1} \quad (0.9)$$

where k_{hm} is the conductivity in a mineral soil, T_s is the surface temperature and T_l is the temperature in the first soil compartment.

For a humus layer thicker than 5 mm but less than half the depth of the top soil layer a steady-state solution, analogous to the one for snow, gives the boundary temperature between humus and mineral soil:

$$T_b = \frac{T_1 + aT_s}{1+a} \quad (0.10)$$

where

$$a = \frac{k_{ho}(\Delta z_1 / 2 - \Delta z_{humus})}{k_{hm}\Delta z_{humus}} \quad (0.11)$$

where k_{ho} is the conductivity of the organic soil, k_{hm} is the conductivity of the mineral soil and Δz_{humus} is the thickness of the humus layer. The temperature, T_b , is used to calculate $q_h(0)$ instead of T_1 , in eq.(1.3).

For humus layers thicker than half the top soil layer, the calcualtion of $q_h(0)$ degenerates into the standard solution, i.e.:

$$q_h(0) = 2k_{ho} \frac{(T_s - T_1)}{\Delta z_1} \quad (0.12)$$

where k_{ho} is the conductivity in the organic soil, T_s is the surface temperature and T_1 is the temperature in the first soil compartment.

Lower boundary condition

Different options exist for the lower boundary (see switch “[Lower Boundary](#)”). The lower boundary condition for heat conduction can be given as a temperature or as a constant flow equal to a constant geothermal contribution parameter, $q_{h,low}$. In the former case the temperature, T_{lowB} is calculated from the assumed value of annual mean air temperature, T_{amean} , and amplitude, T_{aamp} , from an analytical solution of the conduction equation:

$$T_{LowB} = T_{amean} - T_{aamp} e^{-\frac{z}{d_a}} \cos\left((t - t_{ph})\omega - \frac{z}{d_a}\right) \quad (0.13)$$

where t is the time, t_{ph} is the phase shift, ω is the frequency of the cycle and d_a is the damping depth. The frequency is defined as:

$$\omega = \frac{2\pi}{y_{cycle}} \quad (0.14)$$

where y_{cycle} is the length of the temperature cycle (diurnal or annual) and the damping depth, d_a , is given as:

$$d_a = \sqrt{\frac{2D}{\omega}} \quad (0.15)$$

where D is the thermal diffusivity which is given as the ratio between the thermal conductivity, k_h , and the heat capacity, C , of the soil at a moisture content that equals the selected initial conditions.

Heat convection at the lower boundary condition depends on the presence of a ground water table in the profile. For an unsaturated profile convection follows percolation from the lowest soil layer. When a horizontal net ground water flow is present, convection follows this flow and is neglected for all layers below ground water level.

Initial Conditions

Initial conditions may be assigned in different ways depending on the required accuracy and the available information (see switch “[Initial Heat Conditions](#)”).

Exact Soil Temperature

The accuracy of the numerical solution for soil temperature may be tested if boundary conditions and homogeneous soil properties are chosen (see switch “[Analytical Solution](#)”). In such a case an additional auxiliary temperature for each layer may be calculated to test the numerical solution of soil temperatures using the same analytical solution equation as for

the lower boundary temperature above, eq. (1.13). Note that this exact temperature calculation assumes the boundary conditions of a sinus variation and can not be estimated from the energy balance (“Surface Temperature”) or for a non frozen soil.

Switches

Analytical Solution

Value	Meaning
Off	No additional output soil temperature variable.
On	An additional output of soil temperature is calculated based on the analytical solution according to eq. (1.13).

Convection flow

Value	Meaning
Not accounted for	The heat transported by convection of liquid water is disregarded.
Accounted for	The heat transported by convection of liquid water is calculated and added to the heat flow as estimated from conduction and optionally also latent vapour flows.

Heat pump

Value	Meaning
Not used	No extraction of heat from the soil.
Generated by parameters	Heat extraction will be defined by parameter values.
Read from PG-file	Heat extraction will be estimated from values in a PG-input file.

Heat source

Value	Meaning
Not used	No generation of heat from the soil.
One source (z)	Heat production will be estimated based on a base level defined in a parameter table and a sensitivity parameter in the exponential function. This source is expected to be a chemical source of heat. HeatProdCoef_A
One homogenous source	Same as above but with a common base level (HeatProcCoef_AA) for each layers.

Two sources (z)	Heat production will be estimated based and a base level defined in a parameter table HeatProdCoef_A2 and biological temperature sensitivy function (<i>Common abiotic Response module</i>). The O'Neil function is most appropriate for decreased activity at high temperatures..
Two homomogeneous source	Same as above but with a common base level (HeadProcCoef_AA2) for each layers.

Initial Heat Conditions

Value	Meaning
Uniform temperature	A parameter “ SoilInitTempConst ” is used to calculate the initial heat storage.
Temp(z)-Table	A parameter table “ InitialTemperatures ” is used to assign values of initial temperature at different layers for estimation of initial heat storage.
Temp(z)-Estimated	A temperature profile is taken from the analytical solution of the sine variation at the soil surface and a mean value of damping depth for the whole soil profile.
Heat(z)	A parameter table “ InitialHeatStorages ” is used to assign values of initial values for all heat state variable. Note that heat is defined relative to the level of non-frozen water at 0 °C.

Lower Boundary

Value	Meaning
Temperature cycle	The lower boundary is calculated from the analytical solution of the sine variation at the soil surface and a mean value of damping depth for the whole soil profile.
Constant heat flow	A constant heat flow is given by the value of the parameter “ GeothermalFlow ”.

PrecTemperature

Value	Meaning
Equal surface temperature	Convective heat flow by precipitation and irrigation is calculated by assuming water to have the same temperature as the soil surface.

Different air temperature	Convective heat flow is calculated by a temperature which is taken as the difference between air temperature and the value of the parameter “ TempDiffPrec_Air ”.
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Vapour flow

Value	Meaning
Not account for	Heat transport by vapour flow is disregarded.
Accounted for	Heat transport by vapour flow is calculated and accounted for in the heat balance.

Parameters

GeothermalFlow

Geothermal heat flow at the bottom of the soil profile.

Default	Unit	Symbol	Equation	Function
-100 000	J/m ² day	$q_{h,low}$		

HeatProdCoef_AA

Base level of heat production independent of temperature

Default	Unit	Symbol	Equation	Function
3628	J/mday			

HeatProdCoef_B

Temperature sensitivity coefficient in exponential function

Default	Unit	Symbol	Equation	Function
0.0964	/ °C			

SoilInitTempConst

Initial soil temperature conditions, uniform in all layers

Default	Unit	Symbol	Equation	Function
10	°C	T		

Source1 Decay Coef

Rate coefficient for chemical heat source as estimated by using exponential function $\exp(\text{coef} * \text{Number of Days})$

Source2 Decay Coef

Rate coefficient for biological heat source as estimated by using exponential function $\exp(\text{coef} * \text{Number of Days})$

TempDiffPrec_Air

Difference between air temperature and infiltrating precipitation that will be considered for calculation in convective heat transport by precipitation to the soil.

Default	Unit	Symbol	Equation	Function
-2	°C	ΔT_{Pa}	(1.3)	

Parameter Tables

InitialHeatStorages

No. of elements in Table: Number of layers in the model

Name	Default	Unit	Symbol	Comments/Explanations
UpperDepth	0	m	z	
LowerDepth	0.1	m	z	
Heat storage	10	J/m ²		

InitialTemperatures

No. of elements in Table: Number of layers in the model

Name	Default	Unit	Symbol	Comments/Explanations
UpperDepth	0	m	z	
LowerDepth	0.1	m	z	
Temperature	10	°C		

HeatSourceDistribution

No. of elements in Table: Number of layers in the model

Name	Default	Unit	Symbol	Comments/Explanations
UpperDepth	0	m	z	
LowerDepth	0.1	m	z	
ProdCoef_A	0	J/mday		
ProcCoef_A2	0	J/mday		

State Variables

SoilHeat

Total change of heat calculated from 0°C and no frost in the soil.

J/m²

Flow Variables

SoilHeatFlow

Heat flow between soil layers
J/m²/day

SoilHeatSink

Heat flow from a single layer into a sink
J/m²/day

SurfHeatFlow

Heat flow from the soil surface into the soil.
J/m²/day

Auxiliary Variables

ExactTemperature

Soil temperature calculated with an analytical solution to verify the temperatures derived from the numerical solution.
°C

TempSoilSurf

Temperature of the soil surface
°C

Temperature

Temperature of a soil layer
°C

ThermalQuality

Thermal quality (ratio ice/total amount of water) of a soil layer

-

TotalGroundLatFlow

Total latent heat flow from bare soil and snow covered ground to atmosphere
J/m²/day

TotalGroundSensFlow

Total sensible heat flow from bare soil and snow covered ground to atmosphere
J/m²/day

Soil Thermal Properties

Theory

Heat capacity

Soil heat capacity equals the sum of the heat capacities of soil constituents. Solid soil constituents are given on a volumetric basis. Heat capacity of air is negligible, such that:

$$C = f_s \Delta z C_s + \theta C_w + \theta_i C_i \quad (0.16)$$

where index f_s is the volumetric fraction of solid soil material including mineral and organic matter, derived from the porosity of the soil, θ_m . θ and θ_i are soil water contents as liquid water and ice, respectively and C_s , C_w and C_i are specific heat capacities for solid material, water and ice, respectively.

Optionally, the heat capacity of solid soil can be described as a function of depth (see switch “[SolidHeatCapDist](#)”):

$$C = f_s \cdot \Delta z \cdot c_{bulk}(z) + \theta C_w + \theta_i C_i \quad (0.17)$$

where c_{bulk} is the heat capacity of solid soil in different layers.

C is never explicitly given for a partly frozen soil since temperature, in this case, is obtained by special calculations (see eqs. [\(1.29\)-\(1.31\)](#)).

Thermal conductivity, unfrozen soil

Thermal conductivity is a complex function of soil solids and soil moisture. Since the soil often consists of a top humus layer and deeper mineral soil horizons, the conductivity will vary with depth even if the soil moisture is constant throughout the soil profile. If the organic top layer does not have the same thickness as the upper soil compartment, special calculations of the upper boundary condition have to be made (see “[Mixed composition of top layer](#)”).

For humus, i.e., organic matter, the thermal conductivity function is adapted from a figure in de Vries (1975):

$$k_{ho} = h_1 + h_2 \theta \quad (0.18)$$

where h_1 and h_2 are empirical constants. See viewing function “[Unfrozen Organic-type Soil](#)”.

For unfrozen mineral soil an empirical conductivity function is adapted from Kersten (1949):

$$k_{hm} = 0.143 \left(a_1 \log \left(\frac{\theta}{\rho_s} \right) + a_2 \right) 10^{a_3 \rho_s} \quad (0.19)$$

where a_1 , a_2 and a_3 are parameters and ρ_s is the dry bulk soil density (see Figure 1.2). The logarithmic argument, θ/ρ_s , is equivalent to the soil water content by weight. See viewing functions “[Unfrozen Clay-type Soil](#)” and “[Unfrozen Sand-type Soil](#)”.

The thermal conductivity for both the mineral and the organic soils can be scaled with a scaling factor, x_{hf} .

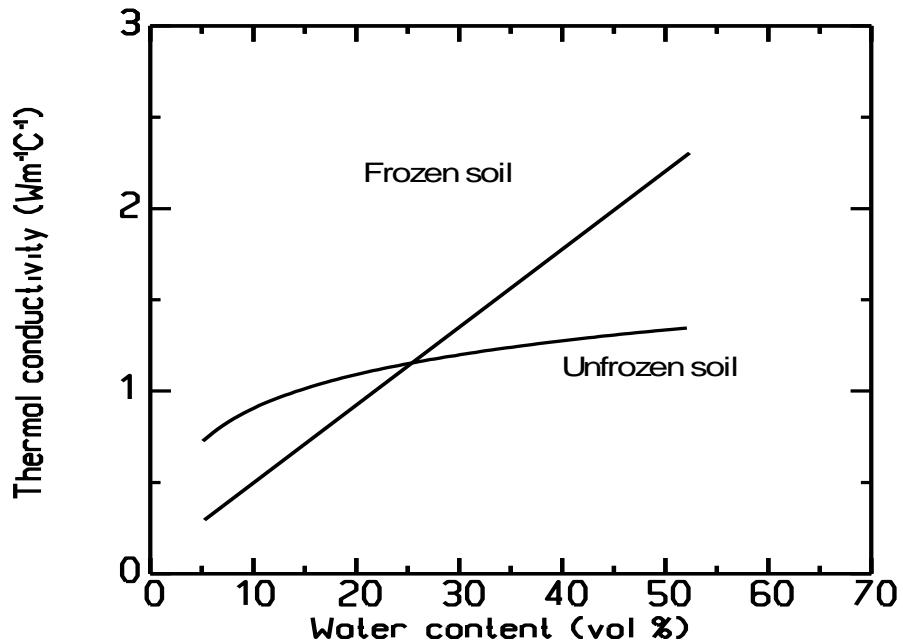


Figure 1.2 Thermal conductivity. Kersten's equations, originally given for water content in percent by weight, are here recalculated to volumetric basis for a specific soil.

Thermal conductivity, frozen soil

Thermal conductivity of a fully frozen organic soil is calculated with a similar equation as for unfrozen organic soils but including a second degree coefficient to account for the influence of ice on the conduction in the soil.

$$k_{ho,i} = \left(1 + h_3 Q \left(\frac{\theta}{100} \right)^2 \right) k_{ho} \quad (0.20)$$

where Q is the thermal quality of the soil layer (see eq.(1.33)) and k_{ho} is the thermal conductivity in the soil when it is not frozen as calculated by eq.(1.18). h_3 is a parameter for organic frozen soils. See viewing function “[Frozen Organic-type Soil](#)”.

Thermal conductivity of fully frozen mineral soil (see Figure 1.2) is adapted from Kersten (1949):

$$k_{hm,i} = b_1 10^{b_2 \rho_s} + b_3 \left(\frac{\theta}{\rho_s} \right) 10^{b_4 \rho_s} \quad (0.21)$$

where b_1 , b_2 , b_3 and b_4 are parameters and ρ_s is the dry bulk soil density. See viewing functions “[Frozen Clay-type Soil](#)” and “[Frozen Sand-type Soil](#)”.

The thermal conductivity in the upper soil layer in frozen soils is reduced by a correction factor, R_f , which is multiplied with the thermal conductivity for mineral and organic soil respectively. The reduction factor is derived from two parameters:

$$R_f = e^{c_f T_s} c_{md} + (1 - c_{md}) \quad (0.22)$$

where T_s is the soil surface temperature and c_f and c_{md} are parameters. See viewing function “[Frozen Surface Damping Function](#)”.

The thermal conductivity for both the mineral and the organic soils can be scaled with a scaling factor, x_{hf} .

Switches

Switches governing the thermal processes in the model.

SolidHeatCapDist

Value	Meaning
Uniform	The heat capacity of solid soil is assumed to be a constant (i.e. $2 \cdot 10^6$).
$f(z)$	The heat capacity of solid soil can vary with depth according to the parameter c_{bulk} .

Parameters

Soil thermal properties, i.e. volumetric heat capacity and thermal conductivity, are treated as functions of the volumetric fractions of solid material, liquid water and ice. For the thermal conductivity, different coefficients are used in these functions depending on whether the soil is dominated by clay, by sand or by organic material. Soils with a pore size distribution below 0.5 and a volumetric water content at wilting point above 10 % are classified as clay soils. The coefficients valid for organic soils are used from the soil surface down to the depth assigned to the OrganicLayerThick parameter. The coefficients used for mineral soil originate from Kersten (1949) and the ones used for organic soils are based on data from de Vries (1973).

CFrozenMaxDamp

Default	Unit	Symbol	Equation	Function
0.9	-	c_{md}	(1.22)	“Frozen Surface Damping Function”

CFrozenSurfCorr

Default	Unit	Symbol	Equation	Function
0.2	$^{\circ}\text{C}^{-1}$	c_f	(1.22)	“Frozen Surface Damping Function”

ClayFrozenC1

Default	Unit	Symbol	Equation	Function
0.00144	-	b_1	(1.21)	“Frozen Clay-type Soil”

ClayFrozenC2

Default	Unit	Symbol	Equation	Function
1.32	-	b_2	(1.21)	“Frozen Clay-type Soil”

ClayFrozenC3

Default	Unit	Symbol	Equation	Function
0.0036	-	b_3	(1.21)	“Frozen Clay-type Soil”

ClayFrozenC4

Default	Unit	Symbol	Equation	Function
0.8743	-	b_4	(1.21)	“Frozen Clay-type Soil”

ClayUnFrozenC1

Default	Unit	Symbol	Equation	Function
0.13	-	a_1	(1.19)	“Unfrozen Clay-type Soil”

ClayUnFrozenC2

Default	Unit	Symbol	Equation	Function
-0.029	-	a_2	(1.19)	“Unfrozen Clay-type Soil”

ClayUnFrozenC3

Default	Unit	Symbol	Equation	Function
0.6245	-	a_3	(1.19)	“Unfrozen Clay-type Soil”

OrganicC1

Linear coefficients of the function for organic soil.

Default	Unit	Symbol	Equation	Function
0.06	-	h_1	(1.18)	“Unfrozen Organic-type Soil”

OrganicC2

Default	Unit	Symbol	Equation	Function
0.005	-	h_2	(1.18)	“Unfrozen Organic-type Soil”

OrganicFrozenC

Default	Unit	Symbol	Equation	Function
2.0	-	h_3	(1.20)	“Frozen Organic-type Soil”

OrganicLayerThick

Thickness of the humus layer. This parameter is only used as a thermal property. A value greater than 0 may also be used in case you want to introduce or account for a thermal barrier between the atmosphere and the soil.

Default	Unit	Symbol	Equation	Function
0	m	Δz_{humus}	(1.11)	

SandFrozenC1

Kerstens equations

Default	Unit	Symbol	Equation	Function
0.00158	-	b_1	(1.21)	“Frozen Sand-type Soil”

SandFrozenC2

Default	Unit	Symbol	Equation	Function
1.336	-	b_2	(1.21)	“Frozen Sand-type Soil”

SandFrozenC3

Default	Unit	Symbol	Equation	Function
0.0375	-	b_3	(1.21)	“Frozen Sand-type Soil”

SandFrozenC4

Default	Unit	Symbol	Equation	Function
0.9118	-	b_4	(1.21)	“Frozen Sand-type Soil”

SandUnFrozenC1

Default	Unit	Symbol	Equation	Function
0.1	-	a_1	(1.19)	“Unfrozen Sand-type Soil”

SandUnFrozenC2

Default	Unit	Symbol	Equation	Function
0.058	-	a_2	(1.19)	“Unfrozen Sand-type Soil”

SandUnFrozenC3

Default	Unit	Symbol	Equation	Function

0.6245	-	a_3	(1.19)	“Unfrozen Sand-type Soil”
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Parameter Tables

Heat Capacity of solids

No. of elements in Table: no of layers

Name	Default	Unit	Symbol	Comments/Explanations
C bulk	$2 \cdot 10^6$	J m ⁻³	c_{bulk}	The heat capacity of soild soil.

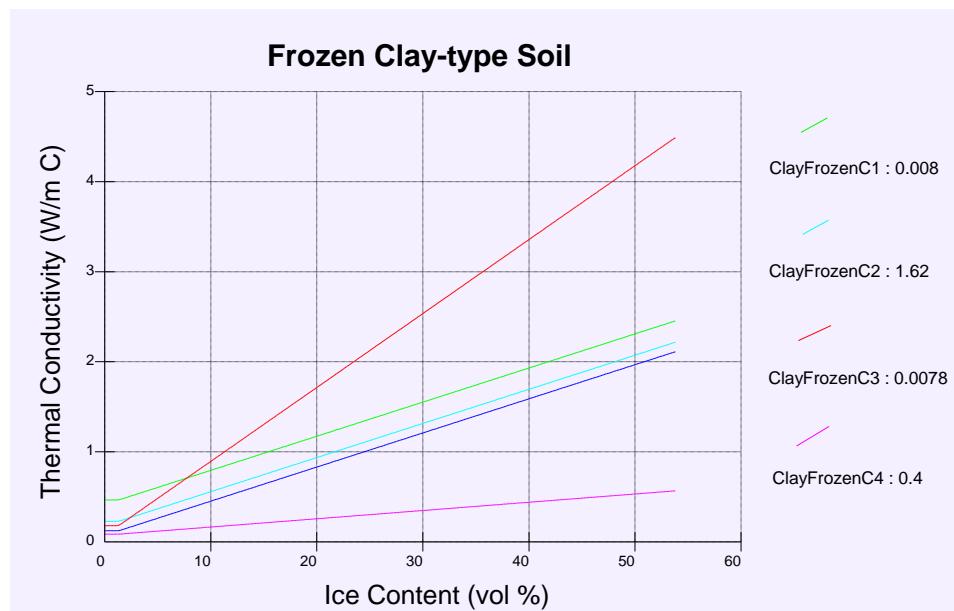
Scaling coefficient

No. of elements in Table: 10

Name	Default	Unit	Symbol	Comments/Explanations
ThScaleLog	0	-	x_{hf}	A multiplicative scaling coefficient (10-log base) for the thermal conductivity applicable for each soil layer for frozen and unfrozen soils. This value is multiplied with the thermal conductivity for mineral soils as estimated from the Kersten's equations and the linear equation used for organic soils.

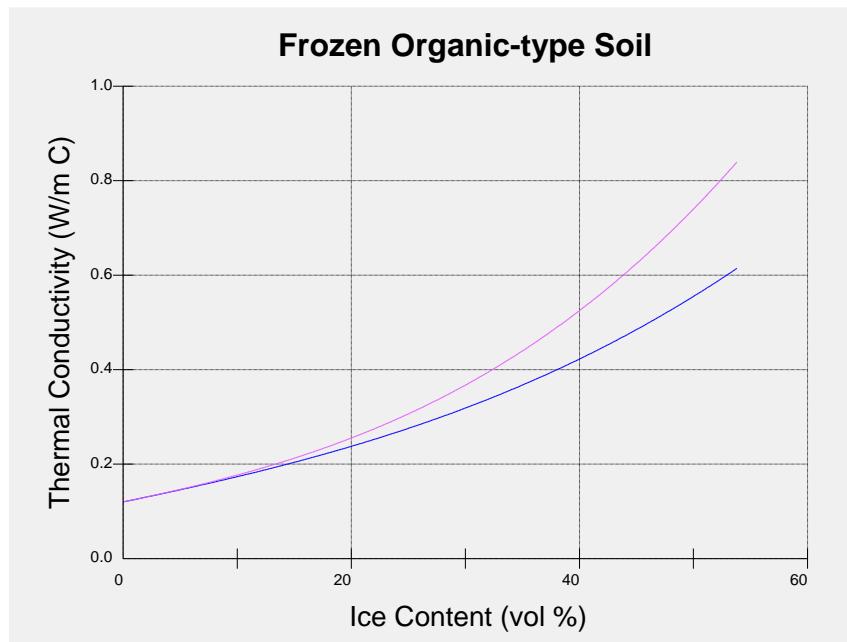
Viewing functions

Frozen Clay-type Soil



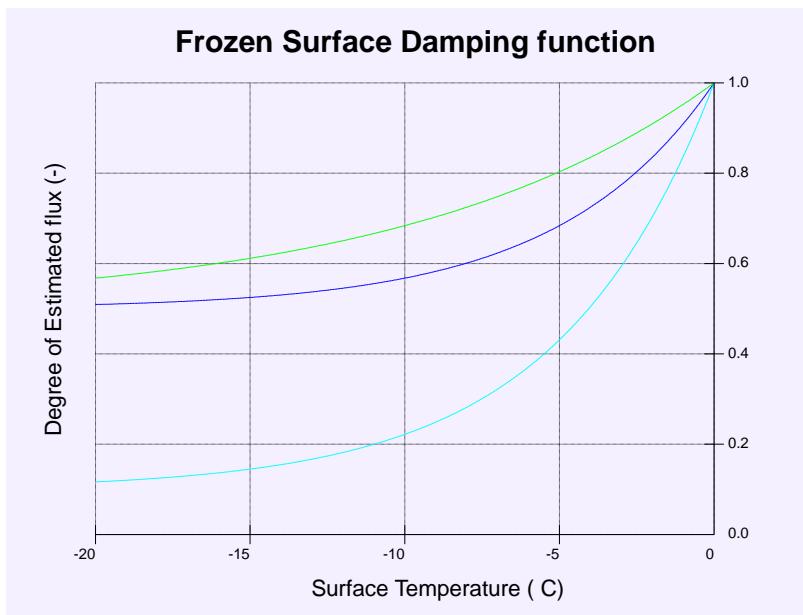
The thermal conductivity dependence on the ice content in a clay soil for four different parameterisations. All parameterisations should be compared to the original parameterisation (blue line) with default values; ClayFrozenC1 = 0.0014, ClayFrozenC2 = 1.32, ClayFrozenC3 = 0.0036 and ClayFrozenC4 = 0.8743.

Frozen Organic-type Soil



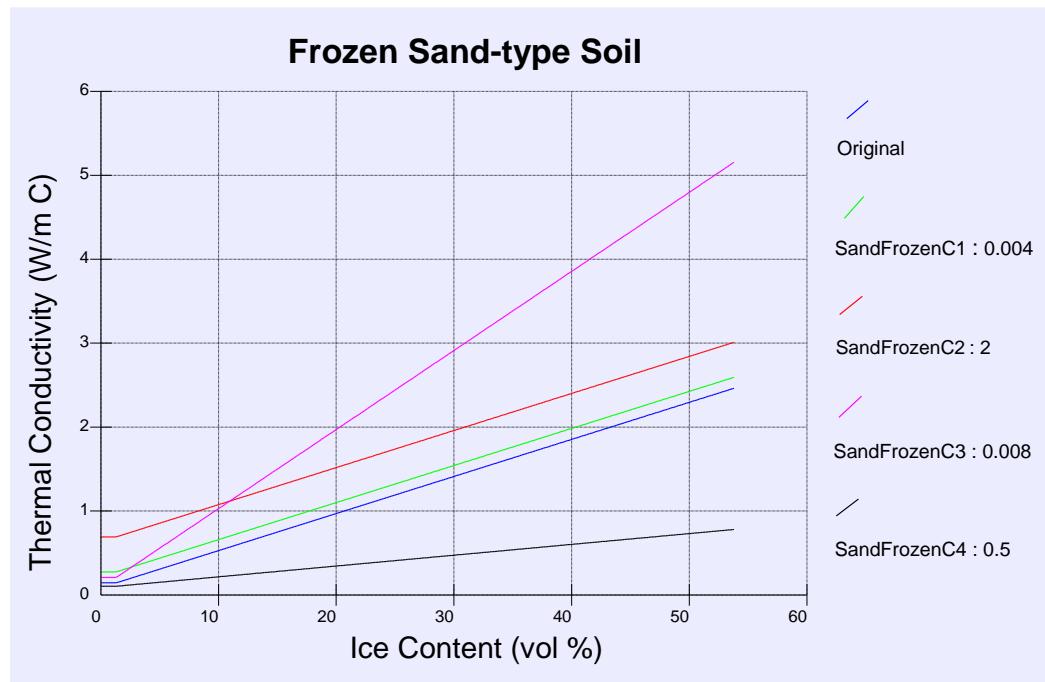
The thermal conductivity dependence on the ice content in an organic soil for two different parameterisations. The parameter Organic frozenC was put to 2 for the violet line and to 4 for the blue line.

Frozen Surface Damping Function



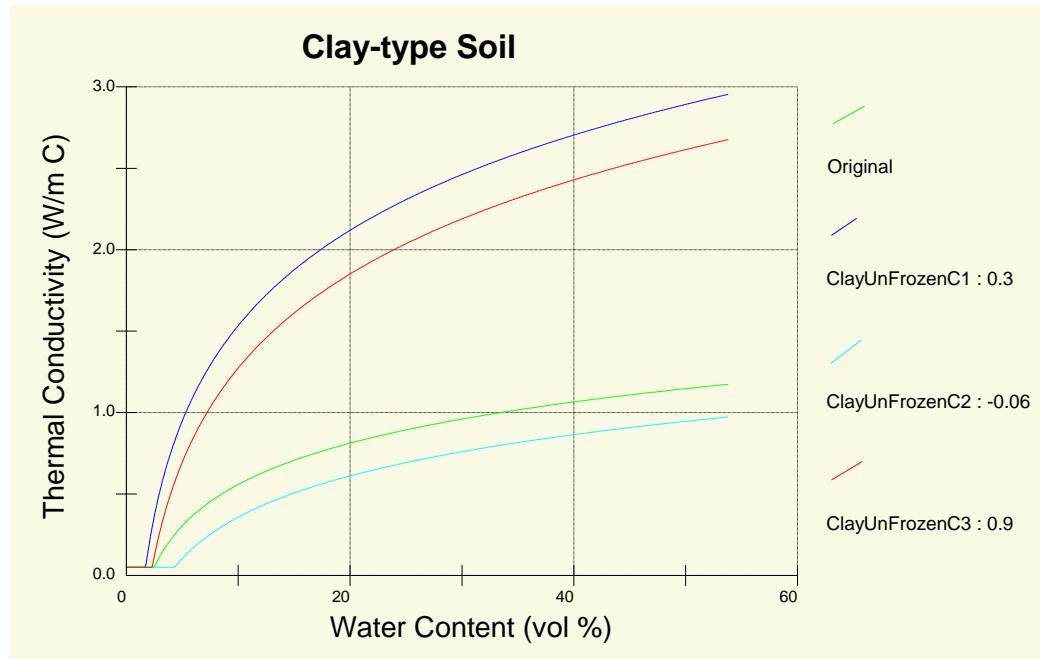
The frozen surface damping function. Effect on heat flux due to low soil temperatures. The turquoise line is the default parameter setting with CfrozenMaxDamp = 0.9 and CfrozenSurfCorr = 0.2. Decreasing the former parameter to 0.5 alters the slope of the curve (blue line) as well as decreasing the latter parameter to 0.1 (green line).

Frozen Sand-type Soil



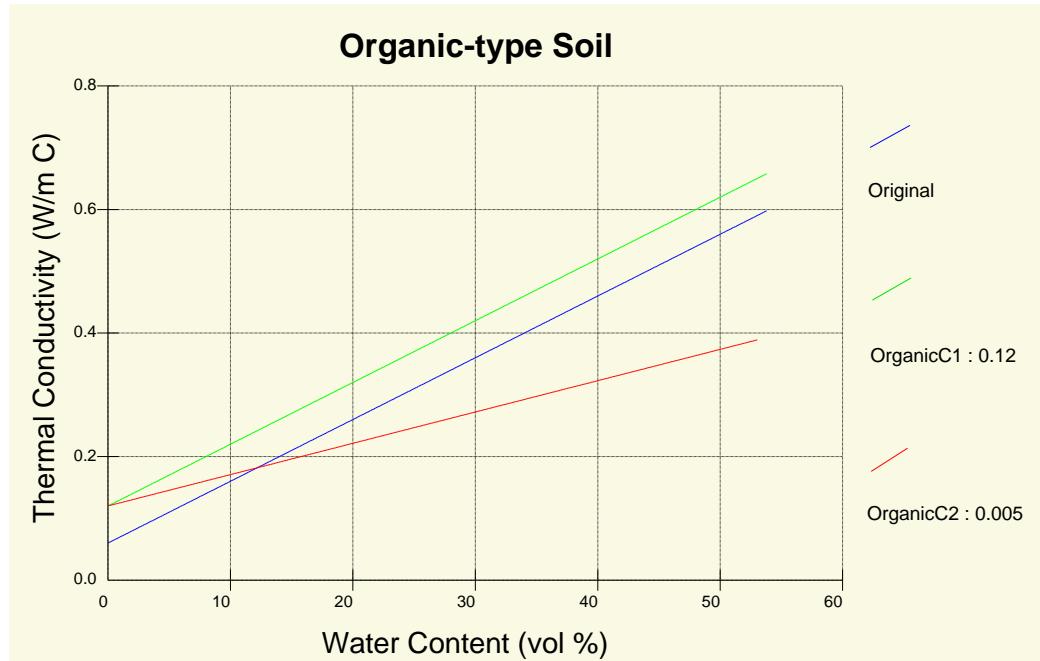
The thermal conductivity dependence on the ice content in a sandy soil for four different parameterisations. All parameterisations should be compared to the original parameterisation (blue line) with default values; SandFrozenC1 = 0.0016, SandFrozenC2 = 1.336, SandFrozenC3 = 0.00375 and SandFrozenC4 = 0.918.

Unfrozen Clay-type Soil



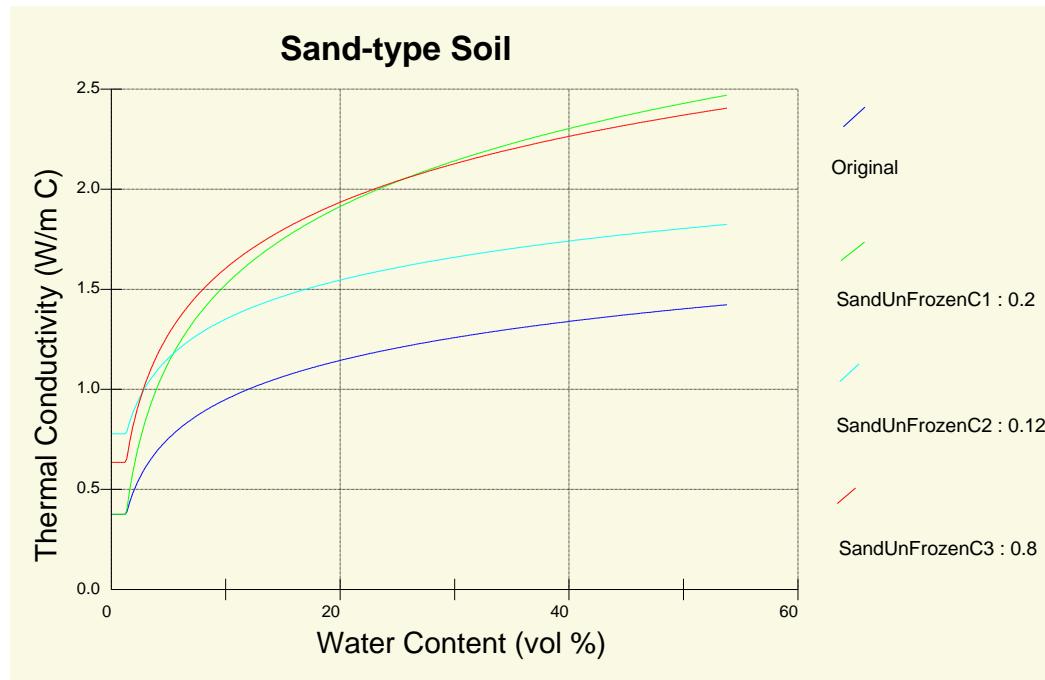
The thermal conductivity dependence on the water content in a clay soil for four different parameterisations. All parameterisations should be compared to the original parameterisation (green line) with default values; ClayUnFrozenC1 = 0.13, ClayUnFrozenC2 = -0.06 and ClayUnFrozenC3 = 0.6245.

Unfrozen Organic-type Soil



The thermal conductivity dependence on the water content in an organic soil for three different parameterisations. All parameterisations should be compared to the original parameterisation (blue line); OrganicC1 = 0.06 and OrganicC2 = -0.01.

Unfrozen Sand-type Soil



The thermal conductivity dependence on the water content in a sandy soil for three different parameterisations. All parameterisations should be compared to the original parameterisation (blue line) with default values; SandUnFrozenC1 = 0.1, SandUnFrozenC2 = 0.058 and SandUnFrozenC3 = 0.6245.

Soil frost

Theory

This section deals with calculations of the coupled heat and water fluxes of frozen soils. In the first part, the heat balance will be discussed with emphasis on the procedure of the latent and sensible heat partitioning during a phase change. In the second part, the water movement in frozen soil layers and at the boundaries of the frozen soil will be assessed.

Heat flux in frozen soils

Soil temperature is the driving force for a flux of energy in the soil profile, eq.(1.1). This flux, q_h , has to be balanced by a change in the energy storage in the soil, eq. (1.2), described by the changes in latent heat content (left hand side terms). However, the calculation of the ratio between sensible and latent heat when the soil freezes is complicated by a depression of the freezing-point. When the temperature drops below 0 °C the energy storage in the soil is changed such that liquid water is converted to ice, i.e. change of latent heat, and simultaneous with the temperature decrease, i.e. change of sensitive heat. The latent heat of freezing, seen in eq. (1.2) as the second left term, is zero when the soil is completely unfrozen or frozen.

Treatment of frost in the soil is based on a function for freezing-point depression and on an analogy between the processes of freezing-thawing and drying-wetting, i.e., the liquid-ice interface is considered equal to the liquid-air interface (see Harlan, 1973). Thus, unfrozen water below zero can be associated with a matric potential and an unsaturated conductivity and therefore affects soil water flows (see switch “[FrostInteract](#)”). Freezing gives rise to a potential gradient which in turn forces a water flow depending on the prevailing conductivity. This causes a capillary rise of water towards the frost zone and it also allows drainage of snow melt through the frost zone when frozen soil temperatures are close to 0 °C.

Sensible and latent heat content of a partially frozen soil

A change in sensible heat content in the soil, H , results in a new soil temperature, which in turn gives rise to an energy flux that affects the energy storage and so forth. Thus the soil temperature is a function of the sensible heat:

$$T = \frac{H}{C_f} \quad (0.23)$$

where H is the sensible heat content and C_f is the heat capacity of the frozen soil, eq.(1.29). The phase change takes place in a temperature interval from 0 °C to T_f , which is the threshold temperature below which the soil is assumed to be completely frozen. In this temperature range, the sensible heat content is not equal to the total energy content in the soil, E , and therefore has to be calculated specifically as:

$$H = E(1 - f_{lat})(1 - r) \quad (0.24)$$

where r is the freezing-point depression, eq.(1.30), and E is the total heat content of the soil (i.e. left hand side of eq.(1.2)). f_{lat} is the ratio of latent heat of ice to the total heat content of the soil, E_f , at the temperature T_f :

$$f_{lat} = \frac{L_f w_{ice}}{E_f} \quad (0.25)$$

where L_f is the latent heat of freezing, E_f is the total heat content of the soil at the temperature T_f (see below) and w_{ice} is the mass of water available for freezing calculated as:

$$w_{ice} = w - \Delta z \theta_{lf} \rho_{water} \quad (0.26)$$

where w is the total mass of water, θ_{lf} is the residual amount of water and ρ_{water} is the density of water.

The simplified assumption is made that all water at the temperature, T_f , is frozen except of a residual unfrozen amount, θ_{lf} calculated as:

$$\theta_{lf} = d_1 \theta_{wilt} \quad (0.27)$$

where d_1 is a constant and θ_{wilt} is volumetric water content at a soil water potential corresponding to pF 4.2.

The heat content of soil, E_f , at the temperature T_f is a function of latent and sensitive heat:

$$E_f = C_f T_f - L_f w_{ice} \quad (0.28)$$

For temperatures between 0 °C and T_f the soil heat capacity, C_f , is calculated as:

$$C_f = f_s C_s + \theta_i C_i + \theta_{lf} C_w \quad (0.29)$$

where C_s is the heat capacity of solid material, C_i is the heat capacity of ice and C_w is the heat capacity of water. θ_i is the water content in the ice and f_s is the volumetric content of the solid material (i.e. 1 - θ_s).

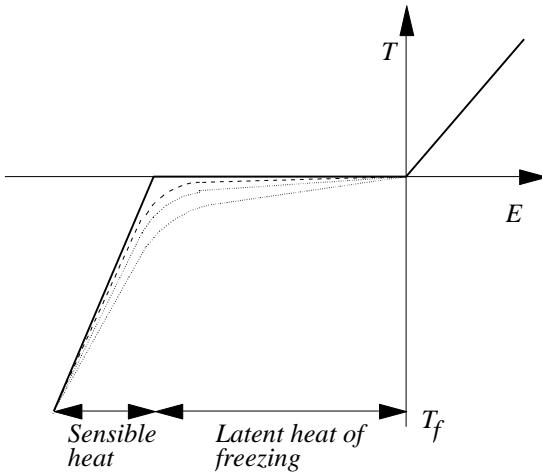


Figure 1.3 Soil temperature (T) as a function of heat content (E) for different degrees of freezing-point depression, i.e. different values of $d_2\lambda + d_3$ (see eq. (1.30)). Both axes are distorted for the sake of clarity. With a completely frozen soil temperature (T_f) of -5°C the ratio between sensible and latent heat is approximately 1:24.

Freezing-point depression (Beskow, 1935), which depends on soil texture (see Figure 1.3), is expressed by the ratio between latent heat contents of E at temperature T (when the temperature is between 0°C and T_f) and E_f at temperature T_f :

$$r = \left(1 - \frac{E}{E_f}\right)^{d_2\lambda + d_3} \min\left(1, \frac{E_f - E}{E_f + L_f w_{ice}}\right) \quad (0.30)$$

where d_2 and d_3 are empirical constants and λ is the pore size distribution index. The second factor in eq. (1.30) is inserted to ensure that temperatures close to T_f never exceed free water temperatures at equivalent heat contents. See viewing function “[Freezing Temperature Function](#)”.

Upper boundary conditions for a partially frozen soil

When the upper boundary condition is given as a measured temperature of the uppermost layer and the temperature is in the range between 0°C and T_f , the heat content, E_1 , is calculated from the temperature, T_1 . This is accomplished through an approximate inversion of eq. (1.30):

$$E_1 = L_f w \left(\frac{T_1}{T_f} \right)^{\frac{\lambda d_3 + d_2}{d_2 d_3}} + C_i T_1 \quad (0.31)$$

where L_f is the latent heat of freezing, w is the total mass of water, d_2 and d_3 are empirical constants, λ is the pore size distribution index and C_i is the heat capacity of ice. See viewing function “[Freezing Temperature Function](#)”.

Thermal conductivity – partially frozen soil

For temperatures between 0°C and T_f a weighted conductivity is used:

$$k_h = Q k_{h,i} + (1 - Q) k_h \quad (0.32)$$

where $k_{h,i}$ is the thermal conductivity of a frozen soil and k_h is the thermal conductivity of an unfrozen soil. The thermal quality, Q , (the mass ratio of frozen water to total amount of water) is deduced from energy relations:

$$Q = -\frac{(E - H)}{L_f w_{ice}} \quad (0.33)$$

where E is the total heat content of the soil, H is the sensitive heat content, L_f is the latent heat of freezing and w_{ice} is the mass of water available for freezing.

Frost boundary

Frost boundaries are calculated as model outputs in a separate subroutine as isotherms of 0 °C. The somewhat less simplistic assumption of a linear heat change between adjacent layers, give these isotherms a strong dependence on the choice of layer thickness. Not more than two frost layers are allowed to occur simultaneously for output purposes.

Influence of ice on water flows

This section deals with soil water flows under partially frozen conditions. Water processes in general are described in the chapter “Soil Water Processes”.

Hydraulic conductivity

When ice is formed in the soil the flow paths of water are altered. Under partially frozen conditions the soil can be considered to consist of two flow domains, one consisting of small pores where water is unfrozen due to a low water potential, and another consisting of large pores that are air-filled because of surface tension effects (see Figure 1.4). In the former one consisting of small sized pores the flow will consequently be much slower than in the high-flow domain, and this domain is thus called the low-flow domain. The other flow domain, the high-flow domain, consists mainly of large air-filled pores that allows for a rapid water flow.

The water content of the low-flow domain is determined by the soil temperature (below 0 °C) and the freezing point depression curve (c.f. sensible and latent heat content of a partially frozen soil), whereas the water content in the high-flow domain depends on the amount of infiltrating water, the hydraulic conductivity of that domain, k_{hf} , and the water refreezing rate, $q_{infreeze}$, (see below).

The flow in the low-flow domain is driven by the water-potential gradient according to Darcy's law (eq. 2.1) as for unfrozen conditions.

The calculation of the water flow in the high flow domain is optional (see switch “[FlowDomains](#)”). Water flow in the high-flow domain is unit gravitational flow based i.e., corresponding to the hydraulic conductivity of that domain, k_{hf} :

$$k_{hf} = e^{-\frac{\theta_i}{c_{\theta,i}}} \left(k_w(\theta_{tot}) - k_w(\theta_{lf} + \theta_i) \right) \quad (0.34)$$

where $k_w(\theta_{tot})$ is the hydraulic conductivity corresponding to all volume occupied by water and $k_w(\theta_{lf} + \theta_i)$ is the hydraulic conductivity corresponding to the volume occupied by water in the low-flow domain and ice. The reduction term, $\theta_i/c_{\theta,i}$, where $c_{\theta,i}$ is the damping ice content, accounts for the blocking effect of ice. See viewing function “[High-Flow Domain Damping Function](#)”.

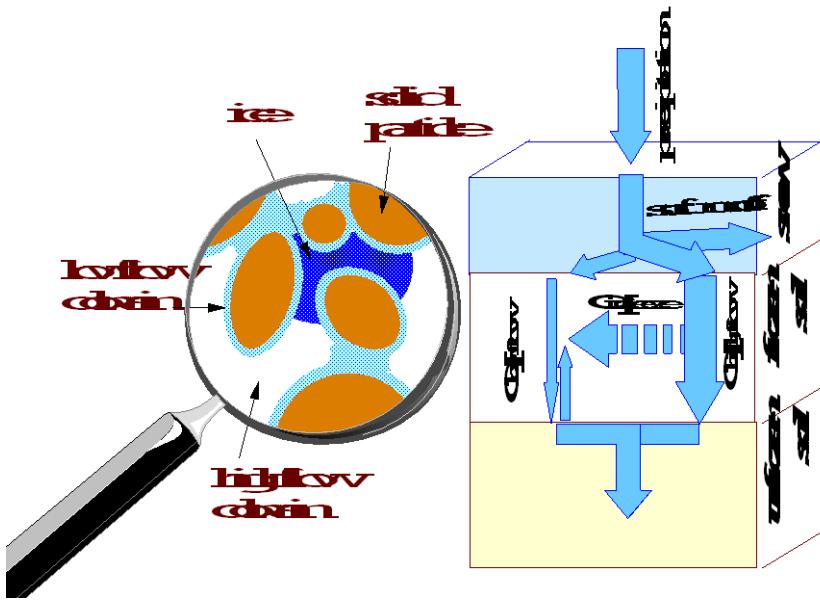


Figure 1.1 The flow paths and the hydraulic conductivities for the two domain approach. (After Stähli et al, 1999)

Freezing front

At the freezing front the hydraulic conductivity changes drastically and therefore needs to be adjusted. Two different calculations are made in the model to reduce the hydraulic conductivity in the low-flow domain under partially frozen conditions. The first procedure affects the boundary conductivity whereas the second one reduces the hydraulic conductivity of a partially frozen soil layer directly.

Normally an upward water flow towards a partially frozen soil layer is calculated based on a conductivity which is the linear interpolated value at the boundary between the adjacent layers. This interpolation procedure for obtaining the boundary conductivity between two layers may optionally be replaced by a procedure in which the boundary conductivity is selected as the minimum conductivity of the two layers (see switch “[k-estimate](#)”). This will normally substantially reduce the flow towards the layer where freezing takes place, such that the clear tendency to overestimate redistribution during freezing will be reduced (Lundin, 1990).

In addition to the alternative interpolation procedure an impedance factor is considered when the hydraulic conductivity of a partially frozen layer, k_{wf} , is calculated:

$$k_{wf} = 10^{-c_{fi}Q} k_w \quad (0.35)$$

where Q is the thermal quality, c_{fi} is an impedance parameter and k_w is the hydraulic conductivity of the layer calculated from the unfrozen water content without accounting for occurrence of ice (see “Soil hydraulic properties”). See viewing function “[Low-flow domain hydraulic impedance function](#)”.

Infiltration

Infiltration of water into the soil when the soil is frozen can be specified in several ways (see switch “[Infiltration](#)”). The easiest approach is to calculate the infiltration as if the soil was always unfrozen. The other two approaches account for flows in either the low-flow domain or in both the low- and the high-flow domain, based on the same equations for estimation of hydraulic conductivity as described above, Eq [\(1.34\)](#) and [\(1.35\)](#).

At the soil surface, water may infiltrate into the low-flow domain until the capacity of this domain is reached, i.e. the unsaturated conductivity $k_{wf}(\theta_{lf})$ times the total water potential gradient. The surplus water enters the air-filled pores in the high-flow domain to a degree that is limited by the conductivity of this domain, k_{hf} . Thus an allocation of water from the low- to the high-flow domain takes place (this occurs only if the high-flow domain is considered in the simulation). If

the capacity of the high-flow domain is also reached by the snow melt or precipitation, the surplus water will be transferred to the surface pool (see “Surface Water”).

Refreezing

Water infiltrating in the high-flow domain is assumed to have a temperature close to 0 °C. As it percolates through the high-flow domain, it may partially refreeze depending on the soil temperature. The heat which is released from freezing in the high-flow domain causes melting of ice in the finest ice-filled pores, shifting the boundary between the low-flow domain and the ice-domain toward larger pores. Thus, refreezing of infiltrating water is treated as a redistribution, q_{infreeze} , from the high- to the low-flow domain:

$$q_{\text{infreeze}} = \alpha_h \Delta z \frac{T}{L_f} \quad (0.36)$$

where α_h is a heat transfer parameter, Δz is the thickness of the layer, T is the temperature of the layer and L_f is the latent heat of freezing. See viewing function “[Refreezing](#)”.

Water potential

The ice in the soil will affect water potential in two ways. First of all the water potential is influenced because of the freezing that will change the amount of unfrozen water. This primarily effect is governed by the switch “[FrostInteract](#)”. If this switch is off, the water potentials will be considered as if all water was unfrozen.

The water potential can also be affected by the load of the soil above the layer where water is located (see switch “[LoadPotential](#)”). When the load potential is accounted for, the water potential of the soil above a specific layer is calculated as:

$$\psi(z) = \psi^*(z) + \frac{\theta_i}{\theta_i + f_a} z \square 200 \quad (0.37)$$

where ψ^* corresponds to the water potential not affected by the load, θ_i is the volumetric ice content, f_a is the volumetric air content (i.e. $\theta_s - \theta$), z is the depth of the layer and the constant 200 is assumed based on an average wet bulk density of 2 g/cm³.

Frost heaving

Frost heave is optionally accounted for (see switch “[FrostSwelling](#)” on page 41) in a simplistic way provided that frost interaction has been chosen. A soil compartment will heave if the total volume of ice and unfrozen water exceeds the porosity of the soil in one layer.

During a situation when the soil tends to swell, the thickness of a compartment is calculated as:

$$\Delta z_t = \Delta z^* \min(f_l + f_i + f_s, 1 + p_{ms}) \quad (0.38)$$

where Δz^* is the orginal thickness of the layer, f_l , f_i and f_s is the volumetric fractions of liquid water, ice and solids respectively, as calculated from the original thickness of the layer. The p_{ms} coefficient represents the parameter that corresponds to the maximal allowed swelling.

During shrinking the correspondent compartment size is calculated as:

$$\Delta z_t = \max(\Delta z_{t-1} - p_{rf} (\Delta z_{t-1} - \Delta z^*), \Delta z^*) \quad (0.39)$$

where Δz_{t-1} is the compartment size for the previous time step and p_{rf} is the maximal shrinking rate parameter. See viewing function “[Shrinkage Function](#)”.

Switches

FlowDomains

Value	Meaning
Low Domain	Unsaturated conductivity for liquid water flow will be calculated from the liquid water present in pores that are smaller than what is given from the total liquid water without any account for the ice in the soil.
Low + High Domain	The conductivity will be calculated based on a two-domain approach where some liquid water is in smaller pores than those occupied by the ice (Low-domain) and some other are in larger pores (High-domain).

FrostInteract

Value	Meaning
No	Water flows will be calculated independent of the soil temperature even if the temperature is below freezing in the soil.
InfluencingWater	Water flows will be influenced by the water potential gradients that are caused by freezing of the soil moisture.

FrostSwelling

Value	Meaning
Off	No swelling of soil layers will be considered.
On	Swelling of soil layers will be considered if the total volume of ice and liquid water exceeds the porosity in a soil layer.

Infiltration

Value	Meaning
No reduction	Infiltration is calculated as if the soil was always unfrozen independent of the amount of ice in the soil.
In Low FlowDomain	Infiltration will be reduced by the ice and the conductivity will be based on liquid water in the low-flow domain only.
Low+High FlowD	Both domains of pores will be accounted for and infiltration is routed into both the low- and the high-flow domain.

LoadPotential

Value	Meaning

Off	No account for the load of the soil on the water potential will be made.
On	The total soil water potential during partially frozen conditions will include the load governed by the mass of soil above the specific soil depth

k-estimate

Value	Meaning
CentralDifference	Upward water flow towards a partially frozen soil layer is calculated based on a conductivity which is the linear interpolated value at the boundary between the adjacent layers.
MinimumValues	Upward water flow towards a partially frozen soil layer is calculated based on the minimum conductivity at the upper and the lower layer.

Parameters

Parameters are found for refreezing, freezing-point depression function and impedance to the normal hydraulic conductivity. In addition also a swelling function may be accounted for.

AlphaHeatCoef

Heat transfer coefficient regulating refreezing of water in the high-flow domain.

Default	Unit	Symbol	Equation	Function
1000	W/m°C	α_h	(1.36)	“Refreezing”

Refreezing is made proportional to the temperature (below 0 °C) of the frozen soil and the inverse of the latent heat of melting. This parameter depends on the shape and the geometry of the pore structure and the interface between the ice and the liquid water in the soil in combination with the thermal properties of ice and liquid water. It has to be determined by calibration and no experience exists concerning appropriate values for different soil types.

The old default value of 1.E5 J/day°C corresponds to 0.11 W/m°C if a compartment size of 0.1 m is considered.

FreezepointF0

Default	Unit	Symbol	Equation	Function
10	-	d_3	(1.30),(1.31)	“Freezing Temperature Function”

This parameter was introduced as complementary to FreezepointF1 in version 9.3 in March 96. The value of d_3 was found by Stähli to be around 10 and makes the d_2 parameter redundant (Stähli & Jansson, 1998).

FreezepointF1

Empirical freezing-point coefficient parameter used to estimated the liquid water content as a function of change of energy storage when freezing takes place in the soil.

Default	Unit	Symbol	Equation	Function

0	-	d_2	(1.30),(1.31)	“Freezing Temperature Function”
---	---	-------	---------------	---

FreezePointFWi

Fraction of wilting point remaining as unfrozen water at -5 °C.

Default	Unit	Symbol	Equation	Function
0.5	-	d_I	(1.27)	“Freezing Temperature Function”

Normal values will be in the range between 0.3 and 1.0.

HighFlowDampC

Scaling coefficient for the high-flow domain.

Default	Unit	Symbol	Equation	Function
5	vol %	$c_{\theta, I}$	(1.34)	“High-Flow Domain Damping Function”

LowFlowCondImped

Decrease of unsaturated conductivity because of freezing (power of ten at completely frozen soil).

Default	Unit	Symbol	Equation	Function
4	-	c_{fi}	(1.35)	“Low-flow domain hydraulic impedance function”

The value of this parameter will be above zero in case of developing ice lenses or other actions which disturb possible flow path for liquid water. A reasonable range is from 0 to 10. The lower values can preferably be used when the switch “[k-estimate](#)” is set to “minimum values”. Chosing “[k-estimate](#)” to “minium value”, or putting LowFlowCondImped to a high value as 8 can result in similar outputs.

MaxSwell

The maximal swelling degree of soil layers during conditions of accumulation of ice and liquid water.

Default	Unit	Symbol	Equation	Function
0.05	-	p_{ms}	(1.38)	

The default value is 0.05 of the original thickness of soil layers.

ShrinkRateFraction

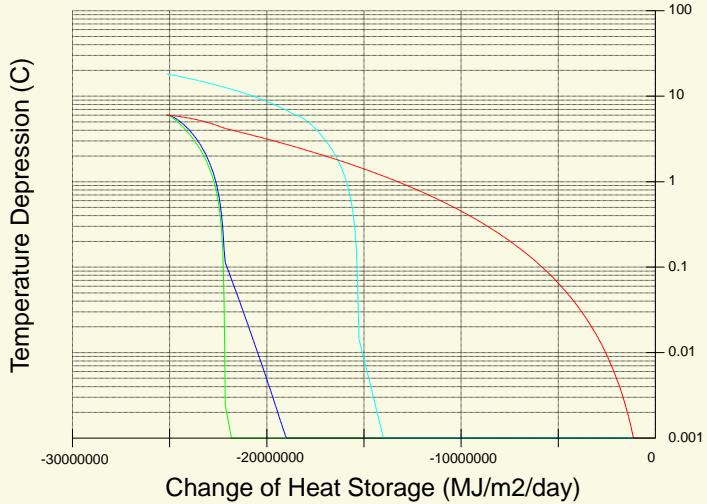
The maximal shrinkage rate of the soil during conditions when the total amount of ice and liquid water decrease after a previous swelling of the soil.

Default	Unit	Symbol	Equation	Function
0.05	1/day	p_{rf}	(1.39)	“Shrinkage Function”

Viewing Functions

Freezing Temperature Function

Freezing Temperature Function of Uppermost Layer

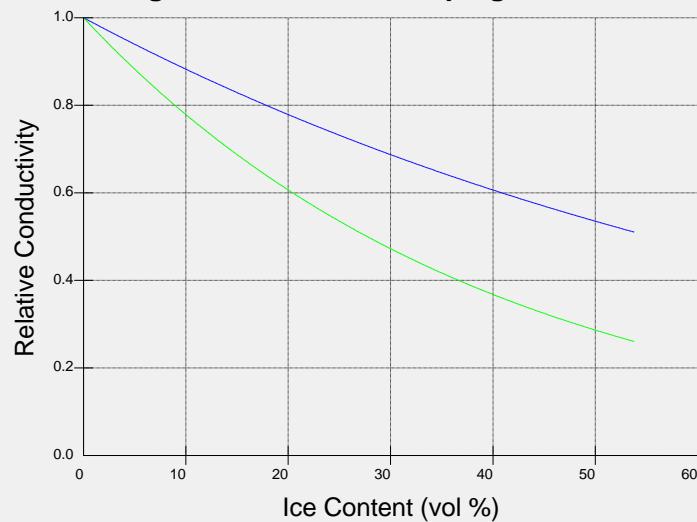


The relationship between temperature depression and change of heat storage for different parameterisations.

	blue	green	turquoise	red
d_3	30	60	30	0
d_2	0	0	0	20
d_1	1	1	1.5	1

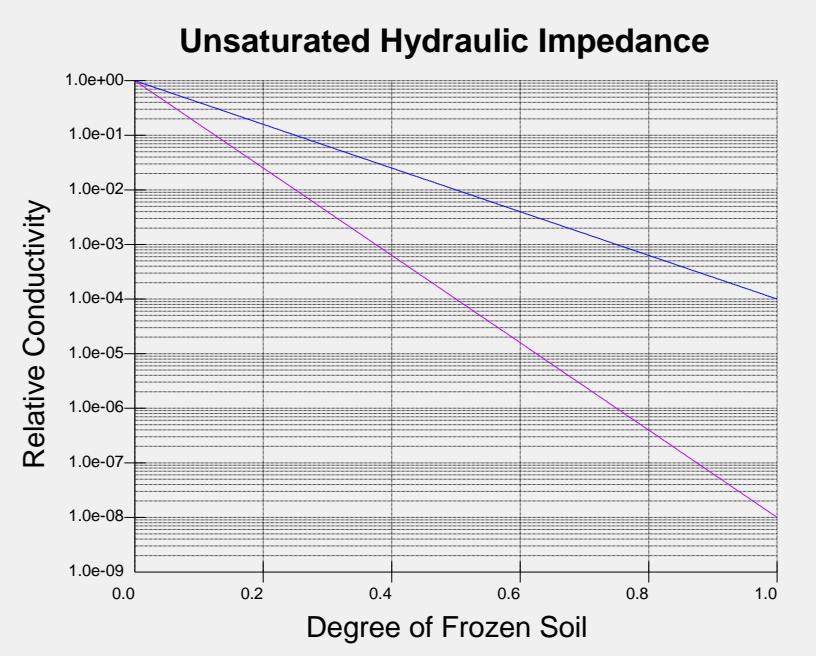
High-Flow Domain Damping Function

High-Flow Domain Damping Function



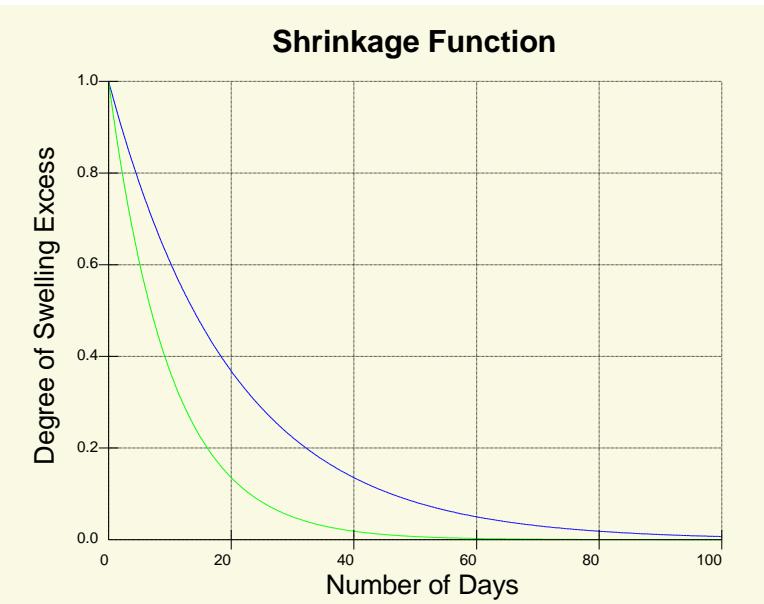
Relative reduction of hydraulic conductivity in the high-flow domain as a function of ice content for different values on $c_{\theta, f}$: 80 (blue) and 40 (green).

Low-flow domain hydraulic impedance function



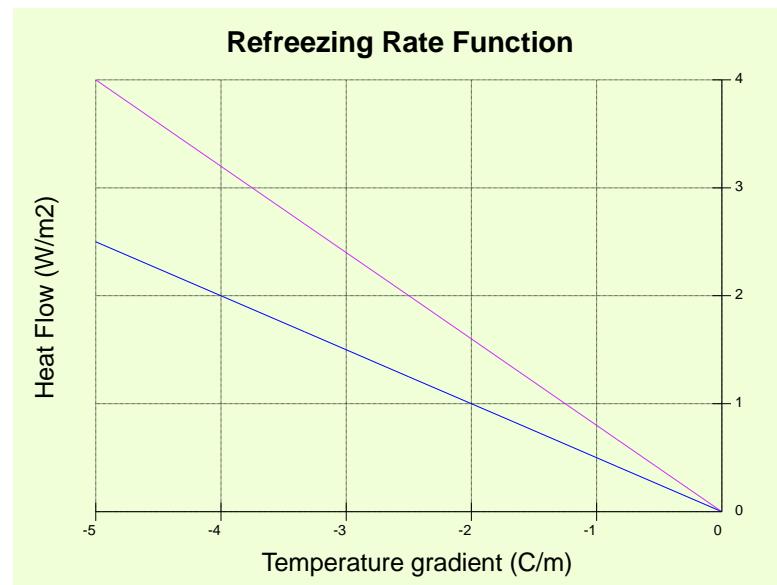
Relative hydraulic conductivity as a function of the degree of frozen soil. The impedance parameter, c_{fi} , was put to 4 (blue) and 8 (violet)

Shrinkage Function



The shrinkage rate as a function of time, after swelling has taken place. p_{rf} was put to 0.05 for the blue line and to 0.1 for the green line.

Refreezing



Amount of heat released when water in the high-flow domain refreezes to form ice. The heat transfer parameter, α_h , was put to 0.5 for the blue line and 0.8 for the violet line.

State Variables

WaterHFD

Amount of water in the high-flow domain in soil layers
mm

Flow Variables

A list of flow variables

InFreeze

Rate of freezing of infiltration water to ice
mm/day

WaterflowHD_LD

Vertical flow of water from high-flow domain (HD) to low-flow domain (LD)
mm/day

WaterflowHFD

Vertical flow of water from high-flow domain to high-flow domain of next layer.
mm/day

WaterflowLD_HD

Vertical flow of water from low-flow domain (LD) to high-flow domain (HD).
mm/day

Auxiliary Variables

FrostLowerBoundary1

Frost depth of first ice body
m

FrostLowerBoundary2

Frost depth of second ice body
m

FrostUpperBoundary1

Upper depth of ice for the first ice body
m

FrostUpperBoundary2

Upper depth of ice for the second ice body
m

Swell

Total change of soil vertical height (=total swelling)
m

Soil Heat Pump

Theory

Extraction of heat from the soil can optionally be included in the model, as determined by the switch “[Heat pump](#)” in section “Soil Heat Flow”. Soil heat extraction rate from a specified layer, z_{nhp} , can be given as measured time series but may also be given as a function of air temperature according to governing rules for commercially available soil heat pump equipment:

$$s_h = \begin{cases} s_{h1} & T_a < 11 \\ s_{h2} \cdot \min(17 - T_{hp\max}, 17 - T_a) + s_{h1} & T_a \geq 11 \end{cases} \quad (0.40)$$

where s_{h1} is a constant heat extraction required for hot water purposes, s_{h2} is a design parameter in the air temperature dependence and $T_{hp\max}$ is the threshold temperature for the maximum heat extraction rate. See viewing function “[Heat pump extraction](#)”.

When the soil temperature drops below T_{hpcut} the extraction rate will be reduced according to

$$s_h = \begin{cases} 0 & T_s \leq T_{hp0} \\ s_h \cdot \frac{T_s - T_{hp0}}{T_{hpcut} - T_{hp0}} & T_s \geq T_{hp0} \end{cases} \quad (0.41)$$

where T_{hp0} is the temperature at which the heat extraction reaches ceases. See viewing function “[Reduction of heat extraction](#)”.

Parameters

HPAmp

The amplitude of heat extraction rate.

Default	Unit	Symbol	Equation	Function
1e5	Jm ⁻² /day/°C	s_{h2}	(1.40)	“Heat pump extraction”

HPBase

The heat extraction base rate.

Default	Unit	Symbol	Equation	Function
0	Jm ⁻² /day	s_{h1}	(1.40)	“Heat pump extraction”

HPCut

Default	Unit	Symbol	Equation	Function
-5	°C	T_{hpcut}	(1.41)	“Reduction of heat extraction”

HPLayer

The layer from which heat is extracted.

Default	Unit	Symbol	Equation	Function
4	-	z_{nhp}		

HPMax

The threshold temperature for maximum heat extraction.

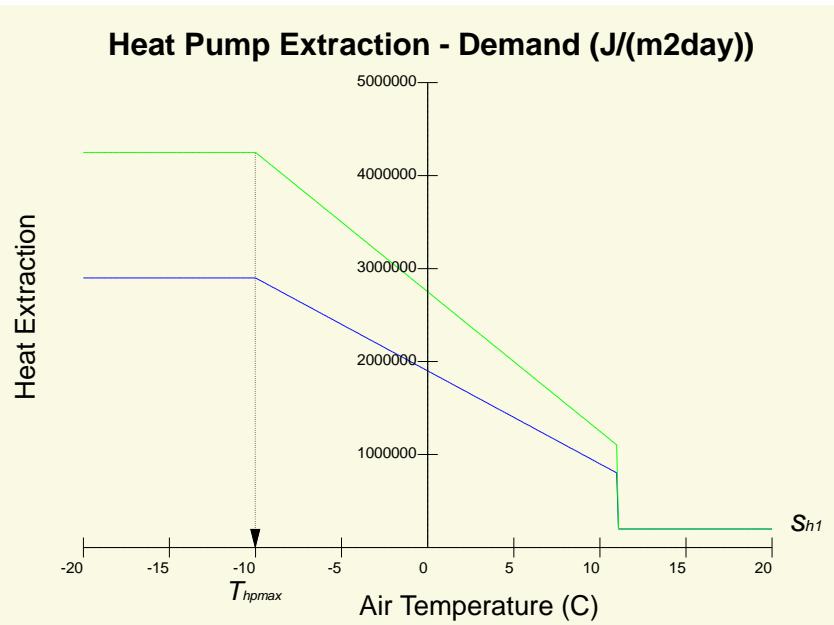
Default	Unit	Symbol	Equation	Function
-10	°C	T_{hpmax}	(1.40)	“Heat pump extraction”

HPZero

Default	Unit	Symbol	Equation	Function
-10	°C	T_{hp0}	(1.41)	“Reduction of heat extraction”

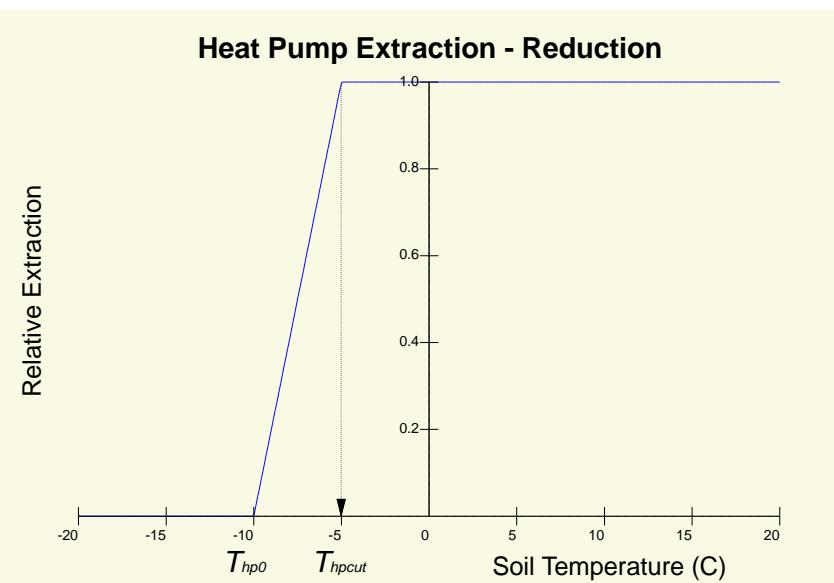
Viewing Functions

Heat pump extraction



The heat pump extraction as a function of air temperature. Above 11 °C the heat extraction rate equals the base extraction rate, s_{h1} . Below this temperature the heat extraction increases to a maximum rate below the threshold temperature, T_{hpmax} . $s_{h2} = 100\ 000 \text{ Jm}^{-2}/\text{day}/^\circ\text{C}$ (blue line), $s_{h2} = 150\ 000 \text{ Jm}^{-2}/\text{day}/^\circ\text{C}$ (green line).

Reduction of heat extraction



Reduction of heat pump extraction due to low soil temperatures.

Flow Variables

Heat pump flow

Heat extraction from the soil.
J/m²/day

Soil Water Processes

Per-Erik Jansson

Soil water flow processes

Theory

Water flow in the soil is assumed to be laminar and, thus, obey Darcy's law as generalised for unsaturated flow by Richards (1931):

$$q_w = -k_w \left(\frac{\partial \psi}{\partial z} - 1 \right) - D_v \frac{\partial c_v}{\partial z} + q_{bypass} \quad (2.1)$$

where k_w is the unsaturated hydraulic conductivity, ψ is the water tension, z is depth, c_v is the concentration of vapour in soil air, D_v is the diffusion coefficient for vapour in the soil and q_{bypass} is a bypass flow in the macro-pores described below. The total water flow, q_w , is thus the sum of the matrix flow, q_{mat} , the vapour flow, q_v , and the bypass flow, q_{bypass} . The general equation for unsaturated water flow follows from the law of mass conservation and eq.(2.1):

$$\frac{\partial \theta}{\partial t} = -\frac{\partial q_w}{\partial z} + s_w \quad (2.2)$$

where θ is the soil water content and s_w is a source/sink term. Under over saturated periods the flow of water in the upper soil compartment can be directed up-wards, and that water is then added to the total surface runoff (see section "[Surface Water](#)").

The transit time for water flow through the soil profile can be calculated for each soil layer separately and also for the whole simulated profile (see switch "[TransitTime Estimation](#)").

Bypass flow in macropores

An optional switch ("[Crack](#)") to account for bypass flow has been included in the model to consider rapid flow in macropores during conditions when smaller pores are only partially filled with water (see below). The amount of water in the macropores is not accounted for explicitly. Instead, the infiltration flow rate at the soil surface or the vertical flow in the macropores at any depth in the soil profile, q_{in} , determines the partitioning of the total liquid water flow ($q_w - q_v$) into ordinary Darcy flow, q_{mat} , and bypass flow, q_{bypass} . (see [Figure 2.1](#)).

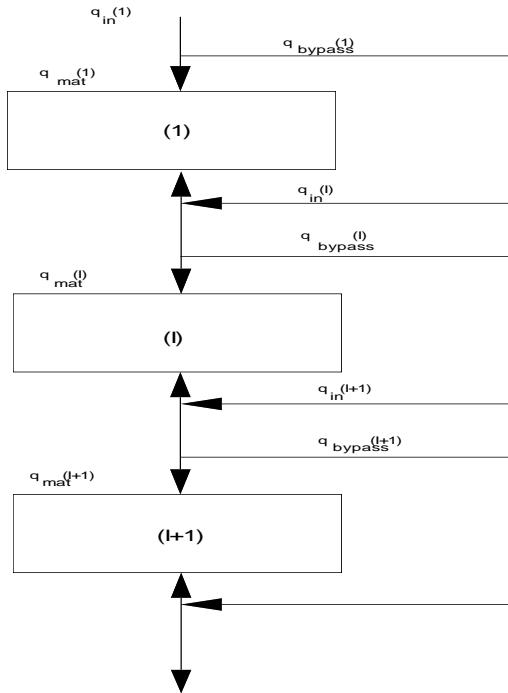


Figure 2.1. Matrix and bypass flow in the model.

$$q_{mat} = \begin{cases} \max\left(k_w(\theta)\left(\frac{\partial\psi}{\partial z} + 1\right), q_{in}\right) & 0 < q_{in} < S_{mat} \\ S_{mat} & q_{in} \geq S_{mat} \end{cases} \quad (2.3)$$

and

$$q_{bypass} = \begin{cases} 0 & 0 < q_{in} < S_{mat} \\ q_{in} - q_{mat} & q_{in} \geq S_{mat} \end{cases} \quad (2.4)$$

where $k(\theta)$ is the unsaturated conductivity at a given water content, ψ is the water tension and z is the depth co-ordinate. At the soil surface, q_{in} is the infiltration rate. At other depths in the soil, q_{in} is the vertical flow rate in the macropores, q_{bypass} , from the layer immediately above. S_{mat} is the sorption capacity rate, i.e. the threshold value for bypass flow in the macropores, defined as:

$$S_{mat} = a_{scale} a_r k_{mat} pF \quad (2.5)$$

where k_{mat} is the maximum conductivity of smaller pores (i.e. matric pores), a_r is the ratio between compartment thickness, Δz , and the unit horizontal area represented by the model, pF is ${}^{10}\log$ of ψ and a_{scale} is an empirical scaling coefficient accounting for the geometry of aggregates.

The calculated water flow in the matric pores, q_{mat} , is used to update the water contents and the water tensions in the numerical solution, whereas q_{bypass} is directed without delay to the next soil compartment. However, q_{bypass} can never reach layers below the water table depth, which is the lower boundary condition for the use of Richard's equation.

Hysteresis effects on water retention and conductivity

The hysteresis may be assumed in the water retention curve and in the unsaturated conductivity function depending on the switch “[Hysteresis](#)” (the water retention curve and the unsaturated conductivity are described in detail in section “[Soil hydraulic properties](#)”).

The calculation of hysteresis is based on three multiplicative functions considering (1) the time since start of sorption loop, R_{hage} , (2) the shift point pF-value, R_{hshift} , and (3) the accumulated rate of water content increase, R_{hacc} . These three functions are governed by common parameter values for all layers and they can all vary between zero and unity. In addition for each layer one parameter p_{hysmax} gives the maximal effect.

Thus:

$$\psi = \psi^* 10^{R_h p_{hysmax}} \quad (2.6)$$

where ψ^* is the reference value of water tension (i.e. the estimated value before any corrections), and R_h is the hysteresis effect calculated as:

$$R_h = R_{hage} R_{hshift} R_{hacc} \quad (2.7)$$

The age response is given as:

$$R_{hage} = e^{-a_{hysk} \Delta t_{shift}} \quad (2.8)$$

where Δt_{shift} is the time elapsed since last major shift from a desorption to a sorption process and a_{hysk} is a parameter.

The shift point response is:

$$R_{hshift} = \max\left(R_{hage}, \min\left(\frac{\log \psi - a_{PF1}}{a_{PF2} - a_{PF1}}, 1\right)\right) \quad (2.9)$$

where a_{PF1} and a_{PF2} are parameters.

Finally the function of accumulated change of water content is defined as:

$$R_{hacc} = \min\left(1, \frac{\Delta \theta_{sorp}}{a_{thetm}}\right) \quad (2.10)$$

where the $\Delta \theta_{sorp}$ is the accumulated increase of water content at a rate that exceeds the threshold value $a_{\theta D}$ since the last major shift from desorption to sorption and a_{thetm} is the maximum moisture parameter value. The $\Delta \theta_{sorp}$ is reset to a value that corresponds to continuous change in the total hysteresis response when a new sorption process starts.

Similar to the water tension the hydraulic conductivity is given as:

$$k_w = k_w^* 10^{R_h p_{hysmaxc}} \quad (2.11)$$

where $p_{hysmaxc}$ is a parameter defined for each layer of the soil.

Water vapour flow

The soil vapour flux was introduced as a switch “[ConvectiveGasFlow](#)” which includes the vapour flow as an optional contribution to both the water and energy flow in the soil, see eqs. (1.1) and (2.1). (In equation (2.1) the convective gas flow is written as a diffusion coefficient for vapour in the soil, D_v , times the vapour concentration as a function of depth. D_v corresponds to the factors d_{vapb}/D_0 below.)

Vapour flows between adjacent soil layers will be calculated from gradients in vapour pressure and diffusion coefficient. The diffusion coefficient is adjusted because of deviations from diffusion in free air by use of a parameter d_{vapb} . The vapour flow is given by:

$$q_v = -d_{vapb} f_a D_0 \frac{\partial c_v}{\partial z} \quad (2.12)$$

where f_a is the fraction of air filled pores (i.e. $\theta_s - \theta$), D_0 is the diffusion coefficient in free air, which is given as a function of the soil temperature as:

$$D_0 = \left(\frac{T + 273.15}{273.15} \right)^{1.75} \quad (2.13)$$

c_v is the vapour concentration, which is given by the vapour pressure. Thus:

$$c_v = \frac{M_{water} e_v}{R(T + 273.15)} \quad (2.14)$$

where M_{water} is the molar mass of water, R is the gas constant, T is the soil temperature and the vapour pressure, e_v , is given by:

$$e_v = e_s e^{\left(\frac{-\psi M_{water} g}{R(T+273.15)} \right)} \quad (2.15)$$

where e_s is the vapour pressure at saturation, ψ is the soil water tension and g is the gravitational constant. The latter expression is used from the basic assumption that the liquid phase is in equilibrium with the gas phase in the soil.

Upper boundary condition

Boundary conditions at the soil surface are given by separate subroutines accounting for snow melt and interception of precipitation by vegetation. In addition a surface pool may be formed on the soil surface. This is described in the section “[Surface Water](#)” below.

Lower boundary condition

Different options exist for the lower boundary depending on whether saturated or unsaturated conditions are assumed. If saturated conditions are assumed a ground water outflow as calculated according to the section below will be added to the lower boundary as defined here. Details on this is found in the section “[Drainage and deep percolation](#)”.

Initial Conditions

The initial conditions can be defined as water content or pressured heads (see switch “[InitialWaterContents](#)”). However, only the latter alternative is possible to combine with the use of a saturated zone of the soil.

Switches

ConvectiveGasFlow

Value	Meaning
off	No account is taken to any mass flow of water vapour for the water balance.
on	A vapour flow, driven by gradients of vapour concentrations will be considered in the mass balance for each compartment in the soil.

Crack

Value	Meaning

No Bypass	The Darcy flow approach. Only one matrix flow gradient will govern the water flow between layers in the soil profile.
Bypass Flow	A bypass water flow is calculated if the incoming flow rate to one layer exceed a sorption capacity rate as calculated from a simple empirical equation.

Hysteresis

Value	Meaning
Off	Hysteresis will be disregarded.
On	Hysteresis will be estimated based on some empirical parameters that change the shape of the primarily desorption water retention curve during rapid sorption.

Initial water conditions

Value	Meaning
Uniform Pressure Head	A single parameter value is used to assign the initial water content from a homogenous profile of pressure head. Note that this value of pressure head may be adjusted if an initial ground water level is assumed.
Uniform Water Content	Similar as above but using a single parameter for the initial water content instead.
Uniform flow	Similar as above but using a single parameter for the initial water flow instead.
Pressure Head(z)	A table of parameter values to assign initial pressured head at each horizon.
Water Contents(z)	A table of parameter values to assign volumetric water contents at each horizon.

TransitTime Estimation

Value	Meaning
Off	Transit time for water flow through the soil profile is not calculated.
On	Transit time for water flow through the soil profile is calculated.

Parameters

AScaleSorption

Sorption scaling coefficient for flow in the matric pore domain.

Default	Unit	Symbol	Equation	Function
0.5	-	a_{scale}	(2.5)	

A low value (<0.001) will result in a poor capacity of the aggregate to adsorb water during infiltration and a high degree will be bypassed in the macropores. High values give the opposite effect. Appropriate values can be found in a wide range depending on the corresponding values assigned to the saturated conductivity for the matric pore domain.

DVapTortuosity

Correction because of non-perfect condition for diffusion. If values larger than unity are chosen an enhancement effect will be calculated.

Default	Unit	Symbol	Equation	Function
0.66	-	d_{vapb}	(2.12)	

HysKExp

The rate coefficient in the hysteresis age function, R_{hage} .

Default	Unit	Symbol	Equation	Function
0.5	-	a_{hysk}	(2.8)	

HysPF1

Parameter in the hysteresis shift point function, R_{hshift} .

Default	Unit	Symbol	Equation	Function
1.5	pF-value	a_{PF1}	(2.9)	

HysPF2

Parameter in the hysteresis shift point function, R_{hshift} .

Default	Unit	Symbol	Equation	Function
4	pF-value	a_{PF2}	(2.9)	

HysThetaD

This is the threshold rate for which a shift from desorption to sorption is triggered and the threshold that must be exceeded for accumulating the rate change hysteresis function.

Default	Unit	Symbol	Equation	Function
0.2	-	$a_{\theta D}$	(2.10)	

HysThetamax

This is the value for which the accumulated rate change hysteresis function, R_{hacc} , reach unity.

Default	Unit	Symbol	Equation	Function
10	vol %	$a_{\theta \text{max}}$	(2.10)	

InitialFlowRate

An initial flow rate that will determine the water content at each soil layer to be used as initial condition.

Default	Unit	Symbol	Equation	Function
0.1	mm/day			

InitialGroundWater

Initial ground water level.

Default	Unit	Symbol	Equation	Function
-1.	m			

InitialPressuredHead

The initial pressured head, uniform for all layers.

Default	Unit	Symbol	Equation	Function
60	cm water			

InitialWaterContent

The initial water content, uniform for all layers.

Default	Unit	Symbol	Equation	Function
20	vol %			

Parameter Tables

Hysteresis Effects

No. of elements in Table: Number of layers in the model

Name	Default	Unit	Symbol	Comments/Explanations
HysMaxEffRet	0	-	p_{hysmax}	Parameter that gives the maximum hysteresis effect on water retention.
HysMaxEffCond	0	-	$p_{hysmaxc}$	Parameter that gives the maximum hysteresis effect on conductivity.

InitialWaterPotentials

No. of elements in Table: Number of layers in the model

Name	Default	Unit	Symbol	Comments/Explanations
IniPressureHeads	60	cm water		

InitialWaterContents

No. of elements in Table: Number of layers in the model

Name	Default	Unit	Symbol	Comments/Explanations
IniWaterContents	10	vol %		

State Variables

WaterStorage

Amount of water in a soil layer

mm

Flow Variables

SurfaceOutFlow

Outflow of water from top soil layer to surface layer that occurs during over-saturated conditions. This water adds to the total runoff from the profile.

mm/day

Vapourflow

Vapour flow between soil layers

mm/day

VapourflowSurf

Vapour flow from mid point of uppermost soil layer to atmosphere

mm/day

Waterflow

Vertical water flow between soil layers, including bypass and vapour flow.

mm/day

Auxiliary Variables

HysEffect

Hysteresis effect factor for soil layers.

-

MeanTransitTime

Mean transit time of water for soil layers.

days

PressureHead

Pressure heads for soil layers.

cm water

TotalWaterContent

Total volumetric water content (ice + liquid) of soil layers.

vol %

TotMeanTransitTime

Total mean transit time of water for all soil layers

days

WBypassflow

Water flow as bypass between soil layers

mm/day

WaterContent

Volumetric water content (liquid non-frozen) of soil layers

vol %

Surface Water

Theory

The infiltration rate, q_{in} , is a function of the infiltration capacity at the soil surface, i_{cap} , calculated from the saturated conductivity of the topsoil and the actual gradient in pressure head from the soil surface ($\psi=0$) to the middle of the uppermost layer according to Darcy's law:

$$q_{in} = \begin{cases} q_{th} & i_{cap} > q_{th} \\ i_{cap} & i_{cap} \leq q_{th} \end{cases} \quad (2.16)$$

where q_{th} is the throughfall of precipitation to the soil surface. In case of above surface irrigation, q_{th} also includes the irrigation water; however, for all types of drip irrigation the water is directly transferred from the storage tank to the soil layers. If soil evaporation is greater than infiltration and the surface pool divided by the simulation time-step is greater than soil evaporation, an extra infiltration of water from the surface pool takes place. The amount of extra infiltration is equal to soil evaporation.

If throughfall exceeds the infiltration capacity a surface pool of water is formed on the soil surface. Water in the surface pool can either infiltrate with a delay into the soil or be lost as surface runoff. The surface runoff, q_{surf} , is calculated as a first order rate process:

$$q_{surf} = a_{surf} (W_{pool} - w_{pmax}) \quad (2.17)$$

where a_{surf} is an empirical coefficient, W_{pool} is the total amount of water in the surface pool and w_{pmax} is the maximal amount, which can be stored on the soil surface without causing any surface runoff. See viewing function "[Surface Runoff Function](#)". If W_{pool} is smaller than w_{pmax} then there is no surface runoff, q_{surf} .

The fraction of the total soil surface that is covered with water, f_{cspool} , is given by:

$$f_{cspool} = p_{max} \left(\frac{W_{pool}}{f_{wcovtot}} \right)^{p_{pot}} \quad (2.18)$$

when the total amount of water is less than $f_{wcovtot}$, which is a parameter value. See viewing function "[Ponded soil cover function](#)".

During conditions with frost in the soil the saturated conductivity can be reduced because of the ice content in the soil (see "Influence of ice on water").

A physical barrier for infiltration such as a roof can also be simulated by setting a value larger than zero for the i_{scov} parameter.

Another special feature is the simulation of a furrow similar pattern on the soil surface (see switch "[Furrow](#)"). In this case a fraction, $f_{infbypass}$, of the infiltration is going directly to the second compartment of the soil. This means that the top layer receives only $1-f_{infbypass}$ of the total infiltration rate originating either from the surface pool or from precipitation.

Switches

Furrow

Value	Meaning
Off	No furrow structure is assumed. All water will infiltrate into the uppermost soil layer.

Irrigation	Furrows are present in the field and they collect irrigation water that is partitioned between the uppermost layer and the second layer of the soil depending on the value of the parameter $f_{inf bypass}$. Note that the degree of irrigation water that reaches the soil and thereby the furrow is governed by the parameter, i_{frac} , which is the irrigation fraction. Only $i_{frac} = 1$ allows all irrigation to reach the furrow directly.
I.+Precipitation	The same as above but in this case also all the precipitation water is collected in the furrow and will be partitioned between the two uppermost layers according to the $f_{inf bypass}$ parameter.

Parameters

InfFurrow

The fraction of the irrigation and/or precipitation water that is infiltrating directly to the second layer of the soil profile beneath a furrow.

Default	Unit	Symbol	Equation	Function
0	-	$f_{inf bypass}$		

SPCoverTotal

The amount of water on the soil surface that corresponds to a complete cover of the whole soil. The fraction of area covered by the surface pool is calculated as a linear function that corresponds to the ratio between the surface pool and *SPCoverTotal*.

Default	Unit	Symbol	Equation	Function
50	mm	$f_{wcovtot}$	(2.18)	“Ponded soil cover function”

SP Max Cover

The maximum surface pool cover.

Default	Unit	Symbol	Equation	Function
1.0	mm	p_{maxt}	(2.18)	“Ponded soil cover function”

SPCovPot

The potential surface cover.

Default	Unit	Symbol	Equation	Function
1.0	-	p_{pot}	(2.18)	“Ponded soil cover function”

SoilCover

The degree of SoilCover will govern how much precipitation, throughfall and drip from the canopy that will infiltrate into the soil. The parameter can be considered as a physical barrier (like a plastic sheet or a roof) that covers the soil and causes losses as surface runoff instead of infiltration into the soil. Normally the parameter will be put to 0, which means that no physical barrier exists for infiltration of water into the soil. A value of 1 will prevent the soil from any type of wetting from precipitation.

Default	Unit	Symbol	Equation	Function
0	-	i_{scov}		

SurfCoef

First order rate coefficient used when calculating the surface runoff from the surface pool exceeding the residual storage, w_{pmax} .

Default	Unit	Symbol	Equation	Function
0.8	1/day	a_{surf}	(2.17)	“Surface Runoff Function”

SurfPoolInit

Initial water content in surface pool.

Default	Unit	Symbol	Equation	Function
0	mm			

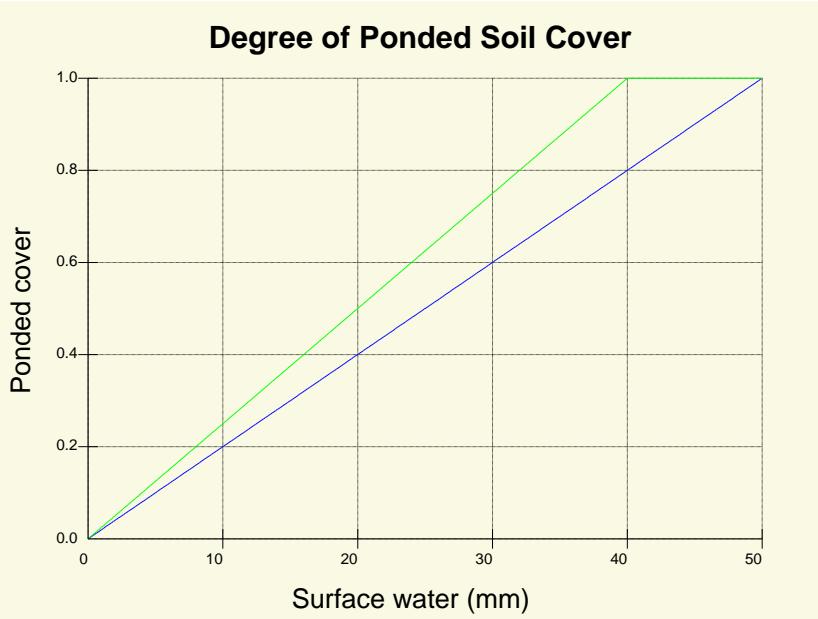
SurfPoolMax

The maximal amount of water that can be stored on the soil surface without causing surface runoff.

Default	Unit	Symbol	Equation	Function
0	mm	w_{pmax}	(2.17)	

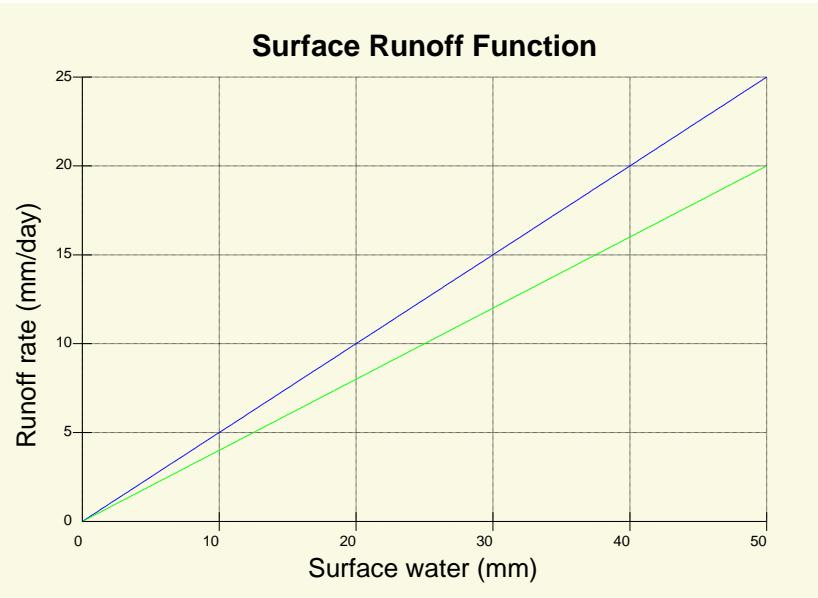
Viewing functions

Ponded soil cover function



The degree of the total soil surface that is covered with water, f_{cspool} , as a function of surface water. The amount of water on the surface that corresponds to a complete cover of the surface, $f_{wcovtot}$, was put to 50 (blue line) and 40 (green line).

Surface Runoff Function



The runoff rate as a function of surface water. The empirical coefficient a_{surf} was put to 0.5 (blue line) and 0.4 (green line).

State Variables

SurfacePool

Amount of water on the soil surface
mm

Flow Variables

FurrowInfil

Rate of infiltration from a furrow directly into second soil layer
mm/day

FurrowPrec

Rate of precipitation on the furrow
mm/day

SoilInfil

Infiltration rate into soil
mm/day

SpoolRunoff

Surface runoff from surface pool
mm/day

SpoolSoilInfil

The infiltration rate that originates from the surface pool
mm/day

SpoolInflow

Inflow rate to the surface pool
mm/day

Auxiliary Variables

SpoolCover

Degree of total ground that is covered by the surface pool

-

Soil hydraulic properties

Theory

Two different soil hydraulic properties, the water retention curve and the unsaturated conductivity function, needs to be determined in order to solve the water balance equation (2.2). Both properties are considered functions of the water content with or without hysteresis effects (hysteresis is described in detail in section “[Soil water flow](#)”). The temperature effect is neglected for the water retention curve but included for the hydraulic conductivity.

To determine these hydraulic properties there is naturally a need to parameterize the model according to measured data. There is plenty of data on soil hydraulic properties for many different soils in the database that can be used as an alternative to own measurements. However, if measurements have been made and the user would like to add them to the model, the level in the soil where the samples were taken very seldom coincides with the heights of the layers in the model. The points of measurement can also be very unevenly distributed in the profile (for example many at the top and few at lower layers). Therefore the measurements are given to the model in a parameter table together with the sampling depth. The model then uses the measured values to interpolate parameter values for each model compartment. This procedure is described in detail in the section “Soil Profile” in “Common Characteristics”. The interpolated values can be viewed in this section in the parameter tables “model boundaries” or “model layers”. Each parameter table in which measured values are added is called “measured horizons” and thus have a corresponding table for interpolated values.

Some parameters can be estimated from others if they are not measured explicitly. This procedure is described at the end of this section.

Water retention curve

In the model there are two options for how to express the water retention function as determined by the switch “[Hydraulic Functions](#)”.

In the first function by Brooks & Corey (1964), the pressure head or actual water tension, ψ , is given by:

$$S_e = \left(\frac{\psi}{\psi_a} \right)^{-\lambda} \quad (2.19)$$

where ψ_a is the air-entry tension and λ is the pore size distribution index. The effective saturation, S_e , is defined as:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \quad (2.20)$$

where θ_s is the porosity, θ_r is the residual water content and θ is the actual water content, see [Figure 2.2](#).

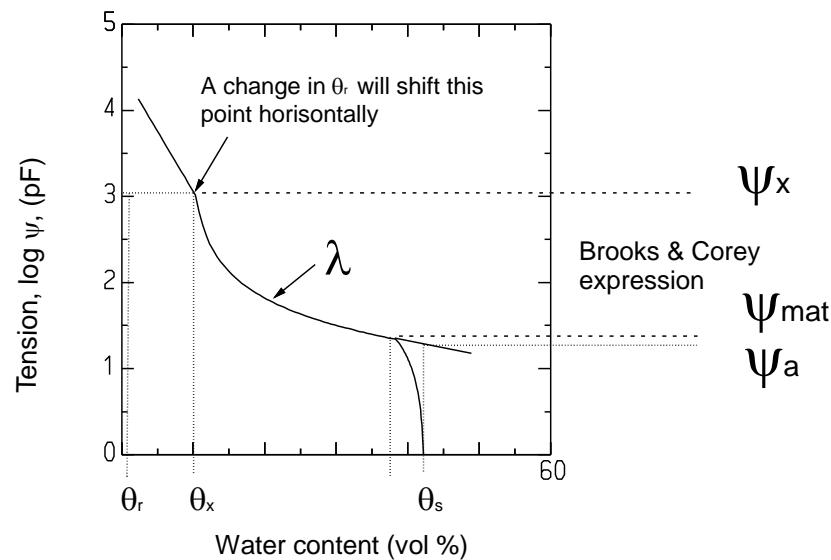


Figure 2.2. Variables in the Brooks and Corey expression.

See viewing functions “[Measured Unsaturated Conductivity, Pressure Head, single layers](#)” and “[Modelled Water Retention, profile](#)”.

As an alternative expression to the Brooks & Corey expressions, the water retention function by van Genuchten (1980) has been introduced:

$$S_e = \frac{1}{(1 + (\alpha\psi)^{g_n})^{g_m}} \quad (2.21)$$

where α , g_n and g_m are empirical parameters.

In order to get a good fit in the whole water content range, eqs.(2.19) and (2.21) are fitted only to data corresponding to tensions below a threshold value, ψ_x (Figure 2.3). The relation between water content and tension above this threshold is assumed log-linear:

$$\frac{\log\left(\frac{\psi}{\psi_x}\right)}{\log\left(\frac{\psi_{wilt}}{\psi_x}\right)} = \frac{\theta_x - \theta}{\theta_x - \theta_{wilt}} \quad \psi_x < \psi < \psi_{wilt} \quad (2.22)$$

where θ_x is the threshold water content at the threshold tension, ψ_x , θ_{wilt} is the water content at wilting point, defined as a tension of 15 000 cm water, i.e. ψ_{wilt} .

In the range close to saturation, i.e. from θ_s to θ_m a linear expression is used for the relationship between water content, θ , and water tension, ψ .

$$\psi = \psi_{mat} - \frac{(\theta - \theta_s + \theta_m)}{\theta_m} \psi_{mat} \quad \psi_s < \psi < \psi_{mat} \quad (2.23)$$

where ψ_{mat} is the tension that corresponds to a water content of $\theta_s - \theta_m$. The three different parts of the water retention curve is illustrated for a sandy soil below.

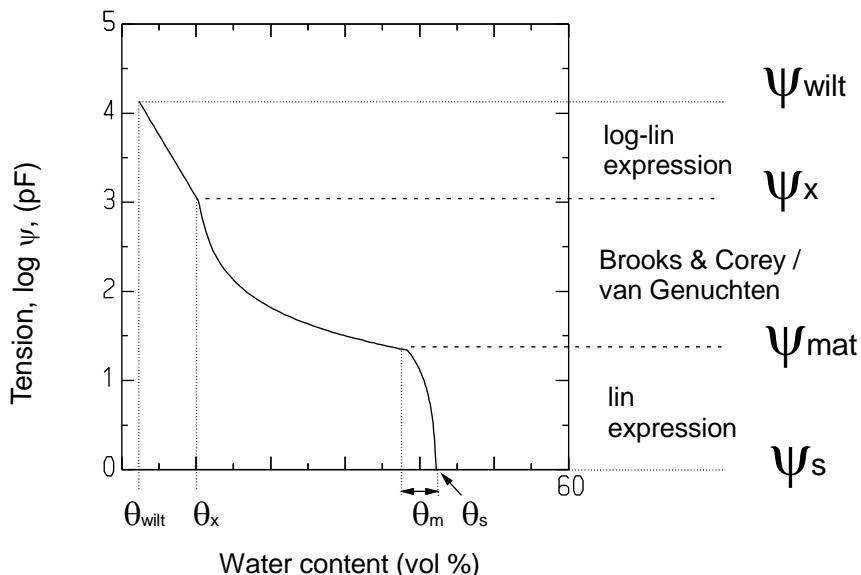


Figure 2.3. An example of how three different expressions in the water retention curve are used in different ranges. The pF value corresponds to the logarithm of tension expressed in cm

It is possible to scale the water retention curve so that the curve is shifted either to the right or the left (see switch “Scaling retention”). This is accomplished by modifying the porosity, θ_s , and the residual water content, θ_r :

$$\theta_s = \theta_s \cdot s_{sscale} + \theta_s \quad (2.24)$$

and

$$\theta_r = \theta_r \cdot s_{rscale} \quad (2.25)$$

where s_{sscale} and s_{rscale} are scaling parameters (see viewing functions “[Scaling of water retention, porosity](#)” and “[Scaling of water retention, residual water content](#)”).

Unsaturated Conductivity

There are three optional ways of determining the unsaturated hydraulic conductivity in the model (see switch “[Conductivity Function](#)”).

Following Mualem (1976), the unsaturated conductivity, k_w^* , is given by:

$$k_w^* = k_{mat} S_e^{\left(\frac{n+2+\lambda}{\lambda}\right)} \quad (2.26)$$

If the Brooks & Corey function for water retention is used, eq.(2.19), the unsaturated conductivity, k_w^* , can then be expressed as:

$$k_w^* = k_{mat} \left(\frac{\psi_a}{\psi} \right)^{2+(2+n)\lambda} \quad (2.27)$$

where k_{mat} is the saturated matrix conductivity and n is a parameter accounting for pore correlation and flow path tortuosity. Eqs. (2.26)- (2.28) are used for water contents in the matric pores.

See viewing functions “[Measured Unsaturated Conductivity, Pressure Head, single layers](#)”, “[Measured Unsaturated Conductivity, Water Content, single layers](#)” and “[Modelled Unsaturated Hydraulic Conductivity, profile](#)”.

In case of using the van Genuchten equation, eq. (2.21), the corresponding equation for the unsaturated conductivity is given by:

$$k_w^* = k_{mat} \frac{\left(1 - (\alpha\psi)^{g_n-1} \left(1 + (\alpha\psi)^{g_n}\right)^{-g_m}\right)^2}{\left(1 + (\alpha\psi)^{g_n}\right)^{\frac{g_m}{2}}} \quad (2.28)$$

where the coefficients α , g_n and g_m are the same parameters as used in eq (2.21)..

As alternative options to the equations of Mualem eqs. (2.26)- (2.28) the unsaturated hydraulic conductivity, k_w^* , can either be calculated as a simple power function of relative saturation:

$$k_w^* = k_{mat} \left(\frac{\theta}{\theta_s} \right)^{p_{nr}} \quad (2.29)$$

or as a simple power function of effective saturation:

$$k_w^* = k_{mat} S_e^{p_{ne}} \quad (2.30)$$

where p_{nr} and p_{ne} are parameters, k_{mat} is the saturated matrix conductivity, θ_s is the water content at saturation, θ is the actual water content and S_e is the effective saturation.

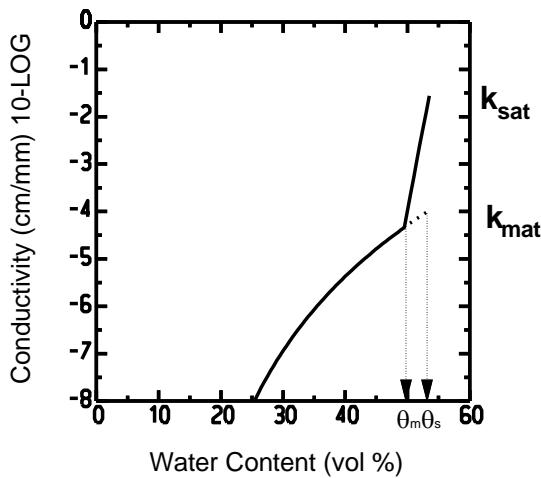


Figure 2.4. The unsaturated conductivity for a clay soil calculated with the parameter values given above.

To account for the conductivity in the macropores, an additional contribution to the hydraulic conductivity is considered when water content exceeds $\theta_s - \theta_m$, i.e. at ψ_{mat} (see Figure 2.4 above). The total hydraulic conductivity close to saturation is thus calculated as:

$$k_w^* = 10^{\left(\log(k_w^*(\theta_s - \theta_m)) + \frac{\theta_s - \theta_m}{\theta_m} \log\left(\frac{k_{sat}}{k_w(\theta_s - \theta_m)}\right) \right)} \quad (2.31)$$

where k_{sat} is the saturated total conductivity, which includes the macropores, and $k_w^*(\theta_s - \theta_m)$ is the hydraulic conductivity below $\theta_s - \theta_m$ (i.e. at ψ_{mat}) calculated from eqs (2.26)-(2.28).

All the hydraulic conductivities are scaled with respect to temperature. The scaling is related to the viscosity of water and is simplified to a linear response in the normal range around 20 °C, which is used as a reference temperature. In addition to this dependence a minimum unsaturated conductivity is also applied. Thus the actual unsaturated hydraulic conductivity after temperature corrections, k_w , is given by:

$$k_w = (r_{AOT} + r_{AIT} T_s) \max(k_w^*, k_{min_uc}) \quad (2.32)$$

where r_{AOT} , r_{AIT} and k_{min_uc} are parameter values. k_w^* is the conductivity according to eqs. (2.26)-(2.31). See viewing function “[Hydraulic conductivity, temperature function](#)”.

Soil matric conductivity

The matric conductivity, k_{mat} , can either be independent of the total saturated conductivity, the same as total saturated conductivity or a function of the total conductivity (see switch “[Matric Conductivity](#)”). In the latter case, actual matric conductivity, k_{mat} , is calculated as:

$$k_{mat} = 10^{(\log k_{sat} - \log h_{com}) \cdot h_{sens} + \log k_{sat}} \quad (2.33)$$

where h_{com} and h_{sens} are parameters and k_{sat} is the total saturated conductivity. See viewing function “[Matric Conductivity Function](#)”.

Estimation of coefficients

The figure below (Figure 2.5) shows how experimental data of water retention can be used when estimating coefficients in the Brooks & Corey equation. The procedure used is based on least square fitting where three coefficients are estimated by allowing the residual water content to vary in a range until the best linear fit will be obtained, see figure below. All data points are given equal weights but the user can select a suitable restricted range to improve the fitting.

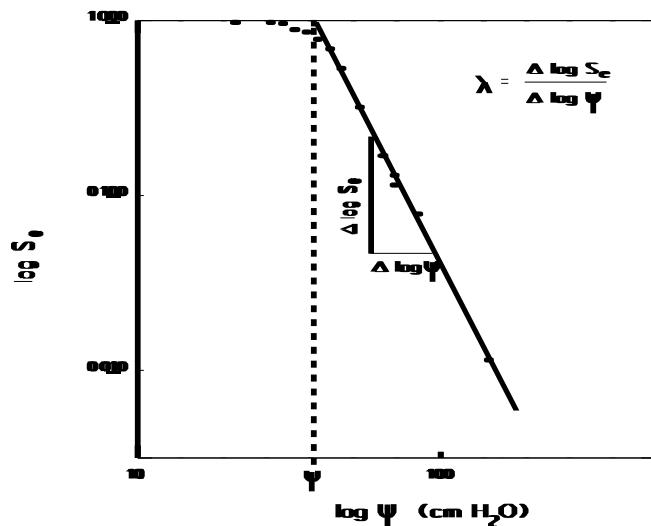


Figure 2.5. $\log S_e$ as a function of $\log \psi$. The air entry pressure (ψ_a) is given at $S_e=1.0$. Pore size distribution index (λ) is the slope of the line

The coefficients in the Brooks & Corey equation can also be estimated by using the pedofunctions as proposed by Rawl and Brankensiek (1980). The θ , λ and ψ_a can be estimated by using the amount of sand, clay and silt as input. Saturated hydraulic conductivity is also estimated from the texture and in addition the saturation value.

The van Genuchten coefficients are not estimated directly but can easily be assigned from the Brooks & Corey coefficients:

$$\alpha = \frac{1}{\psi_a} \quad (2.34)$$

and

$$g_n = 1 + \lambda \quad (2.35)$$

and finally

$$g_m = 1 - \frac{1}{g_n} \quad (2.36)$$

Switches

Hydraulic Functions

Value	Meaning
Brooks & Corey	The water retention curve is given by a modified equation based on the original Brooks and Corey equation in an intermediate range of water contents.
Genuchten	The water retention curve is given by a modified equation based on the original van Genuchten equation in an intermediate range of water contents.

Conductivity Function

Value	Meaning
Mualem	The unsaturated conductivity in the matric domain is given by the equations of Mualem, with the Brooks & Corey or the van Genuchten equation as a base. See eqs. (2.26) and (2.28)
Power of effective saturation	The unsaturated conductivity in the matric domain is given by a simple power function of effective saturation. See eq. (2.30) .
Power of relative saturation	The unsaturated conductivity in the matric domain is given by a simple power function of relative saturation. See eq. (2.29) .

The parameter values for the conductivity functions are found in the tables: “[Hydraulic conductivity, measured horizons](#)” and “[Hydraulic conductivity, model boundaries](#)”.

Matric Conductivity

Value	Meaning
Independent	Actual matric conductivity is independent of total saturated conductivity.
Same as total conductivity	Actual matric conductivity is equal to total saturated conductivity.
Function of total conductivity	Actual matric conductivity is a function of total saturated conductivity.

Scaling retention

Value	Meaning
No	The water retention curve is not scaled.
Yes	The water retention curve can be scaled so that it is shifted either to the right or the left.

Parameters

Common Value

Used if matric conductivity is calculated as a function of total conductivity.

Default	Unit	Symbol	Equation	Function
10	mm/day	h_{com}	(2.33)	“ Matric Conductivity Function ”

MinimumCondValue

The minimum hydraulic conductivity in the hydraulic conductivity function.

Default	Unit	Symbol	Equation	Function

1.E-5	mm/day	$k_{min\ uc}$	(2.32)	“Measured Unsaturated Conductivity, Water Content, single layers”
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Saturation Diff

Used to scale the water retention curve. The value 0.175 (in combination with the suggested value for s_{rscale}) shifts the curve by one standard deviation for many soils.

Default	Unit	Symbol	Equation	Function
0.0	-	s_{sscale}	(2.24)	“Scaling of water retention, porosity”

Scale Coef Residual

Used to scale the water retention curve. The value 2.0 (in combination with the suggested value for s_{sscale}) shifts the curve by one standard deviation for many soils.

Default	Unit	Symbol	Equation	Function
1.0	-	s_{rscale}	(2.25)	“Scaling of water retention, residual water content”

Sensitivity

Used if matric conductivity is calculated as a function of total conductivity.

Default	Unit	Symbol	Equation	Function
0.5	mm/day	h_{sens}	(2.33)	“Matric Conductivity Function”

TempFacAtZero

The relative hydraulic conductivity at 0 °C compared with a reference temperature of 20 °C.

Default	Unit	Symbol	Equation	Function
0.54	-	r_{AOT}	(2.32)	“Hydraulic conductivity, temperature function”

TempFacLinIncrease

The slope coefficient in a linear temperature dependence function for the hydraulic conductivity.

Default	Unit	Symbol	Equation	Function
0.023	°C ⁻¹	r_{AIT}	(2.32)	“Hydraulic conductivity, temperature function”

Parameter Tables

The tables for soil hydraulic properties are linked to a database and some special functions are given to these tables compared to standard tables in the model. Upon resetting (using the Reset key in the tab dialog menu) the values in this parameter table may be either created or retrieved from the database. The values are added to the parameter tables ending with “measured horizons”. These values are interpolated over the soil profile to fit model compartments (see “Common Characteristics”). The result is shown in the tables ending with “model boundaries” or “model layers”.

If the hydraulic conductivity measured horizons table is being edited, the ‘Estimate’ key opens an additional dialog box that enables the saturated conductivity to be estimated from the textural composition of the soil.

If the water retention measured horizons table is being edited, the ‘Estimate’ key allows an estimate of four coefficients in the retention function to be made. The wilting point is always estimated from the clay fraction whereas the other three can be estimated either from the texture or from the water retention points. The estimation based on the water retention points are made by least square fitting and may be restricted to an intermediate range of pressured head that can be specified in the dialog fields. Note that the r^2 value for the regression is given in the listbox together with the coefficient values estimated.

Hydraulic conductivity, measured horizons

No. of elements in Table: 1

Name	Default	Unit	Symbol	Comments/Explanations
UpperDepth	0	m	z	
LowerDepth	0.1	m	z	
Matrix Conductivity	100	mm/day	k_{mat}	Used in eqs.(2.26) - (2.30).
Total Conductivity	1000	mm/day	k_{sat}	See eq.(2.31).
n Tortuosity	1	-	n	Used when Brooks & Corey function is used.
n Power sat rel	$3+2/\lambda$	-	p_{nr}	See eq. (2.29).
n Power sat eff	$3+2/\lambda$	-	p_{ne}	See eq. (2.30).
Macro Pore	4	vol %	θ_m	See eq. (2.31)..

Hydraulic conductivity, model boundaries

No. of elements in Table: 10

Name	Default	Unit	Symbol	Comments/Explanations
mLowerDepth	0.04/0.1	m	z	The first value is used for time resolutions within the day and the second for daily mean values.
bMatrix Conductivity	1	mm/day	k_{mat}	Used in eqs (2.26) - (2.30)..
bTotal Conductivity	10	mm/day	k_{sat}	See eq. (2.31).
b_n Tortuosity	1	-	n	Used when Brooks & Corey function is used.
b_n Power (SatRel)	$3+2/\lambda$	-	p_{nr}	See eq. (2.29).
b_n Power (SatEffective)	$3+2/\lambda$	-	p_{ne}	See eq.(2.30).
bMacro Pore	4	vol %	θ_m	See eq. (2.31).

Brooks and Corey, water retention, measured horizons

No. of elements in Table: 1

Name	Default	Unit	Symbol	Comments/Explanations
UpperDepth	0	m	z	

LowerDepth	0.1	m	z	
Lambda	0.3	-	λ	Pore size distribution index. See eq. (2.19).
Air Entry	10	cm	ψ_a	Air entry pressure. See eq. (2.19).
Saturation	45	vol %	θ_s	Water content at saturation. See eq. (2.20)..
Wilting Point	4	vol %	θ_{wilt}	Water content at wilting point (15 atm).
Residual Water	1	vol %	θ_r	Residual soil water content. See eq.(2.20).
Macro Pore	4	vol %	θ_m	Macro pore volume. See eq.(2.23).
Upper Boundary	8000	cm	ψ_x	Soil water tension at the upper boundary of Brooks & Corey's expression.

Brooks and Corey, water retention, model layers

No. of elements in Table: 1

Name	Default	Unit	Symbol	Comments/Explanations
mUpperDepth	0	m	z	
mLowerDepth	0.1	m	z	
mLambda	0.3	-	λ	Pore size distribution index. See eq. (2.19).
mAIR Entry	0.1	cm	ψ_a	Air entry pressure. See eq.(2.19).
mSaturation	45	vol %	θ_s	Water content at saturation.
mWilting Point	4	vol %	θ_{wilt}	Water content at wilting point (15 atm).
mResidual Water	1	vol %	θ_r	Residual soil water content.
mMacro Pore	4	vol %	θ_m	Macro pore volume.
mUpper Boundary	1500	cm	ψ_x	Soil water tension at the upper boundary of Brooks & Corey's expression.

Genuchten, water retention, measured horizons

No. of elements in Table: 1

Name	Default	Unit	Symbol	Comments/Explanations
UpperDepth	0	m	z	
LowerDepth	0.1	m	z	
m-value	1-1/gn	-	g_m	See eq. (2.21).
n-value	1+λ	-	g_n	See eq. (2.21).
alpha	1/ψ _a	1/cm	α	See eq. (2.21).
Saturation	45	vol %	θ_s	Water content at saturation. See eq. (2.20).
Wilting Point	4	vol %	θ_{wilt}	Water content at wilting point (15 atm).
Residual Water	1	vol %	θ_r	Residual soil water content. See eq. (2.20).
Upper Boundary	8000	cm	ψ_x	Soil water pressured head at the upper boundary of Van Genuchten's expression.

Genuchten, water retention, model layers

No. of elements in Table: 1

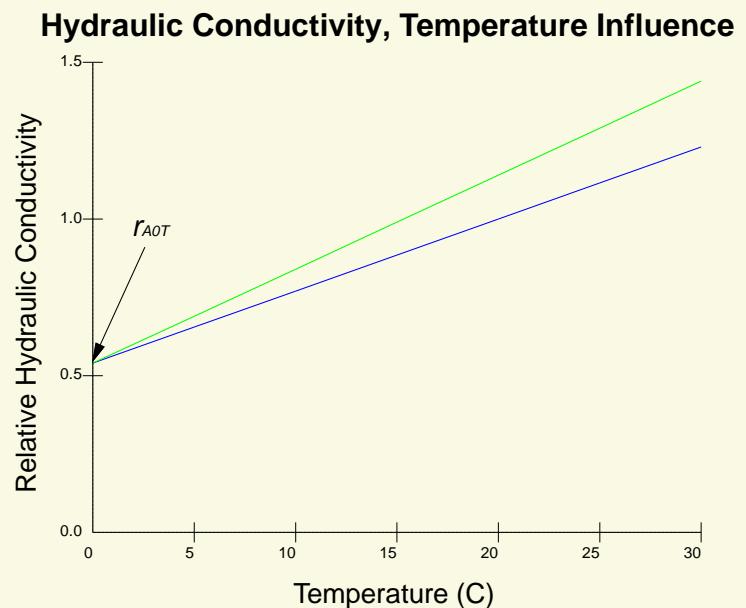
Name	Default	Unit	Symbol	Comments/Explanations

mUpperDepth	0	m	z	
mLowerDepth	0.1	m	z	
m_m-value	$1-1/g_n$	-	g_m	See eq. (2.21).
m_n-value	$1+\lambda$	-	g_n	See eq. (2.21).
mAlpha	$1/\psi_a$	1/cm	α	See eq. (2.21).
mSaturation	45	vol %	θ_s	Water content at saturation. See eq. (2.20)..
mWilting Point	4	vol %	θ_{wilt}	Water content at wilting point (15 atm).
mResidual Water	1	vol %	θ_r	Residual soil water content. See eq. (2.20).
mUpper Boundary	1500	cm	ψ_x	Soil water tension at the upper boundary of Brooks & Corey's expression.

Viewing functions

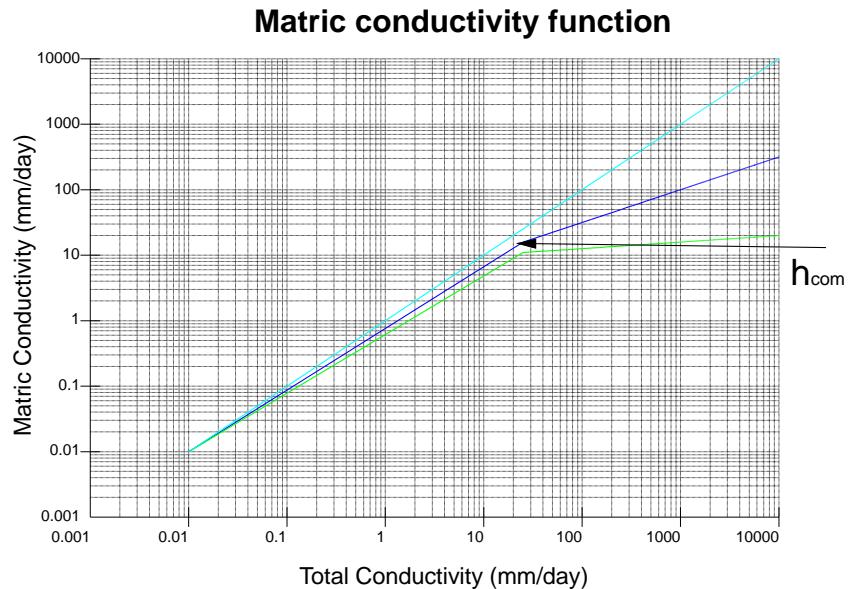
Only a selection of the total amount of viewing function are shown below, due to the large amount of possible plotting options in this section. Some of the plots (as stated in the figure texts) are based on a soil found in the data base, the Lanna 25:1 clay soil from Sweden.

Hydraulic conductivity, temperature function



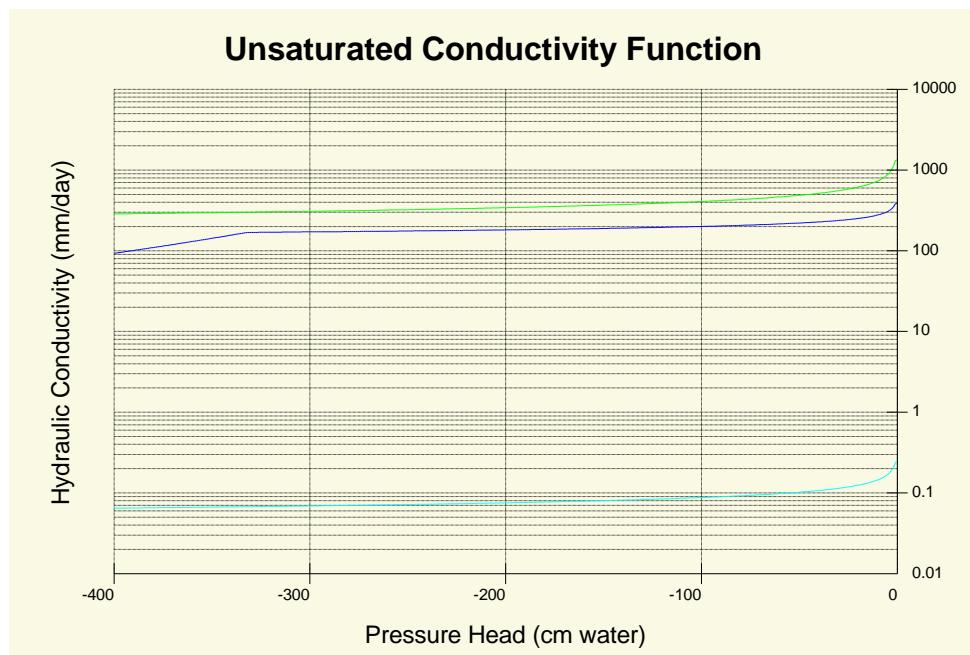
The hydraulic conductivity as a function of temperature. The parameter r_{AIT} changes the slope of the curve and was put to 0.023 for the blue line and to 0.03 for the green line.

Matric Conductivity Function



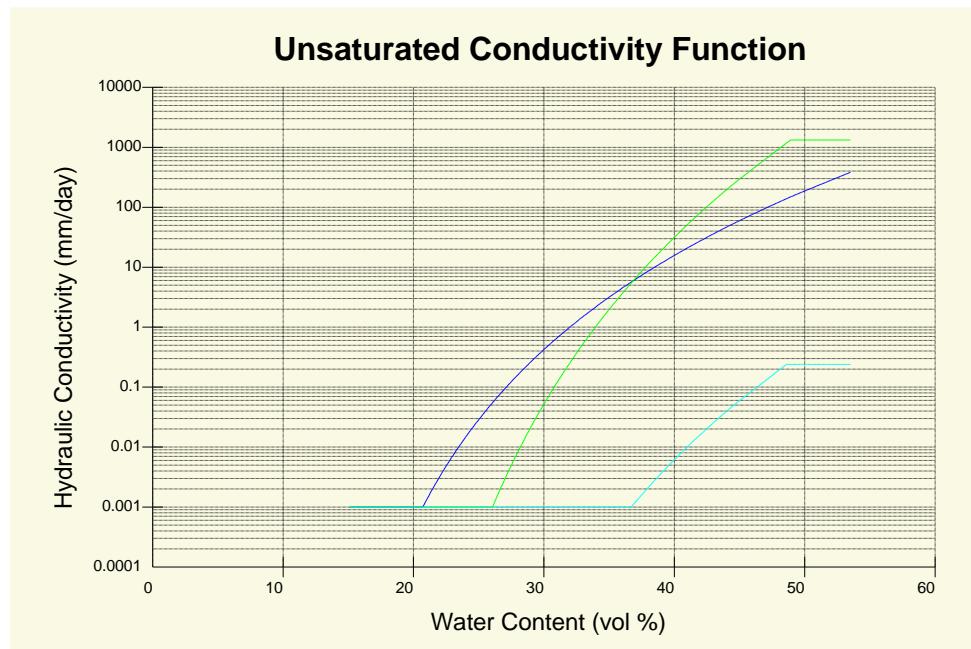
Matric conductivity as a function of total saturated conductivity over the threshold level h_{com} for three different sensitivity values, h_{sens} ; blue = 0.5, green = 0.1 and turquoise = 1.

Measured Unsaturated Conductivity, Pressure Head, single layers



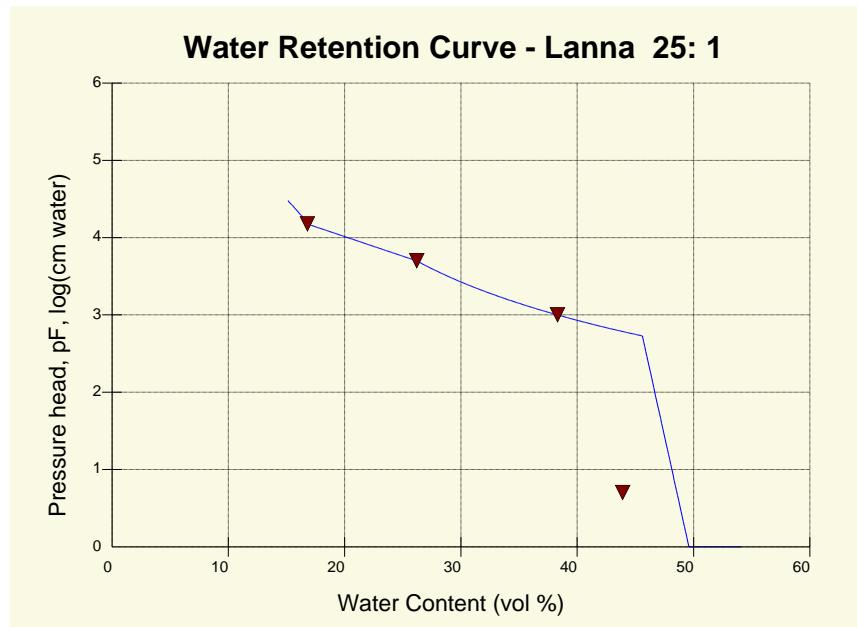
The hydraulic conductivity as a function of water tension for the Lanna 25:1 soil at three depths: blue = 0-0.1m, green = 0.4-0.5m, turquoise = 0.9-1.0m.

Measured Unsaturated Conductivity, Water Content, single layers



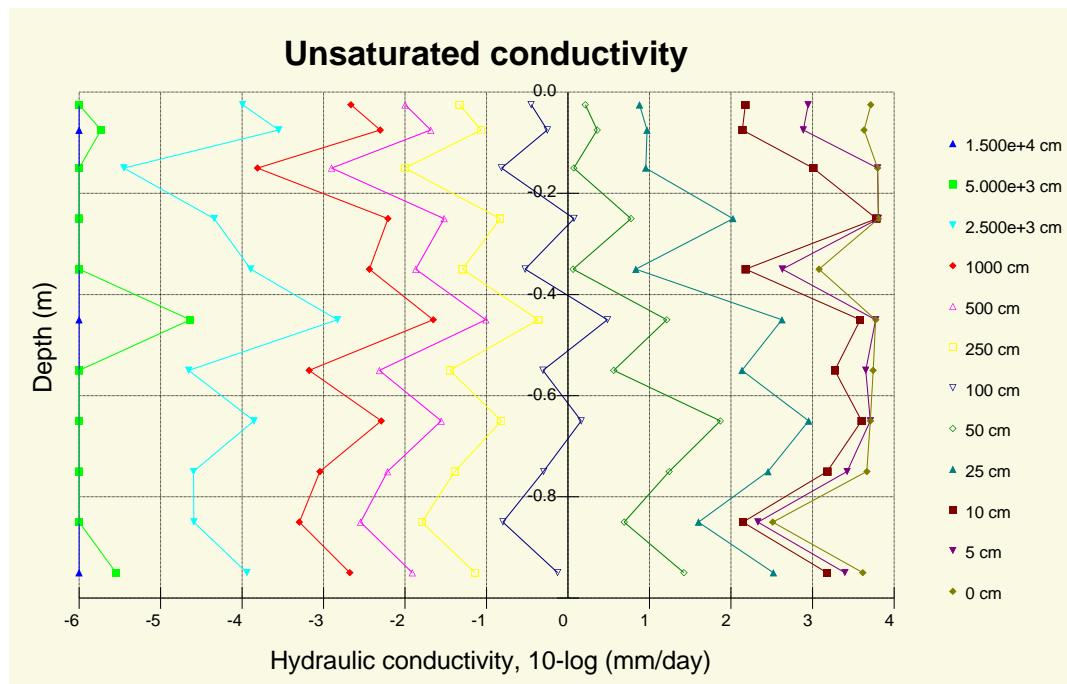
The hydraulic conductivity as a function of water content for the Lanna 25:1 soil at three depths: blue = 0-0.1m, green = 0.4-0.5m, turquoise = 0.9-1.0m.

Measured Water Retention, single layers



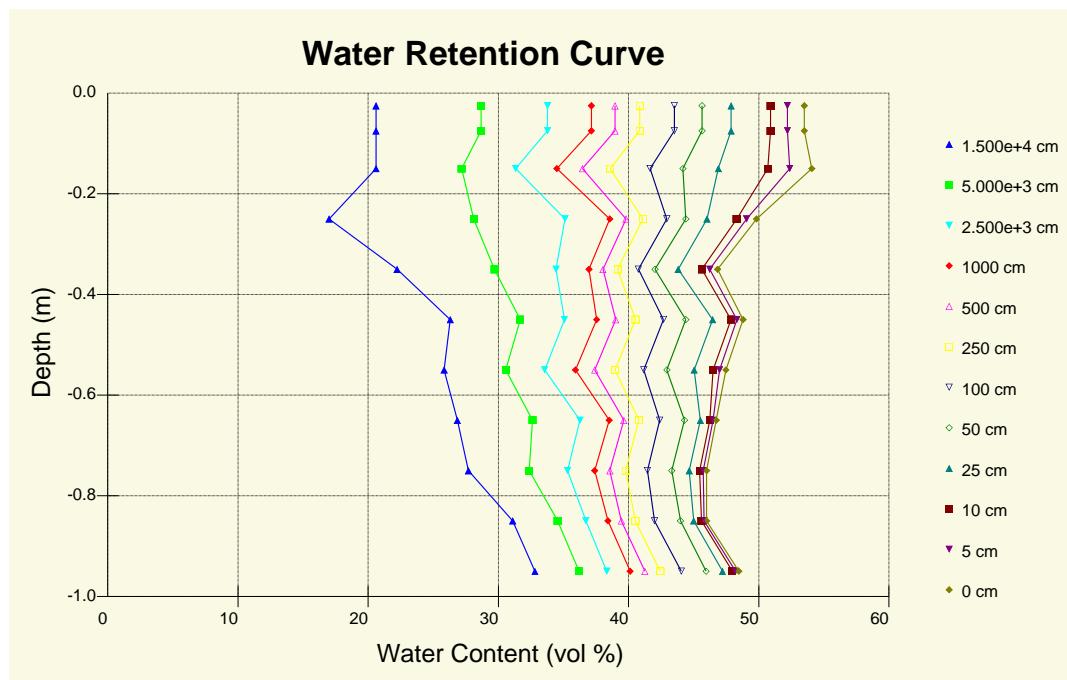
Pressure head as a function of water content in the soil for the Lanna 25:1 soil at 0.2-0.3 m depth estimated from measured values (red triangles).

Modelled Unsaturated Hydraulic Conductivity, profile



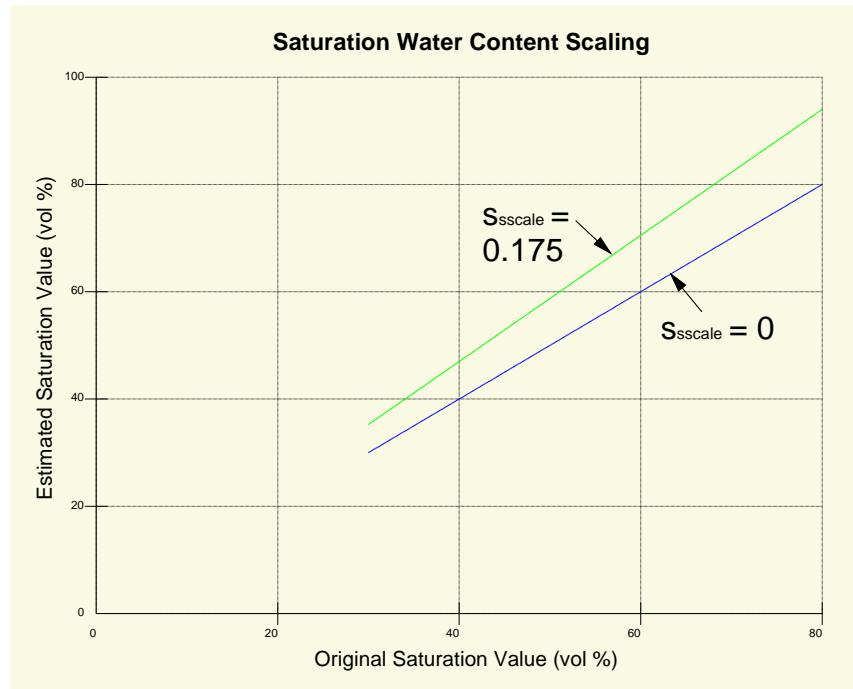
The hydraulic conductivity as a function of depth for different water tensions (Lanna 25:1 soil).

Modelled Water Retention, profile



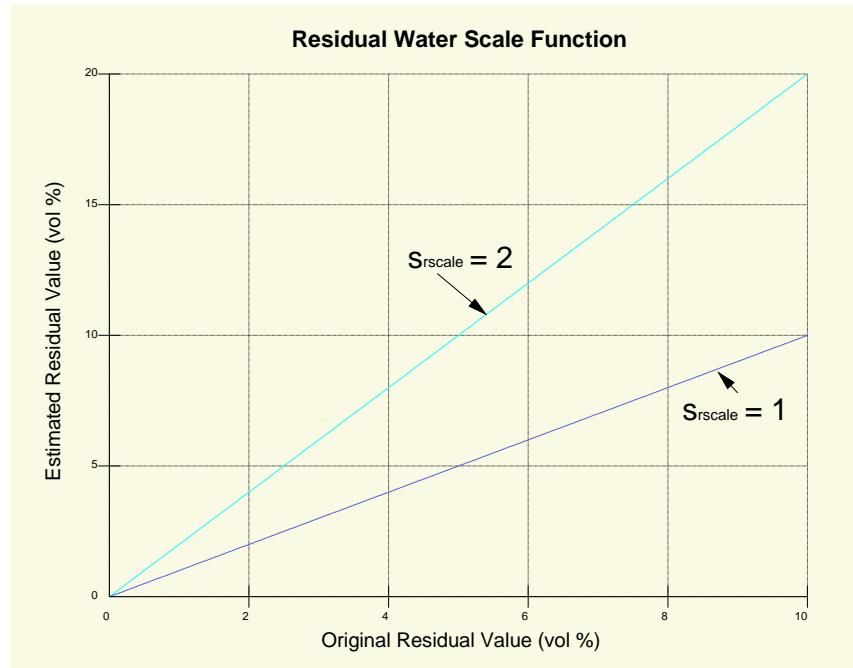
The soil water content as a function of depth for different water tensions (Lanna 25:1 soil).

Scaling of water retention, porosity



Scaling of the water retention curve by modifying porosity with the parameter S_{sscale} .

Scaling of water retention, residual water content



Scaling of the water retention curve by modifying the residual water content with the parameter s_{rscale} .

Drainage and deep percolation

Theory

Groundwater flow (i.e. the lower layer(s) in the soil profile is/are saturated with water) may optionally be chosen in the simulation as determined by the switch “GroundWaterFlow” in “Structure of Model”.

If groundwater is not considered, deep percolation, i.e. a vertical gravitational out flow of water from the lowest layer in the soil profile, may be estimated as a simple lower boundary to the unsaturated soil profile, as further described below. The lower boundary for the water equation can otherwise be calculated by either a given or an estimated value of the pressure head at the bottom of the profile, which in turn will generate deep percolation. These options for an unsaturated profile are determined by the switch “[LBoundUnSaturated](#)”.

Deep percolation can also optionally be assumed when there is a groundwater flow in the soil profile, i.e. when the lower part of the profile is saturated (see switch “[LBoundSaturated](#)”).

The groundwater flows, i.e. drainage, are considered a sink term in the one-dimensional structure of the model. There are several different approaches to account for water flows in various parts of the soil profile depending on the presence of artificial drainage systems and/or topographical and hydrogeological conditions (see switches “[EmpiricalDrainEq](#)” and “[PhysicalDrainEq](#)”). The empirical drainage equation is simpler than the physical equations and therefore it is usually used when there are no parameters available for the physical equation. It is possible to combine the empirical equation with a physical equation e.g. to let one of them symbolise an artificial drainage system. The total drainage from the system, q_{dr} , is therefore the sum of the drainage calculated with the empirical and the physical drainage equation.

A groundwater source flow can optionally be simulated for saturated conditions, as described below. Pumping of water is also possible, and the amount of water removed by pumping is added to the total drainage. Vertical water flows in saturated layers is finally described at the end of the section.

Deep percolation, unsaturated lower boundary

If the soil profile is unsaturated, the bottom of the soil profile can either be assumed to be completely impermeable (“No flow”), or a deep percolation of water out of the profile can be simulated in various ways, as determined by the switch “[LBoundUnSaturated](#)”.

If a unit gradient is assumed (“Unit grad flow”) the vertical water flow (deep percolation) is calculated as:

$$q_{deep} = k_{wlow} \quad (2.37)$$

where k_{wlow} is the hydraulic conductivity in the lowest soil layer. It is thus the *flow* of water from the lowest layer that is the boundary condition that satisfies Richards’s equation [\(2.2\)](#).

The lower boundary can optionally be set by specifying the pressure head in the lowest soil layer i.e. by determining the *state* variable. When solving Richard’s equation any excess water in the lowest layer is lost from the profile as deep percolation. There are three ways of giving the pressure head at the lowest layer to the model. Either the pressure head is given as a parameter (“Constant Psi”). To satisfy the requirement of this constant pressure head, not only a deep percolation, but also a capillary rise of water from the soil below the lowest layer can occur. The parameter could instead be interpreted as a maximum value (“Constant Maximum Psi”) resulting in a deep percolation when the maximum pressure head is exceeded, but in no capillary rise of water if case of a low pressure head in the bottom layer. Finally the pressure head can be specified as a dynamic variable by giving the values from a PG-file (“Dynamic Psi”). In this case a deep percolation (downward flow) or a capillary rise (upward flow) take place between the lowest soil layer and the soil below in order to satisfy the pressure head requirement in the lowest compartment.

Deep percolation, saturated lower boundary

A vertical water flow, i.e. deep percolation, from the lowest compartment (see switch “[LBoundSaturated](#)”) may optionally be calculated by a unit gradient i.e. by gravitational forces (see eq.[\(2.37\)](#))only, it may be assumed equal to zero or, if the lower boundary is saturated, it may be based on the seepage equation and calculated as:

$$q_{deep} = \frac{8k_{sat}(z_{sat} - z_{p2})^2}{d_{p2}^2} \quad (2.38)$$

where k_{sat} is the conductivity of lowest layer, z_{sat} is the simulated depth of the ground water table, z_{p2} is the depth of a drain level with a parallel geometry at a spacing distance of d_{p2} . See viewing function “[Bottom Boundary Seepage Equation](#)”.

Drainage, Simple empirical equations on groundwater outflow

The simplest empirical approach (“[EmpiricalDrainEq](#)”) is based on a first-order recession equation. Unlike the case for the physically-based approach, this sink term will only be calculated in the layer where the ground water table, z_{sat} , is located and no account is taken of flow paths in the saturated part of the soil profile. When the ground-water level, z_{sat} , is above the bottom of the profile, a net horizontal water flow is given as a sum of ‘base flow’ and a more rapid ‘peak flow’:

$$q_{gr} = q_1 \frac{\max(0, z_1 - z_{sat})}{z_1} + q_2 \frac{\max(0, z_2 - z_{sat})}{z_2} \quad (2.39)$$

where q_1, q_2, z_1, z_2 are parameters obtained by fitting techniques. See viewing function “[Empirical drainage equation](#)”.

z_{sat} is defined as the level where the matrix potential is zero and thus calculated from values on soil water content.

Drainage, Physical based equations on groundwater outflow

The physically based-approaches can conceptually be compared with a drainage system (see [Figure 2.6](#)). Water flow to a drainage pipe occurs when the simulated groundwater table, z_{sat} , is above the bottom level of the pipe, i.e. flow occurs horizontally from a layer to drainage pipes when the soil is saturated. Three different options are available for this equation (see switch “[PhysicalDrainEq](#)”).

In addition, a source flow from a water-filled ditch or stream to the soil profile will be simulated based on straightforward use of the Darcy equation (see switch “[ReturnFlow](#)”) when the drainage depth is above the groundwater level in the simulated profile. In this case, the different radial and vertical resistances are neglected and only the horizontal resistance from eq. [\(2.46\)](#) is applied.

The simulated ground water level may optionally be forced to match a certain variation if the drainage level is allowed to change with time (see switch “[DriveDrainLevel](#)”) i.e. a changing z_p (see below).

Linear equation

In the simplest physically based approach (“linear model”), the horizontal flow rate, q_{wp} , is assumed to be proportional to the hydraulic gradient and to the thickness and saturated hydraulic conductivity of each soil layer:

$$q_{wp} = \int_{z_p}^{z_{sat}} k_s \frac{(z_{sat} - z_p)}{d_u d_p} dz \quad (2.40)$$

where d_u is the unit length of the horizontal element i.e. 1m, z_p is the lower depth of the drainage pipe i.e. the drainage level, z_{sat} is the simulated depth of the ground water table and d_p is a characteristic distance between drainage pipes. Note that this is a simplification where the actual flow paths and the actual gradients are not represented. Only flows above the drain level z_p are considered. See viewing function “[Physically based drainage equation](#)”.

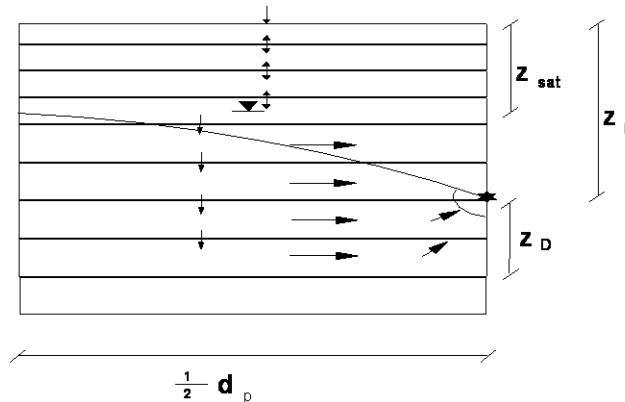


Figure 2.6. The geometrical assumptions behind the groundwater flow towards a sink point in the saturated zone of the soil.

Hooghoudt drainage equation

A more physically correct picture of the flow situation may be considered based on either the classical equations presented by Hooghoudt (1940) or those by Ernst (1956). Using any of these equations drainage flows below the pipes are also considered.

Following Hooghoudt the total flow to the pipes is given by:

$$q_{wp} = \frac{4k_s(z_{sat} - z_p)^2}{d_p^2} + \frac{8k_s z_D (z_{sat} - z_p)}{d_p^2} \quad (2.41)$$

where k_{s1} and k_{s2} are the saturated conductivities in the horizon above and below drainage pipes respectively, z_D is the thickness of the layer below the drains and d_p is the spacing between parallel drain pipes. See viewing function “[Physically based drainage equation](#)”.

The model uses the first term in the Hooghoudt equation to calculate the flows for specific layers above the drain depth, z_p . These calculations are also based on the horizontal seepage flow for heterogeneous aquifers (Youngs 1980):

$$q_{wp1}(z) = \frac{8k_s(z) \left(h_u - h_l + \frac{(h_l^2 - h_u^2)}{2(z_{sat} - z_p)} \right) (z_{sat} - z_p)}{d_p^2} \quad (2.42)$$

where h_u and h_l are the heights of the top and bottom of the compartment above the drain level z_p and k_s is the saturated conductivity. Below the drain depth (corresponding to the second term in the Hooghoudt equation) the flow is calculated for each layer as:

$$q_{wp2}(z) = \frac{8k_s(z)(z_{sat} - z_p)r_{corr}(z)}{d_p^2} \quad (2.43)$$

where the correction factor r_{corr} may be calculated based on the equivalent layer thickness, z_d as:

$$r_{corr}(z) = \frac{z_d \Delta z}{z_D} \quad (2.44)$$

where z_d and d_p are related as:

$$\frac{d_p}{z_d} = \frac{(d_p - z_D \sqrt{2})^2}{z_D d_p} + \frac{8}{\pi \ln\left(\frac{z_D}{r_p \sqrt{2}}\right)} \quad (2.45)$$

where r_p is the diameter of the drain pipe. The diameter of the pipes affects the resistance to the flow in the pipes.

Ernst Drainage equation

Alternatively, the correction factor is based on estimated sums of the radial, r_r , horizontal, r_h , and vertical, r_v , resistances for each layer. The correction factor is then given as:

$$r_{corr}(z) = \frac{(r_v(z) + r_h(z) + r_r(z))\Delta z}{r_{href} z_D} \quad (2.46)$$

where the r_{href} is the horizontal resistance that corresponds to eq.(2.43). The separate resistances for each compartment within the z_D layer are given :

$$r_v(z) = \sum_{i=1}^n \frac{\Delta z}{k(z)} \quad (2.47)$$

$$r_h(z) = \frac{(d_p - \cos(0.5\pi(z_p - z))z_D)^2}{8k(z)z_D} \quad (2.48)$$

$$r_r(z) = \frac{1}{n} \sum_{i=1}^n \frac{d_p}{\pi k(z)} \ln \frac{z_D}{r_p} \quad (2.49)$$

where r_p is the wet perimeter of the drain and can be used for ditches as well as for pipes. As opposed to the Hooghoudt formula, r_p does not stand for the radius of the pipe directly, even though the parameter is still given to the model as “[RadiusPipe](#)”. To get an estimation of the parameter r_p , which should be given to the model as input, the following two formulas can be used for ditches and for pipes respectively, i.e. these functions are not included in the model.

r_p for ditches:

$$r_p = b + 2y\sqrt{(s^2 + 1)} \quad (2.50)$$

where b is the bottom width of the ditch, y is the water depth in the ditch and s is the side slope of the ditch.

r_p for pipes:

$$r_p = b + 2r_0 \quad (2.51)$$

where b is the width of the trench and r_0 is the radius of the drain.

Groundwater inflow

In a similar way to groundwater outflow (drainage), a horizontal source flow may be defined. The source flow could either be the simulated outflow from a previous simulation (for quasi-two dimensional modelling) or set to a constant value, q_{sof} , for a specific layer, q_{sol} (see “[Lateral groundwater inflow](#)” in the files list in chapter “[Common Characteristics](#)”).

Pumping of groundwater

Groundwater can optionally be pumped from the soil when the groundwater level exceeds a certain depth, $z_{pumphigh}$. This option is governed by the switch “[Pump](#)”. Water is pumped from the layers below $z_{pumphigh}$ at a rate q_{pump} , until the groundwater level drops below a minimum level, $z_{pumplow}$. Pumping is resumed when the groundwater level again exceeds $z_{pumphigh}$.

Position of groundwater level and vertical redistribution between the saturated layers

The groundwater level/saturation level is defined as the depth where the pressure head corresponds to atmospheric pressure. The saturation level z_{sat} is thereby given as:

$$z_{sat} = z_i + \psi_i \quad (2.52)$$

where z_i is the depth of the middle of the layer i and ψ is the pressure head of the same layer. The layer with index i is located immediately above the uppermost fully saturated layer. Only one groundwater level is possible to simulate by the model. Horizontal drainage from this layer i is calculated until the pressure head will be lower than the distance to the adjacent midpoint of the layer below.

If full saturation will be obtained as a perched ground water above an unsaturated layer in the soil profile, the layer may reach saturation and also a possible over-saturation may occur with a pressure head higher than atmospheric pressure. This type of perched water table will not cause any net horizontal water flow, instead a vertical redistribution will take place towards layers with a lower pressure head.

For all saturated layers beneath the uppermost of the saturated layers the water content will always be exactly at saturation. No over-saturation will be allowed. All calculated net horizontal flows will be balanced by vertical redistributions to prevent non-saturated conditions. Vertical redistribution within the saturated zone is calculated based on the assumption that the water content will change only in the layer directly above the uppermost of the saturated layers.

Switches

DriveDrainLevel

Value	Meaning
Parameter	The water level in the drainage system is at a fixed level.
Driving File	The water level in the drainage system is specified in a PG-driving variable file. These values must be in meters and must be negative when the water surface is below the ground surface.

EmpiricalDrainEq

Value	Meaning
off	No net loss of ground water is accounted for based on the empirical equation. However, note that drainage can be independently estimated from the empirical equation and the physical based equation.
on	A simple empirical equation is used to estimate the net loss from the entire ground water storage based on two linear functions. The flow is extracted from the layer where the ground water table is located.

LBoundSaturated

Value	Meaning

No Flow	The lower boundary completely impermeable.
Unit Grad Flow	The water flow from the bottom layer is calculated from the saturated conductivity of the bottom layer and assuming a unit gradient gravitational flow.
Seepage Flow	The water flow is calculated from a seepage equation using two parameters.

LBoundUnSaturated

Value	Meaning
Constant Psi	The lower boundary for water equation is calculated from the assumption of a constant pressure head of the bottom layer. The pressure head is given by the value of a parameter.
Constant Maximum Psi	The lower boundary for water equation is calculated from the assumption of a constant pressure head of the bottom layer if an excess of water appear in the lower layer. The pressure head is then given by the value of a parameter. Otherwise the lower boundary will be defined by a zero flow, i.e., no capillary flow from the soil below the lowest layer is allowed.
Dynamic Psi	Similar as "Constant Psi" but the pressure head of the bottom layer is specified as a dynamic variable by using a PG driving variable file where the value of the pressure head is given.
No Flow	No deep percolation. The lower boundary completely impermeable.
Unit Grad Flow	The water flow from the bottom layer is calculated from the unsaturated conductivity of the bottom layer and assuming a unit gradient gravitational flow.

PhysicalDrainEq

Value	Meaning
off	No drainage is calculated to a ditch or a drain tile.
Linear Model	A simple linear model is used to calculate the drainage if the ground water table is above a certain layer. Fluxes are only assigned to layers above the drainage level.
Ernst Model	The drainage equation by Ernst is used to account for resistances caused by the radial and horizontal flows to the drainage system.
Hooghoudt Model	Similar as above but the classical Hooghoudt equation is used instead.

Pump

Value	Meaning
off	No water is pumped from the soil profile.
on	Water is pumped at a constant rate, q_{pump} , when the groundwater level reaches above a certain depth, z_{pumphigh} .

ReturnFlow

Value	Meaning
off	Only water flow from the soil profile to the drainage system is allowed.
on	Water flow is calculated from the drainage level if the ground water level drops below the drainage level based on the same equation as used for the flow to the drainage system.

Parameters

Drainage of the soil profile can be controlled by horizontal flows to drainage pipes and/or by a net horizontal ground water flow to a natural sink. A constant source flow may also be specified. If a source flow with temporal changes is to be used, this flow should be distributed between the different layers in the soil profile and the variables should be included in the driving variable file.

DLayer

The thickness of the layer below the drain pipes and above a vertical impermeable horizon. Used for calculation of the equivalent layer thickness in the Hooghoudt formula.

Note that the Dlayer is normally smaller than the DrainSpacing/4.

Default	Unit	Symbol	Equation	Function
4	m	z_D	(2.41) (2.44) (2.45) (2.46) (2.48) (2.49)	

DrainLevel

Level of drain pipes, negative downwards.

Default	Unit	Symbol	Equation	Function
-1	m	z_p	(2.40) - (2.45) (2.48)	

DrainLevelLowerB

Depth for assumed drainage level for calculation of deep percolation.

Default	Unit	Symbol	Equation	Function
-10	m	z_{p2}	(2.38)	" Bottom Boundary Seepage Equation "

DrainSpacing

Distance between drain pipes, or more exactly the denominator when estimating the gradient necessary for the calculation of the horizontal water flow to drainage pipe.

Default	Unit	Symbol	Equation	Function
10	m	d_p	(2.40) - (2.45) , (2.48) - (2.49)	“Physically based drainage equation”

DrainSpacingLowerB

Distance between assumed drainage system for calculation of deep percolation.

Default	Unit	Symbol	Equation	Function
200	m	d_{p2}	(2.38)	“Bottom Boundary Seepage Equation”

EmpGFLlevBase

Level, negative downwards, for ground water flow to diffuse sink. The values of these parameters depend of local geological and hydrological conditions at each site.

Default	Unit	Symbol	Equation	Function
-3	m	z_2	(2.39)	“Empirical drainage equation”

EmpGFLlevPeak

Level, negative downwards, for ground water flow to diffuse sink. The values of these parameters depend of local geological and hydrological conditions at each site.

Default	Unit	Symbol	Equation	Function
-1	m	z_1	(2.39)	“Empirical drainage equation”

EmpGFlowbase

Maximal rates of ground water flow to diffuse sink. The values of these parameters depend on local geological and hydrological conditions at each site.

Default	Unit	Symbol	Equation	Function
2	mm/day	q_2	(2.39)	“Empirical drainage equation”

EmpGFlowPeak

Maximal rates of ground water flow to diffuse sink. The values of these parameters depend on local geological and hydrological conditions at each site.

Default	Unit	Symbol	Equation	Function

10	mm/day	q_I	(2.39)	“Empirical drainage equation”
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GWSourceFlow

Constant rate of ground water source

Default	Unit	Symbol	Equation	Function
0	mm/day	q_{sof}		

GWSourceLayer

Layer for the ground water source flow

Default	Unit	Symbol	Equation	Function
3	-	q_{sol}		

PressureHeadBottom

A constant lower boundary condition, which can be used when no ground water is present in the profile.

Default	Unit	Symbol	Equation	Function
100	cm water			

PumpFlowRate

The rate at which water is pumped out of the soil profile.

Default	Unit	Symbol	Equation	Function
5	mm/day	q_{pump}		

PumpHighLevel

Groundwater level when pumping of water starts.

Default	Unit	Symbol	Equation	Function
-4	m	$p_{pumphigh}$		

PumpLowLevel

Groundwater level when pumping of water ceases.

Default	Unit	Symbol	Equation	Function
-5	m	$p_{pumplow}$		

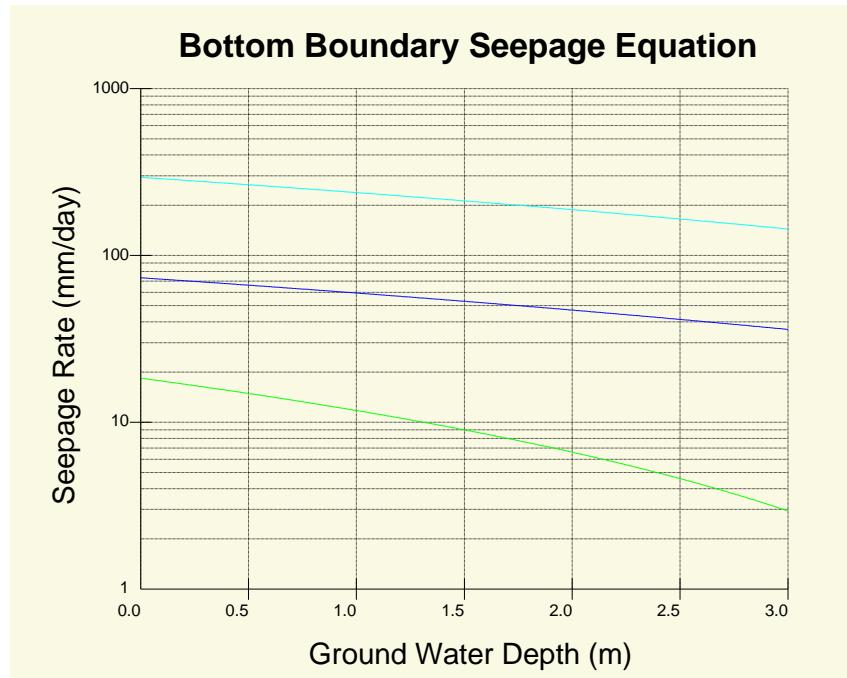
RadiusPipe

The radius of drain pipes used for calculation of the equivalent layer thickness in the Hooghoudt or Ernst formulas.

Default	Unit	Symbol	Equation	Function
0.1	m	r_p	(2.45) (2.49)-(2.51)	

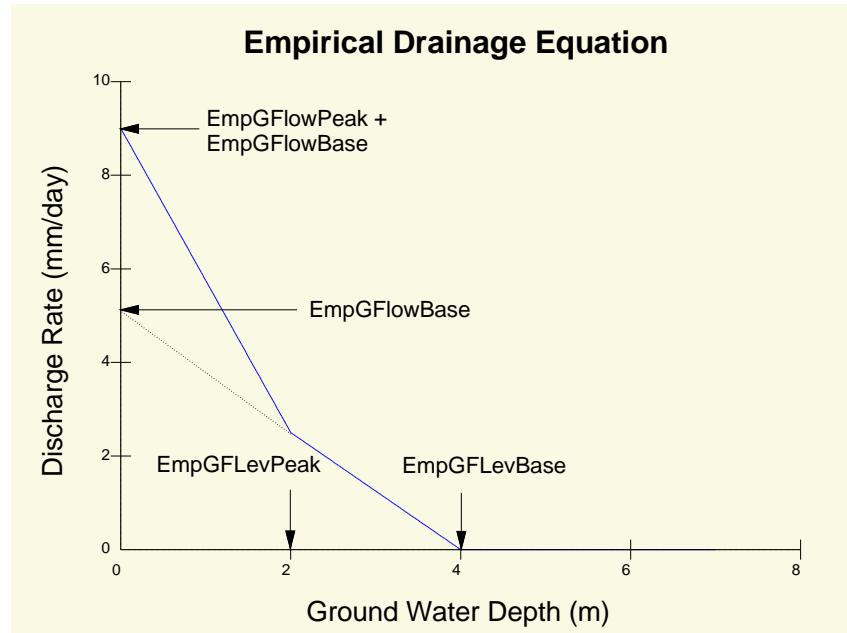
Viewing Functions

Bottom Boundary Seepage Equation



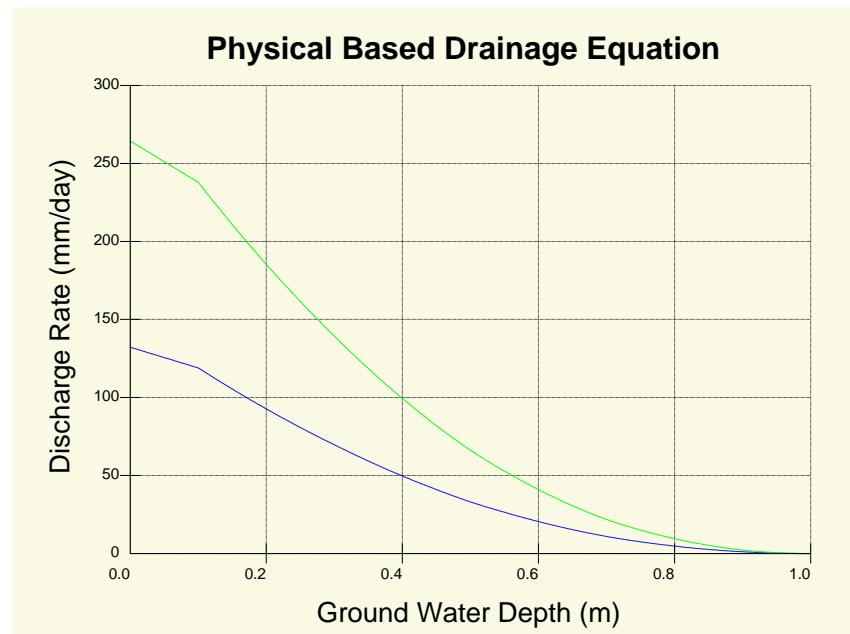
The seepage rate as a function of ground water depth. Blue: $z_{p2} = -10, d_{p2} = 200$.
Green: $z_{p2} = -5, d_{p2} = 200$. Turquoise: $z_{p2} = -10, d_{p2} = 100$.

Empirical drainage equation



The discharge rate as a function of ground water depth. The plot shows the four parameters affecting the discharge rate.

Physically based drainage equation



The discharge rate as a function of ground water depth for two different drainage spacings, d_p ; 20 (blue) and 10 (green).

Flow Variables

DeepPerc

Rate of deep percolation from lowest soil layer
mm/day

WaterDrainflow

Rate of drainage (horizontal flow) from soil layers including pumped water
mm/day

Auxiliary Variables

CorrHeightFactor

Factor, r_{corr} , to be used to adjust estimated fluxes beneath drain depth in the Hooghoudt equation

NetEmpDrainage

Drainage flow rate as calculated from the empirical approach.
mm/day

NetPhysDrainage

Drainage flow rates as calculated from the physically based approach.
mm/day

TotalDrainage

Total drainage from the soil including pumped water
mm/day

TotalRunoff

Total runoff the sum of drainage and surface runoff
mm/day

SaturationLevel

Ground water level (negative below soil surface), i.e. the level where the pressure head is equal to atmosphere pressure.
m

Driving Variables

vDriveDrainLevel

Driving variable governing the drainage level.
m

Salt Tracer including Trace Elements

Theory

Salt accumulation and transport in the ecosystem can optionally be simulated optional (see switch “SaltTracer” in the chapter “[Structure of model](#)”). This section describes how salt enters the ecosystem, how it is transported and stored in the soil profile and how it is leached to the groundwater. An overview is given in [Figure 2.7](#). An accumulation of salts in the soil can reduce plant growth, either by a reduced water uptake by increasing the soil osmotic potential (see chapter “[Plant Water Processes](#)”) or from reduced photosynthesis/increased plant metabolism (see section “[Plant Growth](#)”).

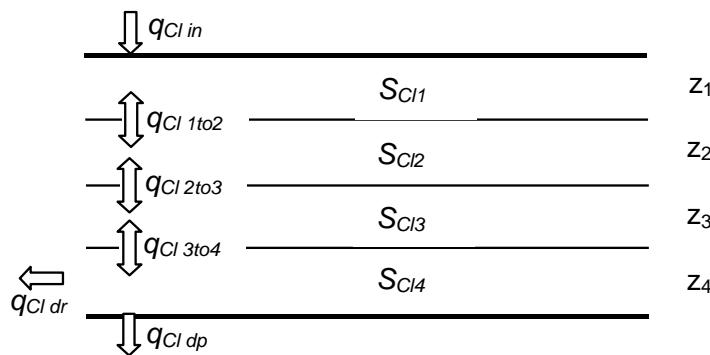


Figure 2.7. Storage and fluxes of salt in the soil profile. Symbols are explained in the text below.

It is also possible to expand the salt model to represent the distribution and transport of a trace element (see switch “[TraceElementUptake](#)”) if nitrogen and carbon processes are included in the simulation. This option allows for a passive and/or active plant uptake of the tracer. In the soil, trace elements are not only dissolved in the soil water, but can also be located in humus or litter (so called organic TE) or can be adsorbed to soil particles or soil organic matter.

The trace element application makes use of the salt pools in the model. In other words, when trace elements are included in a simulation, all pools denoted “Salt”, stands for trace element. The trace element application is described in detail at the end of this section.

Initial values

The initial values of soil water salt concentration, $C_{Cl}(z)$, can either be given as a uniform concentration in the whole soil profile, c_{Cl} , or can be specified for each soil layer in the parameter table “[Initial Salt Concentrations](#)”, as determined by the switch “[Initial Salt Concentration](#)”.

Salt Transport and Storage

Only convection is considered by the model i.e. dispersion/diffusion is not accounted for. Thus the salt transport in the soil is calculated as:

$$q_{Cl} = C_{Cl}(z) \cdot q_{mat} + c_{Cldep} \cdot q_{bypass} \quad (2.53)$$

where q_{mat} is the matrix water flow, q_{bypass} is the bypass water flow in the macro pores and c_{Cldep} is a parameter. If the flow of water is directed upwards there is no bypass flow and consequently the second term in eq. (2.53) is neglected.

The soil salt concentration, $C_{Cl}(z)$, can be estimated by dividing the salt storage, $S_{Cl}(z)$, with the soil water content in each layer. However, if some of the salts are adsorbed to particles in the soil (see switch “[Adsorption](#)”), soil salt concentration, $C_{Cl}(z)$, is instead calculated as:

$$C_{Cl}(z) = \frac{S_{Cl}(z) \cdot (1 - s_{adc}(z))}{\theta(z) \cdot \Delta z} \quad (2.54)$$

where s_{adc} is an adsorption parameter that can vary with depth, θ is the soil water content and Δz is the layer thickness (see viewing function “[Adsorption function](#)”).

Osmotic soil water potential

The osmotic soil water pressure, $\pi(z)$, is a function of the salt concentration in the soil:

$$\pi(z) = R \cdot (T + 273.15) \cdot \frac{C_{Cl}(z)}{M_{Cl}} \quad (2.55)$$

where R is the gas constant, T is soil temperature and M_{Cl} is the molar mass of salt (chloride-ion only).

Upper boundary condition

Salts that infiltrate the soil can come from several sources. Salt deposited from the atmosphere enters the soil profile with the infiltrating water from precipitation, ($q_{in} - i_{ar}$). A road salt application can optionally be chosen (see switch “[RoadSaltApplication](#)”). In this case an additional salt input, q_{Clroad} , is added to the total infiltration during conditions when the air temperature is within a specified range determined by the parameters $t_{salthigh}$ and $t_{saltlow}$. Alternatively, salt can be added to a storage pool on the road (see switch “[SaltRoadStorage](#)”), which emits salt resulting in a salt infiltration rate, $q_{ClRoadInf}$, as described in detail below. Finally, water used for irrigation of crops (see “[Irrigation](#)” below) may also contain salts. The total salt infiltration is calculated as:

$$q_{Clin} = c_{Cldep} \cdot (q_{in} - i_{rate} - i_{drip}) + q_{Clroad} + q_{ClRoadInf} + c_{Clirrig} \cdot i_{rate} \quad (2.56)$$

where c_{Cldep} is the salt deposition concentration, q_{in} is the total amount of infiltrated water, i_{rate} is the irrigation rate, i_{drip} is the irrigation rate for drip irrigation and $c_{Clirrig}$ is the concentration of salts in the irrigation water, which can either be given as a parameter or can be read from a PG-file (see switch “[IrrigConcInput](#)”).

Secondly, salts are removed from the surface through surface runoff, q_{surf} , according to:

$$q_{Clroff} = C_{Clz1} \cdot q_{surf} \quad (2.57)$$

where q_{Clroff} is the removal rate of salts with runoff and C_{Clz1} is the salt concentration in the uppermost soil layer.

Drip irrigation

When saline water is used in combination with drip irrigation, each soil layer receives an amount of salt which is in proportion to the amount of irrigation water allocated to each soil layer. Thus, the drip irrigation salt deposition rate, $q_{Cl\text{dripin}}(z)$, is equal to:

$$q_{Cl\text{dripin}}(z) = c_{Cl\text{irrig}} \cdot i_{\text{driprate}}(z) \quad (2.58)$$

where i_{driprate} is the irrigation rate for drip irrigation and $c_{Cl\text{irrig}}$ is the concentration of salts in the irrigation water, which can either be given as a parameter or can be read from a PG-file (see switch “[IrrigConcInput](#)”).

Lower boundary condition

If there is a horizontal drainage of water from the profile (i.e. if the lower boundary is saturated) some of the dissolved salt will be lost by leaching. The amount of leached salt, $q_{Cl\text{dr}}$, is proportionate to the total amount of drainage water, q_{dr} :

$$q_{Cl\text{dr}} = C_{Cl\text{low}} \cdot q_{dr} \quad (2.59)$$

where $C_{Cl\text{low}}$ is the salt concentration in the bottom layer of the soil profile.

Analogously to this flow, there is a salt flux connected to the deep percolation of water, $q_{Cl\text{dp}}$:

$$q_{Cl\text{dp}} = C_{Cl\text{low}} \cdot q_{deep} \quad (2.60)$$

where q_{deep} is the deep percolation of water.

Depth of salt front

In some situations it might be of interest to follow the spread of salts from the surface through the soil. The depth from the surface to the lowest level of a salt concentration above a threshold level specified by the parameter, $c_{clfront}$, is given as an output to model simulations.

Road salt model

A storage pool for road salt that emits salt to the surrounding areas can be explicitly described (see switch “[SaltRoadStorage](#)”). The input rate to this pool is given in a PG-file. Salts leave the pool through emissions, $q_{Cl\text{RoadEm}}$, calculated as a fraction e_{coef} of the amount of salt in the road salt storage pool, $C_{Cl\text{Road}}$:

$$q_{Cl\text{RoadEm}} = e_{coef} \cdot C_{Cl\text{Road}} \quad (2.61)$$

Only a fraction of the emitted salts infiltrate in the surrounding land, as determined by the coefficient r_{coef} :

$$q_{Cl\text{RoadInf}} = r_{coef} \cdot q_{Cl\text{RoadEm}} \quad (2.62)$$

where $q_{Cl\text{RoadInf}}$ is the infiltration rate of salts originating from the road storage pool.

Trace element application

This application is an expansion of the salt module and is used to model accumulation of a trace element in the soil and plant. [Figure 2.8](#) describes the distribution of trace elements in the ecosystem as represented in the model, as well as the fluxes of tracers between different locations. Some storage pools and fluxes are the same as in the salt module, i.e. $S_{TEM\text{in}} = S_{Cl}$, $q_{TEin} = q_{Cl\text{in}}$, $q_{TEDr} = q_{Cl\text{dr}}$, $q_{TEDp} = q_{Cl\text{dp}}$. Others are specific to the trace element application, i.e. the plant storage pools ($S_{TE\text{Leaf}}$, $S_{TE\text{OldLeaf}}$, $S_{TE\text{Stem}}$, $S_{TE\text{OldStem}}$, $S_{TE\text{Roots}}$, $S_{TE\text{OldRoots}}$ and $S_{TE\text{Grain}}$), the soil storage pools ($S_{TESurfaceLitter}$, $S_{TELitter}$, $S_{TEHumus}$) and the plant uptake of trace elements ($S_{TEPlantUpt}$).

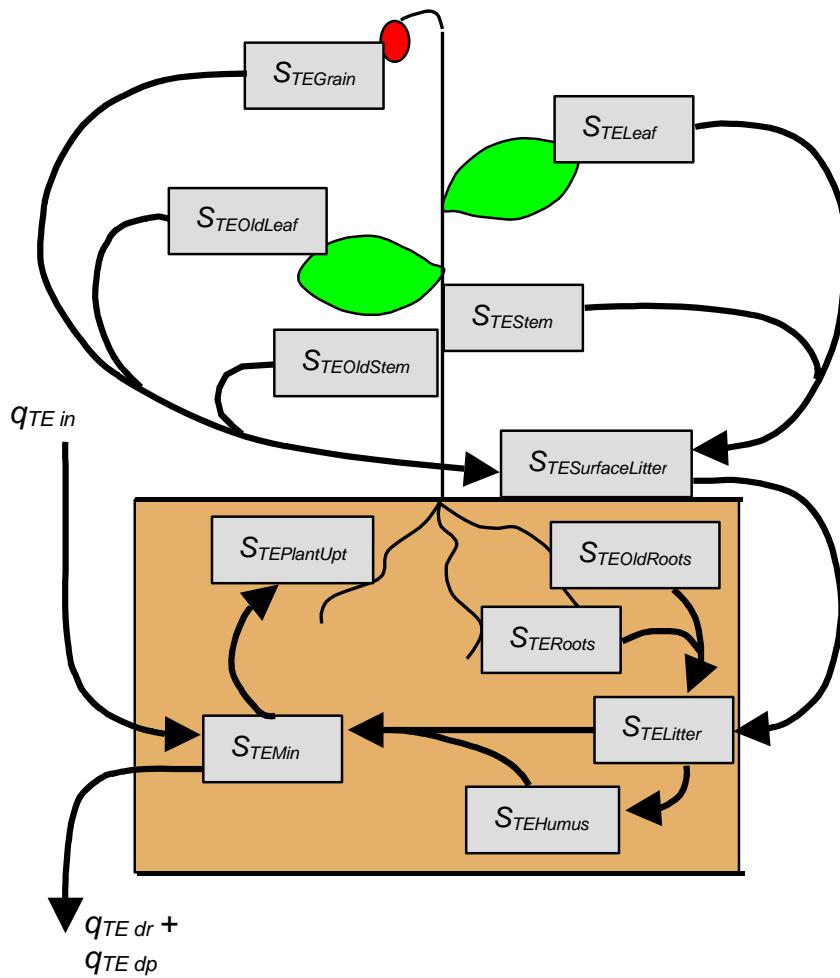


Figure 2.8. The storage and fluxes of trace elements in the model. Symbols are explained below.

Initial values, upper and lower boundary conditions, and calculations of osmotic potential (if applicable) is done in the same way in the salt application. The “mineral” trace element pool, S_{TEMin} , (i.e. the amount of dissolved trace elements in the soil plus adsorbed material) corresponds to the salt storage pool, S_{CL} . The transport between soil layers, as well as the concentration of the trace element, is calculated in the same manner as for salt eq. (2.54). Note that the amount of adsorbed material is not calculated explicitly. All adsorbed material is considered the same, irrespective of whether it is adsorbed to mineral or to organic particles, and it should therefore not be confused with trace elements located in litter and humus.

Some additional processes are specific for the trace element application, such as plant uptake of trace elements, the allocation of trace elements in the plant and the flows of trace elements both to the soil and in the soil. These processes are described below. For detailed descriptions of plant growth or soil organic processes, please refer to the sections “[Plant Growth](#)” and “[Soil Organic Processes](#)” respectively.

Passive plant uptake

A passive plant uptake of trace elements can optionally be chosen in the model (see switch “[PassiveUptake](#)”). This uptake is calculated for the leaf, stem and roots separately, and is a function of plant water uptake, W_{upt} (see section “[Water uptake by roots](#)”). Thus, passive trace element uptake from the mineral pool to the leaf, $S_{TEMin \rightarrow TELeafP}$, is calculated as:

$$S_{TEMin \rightarrow TELeafP} = C_{TEMin} \cdot W_{upt} \cdot S_{PUScale} \cdot f_{PULeaf} \quad (2.63)$$

where C_{TEMin} is the concentration of trace elements in the dissolved phase, $s_{PUscale}$ is a scaling parameter determining the efficiency of the uptake, and f_{PULeaf} is a fraction of the total passive uptake allocated to the leaf.

The same equation is used analogously to calculate the passive uptake to stem, $S_{TEMin \rightarrow TEStemP}$, and roots, $S_{TEMin \rightarrow TERootsP}$, by exchanging f_{PULeaf} to f_{PUStem} or f_{PURoot} respectively. The root fraction, f_{PURoot} , is calculated by:

$$f_{PURoot} = 1 - (f_{PULeaf} + f_{PUStem}) \quad (2.64)$$

The total passive uptake of trace elements, $S_{TEMin \rightarrow TEPlantP}$, is the sum of the passive uptake to the leaves, stem and roots.

Active plant uptake

An active plant uptake of trace elements can optionally be chosen in the model (see switch “[ActiveUptake](#)”). This uptake is calculated for the leaf, stem and roots separately, and is a function of the allocation of assimilates to each pool. Thus, active trace element uptake from the mineral pool to the leaf, $S_{TEMin \rightarrow TELeafA}$, is calculated as:

$$S_{TEMin \rightarrow TELeafA} = \Delta z \cdot \left(\frac{C_{TEMin}}{c_{AUmax}} \cdot s_{AUeffL} \right) \cdot C_{a \rightarrow Leaf} \quad (2.65)$$

where Δz is the layer thickness, C_{TEMin} is the concentration of trace elements in the dissolved phase, c_{AUmax} is a maximum concentration parameter, s_{AUeffL} is an efficiency parameter for active uptake to leaves, and $C_{a \rightarrow Leaf}$ is the allocation of assimilated carbon to leaves. The C_{TEMin} / c_{AUmax} ratio is never allowed to exceed unity. (See viewing functions “[Active uptake function](#)” and “[Active uptake leaf function](#)”).

The same equation is used analogously to calculate the active uptake to stem, $S_{TEMin \rightarrow TEStemA}$, and roots, $S_{TEMin \rightarrow TERootsA}$, by exchanging s_{AUeffL} to s_{AUeffS} or s_{AUeffR} , and $C_{a \rightarrow Leaf}$ to $C_{a \rightarrow Stem}$ or $C_{a \rightarrow Root}$, respectively.

The total active uptake of trace elements, $C_{TEMin \rightarrow TEPlantA}$, is the sum of the active uptake to the leaves, stem and roots.

Plant allocation of trace elements

Allocation of trace elements to the grain pool from roots, leaves and stem is proportionate to the carbon allocation to these pools, multiplied by the trace element / carbon ratio of the source pool. Thus, the transfer of trace elements to grain from leaves, $S_{TELeaf \rightarrow Grain}$, is calculated as:

$$S_{TELeaf \rightarrow Grain} = C_{Leaf \rightarrow Grain} \cdot S_{TELeaf} \quad (2.66)$$

where $C_{Leaf \rightarrow Grain}$ is the allocation of carbon from leaves to grain. S_{TELeaf} is the trace element / carbon ratio of the leaf:

$$S_{TELeaf} = \frac{S_{TELeaf}}{C_{Leaf}} \quad (2.67)$$

where S_{TELeaf} is the trace element content of leaves and C_{Leaf} is the carbon content of leaves. The transfers of tracers from roots to grain, $S_{TERoot \rightarrow Grain}$, and from stem to grain, $S_{TEStem \rightarrow Grain}$, are calculated analogously.

Trace element content in litterfall from leaves, stem, grain and roots are calculated in the same manner.

Every new years day, what remains of the trace elements the plant biomass after litterfall, will be transferred to pools for old plant material, i.e. $S_{TEOldLeaf}$, $S_{TEOldStem}$ and $S_{TEOldRoots}$.

Trace elements in litter formation

Trace elements in above ground litterfall accumulate in the surface litter, $S_{TESurfaceLitter}$. From the surface litter, there is a constant flux of trace elements into the litter pool in the uppermost soil compartment, $S_{TELitter}(z_l)$, calculated as:

$$S_{TESurfaceLitter \rightarrow Litter(z_l)} = l_{l1} \cdot S_{TESurfaceLitter} \quad (2.68)$$

where l_l is a rate coefficient defined in the “[Soil Organic Processes](#)” section. Note that litterfall from roots go directly the corresponding litter compartment in each soil layer.

Trace element fluxes in relation to decomposition

Decomposition of litter results in one flux of trace elements to humus and a second to the dissolved trace element pool, i.e. some form of mineralisation. Both fluxes are a function of the total turnover (i.e. decomposed material). The turnover of litter, $S_{TEDecompL}$, is calculated as:

$$S_{TEDecompL} = k_l \cdot f(T) \cdot f(\theta) \cdot S_{TELitter} \quad (2.69)$$

where k_l is a decomposition rate parameter (see section “[Soil Organic Processes](#)”), $f(T)$ and $f(\theta)$ are the common response functions for temperature and soil moisture (see section “[Common abiotic functions](#)”), and $S_{TELitter}$ is the amount of tracers in litter.

The flux of trace elements from litter to humus, $S_{TELitter \rightarrow Humus}$, is subsequently calculated as:

$$S_{TELitter \rightarrow Humus} = f_{h,l} \cdot S_{TEDecomp} \quad (2.70)$$

where $f_{h,l}$ is the fraction of the total turnover that is allocated to humus (“[Soil Organic Processes](#)”). The remaining decomposed material is the fraction that is mineralised:

$$S_{TELitter \rightarrow Min} = (1 - f_{h,l}) \cdot S_{TEDecomp} \quad (2.71)$$

The decomposition of humus also results in a mineralisation of trace elements, $S_{TEHumus \rightarrow Min}$, calculated by eq (2.68) by substituting k_l with k_h , and $S_{TELitter}$ with $S_{TEHumus}$.

Switches

ActiveUptake

Value	Meaning
Off	No active uptake of trace elements.
On	Active uptake of trace elements governed by plant growth.

Adsorption

Value	Meaning
Off	No adsorption of salt to soil particles.
On	Adsorption of salt to soil particles.

Initial Salt Concentration

Value	Meaning
Uniform conc	Initial salt concentration in the soil is uniformly distributed with depth.
cons(z)	Initial salt concentration in the soil is a function of depth.

IrrigConcInput

Value	Meaning

PG-file	Salt concentration in irrigation water is defined by data in file.
Parameter	Salt concentration in irrigation water is given as a parameter.

PassiveUptake

Value	Meaning
Off	No passive uptake of trace elements.
On	Passive uptake of trace elements governed by water uptake.

RoadSaltApplication

Value	Meaning
Off	Road salt application off.
On	Road salt application on.

SaltRoadStorage

Value	Meaning
Off	No road salt storage
On	A storage of salt on a road is explicitly simulated.

TraceElementUptake

Value	Meaning
Off	Trace element application off.
On	Trace element application on.

Parameters

ActiveUptEffLeaf

Default	Unit	Symbol	Equation	Function
$1 \cdot 10^{-6}$	mg/g	s_{AueffL}	(2.64)	“Active uptake leaf function”

ActiveUptEffRoots

Default	Unit	Symbol	Equation	Function
$1 \cdot 10^{-6}$	mg/g	s_{AueffR}	(2.64)	“Active uptake leaf function”

ActiveUptEffStem

Default	Unit	Symbol	Equation	Function
$1 \cdot 10^{-6}$	mg/g	s_{AueffS}	(2.64)	“Active uptake leaf function”

ActiveUptMaxEffConc

Default	Unit	Symbol	Equation	Function
$1 \cdot 10^{-6}$	mg/l	c_{AUmax}	(2.64)	“Active uptake function”

ConcForFront

Default	Unit	Symbol	Equation	Function
2.0	mg/l	$c_{clfront}$		

EmissionRateCoef

Default	Unit	Symbol	Equation	Function
0.05	-	e_{coef}	(2.60)	

Fraction of Road

Default	Unit	Symbol	Equation	Function
0.01	-	r_{coef}	(2.61)	

Index in PG-file

Default	Unit	Symbol	Equation	Function
1				

PassiveUptAlloFLeaf

Default	Unit	Symbol	Equation	Function
0.2	-	f_{PLLeaf}	(2.62)	

PassiveUptAlloFStem

Default	Unit	Symbol	Equation	Function
0.1	-	f_{PLStem}	(2.62)	

PassiveUptScaling

Default	Unit	Symbol	Equation	Function
0.001	-	$s_{PUscale}$	(2.62)	

Salt Application Rate

Salt application rate for the road salt application

Default	Unit	Symbol	Equation	Function
10000	mg/m ² /day	q_{Clroad}	(2.56)	

SaltInitConc

Initial uniform concentration of salt in a soil profile.

Default	Unit	Symbol	Equation	Function
2	mg/l	c_{Cl}		

SaltInputConc

Default	Unit	Symbol	Equation	Function
1	mg/l	c_{Cldep}	(2.53) , (2.56)	

SaltIrrigationConc

Default	Unit	Symbol	Equation	Function
1	mg/l	$c_{Clirrig}$	(2.56)	

Temp Salt High Limit

Road salt application.

Default	Unit	Symbol	Equation	Function
2	°C	$t_{salthigh}$		

Temp Salt Low Limit

Road salt application.

Default	Unit	Symbol	Equation	Function
-6	°C	$t_{saltlow}$		

Parameter Tables

Adsorption Coefficients

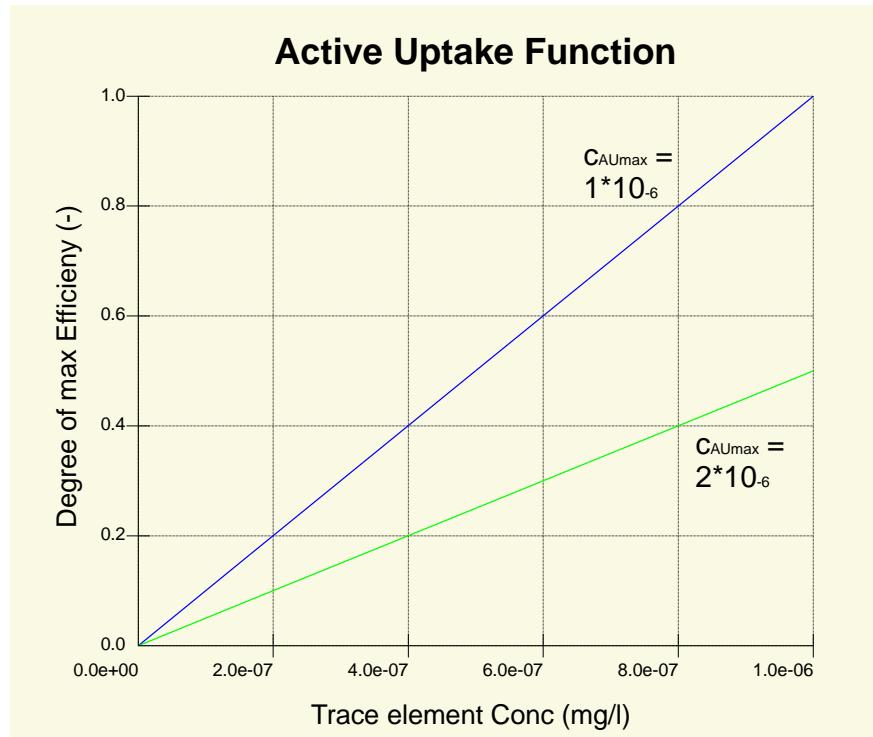
Name	Default	Unit	Symbol	Comments/Explanations
Ad_c	1	-	s_{adc}	Adsorption coefficient that determines how much of the salt that is adsorbed.

Initial Salt Concentrations

Name	Default	Unit	Symbol	Comments/Explanations
Init Salt Cons	2	mg/l	c_{Cl}	Initial salt concentration for each soil layer.

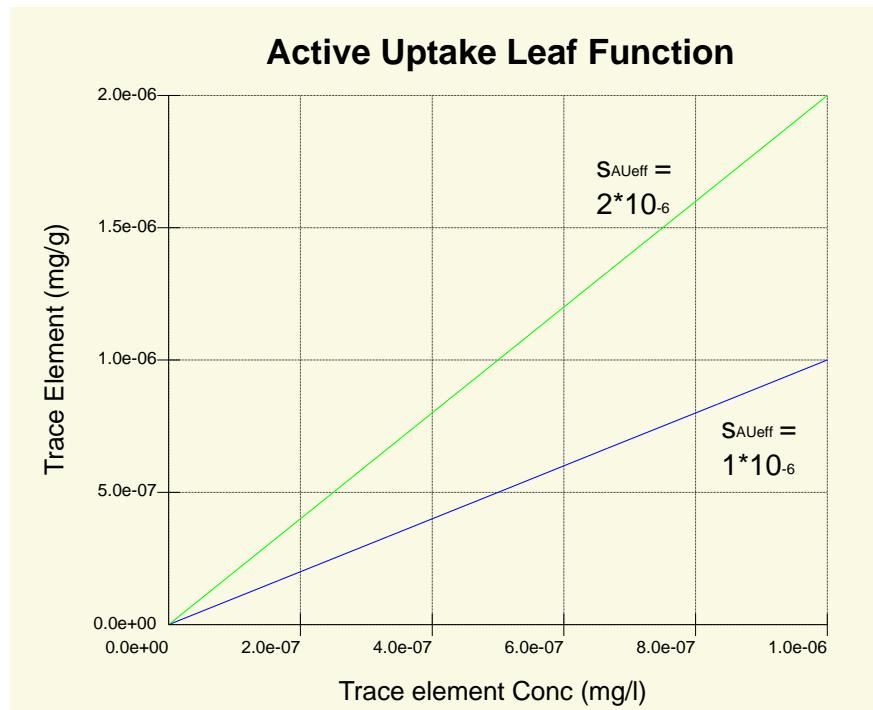
Viewing functions

Active uptake function



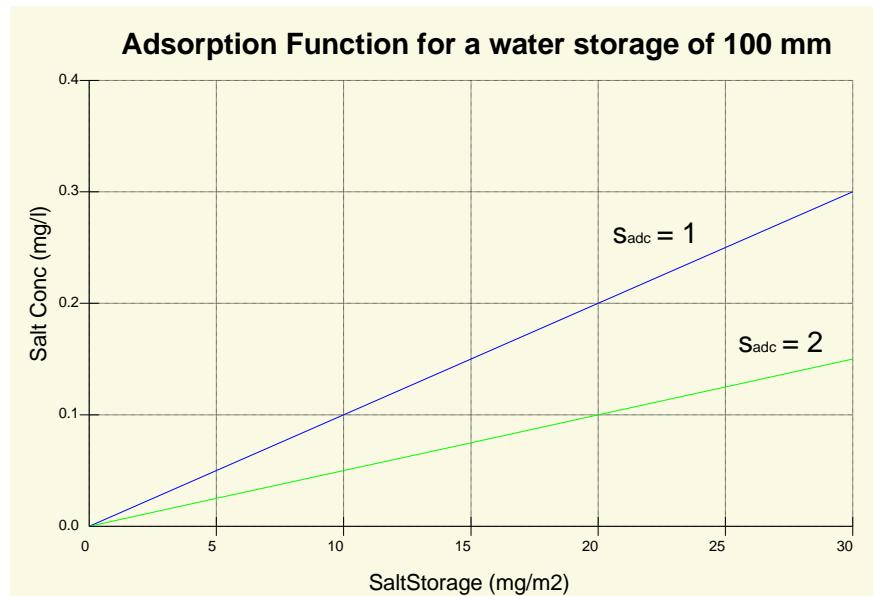
The effect of the maximum active uptake coefficient, c_{AUMax} , on the degree of max efficiency as a function of trace element concentration.

Active uptake leaf function



Trace element uptake per amount assimilated carbon (g/g) as a function of trace element concentration for two different uptake efficiencies, s_{AUEff} .

Adsorption function



Salt concentration as a function of salt storage without adsorption, $s_{adc} = 1$ (blue) and with adsorption, $s_{adc} = 2$ (green).

State Variables

AccSaltInput

Accumulated amount of salt that has entered the soil
mg/m²

AccSaltOutput

Accumulated amount of salt that has drained from the soil
mg/m²

SaltOnRoad

Amount of salt on the road when using the road salt application
mg/m²

SaltStorage

Amount of salt in a soil layer
mg/m²

TE_Balance

Total balance of trace elements (total inflow-storage-outflow) in the ecosystem (zero if correct)
mg/m²

TE Grain

Amount of trace elements in grain
mg/m²

TE Humus

Amount of trace elements in humus
mg/m²

TE Leaf

Amount of trace elements in the leaves
mg/m²

TE Litter1

Amount of trace elements in litter (only Litter 1 pool)
mg/m²

TE OldLeaf

Amount of trace elements in old leaves
mg/m²

TE OldRoots

Amount of trace elements in old roots
mg/m²

TE OldStem

Amount of trace elements in the old stem
mg/m²

TE Roots

Amount of trace elements in the roots
mg/m²

TE Stem

Amount of trace elements in the stem
mg/m²

TE Surface Litter

Amount of trace elements in the surface litter
mg/m²

Flow Variables

SaltDeepPercolation

Flow of salt to ground water from deepest unsaturated layer
mg/m²/day

SaltDrainFlow

Flow of salt as drainage from soil layers
mg/m²/day

SaltEmissions

Emissions of salt from a road to the adjacent
mg/m²/day

SaltFlow

Flow of salt between soil layers
mg/m²/day

SaltInfiltration

Infiltration of salt to the soil profile
mg/m²/day

SaltSourceFlow

Salts in drip irrigation water deposited into each soil layer.
mg/m²/day

SaltSurfaceOutflow

Salts in runoff
mg/m²/day

SaltToRoad

Rate of salt application to a road
mg/m²/day

TE GrainSurfaceLitter

Transfer of trace elements from grain to surface litter
mg/m²/day

TE HumusMinRate

Transfer of trace elements between the dissolved phase trace elements pool and humus
mg/m²/day

TE LeafGrain

Transfer of trace elements from leaves to grain
mg/m²/day

TE LeafOldLeaf

Transfer of trace elements from leaves to old leaves
mg/m²/day

TE LeafSurfaceLitter

Transfer of trace elements from leaves to surface litter
mg/m²/day

TE Litter1HumusRate

Transfer of trace elements from litter to humus for each soil layer (litter pool 1 only)
mg/m²/day

TE Litter1MinRate

Transfer of trace elements between the dissolved phase trace elements pool and litter (litter pool 1 only)
mg/m²/day

TE OldLeafSurfaceLitter

Transfer of trace elements from old leaves to surface litter
mg/m²/day

TE OldRootsLitter

Transfer of trace elements from the roots to litter for each soil layer
mg/m²/day

TE OldStemSurfaceLitter

Transfer of trace elements from the old stem to surface litter
mg/m²/day

TE PlantLeafUptake

Plant active and passive uptake of trace elements from each soil layer to the leaf
mg/m²/day

TE PlantRootUptake

Plant active and passive uptake of trace elements from each soil layer to the roots
mg/m²/day

TE PlantStemUptake

Plant active and passive uptake of trace elements from each soil layer to the stem
mg/m²/day

TE_PlantUptake

Amount of trace elements taken up by active and passive uptake from each soil layer
mg/m²/day

TE_RootsGrain

Transfer of trace elements from roots to grain
mg/m²/day

TE_RootsLitter

Outflow of trace elements from roots to litter for each soil layer
mg/m²/day

TE_RootsLitter1

Inflow of trace elements into litter from roots for each soil layer (litter pool 1 only)
mg/m²/day

TE RootsOldRoots

Transfer of trace elements from roots to old roots
mg/m²/day

TE StemGrain

Transfer of trace elements from stem to grain
mg/m²/day

TE StemOldStem

Transfer of trace elements from stem to old stem
mg/m²/day

TE StemSurfaceLitter

Transfer of trace elements from stem to surface litter
mg/m²/day

TE SurfaceLitter_Humus

Transfer of trace elements from surface litter to humus in the uppermost soil layer
mg/m²/day

TE SurfaceLitter_L1

Transfer of trace elements from surface litter to litter in the uppermost soil layer
mg/m²/day

TotSaltSourceFlow

Salts in drip irrigation water deposited into the whole soil profile.
mg/m²/day

Auxiliary Variables

Depth of Front

Depth of salt front in the soil profile.
m

OsmoticPressure

The osmotic potential of soil water based calculated from salt concentration and temperature.
cm

SaltConc

Salt concentration in each soil layer.
mg/l

TEC RatioGrain

Carbon / trace-element ratio in grain

TEC RatioLeaf

Carbon / trace-element ratio in the leaf

TEC RatioOldLeaf

Carbon / trace-element ratio in old leaves

TEC RatioOldRoots

Carbon / trace-element ratio in old roots

TEC RatioOldStem

Carbon / trace-element ratio in the old stem

TEC RatioRoots

Carbon / trace-element ratio in the roots

TEC RatioStem

Carbon / trace-element ratio in the stem

TE Total Humus

Total amount of trace elements in humus in the soil profile
mg/m²

TE Total Litter

Total amount of trace elements in litter and surface litter in the soil profile
mg/m²

TE Total Litterfall

Total transfer rate of trace elements in litterfall in the ecosystem
mg/m²/day

TE Total Mineral

Total amount of trace elements in the dissolved phase in the soil profile
mg/m²

TE Total Mineralisation

Total mineralisation rate of trace elements in the soil profile
mg/m²/day

TE Total Plant

Total amount of trace elements in all plants in the ecosystem
mg/m²

TE Total PlantUptake

Total trace element uptake rate by plants (passive and active) from all soil layers
mg/m²/day

TE Total Storage

Total amount of trace elements in all soil layers
mg/m²

TotalSaltDrainFlow

Total drainage of salt from all soil layers
mg/m²/day

Driving Variables

SaltInfilConc

Concentration of salt in the infiltrating water (in most cases equal to through fall concentrations).
mg/l

SaltIrrigationConc

Concentration of salt in the irrigation water.
mg/l

Irrigation

Theory

Irrigation can either be given as measured time series or specified to take place at certain soil moisture conditions (see switch “[IrrigationInput](#)”). In the former case, the time series can either be given as a rate or as amount of water (see switch “[UnitIrrig](#)”). Irrigation rate, i_{rate} , is thus equal to the rate given in the PG-file, or the amount of irrigation water specified in the PG-File divided with the time step. On the other hand, if automatic irrigation is used, the control of irrigation is governed by the actual soil water storage, S_{swat} , which is the sum of water storage in a number of layers, n_{isl} . When S_{swat} drops below a critical threshold, s_{min} , irrigation of an amount, i_{am} , takes place at an intensity, i_{ar} , resulting in the irrigation rate, i_{rate} .

The irrigation water can either be applied totally above vegetation, $i_{sfrac} = 0$, totally at the soil surface, $i_{sfrac} = 1$, or with any other partition, $0 < i_{sfrac} < 1$, between the vegetation and the soil.

Drip irrigation

Irrigation can optionally take place as drip irrigation (see switch “[Dripper](#)”). The irrigation water is in this case not added to the soil but is instead used to fill up the a water tank, i_{tank} , at the rate, $i_{tankfill}$. Thus, $i_{tankfill}$ is equal to the irrigation rate, i_{rate} , calculated as explained above. As soon as there is water in the tank, irrigation starts and irrigates the soil at the rate, $i_{driprate}$, until the tank is empty again. This irrigation water is not added to the soil surface but goes directly into the soil layers and is distributed according to the coefficient, i_{dist} . Thus, the rate of which water is added to each soil layer using drip irrigation, $i_{drip}(z)$, is calculated as:

$$i_{drip}(z) = i_{driprate} \cdot i_{dist}(z) \quad (2.72)$$

Switches

Dripper

Value	Meaning
Off	Drip irrigation application on.
On	Drip irrigation application off.

IrrigationInput

Value	Meaning
Driving variable	Irrigation given in PG-file.
Automatic	Irrigation will be generated by the model according to parameter values.

UnitIrrig

Value	Meaning
Rate	Irrigation input is given as a rate (i.e. mm day ⁻¹).
Amount	Irrigation input is given as an amount (i.e. mm).

Parameters

DripIrrigCover

Fraction of wetted soil surface using drip irrigation

Default	Unit	Symbol	Equation	Function
0.2	-	i_{cover}		

DripIrrigRate

Drip irrigation rate. Conventional drip irrigation systems have got discharge rates of approximately 2.0-8.0 l hr⁻¹, whereas the discharge rates for simple drip systems range from 0.2-3.0 l hr⁻¹.

Default	Unit	Symbol	Equation	Function
100	mm/day	$i_{driprate}$		

DripIrrigXCentre

Position of drip irrigation emitter.

Default	Unit	Symbol	Equation	Function
0.5	-	i_{pos}		

Index in File

The index in the PG-bin file if irrigation is read from a file and several irrigation series exist.

Default	Unit	Symbol	Equation	Function

1	-			
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IrrigAmount

The total amount of water added to the soil profile.

Default	Unit	Symbol	Equation	Function
20	mm	i_{am}		

IrrigRate

Irrigation rate. Amount of water added to the soil profile each irrigation occasion. This value will not override the total irrigation amount.

Default	Unit	Symbol	Equation	Function
50	mm/day	i_{ar}		

IStoreLayer

The number of layers counted from the top of the profile used to determine the minimum soil water content threshold for irrigation, IStoreMin.

Default	Unit	Symbol	Equation	Function
4	-	n_{isl}		

IStoreMin

Minimum soil water storage in the layers specified by IStoreLayer below which irrigation takes place.

Default	Unit	Symbol	Equation	Function
50	mm	s_{smin}		

SoilIrrigF

Parameter governing where the irrigated water should be applied. A value of 0 means that all water will be added above the plant, whereas a value of 1 results in all water being added directly to the soil. Any value in between partitions the irrigated water to the soil and the vegetation.

Default	Unit	Symbol	Equation	Function
0	-	i_{sfrac}		

Parameter Tables

Depth distribution of irrigation

Name	Default	Unit	Symbol	Comments/Explanations
InfilDistF	1.0 upper layer / 0.0 lower layers	-	i_{dist}	Distribution coefficient that determines how much water that is allocated to a specific soil layer when using drip irrigation.
mUpper Depth	0	m	z	The height of where the soil layer starts.
mLower Depth	0.1	m	z	The height of where the soil layer ends.

State Variables

DripContainer

Amount of water in the drip container
mm

Flow Variables

DripFill

Inflow of water into the drip container
mm day⁻¹

DripOutlet

Outflow of water from the drip container
mm day⁻¹

Plant water processes

Per-Erik Jansson, Ghasem Alavi, Elisabet Lewan, David Gustafsson, Annemieke Gärdenäs & Louise Karlberg

Description of Plant

Theory

There are three different ways to represent the vegetation in the model. (1) The simplest representation is the implicit big leaf model, where transpiration and soil evaporation are treated as a common flow (no soil evaporation is calculated). In this case the distribution of water uptake from soil layers have to be specified. Potential evapotranspiration is used as a driving variable. (2) The vegetation can also be represented explicitly as one big leaf. Transpiration and soil evaporation are then treated as separate flows and potential transpiration is calculated with the Penman-Monteith equation. (3) Finally vegetation may also be represented by an array of plants, multiple canopies and root systems may also be represented (See Structure of Models, switch “PlantType”).

The “multiple plants” option is similar to the explicit big leaf model. The major difference is that the use of multiple plants makes it possible to assume different properties for different stands covering the same area, and it therefore enables the user to account for competition within a plant community. On the other hand the explicit big leaf option gives the user more alternatives when simulating for example potential transpiration than the multiple plants option.

Temporal development

Some plant properties have typical temporal patterns that vary with the seasons such as LAI, albedo, canopy height and root depth and length. When the vegetation is represented as an implicit single big leaf, none of these plant properties, except for root development, are used in the simulation and therefore they are not defined. Root length is only considered when the water uptake is calculated with the SPAC approach (see “[Steady-state SPAC approach](#)”).

The temporal development of these characteristics can either be simulated, i.e. dynamic development, or be given to the model as parameter values, i.e. a static development. Parameter values of plant properties can either be given as parameters in a table and varied as a function of the day number, t_{day} , or be given as driving variables in a separate file (see “[Crop data](#)”). For albedo an additional alternative (called “Static”) is to have a constant parameter value during the whole growing season. All of these options are determined by the switches: “[LaiInput](#)”, “[AlbedoVeg](#)”, “[CanopyHeightInput](#)” and “[RootInput](#)”. Note that it is possible to choose which of the plant properties should be static or

not, so that if you, for example, choose to simulate leaf area index, you can still give the canopy height as parameter values.

Static development

Plant properties can optionally be given as driving variables in a separate PG-file (refer to “[Crop data](#)” at the end of this section). In this case, only one series of values for a particular plant property can be read by the model in each simulation, and consequently this option puts limitations to the “multiple plants” approach. If a plant property, such as plant height, is specified more than once in the driving variable file (e.g. if data for different plants are included in the same file), the parameter “[Plant, Index in PG-file](#).” determines which of the time series will be used.

Albedo can also be given as one constant value for the whole growing season (switch “[AlbedoVeg](#)”, option “static”). The parameter value, a_{veg} , is specified by the parameter “[AlbedoLeaf](#)”.

Single leaf

The last option for static development is to specify values in a parameter table. These parameters are given differently to the model depending on whether multiple plants are simulated or not. If the single big leaf models are used, then the appropriate properties are found in the tables “[Above ground characteristics with time](#)” and “[Root development with time](#)”. In these tables arrays for the different variables can be specified at different day numbers and interpolations are made using a common temporal function defined as:

$$x = (1 - \alpha)x(i-1) + \alpha x(i) \quad (3.1)$$

where the α is calculated as

$$\alpha = \left(\frac{t - t_{day}(i-1)}{t_{day}(i) - t_{day}(i-1)} \right)^{c_{form}(i-1)} \quad (3.2)$$

when t is in an interval between t at $t_{day}(i-1)$ and $t_{day}(i)$. The parameter c_{form} is defined in a table as an array. See viewing functions “[Leaf Area Index generated from parameters, single canopy](#)” and “[Root Depth generated from parameters, single canopy](#)”.

where $x(i)$ is the parameter defined at day number $t_{day}(i)$ in an array from 1 to n. Up to 5 day numbers can be defined, with values > 0 and ≥ 365 . If $t_{day}(i)$ is set to 0, only indices lower than i will be considered.

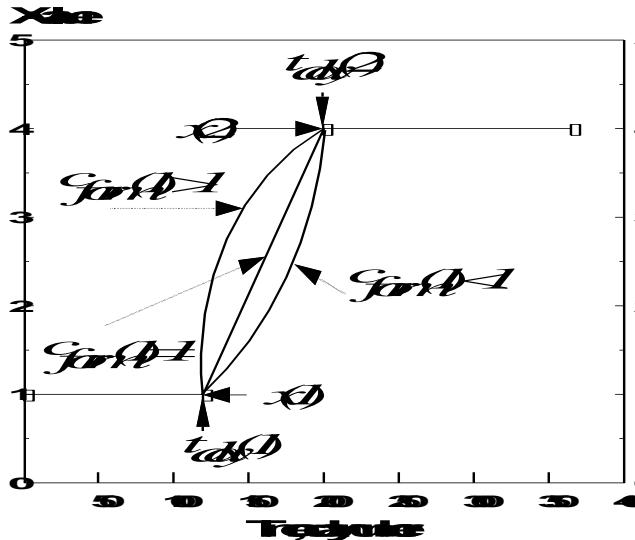


Figure 3.1. Graphical representation of the interpolation procedure used for some plant related properties.

The starting day can optionally be static or a function of air temperature (see switch “[PlantDevelopment](#)”). If the starting day is static, this date is not modified by any environmental property. The starting day, $t_{day}(1)$, can also be put to the day

number in the spring when the accumulated sum of air temperatures, $t_{sumplant}$, above the critical temperature, t_{crit} , reaches the value of the temperature sum starting value, t_{start} . The accumulation of temperatures starts when the day length exceeds 10 hours. Five consecutive days in the autumn with day lengths shorter than 10 hours and with temperatures below a critical temperature, t_{crit} , terminates the growing season. The winter period starts by setting the leaf area index, A_l , roughness length, z_0 , canopy height, H_p , displacement height, d , and surface resistance to the values that correspond to the first index in their vectors. Note that this option concerns single leaf simulations only.

Multiple canopies

If the multiple big leaves model is used the appropriate properties are found in the tables “[Albedo vegetation - multiple canopies](#)”, “[Canopy height - multiple canopies](#)”, “[Leaf Area Index - multiple canopies](#)”, “[Root lengths - multiple canopies](#)” and “[Root depths - multiple canopies](#)”. For multiple plants a different procedure is used to construct the temporal dynamics during the year than for single plants. Temporal functions are defined in intervals of day numbers from start to optimum and from optimum to end. The interpolations are made using the basic eq. (3.1) but with a different definition of the shape factor compared to eq. (3.2). Now the shape factor is instead defined as:

$$\alpha = \sin \left(\left(\frac{t - t_{day}(i-1)}{t_{day}(i) - t_{day}(i-1)} \right) \frac{\pi}{2} \right)^{c_{form}(i-1)} \quad (3.3)$$

The same intervals for interpolation are used for: LAI, A_l , canopy height, H_p , albedo, a_{veg} , root depth, z_{root} , root length, L_r . See viewing functions “[Plant Albedo generated from parameters, multiple canopies](#)”, “[Leaf Area Index - multiple canopies](#)”, “[Canopy Height generated from parameters, multiple canopies](#)”, “[Root Depth generated for parameters, multiple canopies](#)” and “[Root Length generated from parameters, multiple canopies](#)”.

Dynamic development

Simulations of the temporal development of leaf area index, canopy height, albedo and root depth are based on biomass, i.e. carbon content in the plant, when the switch for plant growth is “on” (refer to the Nitrogen and Carbon chapter). Simulations of the temporal development of all these plant properties always take place when growth is simulated, although these values are not further used in the abiotic part of the simulation if the temporal development of a certain plant property has been chosen as static.

When simulating temporal development by the plant growth model some empirical functions are used to convert figures on biomass to the appropriate physical attributes of the plant. Parameters for these conversions are found in a parameter table: “[Size and shape of growing plant](#)”.

LAI

The Leaf area index, A_l , is estimated as:

$$A_l = \frac{B_l}{p_{l,sp}} \quad (3.4)$$

where $p_{l,sp}$ is a parameter and B_l is the total mass of leaf (i.e. the carbon content in the leaves, $C_{Leaf} + C_{OldLeaf}$). See viewing function “[Simulated Leaf Area Index](#)”.

Canopy Height

The canopy height, H_p , is estimated as:

$$H_p = p_{hmax} \left(1 - e^{-p_{h1}B_{ag}} \right) \cdot \left(1 - e^{-p_{h2}\Delta t_{pl}} \right) \cdot \left(p_{h4} + (1 - p_{h4}) \cdot e^{-p_{h3}C_{grain}} \right) \quad (3.5)$$

where p_{hmax} , p_{h1} , p_{h2} , p_{h3} and p_{h4} are parameters. B_{ag} is the above ground biomass (i.e. the carbon content in the leaves and stem, $C_{Leaf} + C_{OldLeaf} + C_{Stem} + C_{OldStem}$),

Albedo

Δt_{pl} is the time that has elapsed since the emergence day (i.e. plant age) and C_{grain} is the carbon content in the grain pool. See viewing function “[Simulated Canopy Height](#)”.

The albedo, a_{veg} , may be specified differently depending on if the plant is in a vegetative stage, a_{pveg} , or a grain stage, a_{pgrain} , of plant development. The growth stage index is used to interpolate between the two values in the grain filling stage:

- Vegetative stage:

$$a_{veg} = a_{pveg}$$

- Grain stage:

$$a_{veg} = (1 - a_{weight}) a_{pveg} + a_{weight} a_{pgrain}$$

$$\text{where: } a_{weight} = GSI - 2 \quad (3)$$

and GSI is the growth stage index described in the “Nitrogen and Carbon” chapter.

Root depth

The root depth, z_r , is estimated as:

Root length

$$z_r = p_{zroot} \left(\frac{B_r}{B_r + \frac{p_{zroot}}{p_{incroot}}} \right) \quad (3.7)$$

where p_{zroot} and $p_{incroot}$ are parameters and B_r is the mass of roots (i.e. the carbon content in the roots, $C_{Roots} + C_{OldRoots}$). See viewing function “[Simulated Root Depth](#)”.

The root length, L_r , is estimated as:

$$L_r = \frac{B_r}{p_{rl,sp}} \quad (3.8)$$

where $p_{rl,sp}$ is a parameter and B_r is the mass of roots (i.e. the carbon content in the roots, C_{Roots}). The old root biomass is not considered since these roots are assumed to play a minor role for water uptake.

Distribution of roots with depth

Depth distribution of roots, $r(z)$, can be defined either as a fraction of roots in each horizon according to parameter values (table) or as a function (uniform, linear or exponential) of depth (see switch “[RootDistribution](#)”). In a similar way to the uniform and linear function the exponential form is normalized making the integral of the whole soil profile equal to unity. The fraction of roots (root density) below a depth z is given by:

$$\int_{z_r}^z r(z) dz = \frac{1 - e^{-k_{rr}(z/z_r)}}{(1 - r_{frac})} \quad (3.9)$$

where it can be shown that the exponential extinction coefficient k_{rr} equals $-\ln(r_{frac})$. r_{frac} is a parameter.

If the distribution of roots is defined as parameter values, these values should be specified in the parameter table “[Root distribution with depth](#)”.

Reduction of leaf area index for snow conditions

When the ground is covered with snow, the leaf area index is reduced by a snow correction factor, $f_{SnowReduceLAI}$:

$$A_l = A_l^* \cdot f_{SnowReduceLAI} \quad (3.10)$$

where A_l^* is the leaf area index before corrections (i.e. calculated by any of the functions described above).

Canopy surface cover

When the multiple leaf option is used the canopy cover of the plant has to be defined in order to estimate the partitioning of intercepted radiation between plants (see chapter “Soil evaporation, snow and radiation processes” for details on the radiation interception). The canopy surface cover is calculated as:

$$f_{cc} = p_{cmax} (1 - e^{-p_{ck} A_l}) \quad (3.11)$$

where p_{cmax} is a parameter that determines the maximum surface cover and p_{ck} is a parameter that governs the speed at which the maximum surface cover is reached. A_l is the leaf area index of the plant. Note that p_{cmax} can also be set to values greater than unity if the horizontal extension of the plant is larger than the soil. This is the case when a plant stands on a smaller area of soil than what it receives light from, e.g. a plant growing in a pot (described in detail below).

A horizontal positioning of plants in one dimension within the unit area of soil is defined in order to represent different degrees of shading between plants. The horizontal position of a plant j is defined by its canopy surface cover $f_{cc,j}$ and its mid-position x_j (Figure 3.2). The mid-position of a plant x_j can be given as a fixed parameter or may be altered randomly each time step using the parameter x_x to initialise the randomiser (see switch “[SpatialDistribution](#)” random vs. parameters). Consequently it is possible to have two canopies covering the same area of soil and these plants will therefore compete for radiation, as described in “Soil evaporation, snow and radiation processes”.

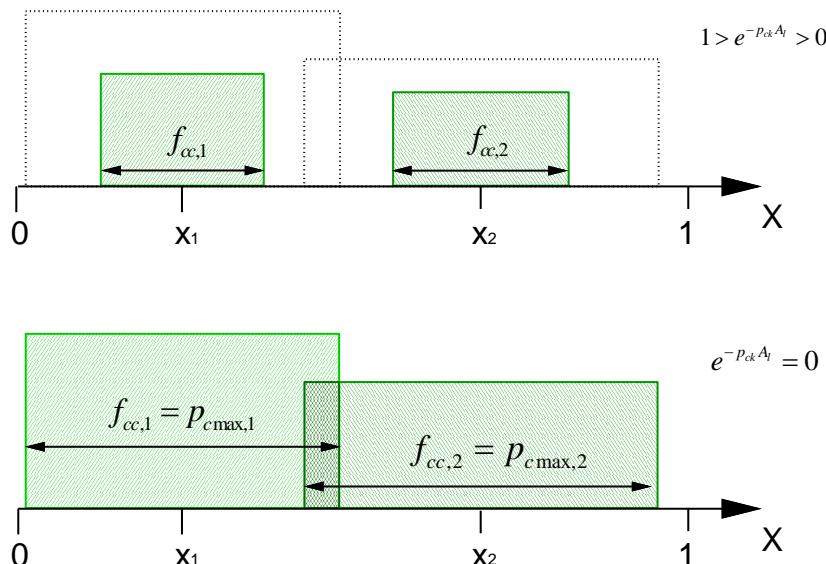


Figure 3.2. Conceptual view of the spatial distribution of multiple canopies in one horizontal dimension, given as a function of the central position, x_j , and the fractional canopy cover, $f_{cc,j}$, of each canopy. p_{cmax} is the maximum horizontal canopy surface cover for each plant.

A canopy that reaches outside the unit area of soil can be considered in two different ways, as is illustrated in Figure 3.3. In a stand of identical neighbours, the part of the plant that is outside the unit area is reflected at the opposite side. The single “multiple” canopy (i.e. the plant in the pot case) is allowed to intercept radiation from a larger area than unity, in contrast to the stand of identical neighbours. The distinction between identical neighbours and single multiple canopies is defined by the switch “[SpatialDistribution](#)”.

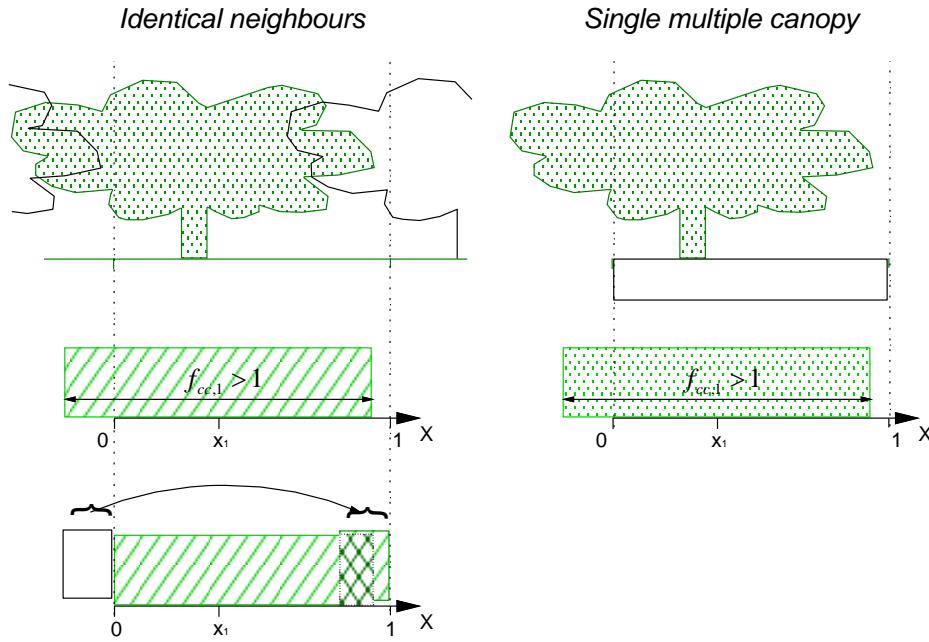


Figure 3.3. Multiple canopies with horizontal extension outside the unit area of soil can be considered as a stand of identical neighbours (left panel) or as a single “multiple” canopy (right panel). The single “multiple” canopy is allowed to intercept radiation from a larger area than unity, in contrast to the stand of identical neighbours.

When using a single leaf the canopy surface cover is assumed to be equal to unity, i.e. completely covering the soil surface.

Switches

AlbedoVeg

Value	Meaning
Static	The value is specified by the parameter (AlbedoLeaf)
Parameters	The value is specified by the parameter LeafAreaIndex given in a table (see Above ground characteristics with time).
Driving variable	The albedo is specified in a PG-file.
Simulated	The albedo is calculated from the parameters: albedo vegetative stage, a_{pveg} , and/or albedo grain stage, a_{pgain} , depending on plant development.

CanopyHeightInput

Value	Meaning
Parameters	The value is specified by the parameter CanopyHeight given in a table (See Above ground characteristics with time).
Driving variable	The canopy height is defined as a driving variable in a PG-file.

Simulated	The canopy height is calculated based on simulated above ground biomass (see “ Dynamic development ”).
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LaiInput

Value	Meaning
Parameters	The value is specified by the parameter LeafAreaIndex given in a table (see Above ground characteristics with time).
Driving variable	The Leaf area index is defined as a driving variable in a PG driving variable file. The leaf area index is defined by the name LEAF or LAI in the identification field of the PG-variable.
Simulated	The leaf biomass is simulated and LAI is calculated based on a simple conversion (see “ Dynamic development ”).

PlantDevelopment

Value	Meaning
Static	The value of the first day number index is fixed and is not influenced by air temperature or any other environmental variable. (See Above ground characteristics with time)
Start=f(TempSum)	The value of DayNumber(1) is put to the day number in the spring when the accumulated sum of air temperatures above “ TempSumCrit ” reaches the value of “ TempSumStart ”. The accumulation of temperatures starts when the day length exceeds 10 hours. Five consecutive days in the autumn with day lengths shorter than 10 hours and with temperatures below “ TempSumCrit ” °C terminates the growing season.

RootDistribution

Value	Meaning
Table	Root distribution from parameter values. Separate fractions are given for each soil layer.
Linear	A linear decrease of root density from soil surface to the root depth.
Constant	A constant root density from soil surface to the root depth.

Exponential	An exponential decrease of the root density from soil surface to the root depth. The root depth is defined as the depth where a fraction given by the parameter “ RootFracExpTail ” remains of the total uptake capacity. The remaining fraction “ RootFracExpTail ” is distributed at layers above the root depth to make the total uptake capacity equal to unity.
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RootInput

Value	Meaning
Parameters	The root depth and length is defined in a parameter table.
Driving variable	The root depth is defined as driving variable in the PG driving variable file. The Root depth is defined by the name ROOT in the identification field in the PG-variable.
Simulated	The root depth and length are calculated from the root biomass (see “ Dynamic development ”).

SpatialDistribution

Value	Meaning
Random – Within Unit Area	The horizontal positions of plants within the unit area of soil are given as a random function. The random numbers are generated by an algorithm, which is initiated by a parameter x_x (RandomNumberSeed). Plants are not allowed to intercept radiation from a larger area than unity.
Fixed – Within Unit Area	The horizontal positions of plants are fixed, defined by the parameter x_i (XposCenter). Plants are not allowed to intercept radiation from a larger area than unity.
Fixed – Unrestricted Area	The horizontal positions of plants are fixed, defined by the parameter x_i (XposCenter). Plants are allowed to intercept radiation from a larger area than unity, which represent a plant that has a larger surface canopy cover than the soil (“Single multiple canopy”).

Parameters

AlbedoLeaf

The value of plant albedo.

Default	Unit	Symbol	Equation	Function
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25	%	a_{veg}		
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Plant, Index in PG-file.

If plant development characteristics are given for more than one plant in the PG-file, only one of them can be used in the simulation. This parameter specifies which plant in the PG-file that will be used in the simulation. The first specified plant is number 1, the second is number 2 and so forth.

Default	Unit	Symbol	Equation	Function
1	-			

RandomNumberInI

Parameter that initiates the randomiser for determining the random mid position for a certain plant.

Default	Unit	Symbol	Equation	Function
1	-	x_x		

RootFracExpTail

The fraction of roots that remains below the given root depth when an exponential decrease is assumed from the soil surface.

Default	Unit	Symbol	Equation	Function
0.1	-	r_{frac}	(3.9)	

This fraction is subsequently added to the root distribution above the root depth using the same exponential decrease.

TempSumCrit

Critical air temperature that must be exceeded for temperature sum calculation.

Default	Unit	Symbol	Equation	Function
5	°C	t_{crit}		

For instructions on how this parameter may be used, see the “[PlantDevelopment](#)” switch above.

TempSumStart

The air temperature sum that is the threshold for start of plant development.

Default	Unit	Symbol	Equation	Function
50	°Cdays	t_{start}		

For instructions on how this parameter may be used, see the “[PlantDevelopment](#)” switch above.

Parameter tables

Above ground characteristics with time

No of elements in Table: 5

Name	Default	Unit	Symbol	Comments/Explanations
AlbedoV	25	%	a_{veg}	Albedo of vegetation. See AlbedoVeg .
CanopyHeight	1	m	H_p	Vegetation height from ground level to top. See CanopyHeightInput .

Cform	1	-	c_{form}	Form factor for interpolation between times, t , given as day numbers of the year. See Temporal development .
DayNumber	120	#	$t_{day}(i)$	Governs the variation of all the parameters in the table below.
LeafAreaIndex	0	m^2/m^2	A_l	Leaf area index of vegetation. See LaiInput .

Albedo vegetation - multiple canopies

Default no of elements in Table: 1

Interpolations are made using eqs. [\(3.1\)](#) and [\(3.3\)](#).

Name	Default	Unit	Symbol	Comments/Explanations
Start DayNo	121	#		Used when albedo is interpolated from parameters.
Optimum DayNo	210	#		Used when albedo is interpolated from parameters.
End DayNo	270	#		Used when albedo is interpolated from parameters.
Shape Start	0.3	-		Used when albedo is interpolated from parameters.
Shape End	3.	-		Used when albedo is interpolated from parameters.
aStart Value	25	%		Used when albedo is interpolated from parameters.
aOptimum Value	20	%		Used when albedo is interpolated from parameters.
aEnd Value	40	%		Used when albedo is interpolated from parameters.
Root LowestDepth	-1.	m	p_{zroot}	See eq. (3.7)

Canopy height - multiple canopies

Default no of elements in Table: 1

Interpolations are made using eqs. [\(3.1\)](#) and [\(3.3\)](#)

Name	Default	Unit	Symbol	Comments/Explanations
Start DayNo	121	#		Used when canopy height is interpolated from parameters.
Optimum DayNo	210	#		Used when canopy height is interpolated from parameters.
End DayNo	270	#		Used when canopy height is interpolated from parameters.
Shape Start	0.3	-		Used when canopy height is interpolated from parameters.
Shape End	3.	-		Used when canopy height is interpolated from parameters.
hStart Value	0.	m		Used when canopy height is interpolated from parameters.
hOptimum Value	0.5	m		Used when canopy height is interpolated from parameters.
hEnd Value	0.	m		Used when canopy height is interpolated from parameters.

Leaf Area Index - multiple canopies

Default no of elements in Table: 1

Interpolations are made using eqs. [\(3.1\)](#) and [\(3.3\)](#)

Name	Default	Unit	Symbol	Comments/Explanations
Start DayNo	121	#		Used when LAI is interpolated from parameters.
Optimum DayNo	210	#		Used when LAI is interpolated from parameters.
End DayNo	270	#		Used when LAI is interpolated from parameters.
Shape Start	0.3	-		Used when LAI is interpolated from parameters.
Shape End	3.	-		Used when LAI is interpolated from parameters.
lStart Value	0.	-		Used when LAI is interpolated from parameters.
lOptimum Value	5.	-		Used when LAI is interpolated from parameters.
lEnd Value	0.	-		Used when LAI is interpolated from parameters.

Root depths - multiple canopies

Default no of elements in Table: 1

Interpolations are made using eqs. [\(3.1\)](#) and [\(3.3\)](#).

Name	Default	Unit	Symbol	Comments/Explanations
Start DayNo	121	#		Used when root depth is interpolated from parameters.
Optimum DayNo	210	#		Used when root depth is interpolated from parameters.
End DayNo	270	#		Used when root depth is interpolated from parameters.
Shape Start	0.3	-		Used when root depth is interpolated from parameters.
Shape End	3.	-		Used when root depth is interpolated from parameters.
rStart Value	0.	m		Used when root depth is interpolated from parameters.
rOptimum Value	-0.5	m		Used when root depth is interpolated from parameters.
rEnd Value	0.	m		Used when root depth is interpolated from parameters.

Root development with time

No. of elements in Table: 5

Name	Default	Unit	Symbol	Comments/Explanations
pRoot DayNumber	120	#		Day number that will govern the pRoot Depth parameter below.
pRoot Depth	-0.1	m	z_r	The deepest level with roots. Negative downwards. The root depth may also be specified in a PG-file (see RootDistribution)
pRoot Length	0.1	m/m^2	L_r	Total length of fine Roots. See Steady-state SPAC approach .

Root distribution with depth

Default no. of elements in Table: 10

Name	Default	Unit	Symbol	Comments/Explanations

Root Fraction	0.1	-	$r(z)$	Relative distribution factor for each layer down to the maximal root depth (the sum must be 1.00). The root distribution may also be specified as a linear function, a constant root density or an exponential function (see RootDistribution).
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Root lengths - multiple canopies

Default no of elements in Table: 1

Interpolations are made using eqs. [\(3.1\)](#) and [\(3.3\)](#).

Name	Default	Unit	Symbol	Comments/Explanations
Start DayNo	121	#		Used when root length is interpolated from parameters.
Optimum DayNo	210	#		Used when root length is interpolated from parameters.
End DayNo	270	#		Used when root length is interpolated from parameters.
Shape Start	0.3	-		Used when root length is interpolated from parameters.
Shape End	3.	-		Used when root length is interpolated from parameters.
rlStart Value	0	m/m ²		Used when root length is interpolated from parameters.
rlOptimum Value	10 000	m/m ²		Used when root length is interpolated from parameters.
rlEnd Value	0	m/m ²		Used when root length is interpolated from parameters.

Size and shape of growing plant

Default no of elements in Table: 1

Details on these functions are found in section “[Dynamic development](#)”.

Name	Default	Unit	Symbol	Comments/Explanations
AlbedoGrainStage	40	%	a_{pgrain}	See eq. (3.6)
AlbedoVegStage	25	%	a_{pveg}	See eq. (3.6)
Height AgeCoef	0.1	1/days	p_{h2}	See eq. (3.5)
Height GrainCoef	0	m ² /g	p_{h3}	See eq. (3.5)
Height MassCoef	0.1	m ² /g	p_{h1}	See eq. (3.5)
Height MaxGrain	0.1	-	p_{h4}	See eq. (3.5)
Max Height	1	m	p_{hmax}	See eq. (3.5)
Specific LeafArea	1	gC/m ²	$p_{l,sp}$	See eq. (3.4) . This is actually the inverse of specific leaf area, i.e. leaf mass per unit leaf area.
Specific RootLength	0.0001	gC/m	$p_{rl,sp}$	See eq. (3.8)
Root IncDepth	-1.	M	p_{inroot}	See eq. (3.7)

Spatial orientation – multiple canopies

Default no of elements in Table: 1

Details are found in the section: Canopy Surface Cover

Name	Default	Unit	Symbol	Comments/Explanations
------	---------	------	--------	-----------------------

XcenterPos	0.5	m	x_j	
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Surface canopy cover - multiple canopies

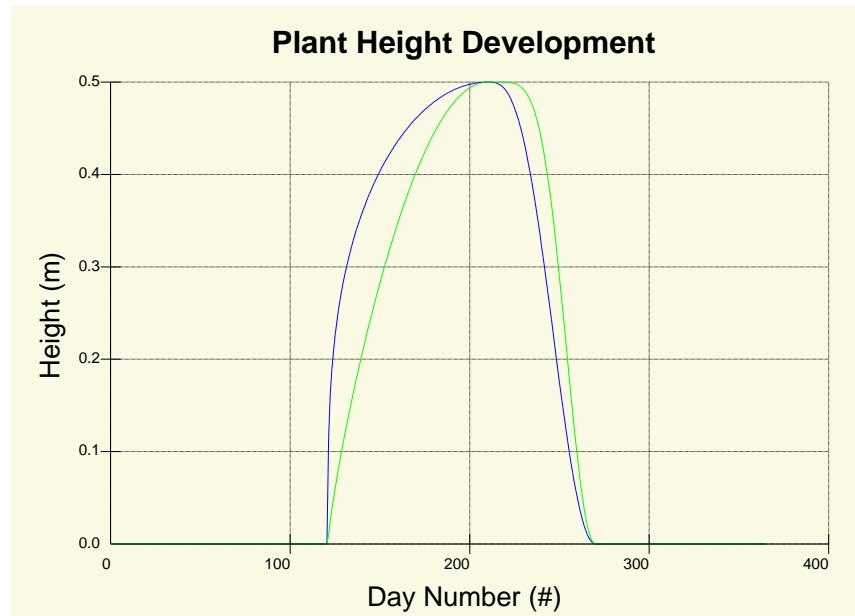
Default no of elements in Table: 1

Details are found in the section "[Canopy surface cover](#)".

Name	Default	Unit	Symbol	Comments/Explanations
Max Cover	1.0	m^2/m^2	p_{cmax}	
Area kExp	0.5	-	p_{ck}	

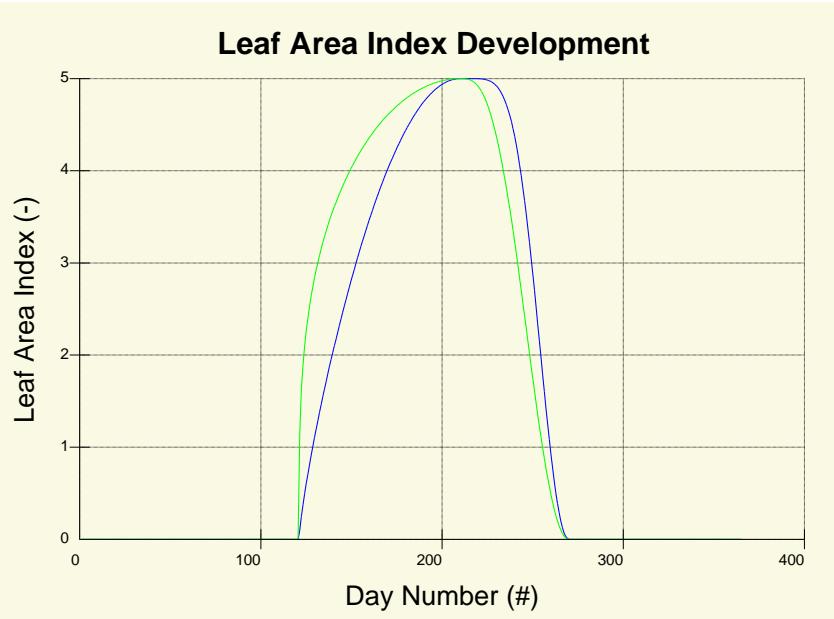
Viewing Functions

Canopy Height generated from parameters, multiple canopies



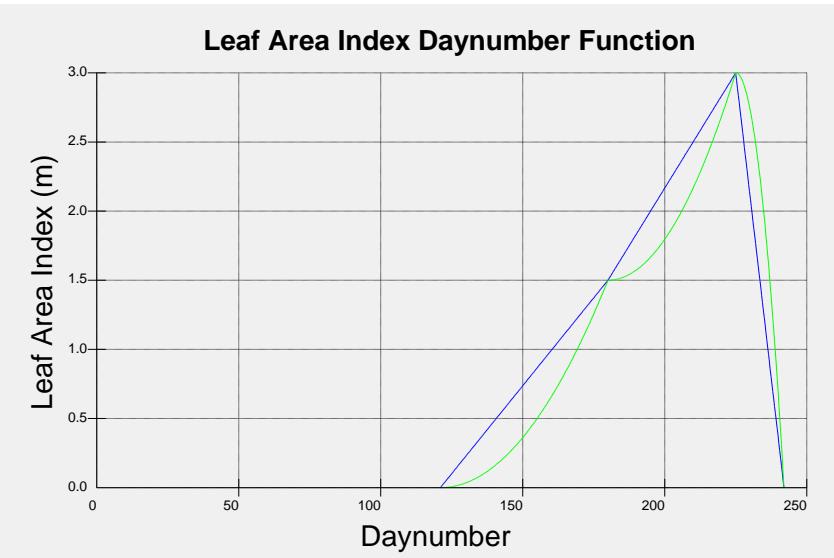
Canopy Height as a function of day number generated from parameters. The Shape Start and Shape End parameters were set to 0.3 and 3 respectively for the blue line and to 0.8 and 6 for the green line. The hStart Value and hEnd Value were both put to 0 whereas the hOptimum Value was put to 5.

Leaf Area Index generated from parameters, multiple canopies



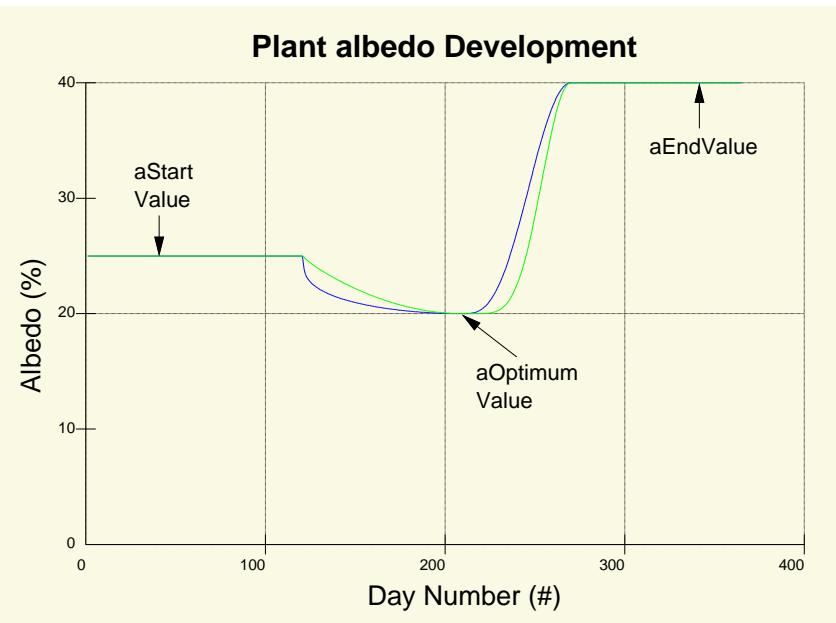
Leaf Area Index as a function of day number generated from parameters. The Shape Start and Shape End parameters were set to 0.3 and 3 respectively for the blue line and to 0.8 and 6 for the green line. The IStart Value and IEnd Value were both put to 0 whereas the lOptimum Value was put to 5.

Leaf Area Index generated from parameters, single canopy



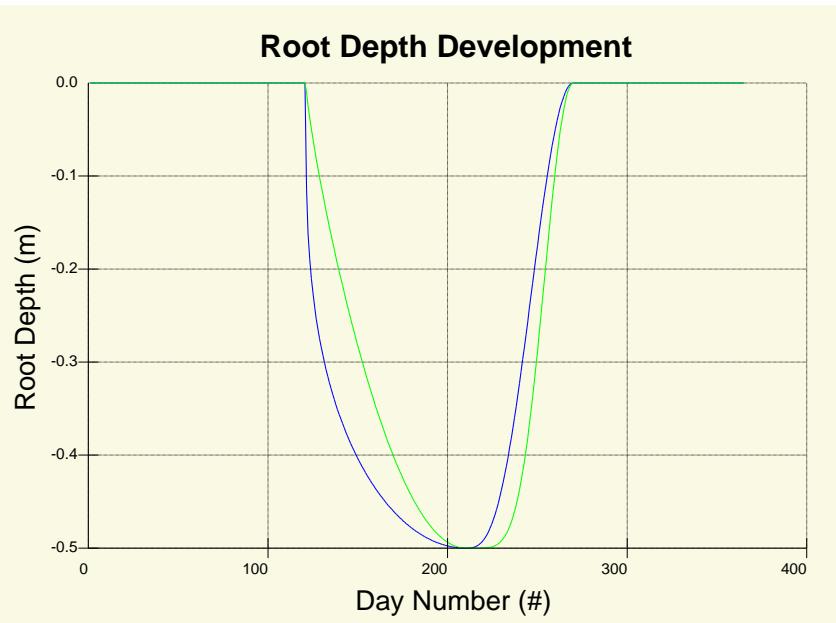
Leaf Area Index as a function of day number. C form is 1 for the blue line and 2 for the green line.

Plant Albedo generated from parameters, multiple canopies



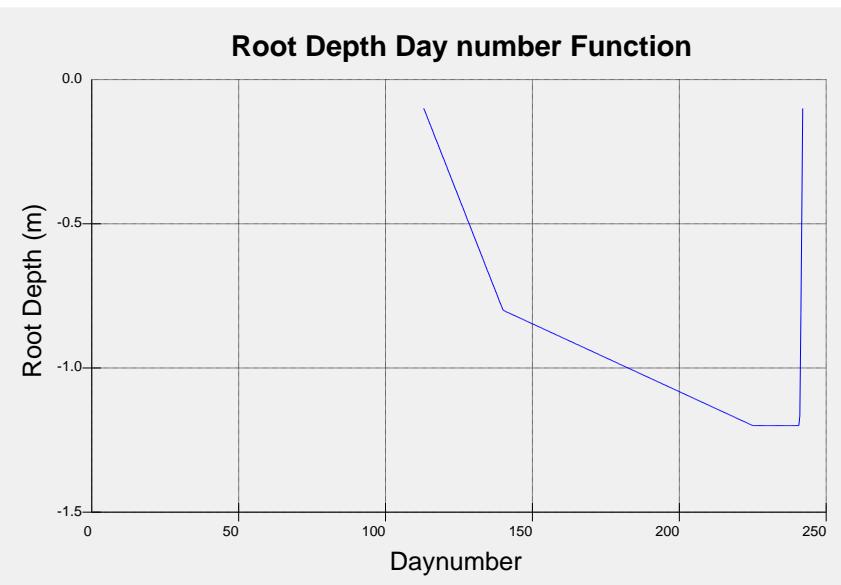
Plant albedo as a function of day number generated from parameters. The Shape Start and Shape End parameters where set to 0.3 and 3 respectively for the blue line and to 0.8 and 6 for the green line.

Root Depth generated for parameters, multiple canopies



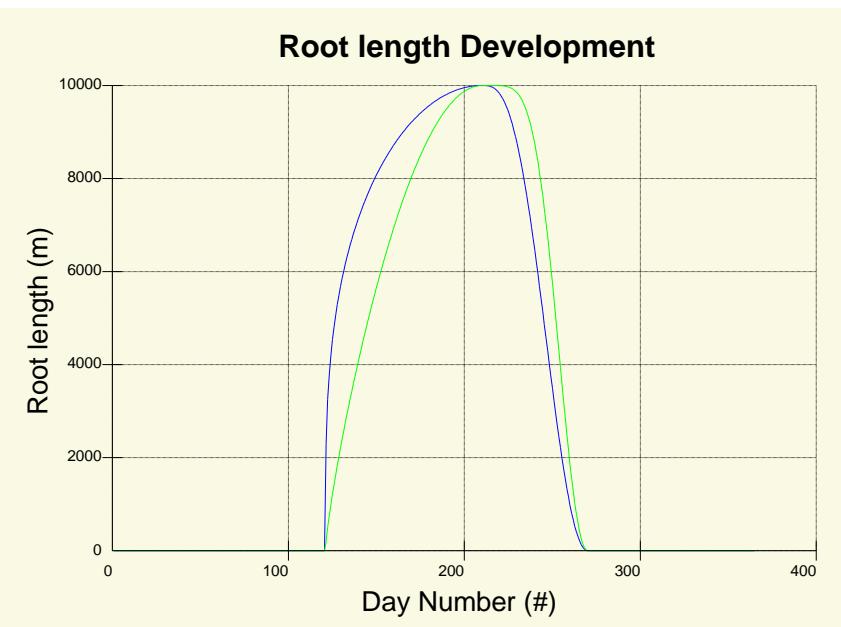
Root Depth as a function of day number generated from parameters. The Shape Start and Shape End parameters where set to 0.3 and 3 respectively for the blue line and to 0.8 and 6 for the green line. The rStart Value and rEnd Value where both put to 0 whereas the rOptimum Value was put to -0.5.

Root Depth generated from parameters, single canopy



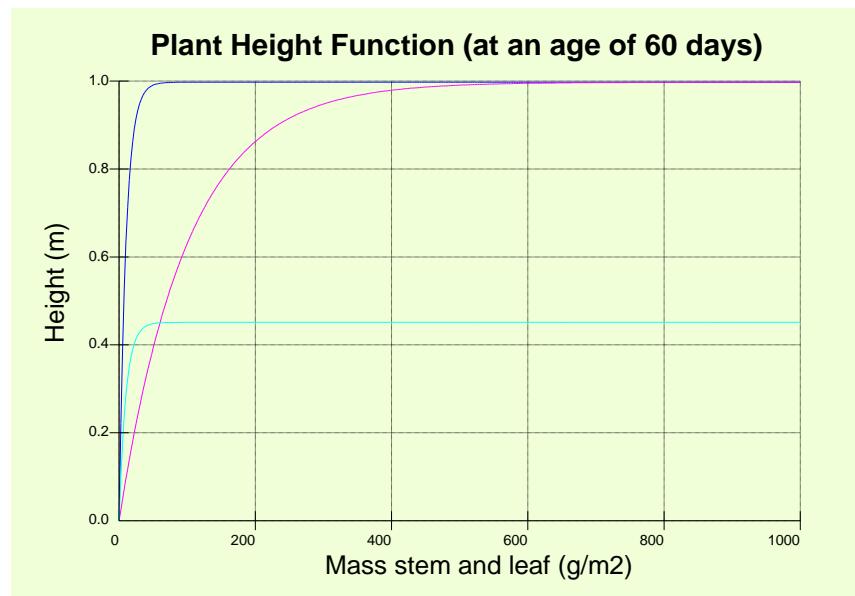
Root depth as a function of day number generated from parameters.

Root Length generated from parameters, multiple canopies



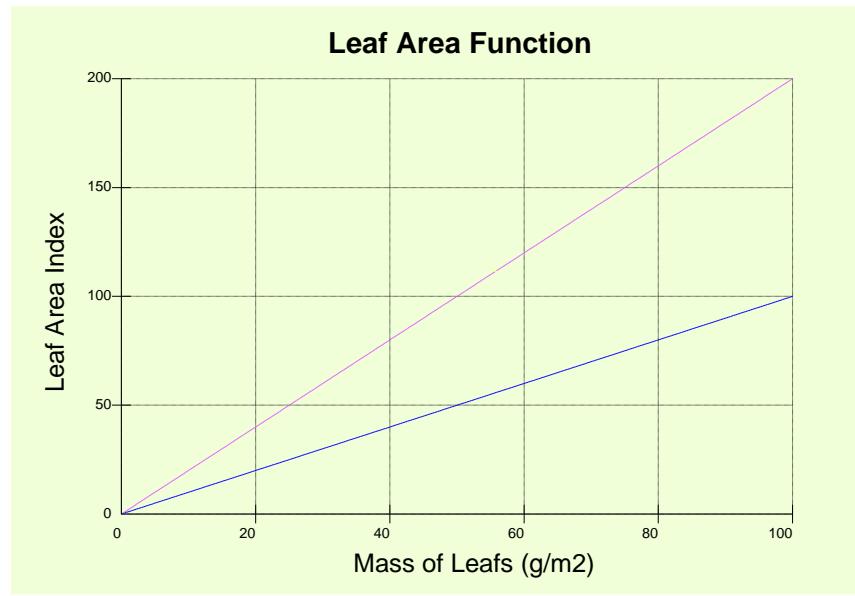
Root Length as a function of day number generated from parameters. The Shape Start and Shape End parameters were set to 0.3 and 3 respectively for the blue line and to 0.8 and 6 for the green line. The rlStart Value and rlEnd Value were both put to 0 whereas the rlOptimum Value was put to 10 000.

Simulated Canopy Height



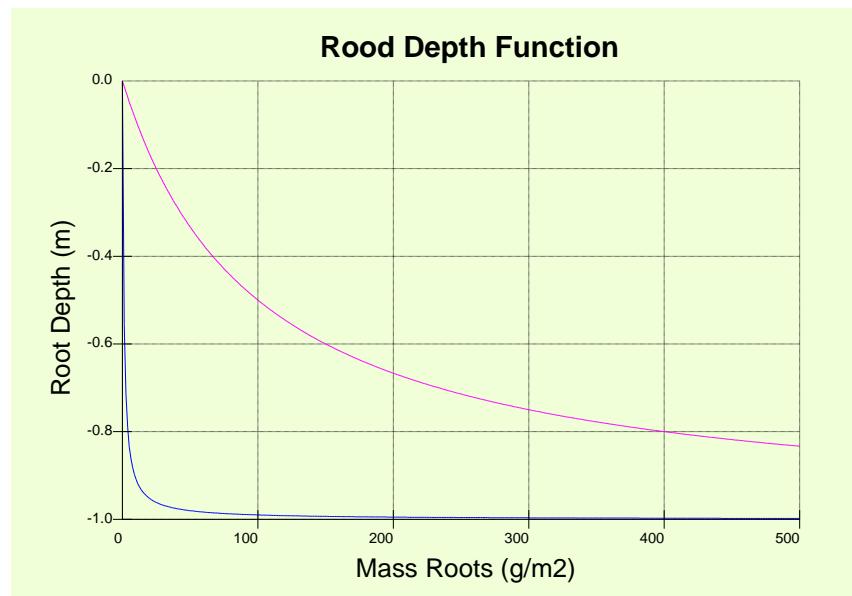
Simulated canopy height as a function of the biomass in the stem and leaves. The maximum height, p_{hmax} , was put to 1 for all three lines. The violet line shows the effect on height of a lower height mass coefficient, p_{hl} , compared with the blue line. The effect of a lower age coefficient, p_{h2} , is instead shown in the turquoise line also compared with the blue line.

Simulated Leaf Area Index



Simulated Leaf Area Index as a function of the biomass in the leaves. The specific leaf area, $p_{l,sp}$, is 1 for the blue line and 0.5 for the green line.

Simulated Root Depth



Simulated root depth as a function of biomass in the roots. The maximum root depth, p_{zroot} , is put to 1 meter for both curves. The root inc depth, $p_{incroot}$, is -1 for the blue line and -0.01 for the green line.

Auxiliary Variables

Canopy Height

Height from the soil surface to the top of the canopy.
m

LeafAreaIndex

Leaf area index (single sided projected area of leafs per ground area).

-

LeafAreaIndexSum

Total leaf area index for all plants if more than one plant is simulated (single sided projected area of leafs per ground area).

-

Plant Albedo

Plant albedo development.
%

Root Depth

Depth of roots.
m

RootLength

Length of roots.
m

RootLength_Total

Total root length for all plants in case of multiple plants.
m

SimLeafAreaIndex

Simulated Leaf Area Index.

-

SimPlantAlbedo

Simulated plant albedo.
%

SimPlantHeight

Simulated plant height.
m

SimRootDepth

Simulated root depth.
m

SimRootLength

Simulated root length.
m

Soil Cover Fraction

The fraction of the soil covered by the plant canopy of each plant.

-

Tot Soil Cover Fraction

The fraction of the soil within the unit area covered by vegetation canopy.

-

TsumPlant

Temperature sum for the estimation of starting day of plant development.
°Cday

Files

Crop data

The Crop data file consist of variables that otherwise should be specified by parameters or simulated by the plant growth model. The ID in the table corresponds to the variable name that has to be specified in the PG file. Note that all crop data either has to be read from the PG file, or all of them have to be simulated.

Variables	Unit	ID	Comments/Explanations
Leaf Area Index	-	LAI or Leaf	See LaiInput switch.
Canopy height	m	Height	See CanopyHeightInput switch.
Surface Resistance (Canopy)	s/m	ResSurf	See RSMETHOD switch.

Roughness length	m	Rough	See Roughness switch.
Root Depth (negative downwards)	m	Root	See RootInput switch.
Albedo of vegetation	%	Albedo	See AlbedoVeg switch.

Potential transpiration

Theory

The potential transpiration has to be calculated to be able to estimate actual transpiration. This is done differently for implicit big leaf simulations compared to explicit single big leaf and multiple plants simulations and will therefore be described separately in the end of this section.

The combination equation for potential transpiration

Transpiration is defined as a potential rate when neither soil water deficits nor low soil temperatures influence the water loss. The potential transpiration, E_{tp} , is calculated from Penman's combination equation in the form given by Monteith (1965):

$$L_v E_{tp} = \frac{\Delta R_n + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma \left(1 + \frac{r_s}{r_a} \right)} \quad (3.12)$$

where R_n is net radiation available for transpiration (i.e. $R_{na} - R_{ns}$, see "Partitioning of net radiation", for multiple plants the fraction of radiation to each plant is calculated in the radiation section, see "Partitioning of radiation between plants"), e_s is the vapour pressure at saturation, e_a is the actual vapour pressure, ρ_a is air density, c_p is the specific heat of air at constant pressure, L_v is the latent heat of vaporisation, Δ is the slope of saturated vapour pressure versus temperature curve, γ is the psychrometer "constant", r_s is an "effective" surface resistance and r_a is the aerodynamic resistance. See viewing function "[Penman-Monteith combination equation](#)".

The saturated vapour pressure function, $e_s(T)$, is defined by:

$$e_s(T) = 10^{\left(\frac{12.5553 - \frac{2667}{T+273.15}}{11.4051 - \frac{2353}{T+273.15}} \right)} \quad T < 0 \quad (3.13)$$

$$e_s(T) = 10^{\left(\frac{11.4051 - \frac{2353}{T+273.15}}{12.5553 - \frac{2667}{T+273.15}} \right)} \quad T > 0$$

where e_s is calculated in Pa and T in °C.

The Δ slope of this function is given as:

$$\Delta(T) = e_s(T) \frac{2667}{(273.15+T)^2} \quad T < 0 \quad (3.14)$$

$$\Delta(T) = e_s(T) \frac{2353}{(273.15+T)^2} \quad T > 0$$

Aerodynamic resistance

The aerodynamic resistance can be calculated with and without stability correction (see switch "[Aerodyn.Resistance](#)"). Without stability correction the aerodynamic resistance is calculated as:

$$r_a^* = \frac{\ln^2 \left(\frac{z_{ref} - d}{z_o} \right)}{k^2 u} \quad (3.15)$$

where the wind speed, u , is given at the reference height, z_{ref} , k is von Karman's constant, d is the displacement height and z_o is the roughness length. See viewing functions “[Air and canopy resistances](#)”, “[Aerodynamic resistance affected by the parameters \$p_{densm}\$ and \$p_{addind}\$](#) ” and “[Aerodynamic resistance affected by the parameter \$z_{0min}\$](#) ”.

If the aerodynamic resistance is calculated as a function of the Richardson's number, eq. (3.15) is multiplied by the Richardson's stability function as described in eq. (4.14)-(4-17). The stability correction can also be accounted for by calculating the aerodynamic resistance by the Monin-Obukhov stability function (eq. 4.18) instead of eq.(3.15). In both cases the roughness length used in the calculation of r_a is the roughness length calculated for each plant (i.e. eq. (3.17)) and the parameter $c_{H0,soil}$ is exchanged to $c_{H0,canopy}$.

If more than one canopy exist (see “[Description of Plant](#)”) additional contributions to the aerodynamic resistance will be estimated because of eventual shadowing of other canopies. The aerodynamic resistance for a specific canopy (i) is then calculated as:

$$r_{a,i} = r_a^* + A_{la,i} p_{ral} \quad (3.16)$$

where p_{ral} is a parameter and $A_{la,i}$ is the leaf area index of all other canopies above the present canopy i . Roughness length and displacement height will be calculated based on either the height of the highest plant or for each plant individually (see switch “[MultiRoughness](#)”).

When simulating an explicit single big leaf plant the roughness length, z_o , can either be given in a PG-file, read from a parameter table or estimated by functions following data presented by Shaw and Pereira (1982) (see “[Roughness](#)”). For multiple plants the roughness length is either calculated by the Shaw and Pereira function or is estimated by linear functions (see “[Roughnessfunc](#)”).

The Shaw and Pereira function calculate the roughness length as:

$$\begin{aligned} z_0 &= z_{0max} & z_0 &> z_{0max} \\ z_0 &= H_p \min(f_1, f_2) & z_{0min} &> z_0 > z_{0max} \\ z_0 &= z_{0min} & z_0 &< z_{0min} \end{aligned} \quad (3.17)$$

where z_{0max} and z_{0min} are parameters and where f_1 and f_2 are defined as:

$$\begin{aligned} f_1 &= 0.175 - 0.098 p_{densm} + (-0.098 + 0.045 p_{densm}) \log(A_{PAI}) \\ f_2 &= 0.150 - 0.025 p_{densm} + (0.122 - 0.0135 p_{densm}) \log(A_{PAI}) \end{aligned} \quad (3.18)$$

and A_{PAI} is the plant area index, which is defined as the sum of leaf area index, A_l , and the p_{addind} which is a parameter together with H_p , p_{densm} and z_{0min} . See viewing functions “[Roughness length, Shaw and Pereira, \$z_{0min}\$, \$z_{0max}\$ and \$p_{addind}\$](#) ” and “[Roughness length, Shaw and Pereira, \$p_{densm}\$](#) ”.

If snow is included in the simulation, the function for estimating roughness has to be adjusted in the following way:

$$z_0 = (H_p - \Delta z_{snow} \min(f_1, f_2)) + \Delta z_{snow} \quad (3.19)$$

where Δz_{snow} is the snow depth.

If roughness is determined by linear functions, f_1 and f_2 in eqs.(3.17) and (3.19) are replaced by the linear function calculated by eq.(3.3) and values found in the parameter table “[Roughness coefficients – multiple canopies](#)”. See viewing function “[Roughness length, linear function](#)”.

Also the displacement height, d , can be given in a PG file, read from a parameter table, or estimated by a function derived from suggestions presented by Shaw and Pereira (1982) (see switch “[Displacement](#)”). For multiple plants displacement is either calculated by the Shaw and Pereira function or is estimated by linear functions (eq.(3.3)) (see “[Roughnessfunc](#)”).

The Shaw and Pereira function calculates the displacement height as:

$$d = \min \left(\begin{array}{l} z_{ref} - 0.5, \\ \left((0.80 + 0.11 p_{densm}) - (0.46 - 0.09 p_{densm}) e^{-(0.16+0.28 p_{densm}) PAI} \right) H_p \end{array} \right) \quad (3.20)$$

See viewing function “[Displacement height, Shaw and Pereira](#)”.

If snow is included in the simulation, the function for estimating displacement height has to be adjusted in the following way:

$$d = \min \left(\begin{array}{l} z_{ref} - 0.5, \\ \left((0.80 + 0.11 p_{densm}) - (0.46 - 0.09 p_{densm}) e^{-(0.16+0.28 p_{densm}) PAI} \right) (H_p + \Delta z_{snow}) \end{array} \right) + \Delta z_{snow} \quad (3.21)$$

where Δz_{snow} is the snow depth.

If the displacement height is determined by linear functions, eq.(3.20) is modified into:

$$d = \min \left(\begin{array}{l} z_{ref} - 0.5, \\ f_3 \cdot H_p \end{array} \right) \quad (3.22)$$

The linear function, f_3 , is calculated by eq.(3.3) and values found in the parameter table “[Displacement coefficients – multiple canopies](#)”. Eq.(3.21) is modified analogously. See viewing function “[Displacement height, linear function](#)”.

Surface resistance

The surface resistance in an explicit single big leaf can be considered as a direct function of parameter values either from a PG file or from a parameter table, or it may be calculated as a function of leaf area index, A_l , global radiation, R_{is} , and vapour pressure deficit, $e_s - e_a$, i.e. the “Lohammar equation” option (see switch “[RSMethod](#)”). The latter option is always used for multiple plants i.e.:

$$r_s = \frac{1}{\max(A_l g_l, 0.001)} \quad (3.23)$$

where g_l is the leaf conductance which is given by the Lohammar equation (Lohammar et al., 1980; Lindroth, 1985) as:

$$g_l = \frac{R_{is}}{R_{is} + g_{ris}} \frac{g_{max}}{1 + \frac{(e_s - e_a)}{g_{vpd}}} \quad (3.24)$$

where g_{ris} , g_{max} and g_{vpd} are parameter values. See viewing functions “[Air and canopy resistances](#)”, “[Lohammar equation, function of global radiation](#)”, “[Lohammar equation, function of vapour pressure deficit](#)” and “[Lohammar equation surface resistance, canopy](#)”.

The Lohammar equation can optionally be used only during the growing season. In this case the maximum conductivity after and before the growing season (i.e. during winter) is given by the parameter g_{maxwin} . This forth alternative is only valid for explicit single leaf simulations.

Potential transpiration – implicit big leaf

If an implicit single big leaf is simulated the potential transpiration can be read from a PG file or be generated from parameters (see switch “[PotTranspInput](#)”). In the latter case the potential transpiration is a sine curve with a fixed

maximum potential transpiration, j_{max} , on a specified day, j_{day} , and a period of days that transpiration will take place, j_{period} , i.e. half of these days will be before the maximum transpiration and the rest will be after this day. See viewing function “[Potential evaporation, implicit single leaf](#)”.

Switches

Aerodyn.Resistance

Value	Meaning
Without stability correction	No stability correction is made.
f(Richardson number)	Stability correction is calculated as a function of Richardson's number.
f(Monin-Obukhov length)	Stability correction is calculated as a function of the Monin-Obukhov length.

Displacement

Value	Meaning
Parameters	The value is specified by the parameter Displace given in a table (see “ Evapotranspiration – single canopy ”).
Driving variable	The displacement height is defined as a driving variable in the PLANT driving variable file. The displacement height is defined by the name DISPL in the identification field of the PG-variable.
f(canopy)	The displacement height is estimated as a function of canopy height according to empirical equation after Shaw and Pereira (1982).

MultiRoughness

Value	Meaning
No (common)	The roughness length and displacement height are calculated for the highest plant if there are several plants.
Individual	The roughness length and displacement height are calculated for each plant individually if there are several plants.

RSMethod

Value	Meaning
Parameter	The value is specified by the parameter ResSurface given in a table (see “ Evapotranspiration – single canopy ”).
Driving variable	The surface (canopy) resistance is defined as a driving variable in the PLANT driving variable file. The surface resistance is defined by the name RESSURF in the identification field of the PG-variable.

Lohammar Eq	The surface resistance will be calculated from the leaf area index and the Lohammar equation during the whole year (see “ Evapotranspiration – single canopy ” or “ Evapotranspiration - multiple canopies ”).
Loh.Eq (T>DayNum)	The surface resistance will be calculated from the leaf area index and the Lohammar equation during the “growing season”. The growing season starts when the actual day number exceeds the parameter DayNumber(Index=1) as given by the “ PlantDevelopment ” switch.

Roughness

Value	Meaning
Parameters	The value is specified by the parameter RoughLength given in a table (Evapotranspiration – single canopy)
Driving variable	The roughness length is defined as a driving variable in the PLANT driving variable file. The roughness length, z_0 , is defined by the name ROUGH in the identification field of the PG-variable.
f(canopy)	The roughness length, z_0 , is calculated according to the function derived from Shaw and Pereira (1982) (see “ Evapotranspiration – single canopy ” or “ Evapotranspiration - multiple canopies ”).

Roughnessfunc

Value	Meaning
Shaw & Pereira	The roughness length, z_0 , is calculated according to the function derived from Shaw and Pereira (1982) (see “ Evapotranspiration – single canopy ” or (see “ Evapotranspiration - multiple canopies ”).
linear	Roughness length and displacement is calculated by linear functions.

Parameters

CanDensMax

The density maximum of canopy in relation to the canopy height, H_p . Single plant only.

Default	Unit	Symbol	Equation	Function
0.7	-	p_{densm}	(3.18), (3.20)	“ Aerodynamic resistance affected by the parameters p_{densm} and p_{addind} ”

Please distinguish between the reference height for meteorological data, z_{ref} , and the canopy height; H_p . Reasonable values are in the range 0.2-0.9

CondMax

The maximal conductance of fully open stomata. Single plant only.

Default	Unit	Symbol	Equation	Function
0.02	m/s	g_{max}	(3.24)	“Lohammar equation surface resistance, canopy”

Valid when the switch RSMethod is set to Lohammar.

CondMaxWinter

The maximal conductance of fully open stomata. Single plant only.

Default	Unit	Symbol	Equation	Function
0.002	m/s	g_{maxwin}	(3.24)	“Lohammar equation surface resistance, canopy”

Valid when the switch RSMethod is set to Lohammar.

CondRis

The global radiation intensity that represents half-light saturation in the light response. Single plant only.

Default	Unit	Symbol	Equation	Function
5E+006	J/m ² /day	g_{ris}	(3.24)	“Lohammar equation, function of global radiation”

Valid when the switch RSMethod is set to Lohammar.

CondVPD

The vapour pressure deficit that corresponds to a 50 % reduction of stomata conductance. Single plant only.

Default	Unit	Symbol	Equation	Function
100	Pa	g_{vpd}	(3.24)	“Lohammar equation, function of vapour pressure deficit”

EPMaxDay

Day that represents maximum transpiration rate in a simple analytical function of day number of the year. Implicit big leaf simulations.

Default	Unit	Symbol	Equation	Function
195	#	j_{day}		“Potential evaporation, implicit single leaf”

EPMaxRate

Maximum rate of transpiration in the simple analytical function. Implicit big leaf simulations.

Default	Unit	Symbol	Equation	Function
4	mm/day	j_{max}		“Potential evaporation, implicit single leaf”

EPPeriod

Total length of transpiration period in the simple analytical function. Implicit big leaf simulations.

Default	Unit	Symbol	Equation	Function
200	days	j_{period}		“Potential evaporation, implicit single leaf”

PAddIndex

The plant area index excluding the leaves given by the leaf area index. Single plant only.

Default	Unit	Symbol	Equation	Function
1	-	p_{addind}		“Roughness length, Shaw and Pereira, z_{0min}, z_{0max} and p_{addind}”

This parameter is only used to calculate the roughness lengths using the function originating from Shaw and Pereira (1982). Normal value range from 0.3 to 2.0

RoughLMin

A minimum value of roughness length representing a bare soil. Single plant only.

Default	Unit	Symbol	Equation	Function
0.01	s/m	z_{0min}	(3.17)	“Roughness length, Shaw and Pereira, z_{0min}, z_{0max} and p_{addind}”

This parameter is only used to calculate the roughness lengths using the function originating from Shaw and Pereira (1982).

Normal value range from 0.01 to 0.1

WindLessExchangeCanopy

Default	Unit	Symbol	Equation	Function
0.001	m/s	$c_{HO,canopy}$		

Parameter tables

Displacement coefficients – multiple canopies

Name	Default	Unit	Symbol	Comments/Explanations
Start DayNo	121	#		Used when displacement height is not calculated by the Shaw and Pereira function.
Optimum DayNo	210	#		Used when displacement height is not calculated by the Shaw and Pereira function.
End DayNo	270	#		Used when displacement height is not calculated by the Shaw and Pereira function.
Shape Start	0.3	-		Used when displacement height is not calculated by the Shaw and Pereira function.
Shape End	3.	-		Used when displacement height is not calculated by the Shaw and Pereira function.
dStart Value	0.66	-		Used when displacement height is not calculated by the Shaw and Pereira function.

dOptimum Value	0.66	-		Used when displacement height is not calculated by the Shaw and Pereira function.
dEnd Value	0.66	-		Used when displacement height is not calculated by the Shaw and Pereira function.

Evapotranspiration – single canopy

Default number of elements for each of the parameters in the table: 5

Name	Default	Unit	Symbol	Comments/Explanations
DayNumber	120	#	$t_{day}(i)$	Governs the variation of all the parameters in the table below.
Roughness Length	0.01	m	z_0	Roughness length. The value of the roughness length can be estimated from the stand height. A well-known relation says 1/10 of stand height.
Displace	0.01	m	d	Displacement height of vegetation cover. The value can as a rule of thumb be put to 70% of the stand height. For short crops the displacement will be close to zero.
Resistance Surface	100	s/m	r_s	Surface resistance. The surface resistance can be estimated by fitting techniques or found from micrometeorological measurements. Forest surface resistance will be found in a range from 100-300, whereas crops is in the range 20-70 s/m.
AlbedoV	25	%	a_{veg}	Albedo of vegetation. This parameter can optionally be defined in the section “ Description of Plant ”.
CanopyHeight	1	m	H_p	Height of canopy optionally used to estimate roughness length by using the equation originating from Shaw and Pereira (1982). This parameter can optionally be defined in the section “ Description of Plant ”.

Evapotranspiration - multiple canopies

Default no of elements in Table: 1

Name	Default	Unit	Symbol	Comments/Explanations
Canopy DensMax	0.7	-	p_{densm}	The density maximum of canopy in relation to the canopy height (see “ Aerodynamic resistance ”).
Plant AddIndex	1	-	p_{addind}	The plant area index excluding the leaves that are given by the leaf area index. Used to estimate “ Aerodynamic resistance ”.
Roughness Min	0.01	m	z_{0min}	The minimum roughness length used when estimating roughness length of different canopies (see “ Aerodynamic resistance ”).
Roughness Max	3	m	z_{0max}	The maximum roughness length used when estimating roughness length of different canopies (see “ Aerodynamic resistance ”).
Air Resist. LAI Effect	20	s/m	p_{ral}	The increase of air resistance inside a canopy as a factor of LAI. See also correspondent resistance for the soil evaporation (see “ Aerodynamic resistance ”).
Conduct. Ris	5E+006	J/m ² /day	g_{ris}	The global radiation intensity that represents half-light saturation in the light response (see “ Surface resistance ”).

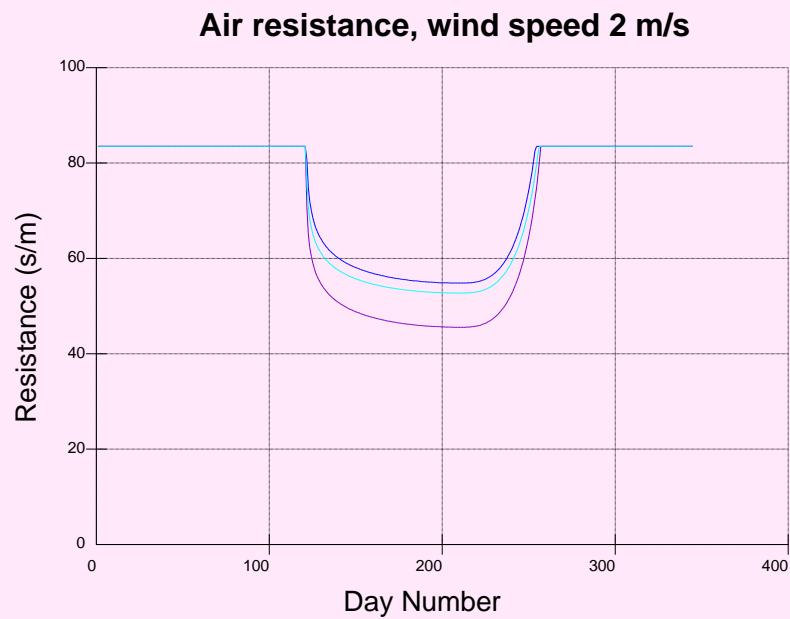
Conduct. VPD	100	Pa	g_{vpd}	The vapour pressure deficit that corresponds to a 50 % reduction of stomata conductance (see “ Surface resistance ”).
Conduct. Max	0.02	m/s	g_{max}	The maximal conductance of a fully open stomata (see “ Surface resistance ”).

Roughness coefficients – multiple canopies

Name	Default	Unit	Symbol	Comments/Explanations
Start DayNo	121	#		Used when displacement height is not calculated by the Shaw and Pereira function.
Optimum DayNo	210	#		Used when displacement height is not calculated by the Shaw and Pereira function.
End DayNo	270	#		Used when displacement height is not calculated by the Shaw and Pereira function.
Shape Start	0.3	-		Used when displacement height is not calculated by the Shaw and Pereira function.
Shape End	3.	-		Used when displacement height is not calculated by the Shaw and Pereira function.
zStart Value	0.1	-		Used when displacement height is not calculated by the Shaw and Pereira function.
zOptimum Value	0.1	-		Used when displacement height is not calculated by the Shaw and Pereira function.
zEnd Value	0.1	-		Used when displacement height is not calculated by the Shaw and Pereira function.

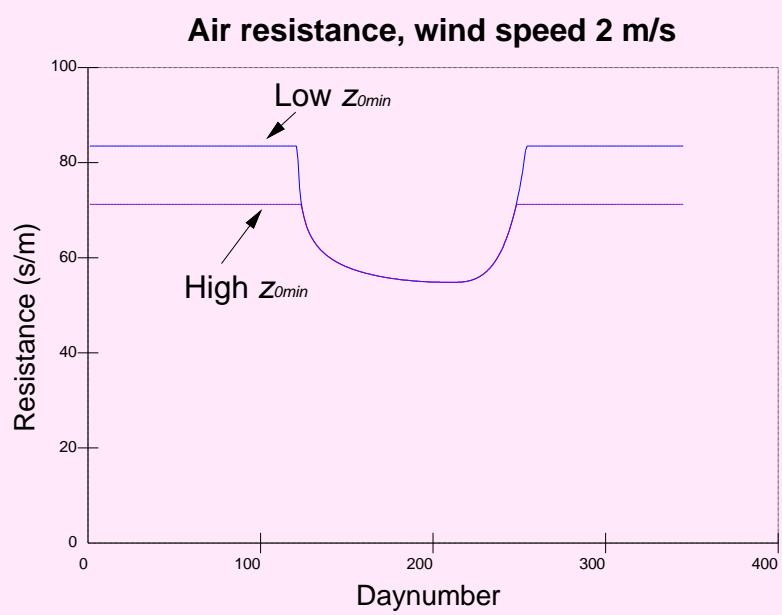
Viewing functions

Aerodynamic resistance affected by the parameters p_{densm} and p_{addind}



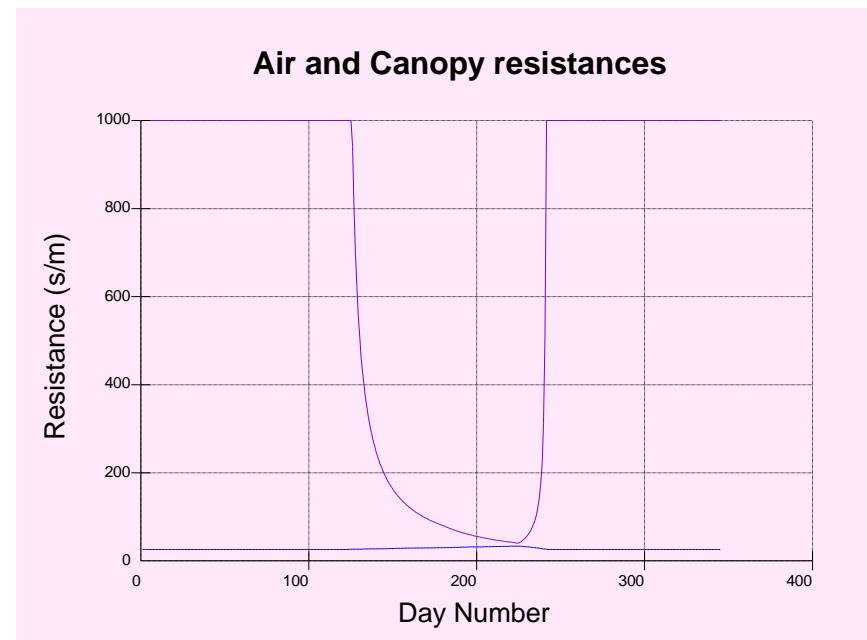
The aerodynamic resistance as a function of day number. The blue line shows the original parameter settings. The turquoise line shows the effect of a **lower** p_{densm} whereas the violet line shows the effect of a **lower** p_{addind} .

Aerodynamic resistance affected by the parameter z_{0min}



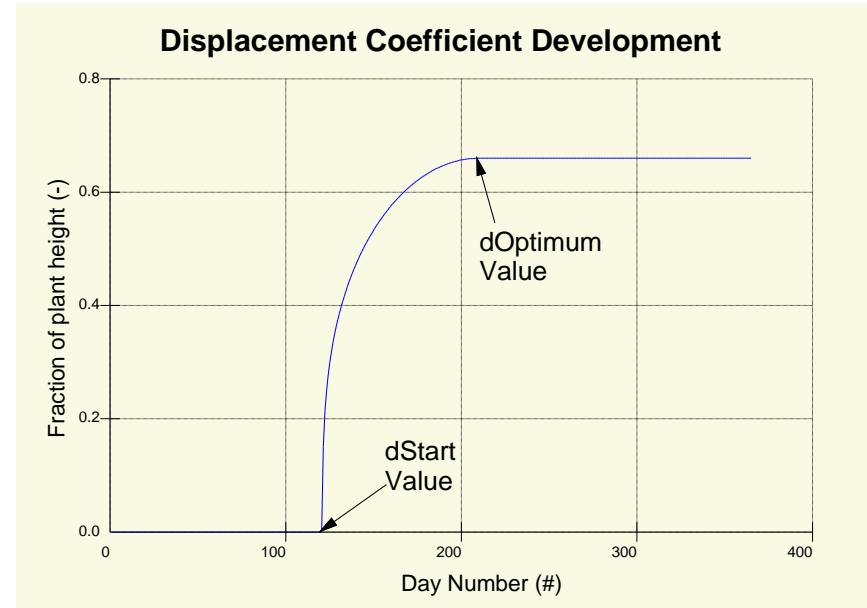
The aerodynamic resistance as a function of day number. The blue line shows the effect of a **low** z_{0min} whereas the violet line shows the effect of a **high** z_{0min} .

Air and canopy resistances



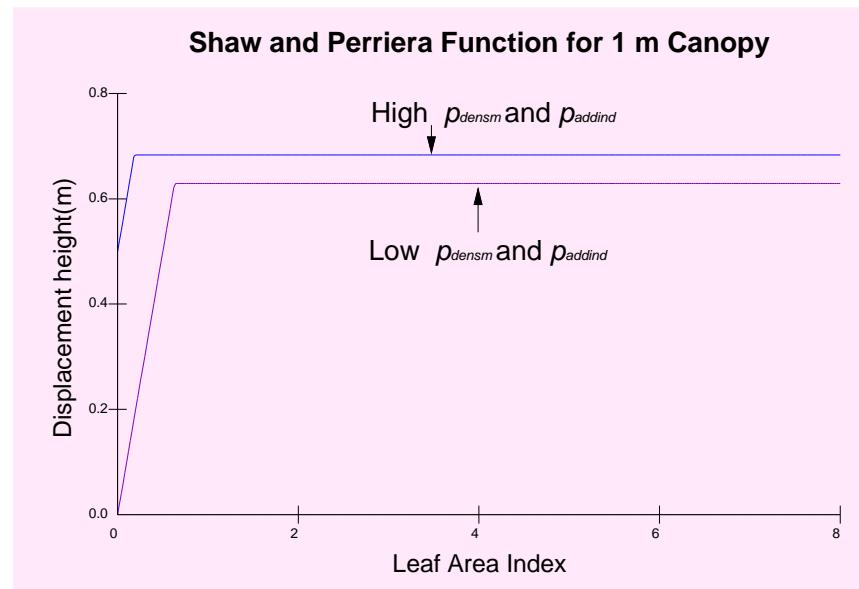
A comparison between air (blue) and canopy (violet) resistance.

Displacement height, linear function



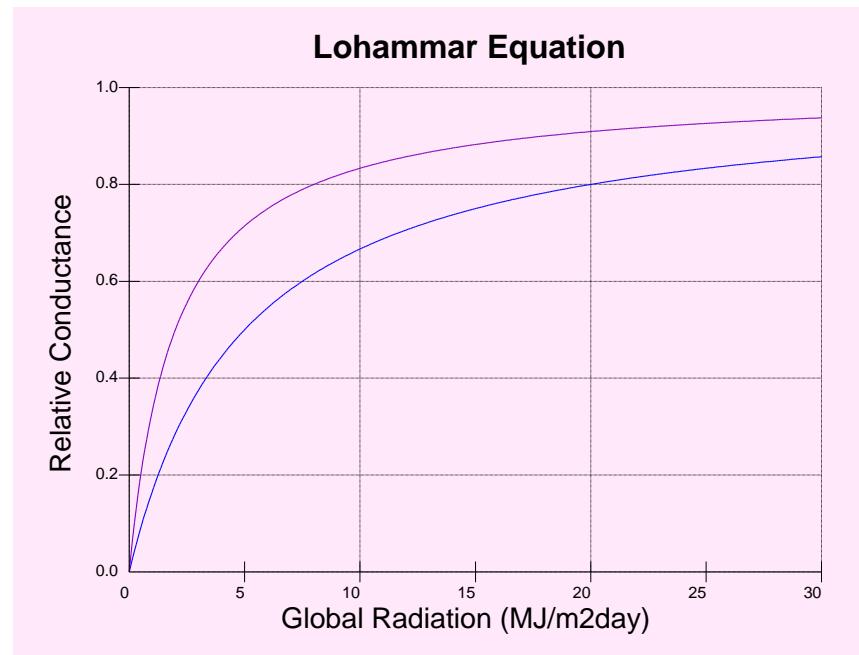
The displacement height coefficient estimated from parameters. The optimum and the end value were the same.

Displacement height, Shaw and Pereira



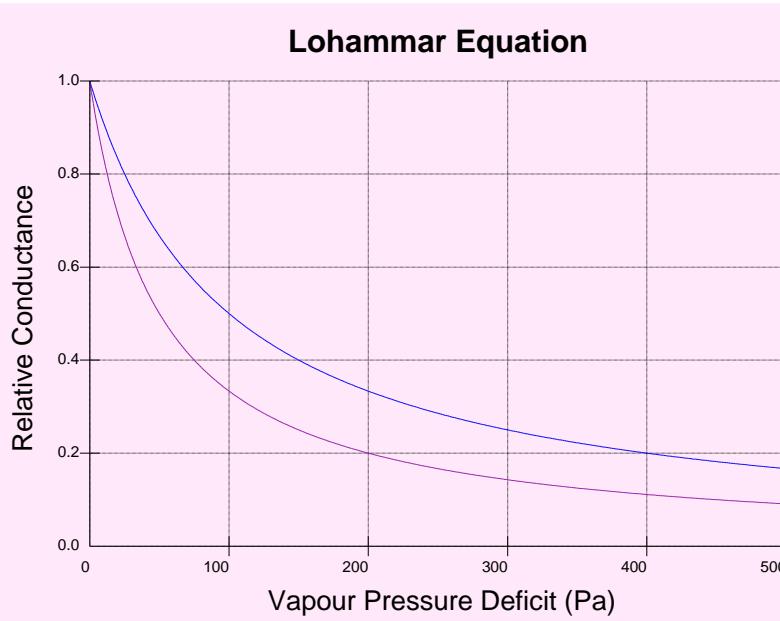
The displacement height as a function of leaf area index. Blue line shows the function with high values on the parameters p_{densm} and p_{addind} whereas the violet curve shows the function with low values on these two parameters.

Lohammar equation, function of global radiation



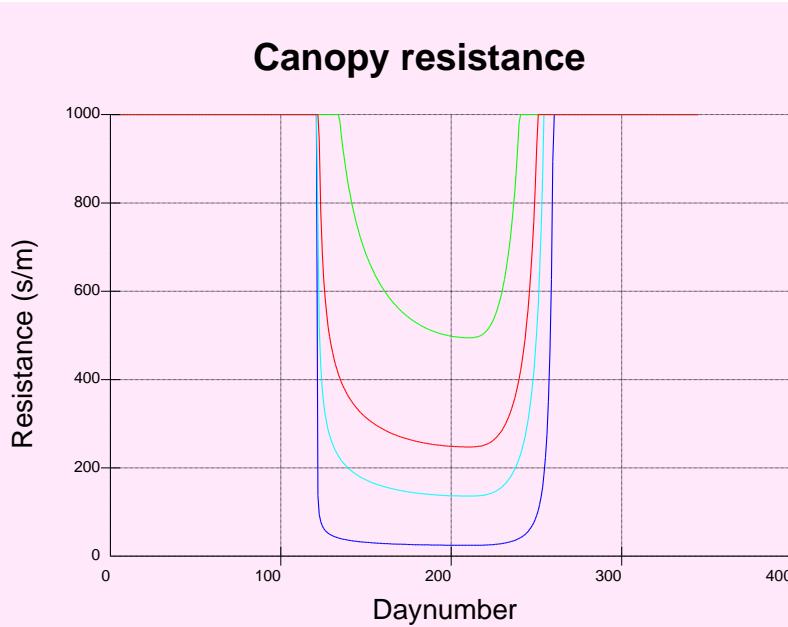
The relative effect on surface conductance from different amounts of global radiation calculated from the Lohammar equation. The parameter, g_{ris} , was put to 5.0e6 (blue line) and 2.0e6 (violet line).

Lohammar equation, function of vapour pressure deficit



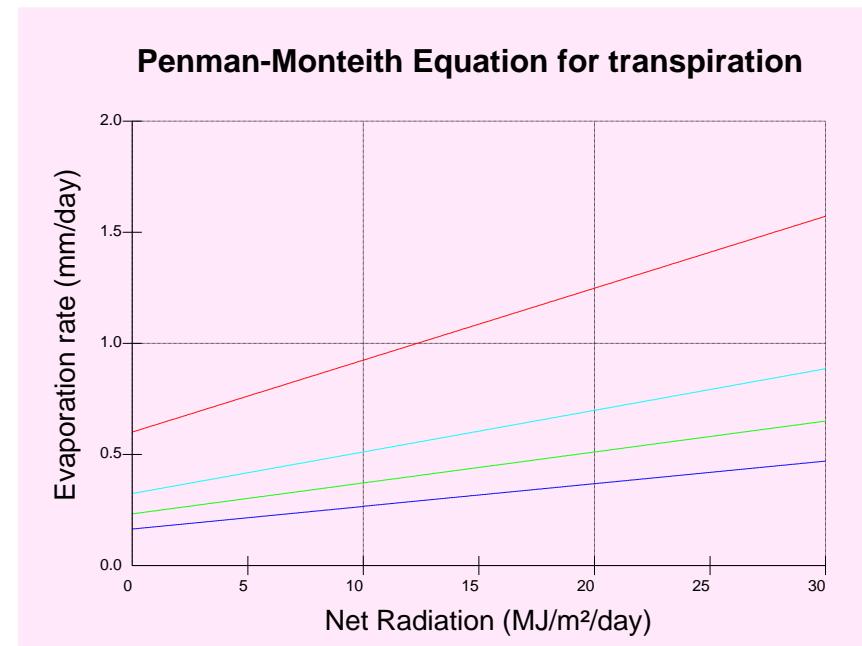
The relative effect on surface conductance from different vapour pressure deficits calculated from the Lohammar equation. The parameter, g_{vpd} , was put to 100 (blue line) and 50 (violet line).

Lohammar equation surface resistance, canopy



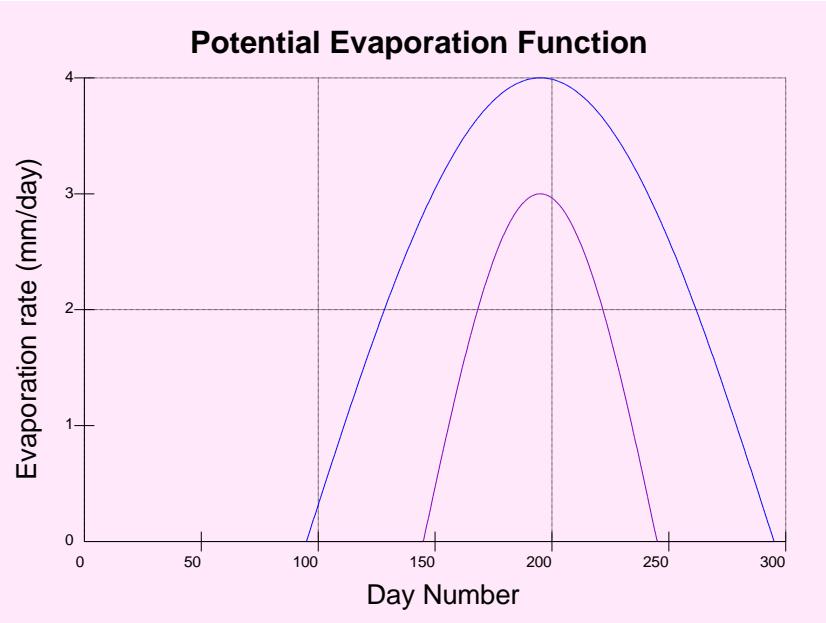
The surface resistance as a function of leaf area index calculated from the Lohammar equation. The blue line shows the original parameter setting. The green curve shows the effect of a **higher** g_{ris} , the turquoise line shows the effect of a **lower** g_{vpd} and the red line shows the effect of a **lower** g_{max} . The wind speed was 2 m/s, the light was 25 MJ/m²/day and the VPD was 100 Pa.

Penman-Monteith combination equation



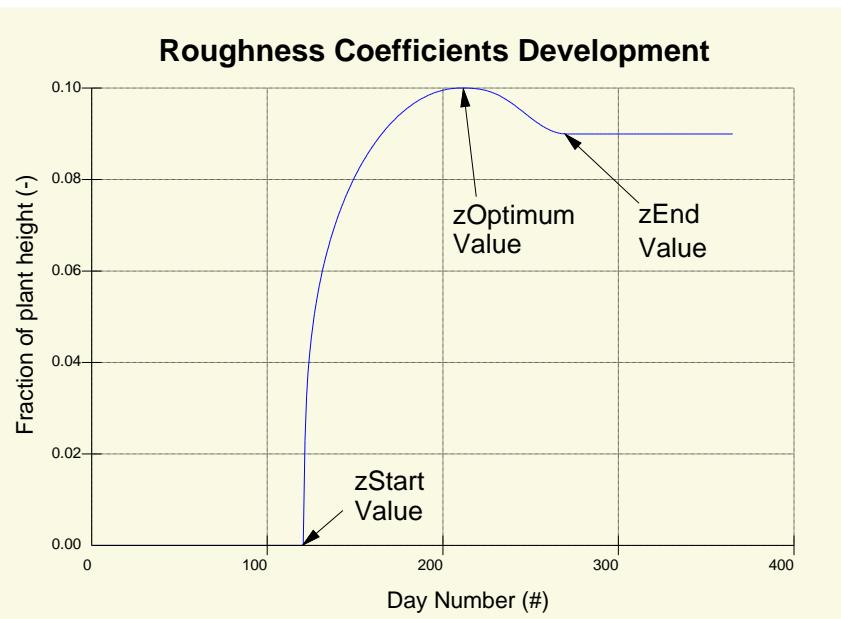
The evaporation rate as a function of the net radiation for different air temperatures calculated with the Penman-Monteith combination equation for transpiration. Blue = 0°C, Green = 5°C, Turquoise = 10°C and Red = 20°C.

Potential evaporation, implicit single leaf



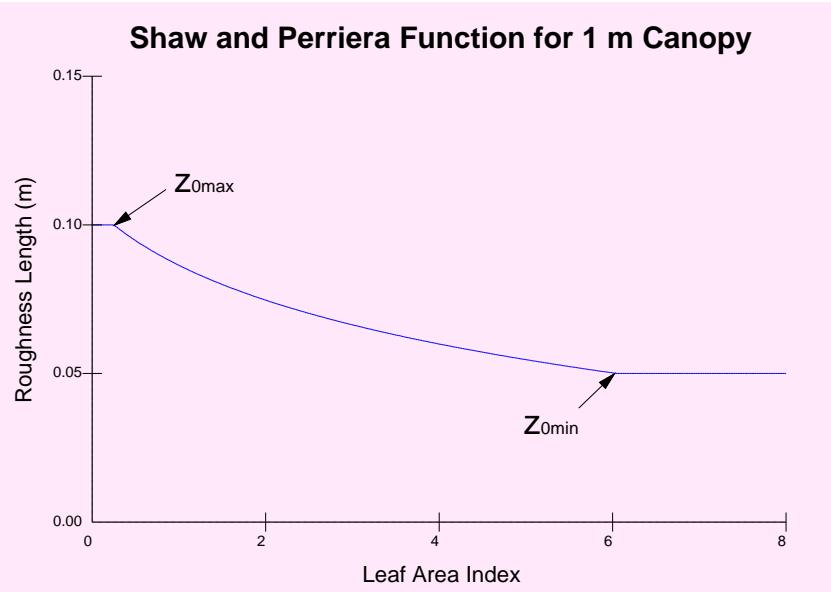
The evaporation rate as a function of day number for an implicit single leaf. j_{day} was put to 195. The blue line shows a maximum rate, j_{max} , of 4 and a period length, j_{period} , of 200 days whereas for the violet line these parameters are put to 3 and 100 respectively.

Roughness length, linear function



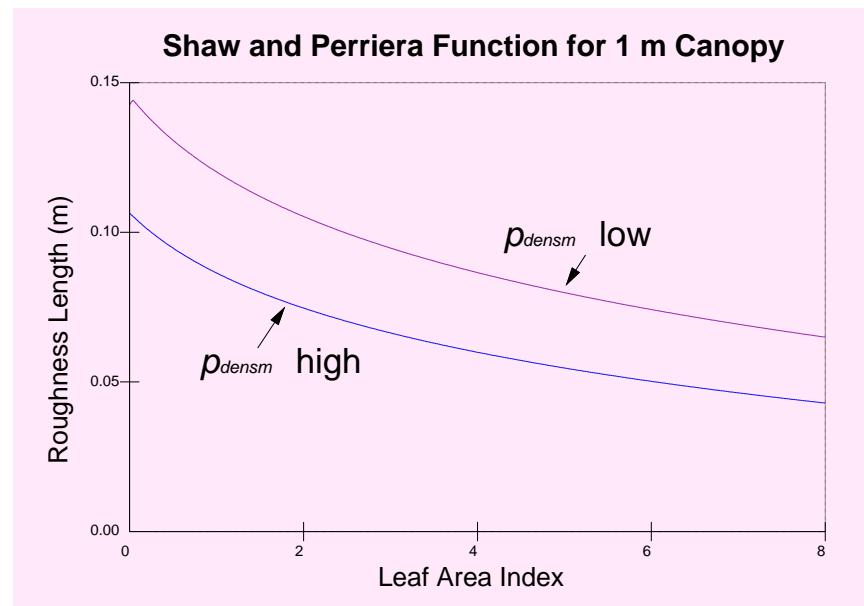
The roughness length coefficient estimated from parameters.

Roughness length, Shaw and Pereira, z_{0min} , z_{0max} and p_{addind}



The roughness length as a function of leaf area index. Decreasing the parameter p_{addind} will shift the curve upwards.

Roughness length, Shaw and Pereira, p_{densm}



The roughness length as a function of leaf area index. Decreasing the parameter p_{densm} will shift the curve upwards.

Auxiliary Variables

CanopyHeight

Height from the soil surface to the top of the canopy.
m

DisplacementHeight

Displacement height (single big leaf)
m

Pot Transpiration

Potential transpiration for a certain canopy
mm/day

ResSurfVegetation

Surface resistance of the big leaf or canopy resistance
s/m

Resist Air Canopy

Air resistance from a given canopy to the reference height
s/m

Resist Air Mean

Mean resistance of all flows from all canopies to the reference height.
s/m

Resistance Canopy

Canopy resistance (surface resistance for a certain canopy)
s/m

Rough Length

Roughness length for a single canopy
m

Roughness Length

Roughness length for each canopy, multiple plants.
m

Water uptake by roots

Theory

Background

The plant water uptake is primarily determined by the switch “[Basic equation](#)”, which presents two approaches. In the “SPAC” (Soil Plant Atmosphere Continuum) approach (option: “Darcy based”), the plant and soil properties are explicitly considered and empirical functions for the plant resistance and for the soil rhizosphere resistance are used to calculate the water uptake rate. The other option “Pressure head response” is a simplified approach that is chosen by default if the time resolution is not within the day. In this latter approach simple response functions are used to estimate the water uptake from different soil layers. Water uptake in the “Pressure head response” approach is considered to be a fraction of the atmospheric demand of water, whereas in the “SPAC” approach the uptake is considered to be the result of different water potentials in the plant and the soil.

In the “SPAC” approach the default option is to consider the water uptake equal to transpiration and consequently there is no storage of water in the plant. Plant water storage during the day can optionally be simulated if the “SPAC” approach is used to calculate *water uptake* and another function is used to calculate *transpiration*. This third option is determined by the switch “[PlantWaterStorage](#)”. Some authors like Waring et al. (1979) indicated that, for forests, water in vegetation may contribute to a considerable amount of transpiration during short periods, and the variations in plant water within the day, i.e. plant water storage, could therefore be important to account for. If plant water storage is simulated, compensatory water uptake by roots due to water shortage in one soil layer, so called “[DemandRedistribution](#)”, cannot be accounted for.

In the following text these three different approaches (“dynamic SPAC approach”, “steady-state SPAC approach” and “Pressure head response”) are described in reversed order.

There are five switches that could be used depending on the context (=the options set by other switches).

Switch	Context
Basic equation	Requires time resolution within day
DemandRedistribution	Used if no plant water storages is considered
	Requires SPAC approach and that salt is considered
PlantWaterStorage	Requires dynamic SPAC approach
Salt Influence	Requires that salt is considered

Simple approach with response functions

Actual transpiration is calculated in two steps to account for possible compensatory uptake of water by roots in layers with no water stress if there are roots in other layers that are exposed to water stress. The actual transpiration is given as:

$$E_{ta} = E_{ta}^* + f_{umov} \cdot (E_{tp}^* - E_{ta}^*) \quad (3.25)$$

where f_{umov} is the degree of compensation, E_{ta}^* is the uptake without any account for compensatory uptake and E_{tp}^* is the potential transpiration with eventual reduction due to interception evaporation. The compensatory uptake is distributed to the layers where no water stress occurs and in accordance with the relative fraction of the roots in these layers. In a first step the E_{ta}^* is calculated as the result of possible stresses at each depth and finally integrated as:

$$E_{ta}^* = E_{tp}^* \int_{z_r}^0 f(\psi(z)) f(\pi(z)) f(T(z)) r(z) \quad (3.26)$$

where n_r is the layer with the deepest roots, $r(z)$ is the relative root density distribution, z_r is root depth and $f(\psi(z))$, $f(\pi(z))$ and $f(T(z))$ are response functions for soil water potential, soil osmotic potential and soil temperature. Root density may be expressed by root length per unit soil volume, or by any other pertinent measure of roots.

Reduction because of dry soil is supposed to act through the stomatal mechanism and xylary tissue resistance, which both have shown to be very sensitive to the demand rate. The water potential response function, $f(\psi(z))$, has been given a simple analytical form in the dry range:

$$f(\psi(z)) = \min \left(\left(\frac{\psi_c}{\psi(z)} \right)^{p_1 E_{tp} + p_2}, f_\theta \right) \quad (3.27)$$

where p_1 , p_2 and ψ_c are parameters (Jansson, 1981). See viewing function “[Soil moisture response, simple response function](#)”. If the soil water potential is reaching the wilting point, ψ_{wilt} , the uptake is assigned to be zero from that horizon. An additional response function, f_θ , correspond to the normal need of oxygen supply to fine roots and it has been given as:

$$f_\theta = 10^{-p_{ox} S_{ox}} \quad (3.28)$$

where p_{ox} is an empirical parameter and S_{ox} is a critical saturation range defined as:

$$S_{ox} = \frac{(\theta - \theta_{ox})}{(\theta_s - \theta_{ox})} \quad (3.29)$$

when the soil moisture, θ , is above the critical soil moisture threshold, θ_{ox} . The value of θ_{ox} is calculated as the difference between the water content at saturation, θ_s , and the minimum air content, given as a parameter, θ_{Amin} . In case θ is less than the S_{ox} , S_{ox} is given a value of zero, which means that the response function is equal to unity, i.e. the maximum value.

Reduction because of low soil temperatures acts primarily through a lowered conductivity between root surface and xylem and is, thus, responding to temperature at each depth. There are different ways of estimating the soil temperature response, $f(T(z))$, which is determined by the switch “[Temperature response](#)”. By choosing “none”, there will be no reduction water uptake due to soil temperature:

$$f(T(z)) = 1 \quad (3.30)$$

The second option “Double-exponential”, is an analytical form of the soil temperature response, $f(T(z))$, which was proposed by Axelsson & Ågren (1976):

$$f(T(z)) = 1 - e^{-t_{WA} \max(0, T(z) - T_{trig})^{WB}} \quad (3.31)$$

where t_{WA} and t_{WB} are parameters. T_{trig} is the triggering temperature (see below). See viewing functions “[Soil temperature response, plant resistance](#)” and “[Soil temperature response, double-exponential](#)”.

A single-exponential function for the temperature response, $f(T(z))$, can also be used:

$$f(T(z)) = 1 - e^{\log(0.02) \max(0, T(z) - T_{trig}) / (t_{WD} - T_{trig})} \quad (3.32)$$

where t_{WD} is a parameter. T_{trig} is the triggering temperature (see below). See viewing functions “[Soil temperature response, plant resistance](#)” and “[Soil temperature response, single-exponential](#)”.

The forth alternative is to use a polynomial function for the temperature response, $f(T(z))$:

$$f(T(z)) = \left[\frac{T(z) - T_{trig}}{t_{WD} - T_{trig}} \right]^{t_{WE}} \quad (3.33)$$

where t_{WD} and t_{WE} are parameters. T_{trig} is the triggering temperature (see below). See viewing functions “[Soil temperature response, plant resistance](#)” and “[Soil temperature response, polynomial](#)”.

The triggering temperature, T_{trig} , can either be a static parameter, t_{WC} , or a function of air temperature (see switch “[Trigging Temperature](#)”). In the latter case the accumulated daily average air temperature above a threshold temperature determines the triggering temperature:

$$T_{trig} = t_{WC} + t_{WF} \cdot T_{sumplant} \quad (3.34)$$

where t_{WC} and t_{WF} are parameters. $T_{sumplant}$ is the accumulated sum of air temperatures above a critical temperature, t_{crit} (see “[Description of Plant](#)”).

The switch “[Salt Influence](#)” governs reduction of water uptake due to soil salinity. If the salt influence is set to be added to pressure head, the osmotic pressure, $\pi(z)$, is added to the soil water potential, $\psi(z)$, in eq (3.27). If this option is chosen the salinity response function, $f(\pi(z))$, in eq (3.26) will be put to unity. Alternatively the salt influence can be included as an independent response function by choosing “Add multiplicative response” or “Add minimum response”. This response function was proposed by van Genuchten et al (van Genuchten, 1983; van Genuchten & Hoffman, 1984; van Genuchten & Gupta, 1993) as:

$$f(\pi(z)) = \sum_{i=1}^{n_r} r_i(\Delta z) \cdot \frac{1}{\left(1 + \left(\frac{\pi(z)}{\pi_c} \right)^{p_\pi} \right)} \quad (3.35)$$

where $r_i(\Delta z)$ is the relative root distribution, and π_c and p_π are empirical parameter values. See viewing function “[Soil salinity response](#)”. The “Add Multiplicative response” option will multiply the response function for salinity, $f(\pi(z))$, with the other response functions for water and temperature as written in eq (3.26). On the other hand if the “Add minimum response” option is chosen, the smallest of the two response functions for soil moisture and salt, will instead be used in determining the water uptake, modifying eq (3.26) slightly into:

$$E_{ta}^* = E_{tp}^* \int_{z_r}^0 \min((f(\psi(z)), f(\pi(z))) \cdot f(T(z)) r(z) \quad (3.36)$$

Steady-state SPAC approach

The compensatory uptake is calculated in the same way as for the simple response approach. But the uptake with any compensation is given as:

$$E_{ta}^* = \sum_{i=1}^{n_r} r_i(\Delta z) \min \left(\frac{(\psi(z) - \psi_{min} - (H_p + z))}{r_{p,i}(\Delta z) + r_{s,i}(\Delta z)}, E_{tp}^* \right) \quad (3.37)$$

where $\psi(z)$ is the actual water potential in a soil layer z , ψ_{min} is a parameter that represents the lowest possible water potential of the plant (maximal suction), H_p is the height of the plant, $r_{p,i}$ is the plant resistance, $r_{s,i}$ is the soil rhizosphere resistance, $r_i(\Delta z)$ is the relative root density distribution (from eq (3.9)), E_{tp}^* is the potential transpiration with eventual reduction due to interception evaporation and n_r is the deepest soil horizon with roots present. See viewing function “[Soil moisture response, steady-state SPAC approach](#)”. The resistance of the plant is given as:

$$r_{p,i}(\Delta z) = \left(\frac{r_{xylem} H_p}{r_i(\Delta z)} + \frac{r_r}{L_r r_i(\Delta z)} \right) \frac{1}{f(\pi(z))} \frac{1}{f(T(z))} \frac{1}{f(\theta(z))} \quad (3.38)$$

where r_{xylem} and r_r are parameters for resistivity in the xylem and the roots, L_r is the root length, and $r_i(\Delta z)$ is the relative root density distribution. The response functions for osmotic pressure, $f(\pi(z))$, temperature, $f(T(z))$, and oxygen supply at high soil water content, $f(\theta(z))$, are described in the former section. See viewing function “[Plant resistance function](#)”.

The soil rhizosphere resistance is described as:

$$r_{s,i}(\Delta z) = \frac{f_{\Delta l}(\Delta z)}{k_w(z) r_i(\Delta z)} \quad (3.39)$$

where k_w is the unsaturated hydraulic conductivity of the soil layers and $f_{\Delta l}$ is a characteristic length that depends on the root geometry and many related factor in a complicated way. The characteristic length is estimated from a simple function that accounts for the root density as:

$$f_{\Delta l} = \Delta_{l_{min}} + (\Delta_{l_{max}} - \Delta_{l_{min}}) e^{-p_{\delta} r_{\delta}(z)} \quad (3.40)$$

where $r_{\delta}(z)$ is the root density in cm/cm³ estimated from the root length, L_r . Three empirical parameters: $\Delta_{l_{min}}$, $\Delta_{l_{max}}$ and p_{δ} are used to estimate the numerical value of this characteristic length. See viewing functions “[Plant and Soil Resistances](#)” and “[Soil rhizosphere distance](#)”.

Salt stress is considered quite differently and is more developed in the steady-state SPAC approach compared to the former one. There are different ways to simulate osmotic effects of salinity on water uptake, and these options resemble the options for the pressure head response approach. By switching “[Salt Influence](#)” the choice between different approaches is made. Firstly, salt influence can be added to the pressure head (“Added to pressure head”). In that case the osmotic pressure, $\pi(z)$, is added to the soil water potential, $\psi(z)$, in eq.(3.37). Secondly the salt response function, $f(\pi(z))$, (eq. (3.35)) can be an “added multiplicative response”. This means that the function is multiplied by the actual water uptake calculated in eq. (3.37), here called E_{ta} , to separate it from the final water uptake after reduction due to salinity, E_{ta}^* :

$$E_{ta}^* = f(\pi(z)) E_{ta} \quad (3.41)$$

Should the response instead be an added minimum response, the actual water uptake calculated in eq (3.37) (again labelled E_{ta}) is substituted with the potential water uptake times the salt response function, $f(\pi(z))$, if the latter is smaller than the other:

$$E_{ta}^* = \min(f(\pi(z)) r_i(\Delta z) E_{tp}^*, E_{ta}) \quad (3.42)$$

In the steady-state SPAC approach there is yet another way of accounting for soil salinity, and that is by affecting the plant resistance (see switch “[PlantResistance](#)”). Plant resistance, $r_{p,i}$, is calculated by eq. (3.38). In this equation there is one term in which the salt response function, $f(\pi(z))$, is included. This term is normally put to unity if salt effects are ignored, but by switching “[Plant Resistance](#)” to “[Salt effect by osmotic pressure](#)” the salt response function, $f(\pi(z))$, is calculated as described in eq. (3.35).

Dynamic SPAC approach

In this approach the change of water storage in the plant, S_p , is calculated during the day. The change of plant water storage is defined as:

$$\frac{\Delta S_p}{\Delta t} = E_{ta} - q_{upt} \quad (3.43)$$

where q_{upt} is the water uptake rate calculated with an equation similar to the steady-state SPAC approach, eq. (3.37), but now without the direct connection to the potential demand:

$$q_{upt} = \sum_{i=1}^{n_r} \min \left(\begin{array}{l} \frac{(\psi(z) - \psi_l - (H_p + z))}{r_{p,i}(\Delta z) + r_{s,i}(\Delta z)}, \\ r_i(\Delta z) E_{tp}^* + p_{excess}, \\ P_{max} - S_p \end{array} \right) \quad (3.44)$$

where p_{excess} is a parameter determining the flow rate in excess of the potential demand from the atmosphere and f_{pmax} is a function that gives the maximal plant water storage as a function of LAI of the plant (see below). This parameter corresponds to the compensatory uptake rate from a single layer.

Note that in this approach the additional compensatory uptake mechanism that was included in the previous two more simplistic approaches are not applicable since the uptake rate is governed by a potential gradient and not a flux as in the previous approaches.

Since the SPAC-based formula is now used to calculate water uptake, the transpiration is instead given as:

$$E_{ta} = f(\psi_l) E_{tp} \quad (3.45)$$

where $f(\psi_l)$ is a function that controls the opening of the stomata as a function of the leaf water potential, ψ_l :

$$f(\psi_l) = \begin{cases} 1 & \psi_l \geq \psi_{th} \\ (\psi_l - \psi_{min}) / (\psi_{th} - \psi_{min}) & \psi_{th} > \psi_l > \psi_{min} \\ 0 & \psi_l \leq \psi_{min} \end{cases} \quad (3.46)$$

where ψ_{min} and ψ_{th} are parameters.

The leaf water potential is a linear function of the plant water storage given as:

$$\psi_l = \left(1 - \frac{S_p}{f_{pmax}} \right) (\psi_{min} + H_p) - H_p \quad (3.47)$$

where S_p is the actual active plant water storage and f_{pmax} is a function that gives the maximal plant water storage as a function of LAI of the plant (if “f(LAI)” has been chosen):

$$f_{pmax} = p_{psi} A_l \quad (3.48)$$

where p_{psi} is a parameter. Alternatively the plant height may also be included in the function as (if “f(LAI, height)” has been chosen):

$$f_{pmax} = p_{pslh} A_l H_p \quad (3.49)$$

where p_{pslh} is a parameter similar to p_{psi} .

Salt is treated analogous to the steady-state SPAC approach.

Switches

Basic equation

This switch will be used only when working with time resolutions within the day.

Value	Meaning
Pressure head response	Water uptake by roots will be calculated from a potential demand and possible reductions based on empirical functions of soil water pressure head, soil temperature and osmotic potential.
Darcy based	Water uptake by roots will be made proportional to a difference in water potential between the soil and the plant divided by estimated resistances of soil rhizosphere and plant, the so called SPAC approach. The water potential of the plant can either be assigned as a fixed value or calculated as a state variable (see " PlantWaterStorage "). This option is only applicable when the time resolution is chosen to be within the daily course of the day.

DemandRedistribution

Only used when the dynamic plant water storage is not considered as a state variable.

Value	Meaning
Without flexible roots	Water uptake by roots will be calculated based on an uptake distribution function that will not change depending on the availability of soil moisture in the soil profile.
With flexible roots	Water uptake by roots will initially be based on a static uptake distribution function. If deficiency occurred at some layers additional water uptake will be made from layers where water is fully available.

PlantResistance

Only considered when the SPAC approach is used in combination with salt in the soil.

Value	Meaning
No salt effect	Plant resistance is a function of temperature and air content of the soil but it is not influenced by salt.
Salt effect by osmotic pressure	As above but in addition a multiplicative response of salt is considered to simulate a specific ion effect.

PlantWaterStorage

Only considered when the SPAC approached is used.

Value	Meaning
Not considered	The water uptake is made equal to transpiration. No explicit account of plant water storage is made.
f(LAI)	The water potential of the leaf is calculated as a state variable of the model using a maximal plant water deficit that is calculated from the leaf area index of the plant.
f(LAI, height)	As above but also the plant height is considered for estimating the maximal plant water deficit.

Salt Influence

Only used when a SaltTracer is considered.

Value	Meaning
Not considered	Salt will not influence the water uptake or transpiration
Add minimum response	Salt will influence uptake by using an independent response function that will influence the water uptake rate directly. However this is only made if the value of the response is less than the valued as suggested by the water stress.
Add multiplicative response	Salt will influence water uptake by using an independent response function that will influence the water uptake rate directly. This is made by multiplication on top of other possible limitation functions.
Added to pressure head	Salt will influence water uptake as an integrated effect of the soil water potential. The osmotic pressure is added to the pressure head to obtain a total potential for the response of salt and moisture.

Temperature response

This switch will be used only when working with time resolutions within the day.

Value	Meaning
None	No temperature response on water uptake is included in the simulation.
Double-exponential	A double exponential function is used to estimate the temperature response on water uptake.
Single-exponential	A single exponential function is used to estimate the temperature response on water uptake.
Polynomial	A polynomial exponential function is used to estimate the temperature response on water uptake.

Trigging Temperature

This switch is only used if a temperature response is simulated.

Value	Meaning
Static	The triggering temperature for calculating the temperature response is given as a parameter value, t_{WC} .
f(tempsum)	The triggering temperature for calculating the temperature response is a function of daily average air temperature above a threshold temperature, t_{crit} . This option can only be chosen if the " PlantDevelopment " switch is set to "start=f(TempSum)".

Parameters

AirMinContent

The minimum amount of air that is necessary to prevent any reduced uptake of water from the soil

Default	Unit	Symbol	Equation	Function
5	vol %	θ_{Amin}	(3.29)	"Soil moisture response, steady-state SPAC approach"

AirRedCoef

A rate coefficient that governs how rapidly the plant resistance will increase because of the lack of oxygen when the water content of the soil exceeds the value give by the actual soil moisture content, θ .

Default	Unit	Symbol	Equation	Function
4	-	p_{ox}	(3.28)	"Soil moisture response, steady-state SPAC approach"

CritThresholdDry

Critical pressure head for reduction of potential water uptake. A wide range (100-3000 cm water) of values has been reported in the literature. Lower values are expected for sandy soils with low root densities and higher values are expected for clayey soils with high root densities

Default	Unit	Symbol	Equation	Function
400	cm water	ψ_c	(3.27)	"Soil moisture response, steady-state SPAC approach"

DemandRelCoef

Coefficient for the dependence of potential water uptake in the reduction function. The dependence of the potential uptake rate has frequently been reported as an important phenomenon for reduction of water uptake.

Default	Unit	Symbol	Equation	Function
0.3	1/day	p_1	(3.27)	“Soil moisture response, steady-state SPAC approach”

FlexibilityDegree

A compensatory uptake of water will be calculated if a deficiency occurs because of too high water tensions in some layers in the soil profile simultaneously as the water tension is below the critical threshold in other layers. The degree of compensation is governed by this parameter. A value of unity will cause total compensation, which means that water will be extracted at the potential rate from the soil until all layers within the root zone reach the critical threshold for reduction of potential water uptake, ψ_c .

Default	Unit	Symbol	Equation	Function
0.6	-	f_{umov}	(3.25)	

LeafThresholdSuction

The water suction of the negative leaf water potential when the stomata start to close.

Default	Unit	Symbol	Equation	Function
1000	cm water	ψ_{th}	(3.46)	

NonDemandRelCoef

Coefficient in moisture reduction function. The degree of reduction when the actual pressure head exceeds the critical threshold, ψ_c , is controlled by this coefficient together with p_1 and the potential transpiration rate, E_{tp} .

Default	Unit	Symbol	Equation	Function
0.1	kg/m ² /day	p_2	(3.27)	“Soil moisture response, steady-state SPAC approach”

PlantMaxSuction

The highest suction or the lowest plant water potential that will be assumed or used as driving force for the water extraction from the soil.

Default	Unit	Symbol	Equation	Function
15000	cm water	ψ_{min}	(3.37),(3.46)	“Plant and Soil Resistances”

PlantWatRelLAI

The value scales the active possible storage of plant water by using LAI of plant.

Default	Unit	Symbol	Equation	Function
1	mm	p_{psl}	(3.48)	

PlantWatRelLAI_height

The value scales the active possible storage of plant water by using the product of LAI and plant height.

Default	Unit	Symbol	Equation	Function
0.5	mm/m	p_{pslh}	(3.49)	

ResistivityRoot

The resistance that correspond to the cross section area of 1 m of fine roots. The roots are connected in parallel to each other when the total resistance of one horizon is calculated.

Default	Unit	Symbol	Equation	Function
1000	m/days	r_r	(3.38)	“Plant resistance function”

ResistivityXylem

The resistance of one meter of plant height in the xylem of the plant. The different sections of the plants are assumed to be connected in series when the total resistance of entire plant is calculated.

Default	Unit	Symbol	Equation	Function
1	days/m	r_{xylem}	(3.38)	“Plant resistance function”

RootDensityCoef

A rate coefficient that governs the change from RootDistMax to RootDistMin as a function of root density.

Default	Unit	Symbol	Equation	Function
0.5	m^2	p_δ	(3.40)	“Soil rhizosphere distance”

RootDistMax

Maximal value of characteristic distance used to estimate Rhizosphere resistance of water uptake.

Default	Unit	Symbol	Equation	Function
0.01	m	Δ_{lmax}	(3.40)	“Soil rhizosphere distance”

RootDistMin

Minimum value of characteristic distance used to estimate Rhizosphere resistance of water uptake.

Default	Unit	Symbol	Equation	Function
0.001	m	Δ_{lmin}	(3.40)	“Soil rhizosphere distance”

SaltHalfReduction

Critical value for reduction of water uptake or increasing plant resistance because of osmotic potential in the van Genuchten equation.

Default	Unit	Symbol	Equation	Function
5000	cm water	π_c	(3.35)	“Soil salinity response”

SaltPowerCoef

Power coefficient for reduction of water uptake or increasing plant resistance because of osmotic potential in the van Genuchten equation.

Default	Unit	Symbol	Equation	Function
3	-	p_π	(3.35)	“Soil salinity response”

TempCoefA

Temperature coefficient in the temperature response function. Used only if the temperature response is double-exponential.

Default	Unit	Symbol	Equation	Function
0.8	-	t_{WA}	(3.31)	“Soil temperature response, double-exponential”

TempCoefB

Temperature coefficient in the temperature response function. Used only if the temperature response is double-exponential.

Default	Unit	Symbol	Equation	Function
0	-	t_{WB}	(3.31)	“Soil temperature response, double-exponential”

TempCoefC

Temperature coefficient governing the triggering temperature.

Default	Unit	Symbol	Equation	Function
15	-	t_{WC}	(3.34)	

TempCoefD

Temperature coefficient in the temperature response function. Used only if the temperature response is single-exponential or polynomial.

Default	Unit	Symbol	Equation	Function

1	-	t_{WD}	(3.32)-(3.33)	“Soil temperature response, single-exponential”
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TempCoefE

Temperature coefficient in the temperature response function. Used only if the temperature response is polynomial.

Default	Unit	Symbol	Equation	Function
0	-	t_{WE}	(3.33)	“Soil temperature response, polynomial”

TempCoefF

Temperature coefficient influencing governing the triggering temperature for the water response function.

Default	Unit	Symbol	Equation	Function
0.4	-	t_{WF}	(3.34)	

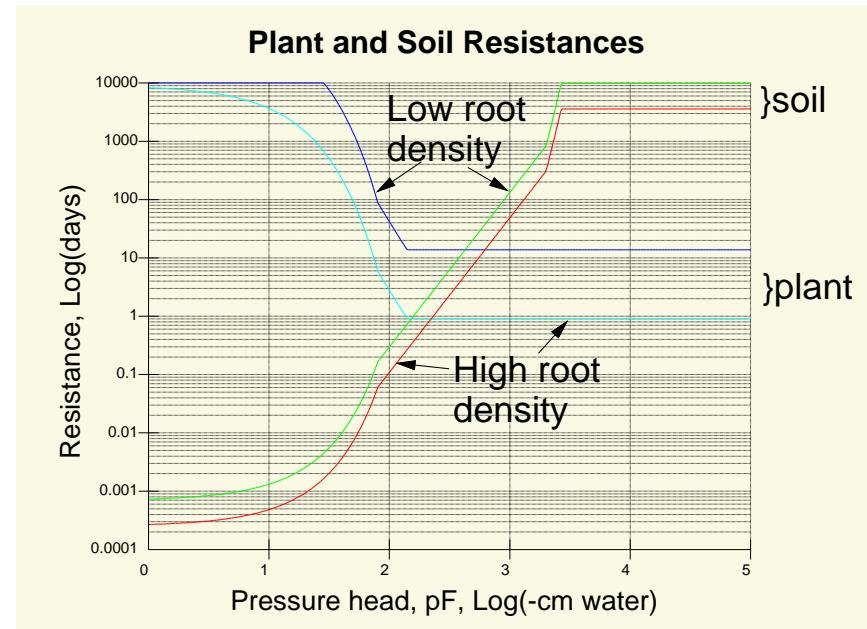
Upt_Excess

Maximal flow rate in excess of the rate that corresponds to the potential demand rate from atmosphere.

Default	Unit	Symbol	Equation	Function
2.0	mm/day	p_{excess}	(3.44)	

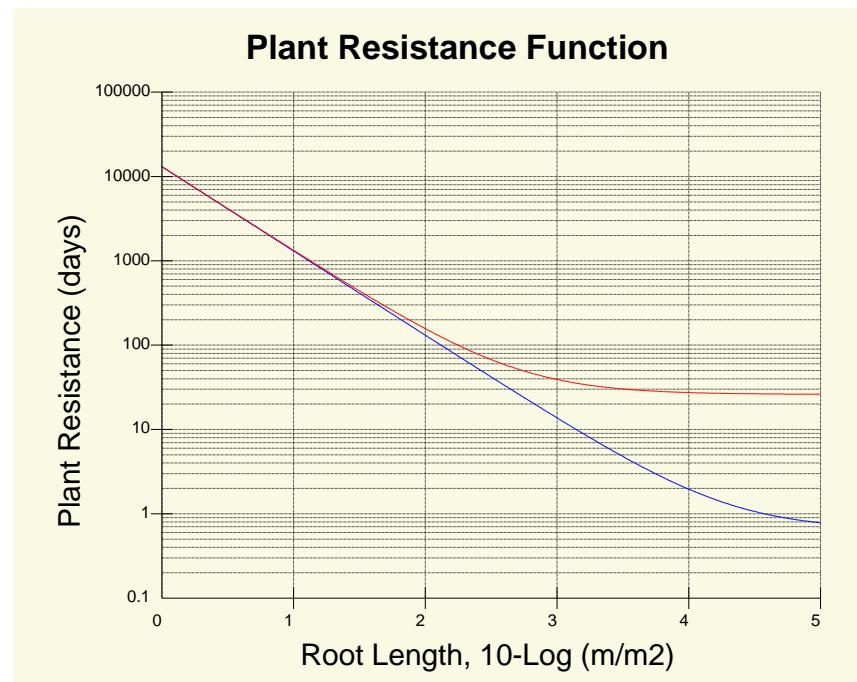
Viewing functions

Plant and Soil Resistances



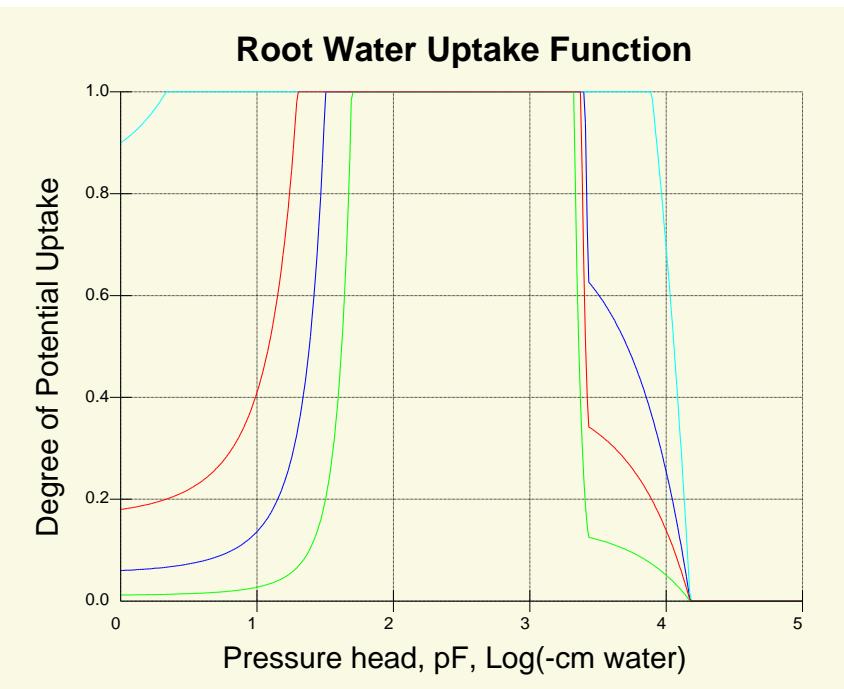
A comparison between soil and plant resistance as functions of pressure head.
Soil resistance increases with higher pressure head whereas plant resistance decreases with higher pressure head.

Plant resistance function



The plant resistance in one layer in the midzone as a function of root length for a normal crop of 0.5 m (blue) and a forest of 20 m (red). A higher root length results in less plant resistance.

Soil moisture response, steady-state SPAC approach



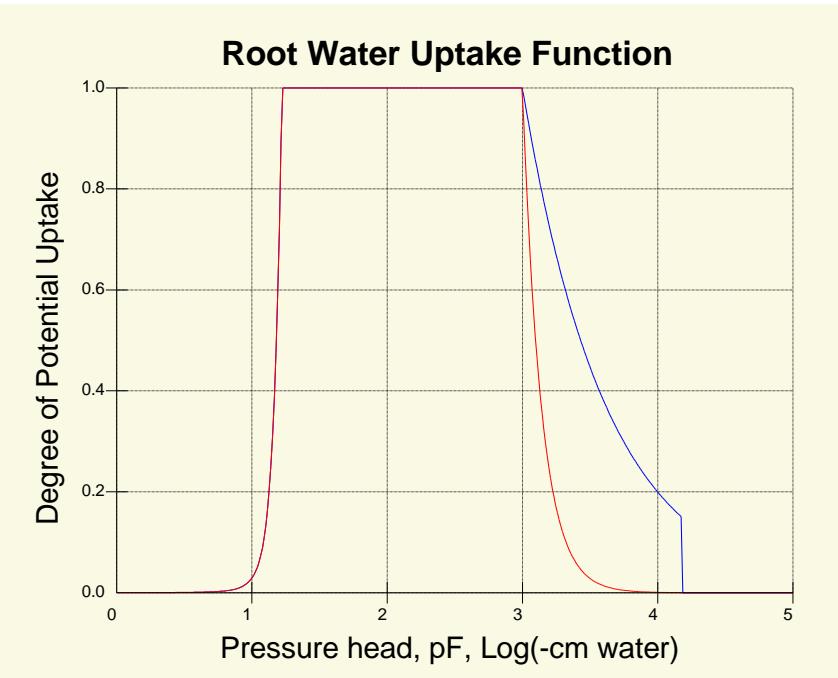
The degree of potential water uptake as a function of pressure head with different atmospheric demands and different root densities.

High demand, low root density = green. Low demand, low root density = red.

High demand, high root density = blue. Low demand, high root density = turq.

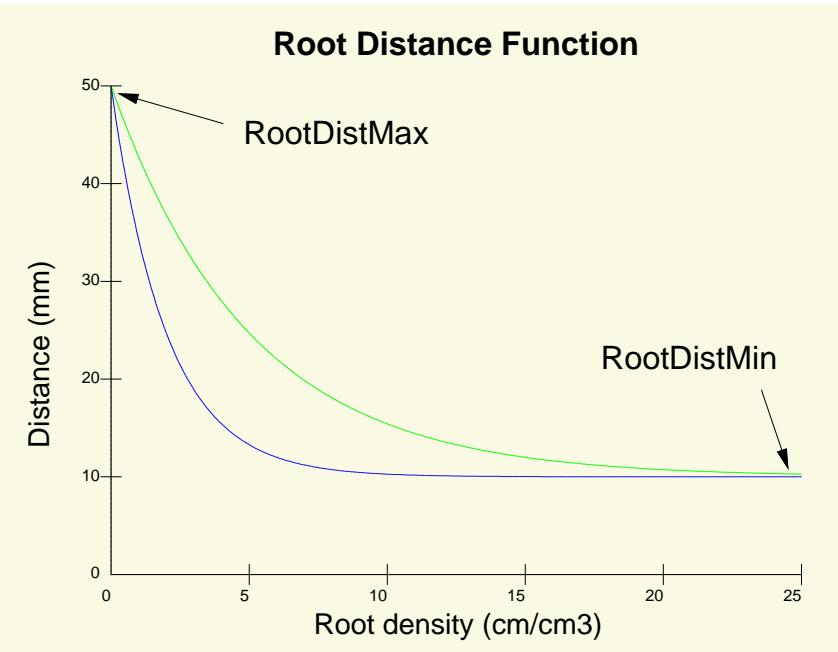
The figures are the result of estimates based on a sandy soil from one horizon in the middle of the root zone. The low root density corresponds to a total root length of 1 km/m^2 and the high root density corresponds to 50 km/m^2 .

Soil moisture response, simple response function



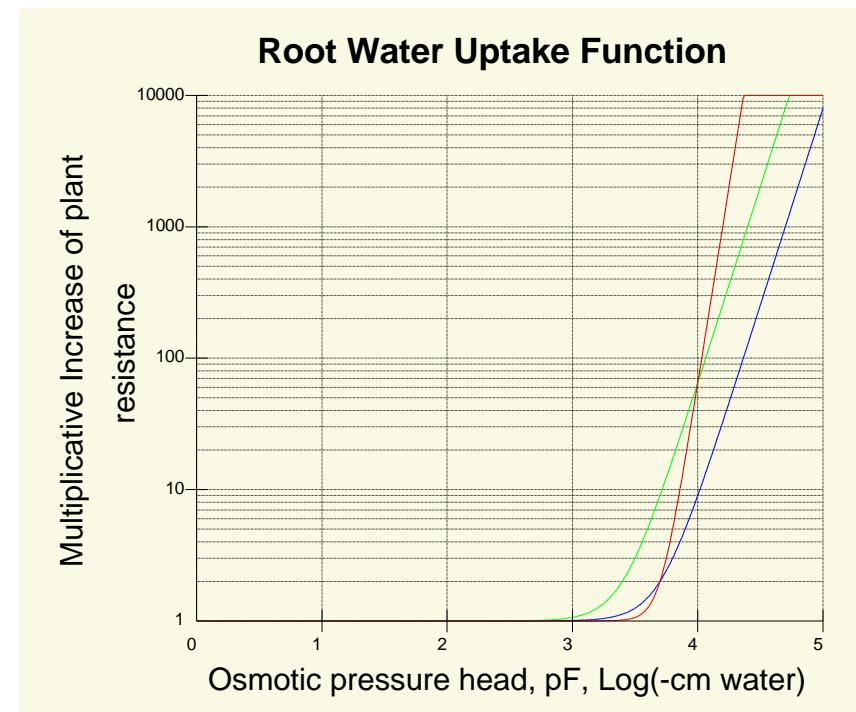
The degree of potential water uptake as a function of pressure head for a high (red) atmospheric demand of water and a low (blue) atmospheric demand of water.

Soil rhizosphere distance



The root distance as a function of root density with a high root density coefficient, p_δ (blue line) and a low p_δ (green line). The distance decreases as the density increases until the root dist min, A_{lmin} , is reached.

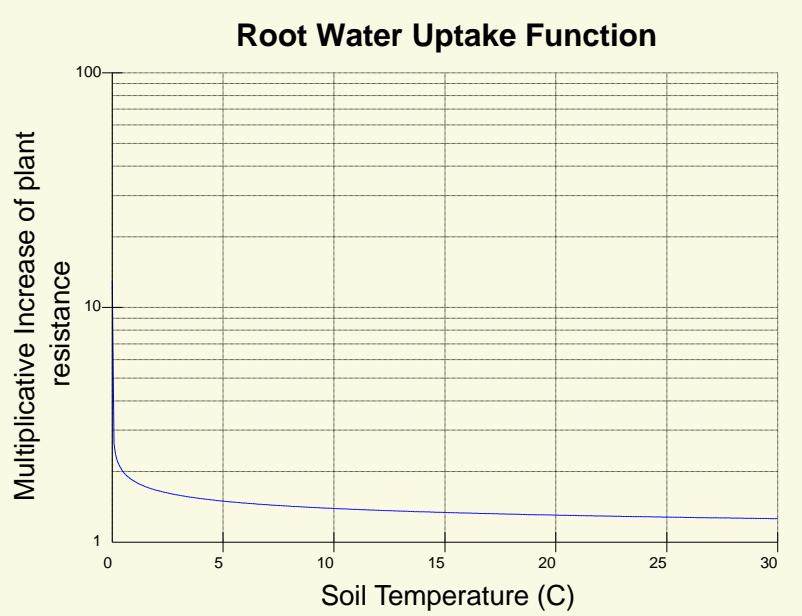
Soil salinity response



The plant resistance as a function of osmotic pressure. Low osmotic potential will decrease the possibilities for water uptake. The blue line shows the original parameter settings. Decreasing the parameter π_c results in a curve shift (green line) and increasing the parameter p_π alters the slope of the curve (red line).

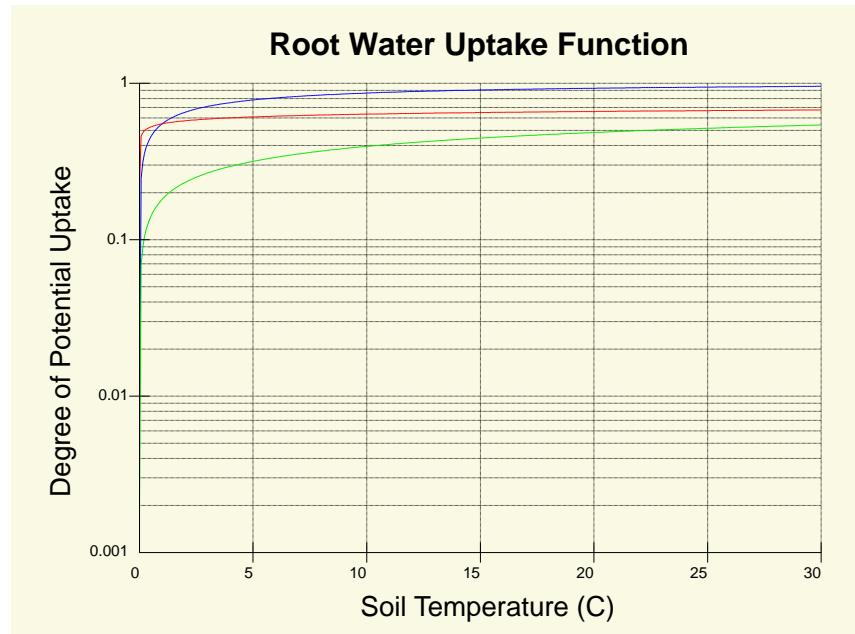
Soil temperature response, plant resistance

The function that will influence the plant resistance is the inverse of eq.(3.31). This is the one shown to the right.



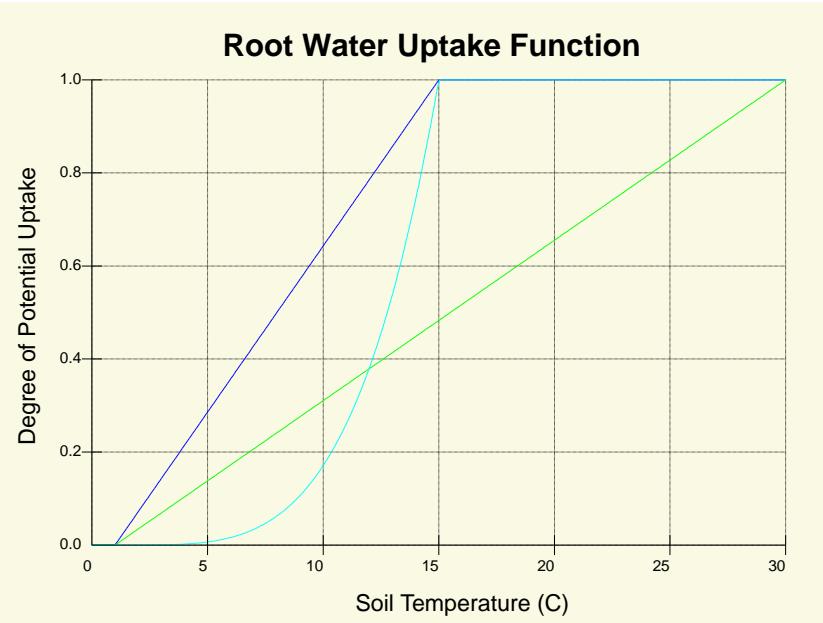
Low soil temperatures will increase the rhizosphere resistance.

Soil temperature response, double-exponential



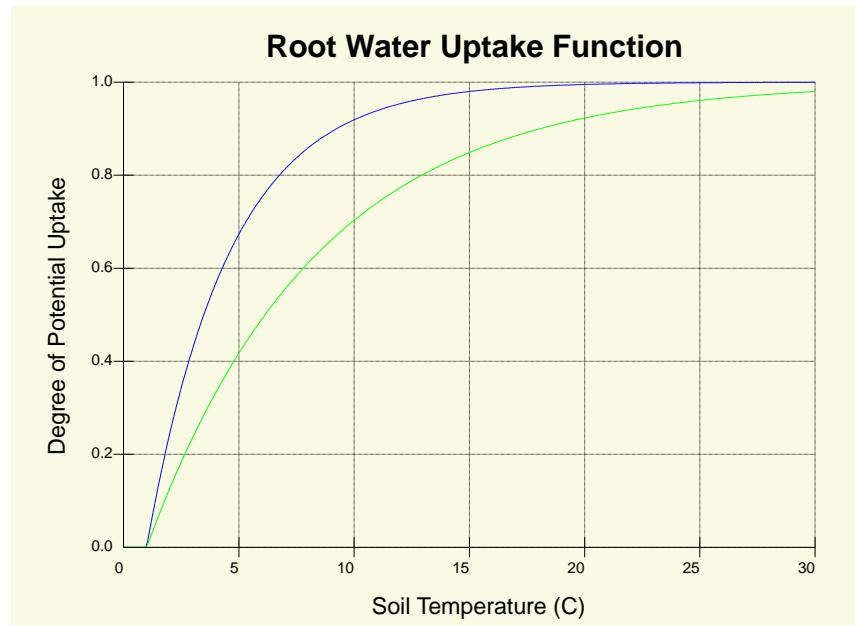
Low soil temperatures will decrease the potential water uptake. Blue line is the original parameter setting. A lower t_{WA} shifts the curve downwards (green line) and a lower t_{WB} changes the slope of the curve (red line).

Soil temperature response, polynomial



Low soil temperatures will decrease the potential water uptake. Blue line is the original parameter setting. A higher t_{WD} shifts the curve downwards (green line) and a higher t_{WE} changes the slope of the curve (red line).

Soil temperature response, single-exponential



Low soil temperatures will decrease the potential water uptake. Blue line is the original parameter setting. A higher t_{WD} shifts the curve downwards (green line).

State Variables

PlantWater

Amount of water within plant.
mm

Flow Variables

PlantWaterUptake

Water uptake from each plant (canopy).
mm/day

Transpiration

Transpiration rate from each plant (canopy).
mm/day

WUptakeRate

Water uptake rate from each soil horizon.
mm/day

Auxiliary Variables

Plant PotWaterUptake

Potential water uptake rate of each plant (canopy).
mm/day

PlantWaterPotential

Plant water potential for each plant (canopy).
cm water

PotWaterUptake

Potential water uptake rate of a single plant.
mm/day

RedCMoisture

Response coefficient caused by moisture effects on water uptake.

RedCTemperature

Response coefficient caused by soil temperature effects on water uptake.

RedCTotal

Response coefficient caused by all limiting factors on water uptake.

RedCTotal all plant

Mean response coefficient by all limiting factors and all plants.
mm

Resist Plant

Total resistance for water flow within plant for each plant.
days

Resist Soil_Plant

Total resistance for water flow from bulk soil to root surface of each plant.
days

Transpiration all pl

Total sum of transpiration from all plants (canopies).
mm/day

WaterUptake TrigTemp

The triggering temperature for water uptake.
°C

Interception

Theory

Interception, i.e. the storage of rain water, irrigation water or snow on leaves, can optionally be accounted for in the CoupModel (see switch “[PrecInterception](#)”). The basic idea behind the interception process is that a water storage exists on the leaf surfaces from which water can evaporate directly back to the atmosphere, be temporarily stored or form throughfall to the soil or the snow according to:

$$\Delta S_i = P - E_{ia} - q_{th} \quad (3.50)$$

where ΔS_i is the change of intercepted water/snow in the canopy, P is precipitation, E_{ia} is the evaporation of intercepted water and q_{th} is the throughfall. These variables are described in more detail in this section.

Snow interception can optionally be simulated (see switch “[SnowInterception](#)”), which means that the interception capacity is dependent on the relative amount of liquid and frozen intercepted water. If irrigation water is added in the simulation, the amount of water that is irrigated from above the canopy can be intercepted, and is therefore implicitly included in the term “Precipitation, P ”.

There are different structures for the path of water depending on whether the approach with multiple plants is used or not. In the case of a single big leaf, only one storage is considered. In case of multiple canopies each plant is divided into an upper and a lower compartment (see [Figure 3.4](#)).

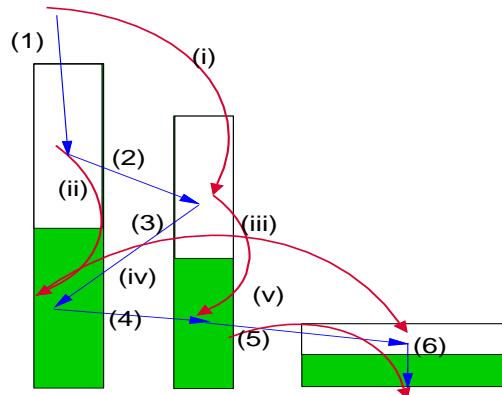


Figure 3.4. The interception process. Direct water fluxes from layer to layer are shown with blue lines and arabic numbers whereas the bypassing water fluxes are shown with red lines and roman numbers.

Interception rate and interception storage

Interception rate can be calculated either by a simple threshold formulation or by an exponential function (see switch “[InterceptionModel](#)”). The threshold function gives the interception rate, I (mm day^{-1}), by the vegetation canopy.:

$$I = \min\left(P(1-f_{th,d}), \frac{(S_{i\max} - S_i(t-1))}{\Delta t}\right) \quad (3.51)$$

where P is precipitation, $f_{th,d}$ is the fraction of the precipitation that directly reaches the soil surface without being affected by the vegetation, $S_{i\max}$ is the interception capacity, and $S_i(t-1)$ is the interception storage remaining from the previous time step.

Alternatively, the interception rate, I , is calculated by an exponential function (Hedström & Pomeroy, 1998):

$$I = \min\left(P(1-f_{th,d}), f_{\Delta t, \text{snow}} \frac{(S_{i\max} - S_i(t-1))}{\Delta t} \left(1 - \exp\left(-\frac{P(1-f_{th,d})}{S_{i\max}}\right)\right)\right) \quad (3.52)$$

where $f_{\Delta t, \text{snow}}$ is a time step dependent “snow unloading” coefficient, representing the influence of snow falling of the canopy during and interception event. It is automatically set to unity if snow interception is not treated (see switch SnowInterception) and/or in case of liquid precipitation. For snow, $f_{\Delta t, \text{snow}}$ is set to 0.7 for hourly time steps, and empirically corrected to obtain the same interception rates if other time steps are chosen.

The interception capacity (maximum storage) $S_{i\max}$ is a function of the leaf area index, A_l :

$$S_{i\max} = i_{LAI} A_l + i_{base} \quad (3.53)$$

where i_{LAI} and i_{base} are parameters. See viewing function “[Interception storage as a function of LAI](#)”.

The change in interception storage, ΔS_i , is calculated as the difference between the interception rate, I , and the actual interception evaporation, E_{ia} :

$$\Delta S_i = I - E_{ia} - U \quad (3.54)$$

where U is the amount of snow falling off the canopy due to a changed interception capacity i.e. increased air temperature or snow melt in the canopy (cf. section “[Interception capacity with snow interception](#)”):

$$U = \max\left(0, \frac{S_i - S_{i\max}}{\Delta t}\right) \quad (3.55)$$

Interception capacity with snow interception

If snow interception is included in the simulation, the interception capacity, $S_{i\max}$, can be calculated in two different ways, either as a function of thermal quality or as a function of air temperature (see switch “[SnowIntUnload](#)”). In the latter case interception capacity is calculated as:

$$\begin{aligned} S_{i\max} &= i_{LAI\text{snow}} \cdot A_l + i_{LAI} \cdot A_l + i_{base} & T_a < 0 \\ S_{i\max} &= i_{LAI} \cdot A_l + i_{base} & T_a > 0 \end{aligned} \quad (3.56)$$

where $i_{LAI\text{snow}}$, i_{LAI} and i_{base} are parameters, and A_l is the leaf area index. In this case, thermal quality Q_I^* is assumed to be equal to the thermal quality of precipitation, Q_P calculated in eq.(4.36).

When the interception capacity is a function of thermal quality, it is instead calculated as:

$$S_{i\max} = i_{LAI\text{snow}} \cdot Q_I^{*2} \cdot A_l + i_{LAI} \cdot A_l + i_{base} \quad (3.57)$$

Q_I^* is the thermal quality (fraction of frozen water) of the intercepted water and can either be calculated as a weighted sum of the thermal quality of the intercepted water from the previous time-step, Q_I , and the thermal quality of new precipitation. Thermal quality is calculated as:

$$Q_I^* = f_{new} \cdot Q_P + (1 - f_{new}) \cdot Q_I \quad (3.58)$$

where Q_P is the thermal quality of precipitation calculated in eq.(4.36). f_{new} is the fraction of new intercepted precipitation in relation to total intercepted storage:

$$f_{new} = \frac{P}{S_i + P} \quad (3.59)$$

where P is precipitation and S_i is the interception storage.

When the interception storage, S_i , has been calculated in each time-step, a new value on thermal quality of intercepted water, Q_I , is calculated:

$$Q_I = \frac{Q_I^* \cdot S_i - S_{melt}}{S_i} \quad (3.60)$$

where Q_I^* is the thermal quality of intercepted water calculated in the beginning of the time-step and S_i is the interception storage. The amount of melted intercepted storage, S_{melt} , is estimated by:

$$S_{melt} = i_{scale} \cdot M(S_{snowthick}) \quad (3.61)$$

where i_{scale} is a parameter and $M(S_{snowthick})$ is the function for calculating snow melt, eq.(4.32)-(4.34). $S_{snowthick}$ replaces Δz_{snow} and is calculated as:

$$S_{snowthick} = \frac{S_i \cdot \rho_{water}}{\left(\rho_{water} \cdot (1 - Q_I^*) + 100 \cdot Q_I^*\right) \cdot A_l} \quad (3.62)$$

where S_i is the interception storage, ρ_{water} is the density of water, Q_I^* is the thermal quality of intercepted water calculated in the beginning of the time-step and A_l is the leaf area index. The figure 100 in the equation is an approximation of the snow density.

Throughfall of precipitation

Throughfall in case of only one canopy storage is calculated as:

$$q_{th} = \max(0, P(1 - f_{th,d}) - I + U) + f_{th,d}P \quad (3.63)$$

where $f_{th,d}$ is the fraction of the precipitation that directly reaches the soil surface without being affected by the vegetation.

In case of multiple canopies the throughfall is separated in a direct fraction, $f_{th,d}$, and a bypassing fraction, $f_{th,b}$, i.e. drops from one canopy to the other. The flux is calculated from above and downwards splitting the canopy storage into two equally high segments. The direct fraction of throughfall is passing each mid point of canopies from top to bottom. The indirect fraction is always bypassing one segment. The bypassing fraction, $f_{th,b}$, is calculated as:

$$f_{th,b} = 1 - \left(c_{\max} \left(1 - e^{c_{LAIsens} A_l} \right) \right) \quad (3.64)$$

where c_{\max} and $c_{LAIsens}$ are parameters given in a table. See viewing function “[Rain Interception Canopy Cover Function](#)”.

Potential evaporation

In forests, evaporation of intercepted water may considerably exceed transpiration rates with equivalent local-climatic conditions.

When potential transpiration is used as a driving variable, i.e. for implicit big leaf simulations, a constant relation between wet surface evaporation rate and potential transpiration rate is assumed:

$$E_{ip} = e_{rat} E_{tp} \quad (3.65)$$

where e_{rat} is a parameter.

Otherwise the potential evaporation rate, E_{ip} , from interception storage is calculated from the Penman combination equation assuming a surface resistance, r_{sint} , representing the resistance to the single source point of the whole canopy, see eq.(3.12). See viewing function “[Potential interception evaporation](#)”.

The potential interception evaporation rate, E_{ip} , is decreased if the water on the leaves does not cover the entire leaf, as determined by the parameter, $i_{fracmin}$:

$$E_{ip}^* = \max\left(\frac{S_i}{S_{i\max}}, i_{fracmin}\right) \cdot E_{ip} \quad (3.66)$$

where S_i is the interception storage and $S_{i\max}$ is the interception capacity.

When the Penman combination equation is used to calculate E_{ip} , the e_{rat} value is calculated with eq. (3.65), and used for example in eq. (3.67).

Actual evaporation

Actual evaporation from the canopy is limited either by the potential interception evaporation rate, E_{ip}^* , or by the interception storage, S_i :

$$E_{ia} = \min\left(e_{rat} E_{ip}^*, \Delta S_i + \frac{S_i(t-1)}{\Delta t}\right) \quad (3.67)$$

where $S_i(t-1)$ is the residual intercepted water which remains from the previous time step (Δt) if the actual evaporation, E_{ia} , was smaller than the interception storage. Remaining intercepted water at the present time step, $S_i(t)$, is calculated as:

$$S_i(t) = S_i(t-1) + (\Delta S_i - E_{ia}) \Delta t \quad (3.68)$$

Reduction of potential transpiration

When evaporation of intercepted water, E_{ia} , takes place the potential transpiration rate, E_{tp} is reduced based on the assumption that evaporation and transpiration are complementary in time:

$$E_{tp}^* = \max\left(0, E_{tp} - \frac{E_{ia}}{e_{rat}}\right) \quad (3.69)$$

where e_{rat} is the ratio between potential evaporation rate from interception storage and potential transpiration. This reduced value of potential transpiration is used to calculate water uptake.

Switches

InterceptionModel

Value	Meaning
Threshold	Interception rate is calculated by a simple threshold function.
Exponential	Interception rate is calculated by an exponential function according to Hedström and Pomeroy (1998).

PreInterception

Value	Meaning
off	No Interception of precipitation is accounted for.
on	A simple model considers precipitation interception.

SnowInterception

Value	Meaning
off	No Interception of snow is accounted for.
on	A simple model considers snow interception.

SnowIntUnload

Value	Meaning

Thermal Quality	Interception capacity when snow is intercepted is a function of thermal quality.
Air Temperature	Interception capacity when snow is intercepted is a function of air temperature.

Parameters

DirectThroughfall

The direct throughfall is the fraction of the precipitation that passes through the canopy and continues directly to the soil surface.

Default	Unit	Symbol	Equation	Function
0	-	$f_{th,d}$	(3.51) , (3.63)	

IntEvapFracMin

Scaling parameter for the leaf coverage of intercepted water used in the calculation of potential interception evaporation.

Default	Unit	Symbol	Equation	Function
1	-	$i_{fracmin}$	(3.66)	

IntSnowMeltScale

Scaling parameter for the intercepted snow melt function.

Default	Unit	Symbol	Equation	Function
1	-	i_{scale}	(3.61)	

Ratio_Eva-Transp

Ratio between potential evaporation rate from interception storage and potential transpiration.

Default	Unit	Symbol	Equation	Function
3	-	e_{rat}	(3.65) , (3.67) , (3.69)	

For short crops a value close to 1 may be reasonable whereas values as high as 3-5 are relevant for forests. The parameter only makes sense when the plant is represented implicitly as one big leaf.

SnowCapacityPerLAI

Interception snow storage capacity per LAI unit.

Default	Unit	Symbol	Equation	Function
1	mm/m ²	$i_{LAI snow}$	(3.57)	

WaterCapacityBase

Interception storage capacity per LAI unit.

Default	Unit	Symbol	Equation	Function

0	mm	i_{base}	(3.53)	“Interception storage as a function of LAI”
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WaterCapacityPerLAI

Interception water storage capacity per LAI unit.

Default	Unit	Symbol	Equation	Function
0.2	mm/m ²	i_{LAI}	(3.53)	“Interception storage as a function of LAI”

WithinCanopyRes

Surface resistance when intercepted water occurs used to calculate potential evaporation with the Penman combination equation.

Default	Unit	Symbol	Equation	Function
0.5	s/m	r_{sint}	(3.12)	“Potential interception evaporation”

The value may be in the range from 0-10 s/m, with the higher ones for closed canopies. The parameter only makes sense when the plant is explicitly represented.

Parameter tables

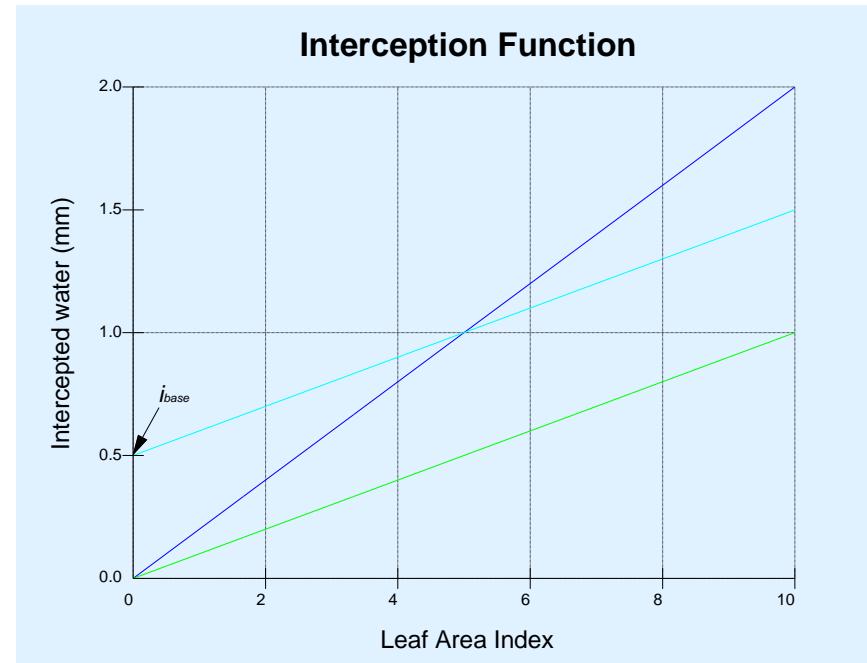
Surface cover function for different plants

These parameters are used by multiple plants to calculate drops from one canopy to another canopy below.

Name	Default	Unit	Symbol	Comments/Explanations
LAI Cover Sensitivity	0.5	-	$c_{LAIsens}$	
Maximal Cover	0.6	-	c_{max}	

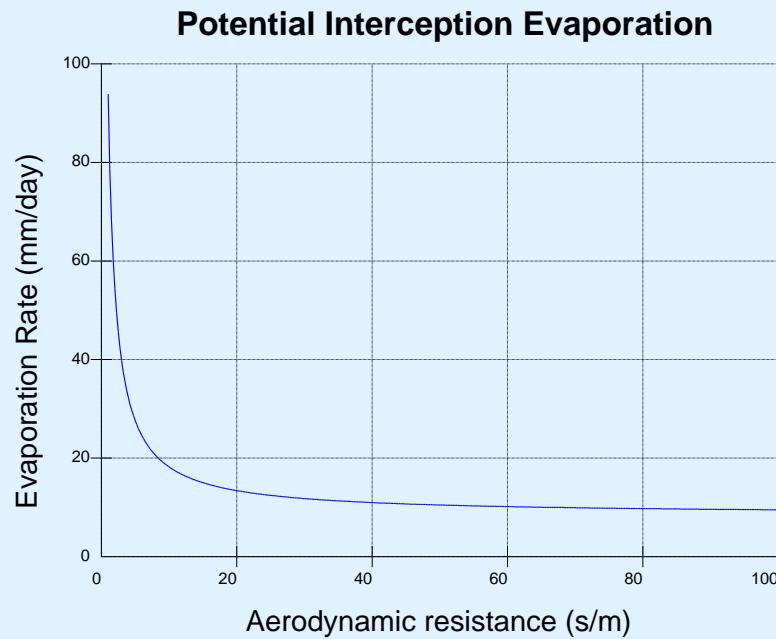
Viewing functions

Interception storage as a function of LAI



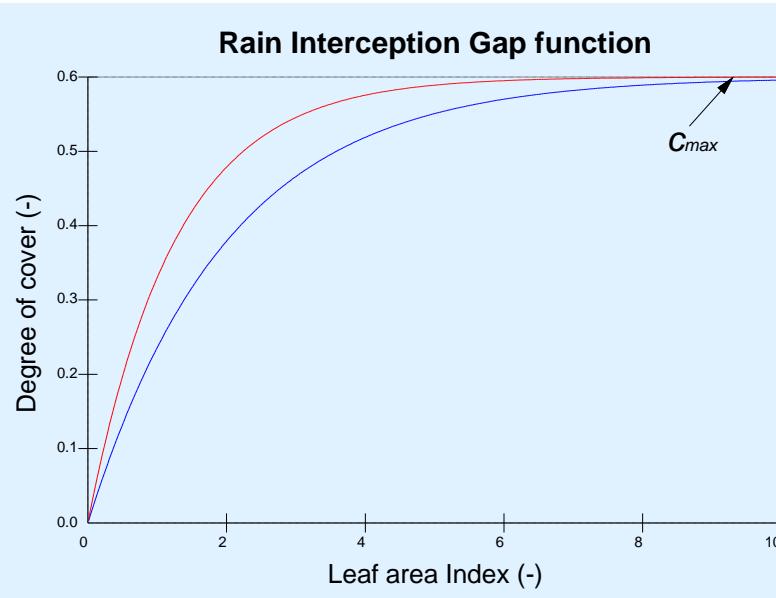
The amount of intercepted water increases with higher leaf area index. The relationship is determined by the parameter i_{LAI} . For the blue line this parameter was put to 0.2 and for the green 0.1. The turquoise line shows the effect of altering the parameter i_{base} from 0 to 0.5.

Potential interception evaporation



The potential evaporation rate, calculated with the Penman equation, decreases with increasing aerodynamic resistance.

Rain Interception Canopy Cover Function



The surface cover function for calculating drops from one canopy to another canopy below. The parameter c_{LAI}_{sens} changes the slope of the curve (blue=0.5, red=0.8).

State Variables

Canopy IntercStorage

Actual interception storage of each canopy.
mm

Flow Variables

Canopy Interc ActEva

Actual evaporation rate from the interception storage of each canopy.
mm/day

Auxiliary Variables

Canopy Interc Capac

Interception capacity for each canopy.
mm

Canopy Interc PotEva

Potential evaporation rate from interception storage of each canopy when simulating multiple plants.
mm/day

Interceptedwater_ThQ

Thermal quality (fraction of frozen water) of intercepted precipitation (end of time-step).
-

InterceptionActEva

Actual interception rate from interception storage of a single canopy
mm/day

InterceptionCapacity

Interception capacity of a single canopy.
mm

InterceptionPotEva

Potential evaporation rate from intercepted storage of a single canopy.
mm/day

InterceptionRate

Actual interception rate of a single canopy
mm/day

InterceptionStorage

Actual interception storage of a single canopy
mm

Throughfall

Total throughfall to soil/snow
mm/day

Soil evaporation, Snow and Radiation processes

David Gustafsson, Per-Erik Jansson, Gunnel Alvenäs & Elisabet Lewan

Evaporation from the soil surface

Evaporation from the soil surface (“Soil evaporation”) can be calculated by two different approaches in the model: (a) by a more empirical approach based on the Penman-Monteith equation and (b) by a more physically based approach, which is based on an iterative solution of the surface energy balance including both water and heat fluxes at the soil surface. The empirical approach is normally used when the water balance conditions are of major interest. It does not influence the soil surface temperature or heat flow. The iterative solution of the energy balance is recommended when the feedback between temperature and water conditions is of interest. Any of these alternative approaches can be chosen with the switch “[Evaporation Method](#)”. The physically based approach corresponds to the option “Iterative Energy Balance” and is described below under “[Surface energy balance approach](#)”. The other options except for “Not Estimated” applies to the empirical approach and are described under “[Empirical approach for soil evaporation](#)”.

Partitioning of net radiation

Common to both approaches is the partitioning of net radiation between the plant canopy and the soil surface assuming the Beer’s law to be valid (Impens & Lemeur, 1969):

$$R_{ns} = R_{n,tot} e^{-k_m A_l} \quad (4.1)$$

where $R_{n,tot}$ is the net radiation above the plant canopy, R_{ns} is the net radiation at the soil surface, k_m is an extinction coefficient and A_l is the leaf area index. The partitioning of net radiation between plant canopies and the soil is calculated slightly different if the multiple plant option is used, which is described in detail below in section “[Radiation processes](#)”.

The energy fluxes and resistances in the soil-plant-atmosphere system are illustrated below (see [Figure 4.1](#)). The net radiation above the plant canopy, $R_{n,tot}$, is partly intercepted by the canopy according to Beer’s law described above. The remaining radiation at the soil surface, R_{ns} , is balanced against latent heat flux to the air, $L_v E_s$, sensible heat flux to the air, H_s , and the heat flux to the soil, q_b . The soil evaporation, E_s , is thus estimated from the latent heat flux, $L_v E_s$, (i.e. the

energy used for evaporating water from the surface). Several resistances act on the fluxes of energy e.g. soil surface resistance, r_{ss} , canopy resistance, r_s , aerodynamic resistance above the canopy, r_a and the aerodynamic resistance from the soil to the reference height above the canopy, r_{as} .

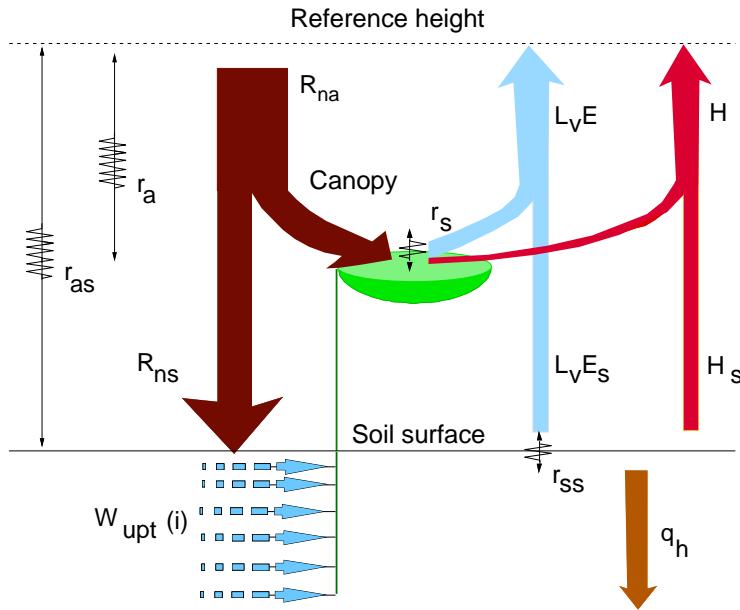


Figure 4.1. The energy flows and resistances at and above the canopy and soil surfaces. R_{na} is the same as $R_{n,tot}$

Surface energy balance approach

The physically based approach, for calculating soil evaporation, originates from the idea of solving an energy balance equation for the soil surface. According to the law of conservation of energy the net radiation at the soil surface, R_{ns} , is assumed to be equal to the sum of latent heat flux, L_vE_s , sensible heat flux, H_s and heat flux to the soil, q_h :

$$R_{ns} = L_vE_s + H_s + q_h \quad (4.2)$$

The three different heat fluxes are estimated by an iterative procedure where the soil surface temperature, T_s , is varied according to a given scheme until eq. (4.2) is balanced:

$$H_s = \rho_a c_p \frac{(T_s - T_a)}{r_{as}} \quad (4.3)$$

$$L_vE_s = \frac{\rho_a c_p}{\gamma} \frac{(e_{surf} - e_a)}{r_{as}} \quad (4.4)$$

$$q_h = k_h \frac{(T_s - T_1)}{\frac{\Delta z_1}{2}} + L q_{v,s} \quad (4.5)$$

where r_{as} is the aerodynamic resistance calculated as a function of wind and temperature gradients (Eq. (4.12) - (4.24)), k_h is the thermal conductivity of the top soil layer, e_{surf} is the vapour pressure at the soil surface (eq. (4.7)) and e_a is the actual vapour pressure in the air. The density, ρ_a , heat capacity of air, c_p , the latent heat of vaporisation, L_v , as well as the psychrometer constant, κ are all considered as physical constants. The vapour flow, $q_{v,s}$, (following eq. 2.12) from the soil surface to the central point of the uppermost compartment is given by:

$$q_{v,s} = -d_{vapb} f_a D_0(T) \frac{c_{v1} - c_{vs}}{\Delta z} \quad (4.6)$$

where d_{vapb} is the tortuosity given as an empirical parameter, D_0 is the diffusion coefficient for a given temperature, f_a is the fraction of air filled pores ($\theta_s - \theta$) and c_{vs} and c_{v1} are the concentrations of water vapour at the soil surface and at the middle of the uppermost compartment respectively.

A plastic sheet can optionally be included in the simulation (see switch “Surface cover”). This sheet prevents soil evaporation from the fraction, $i_{scovevap}$.

Vapour pressure at the soil surface

Vapour pressure at the soil surface is given by the surface temperature, T_s , the water tension of the uppermost layer, Ψ_L , and an empirical correction factor, e_{corr} , accounting for steep gradients in moisture between the uppermost layer and the soil surface (Alvenäs & Jansson, 1997):

$$e_{surf} = e_s(T_s) e^{\left(\frac{-\Psi_L M_{water} g e_{corr}}{R(T_s + T_{abszero})} \right)} \quad (4.7)$$

where R is the gas constant, M_{water} is the molar mass of water, g is the gravity constant and e_s is the vapour pressure at saturation (see viewing function “Vapour pressure at the soil surface”).

The empirical correction factor, e_{corr} , depends on an empirical parameter ψ_{eg} and a calculated mass balance at the soil surface, δ_{surf} , which is allowed to vary between the parameters s_{def} and s_{excess} given in mm of water.

$$e_{corr} = 10^{(-\delta_{surf} \psi_{eg})} \quad (4.8)$$

$$\begin{aligned} \delta_{surf}(t) = \max(s_{def}, \min \\ (s_{excess}, \delta_{surf}(t-1) + W_{pool} + (q_{in} - E_s - q_{v,s} + i_{drip}(z_1)) \Delta t)) \end{aligned} \quad (4.9)$$

where W_{pool} is the surface water pool, q_{in} is the infiltration rate, E_s is the evaporation rate, $q_{v,s}$, is the vapour flow from soil surface to the central point of the uppermost soil layer, and i_{drip} is the irrigation rate to the uppermost soil layer.

Resistance approach for soil heat flow

The soil surface heat flux is calculated using a simplified resistance approach when a daily time resolution is used (i.e. if the “daily mean values”-option is chosen under “Run options” in Common Characteristics). The soil surface heat flux is then given by:

$$q_h = \frac{T_s - T_1}{r_{soil}} \quad (4.10)$$

where the r_{soil} represents the integrated resistance of the uppermost 20 cm of the soil profile:

$$r_{soil} = \sum_i \frac{\Delta z_i}{k_{h,i}} , 0 < z_i \leq 20\text{cm} \quad (4.11)$$

where Δz is the thickness of the soil layers, and z is the mid-point of the soil layers.

Aerodynamic resistance with stability correction below vegetation canopy

The aerodynamic resistance above the soil surface, r_{as} , is calculated as a sum of two components – a function of wind speed and temperature gradients, r_{aa} , which is corrected for atmospheric stability, and an additional resistance representing the influence of the crop cover, r_{ab} (see viewing function “[Aerodynamic Resistance, \$r_{as}\$](#) ”):

$$r_{as} = r_{aa} + r_{ab} \quad (4.12)$$

The influence of the crop canopy on the aerodynamic resistance above the soil surface is made proportional to the leaf area index, A_l :

$$r_{ab} = r_{alai} A_l \quad (4.13)$$

where r_{alai} is an empirical parameter (see viewing function “[Aerodynamic Resistance below canopy, \$r_{ab}\$](#) ”).

The influence of atmospheric stability on the aerodynamic resistance, r_{aa} , can be calculated either as (**I**) an analytical function of the Richardson number or (**II**) as a function of the Monin-Obukhov stability parameter (see switch “[Stability Correction](#)”). Method (**I**) is preferred from a computational point of view, since (**II**) involves an iterative solution of the relation between the Richardson number and the Monin-Obukhov stability parameter (Eq.(4.19)). However, only method (**II**) allows for a consistent treatment of variations in the roughness lengths for momentum and heat.

(**I**) The aerodynamic resistance at neutral conditions is multiplied by an analytical stability function:

$$r_{aa} = \frac{1}{k^2 u} \ln \left(\frac{z_{ref} - d}{z_{0M}} \right) \ln \left(\frac{z_{ref} - d}{z_{0H}} \right) f(R_{ib}) \quad (4.14)$$

where u is the wind speed at the reference height, z_{ref} , d is the zero level displacement height (c.f. Potential Transpiration in Plant Water Processes), R_{ib} is the bulk Richardson number (eq.(4.17)), k is the von Karmans constant and z_{0M} and z_{0H} are the surface roughness lengths for momentum and heat respectively. If z_{0M} is exchanged to $z_{0M,snow}$ the equation can be used for snow surfaces. $f(R_{ib})$ is a function that governs the influence of atmospheric stability:

$$f(R_{ib}) = \begin{cases} (1 + a_{ri,1} R_{ib})^{b_{ri,1}} & , R_{ib} > 0 \\ (1 - a_{ri,2} R_{ib})^{-b_{ri,2}} & , R_{ib} \leq 0 \end{cases} \quad (4.15)$$

where $a_{ri,1}$, $b_{ri,1}$, $a_{ri,2}$ and $b_{ri,2}$ are empirical parameters.

The surface roughness length of momentum, z_{0M} , can either be given as a specific parameter for different sub-surfaces (i.e. bare soil, snow and canopies) or as a function of canopy height (c.f. “Potential transpiration” in Plant Water Processes). The surface roughness length of heat, z_{0H} , is then derived from:

$$kB^{-1} = \ln\left(\frac{z_{0M}}{z_{0H}}\right) \quad (4.16)$$

where $\underline{kB}^{\text{l}}$ is a parameter with a default value 0 (implies $z_{0H}=z_{0M}$). The parameter is the product of a von Karmans constant, \underline{k} , and a parameter, B , but since it is often found in the literature as $\underline{kB}^{\text{l}}$ we have kept it as such in the model.

The bulk Richardson's number is calculated as:

$$R_{ib} = \frac{g}{(T_a + 273.15)} \frac{(T_a - T_s)}{u^2} (z_{ref} - d) \quad (4.17)$$

(II) The aerodynamic resistance as a function of the Monin-Obukhov stability parameter, (adopted from Beljaars and Holtslag, 1991):

$$\begin{aligned} r_{aa} = & \frac{1}{k^2 u} \left\{ \ln\left(\frac{z_{ref} - d}{z_{0M}}\right) - \psi_M\left(\frac{z_{ref} - d}{L_O}\right) + \psi_M\left(\frac{z_{0M}}{L_O}\right) \right\} \times \\ & \times \left\{ \ln\left(\frac{z_{ref} - d}{z_{0H}}\right) - \psi_H\left(\frac{z_{ref} - d}{L_O}\right) + \psi_H\left(\frac{z_{0H}}{L_O}\right) \right\} \end{aligned} \quad (4.18)$$

where L_O is the Obukhov length and ψ_M and ψ_H are empirical stability functions for momentum and heat respectively (unfortunately the nomenclature coincides with that for latent heat of vaporisation and water tension). The relation between the Obukhov length and the Richardson number is specified by the following equation:

$$\frac{z_{ref} - d}{L_O} = R_{ib} \frac{\left(\ln\left(\frac{z_{ref} - d}{z_{0M}}\right) - \psi_M\left(\frac{z_{ref} - d}{L_O}\right) + \psi_M\left(\frac{z_{0M}}{L_O}\right) \right)^2}{\left(\ln\left(\frac{z_{ref} - d}{z_{0H}}\right) - \psi_H\left(\frac{z_{ref} - d}{L_O}\right) + \psi_H\left(\frac{z_{0H}}{L_O}\right) \right)} \quad (4.19)$$

which is solved by an iterative procedure following Beljars and Holtslag (1991). The empirical stability functions is calculated for *unstable conditions* ($(z_{ref}-d)/L_O < 0$) by:

$$\psi_M = 2 \ln\left[\left(1+x\right)/2\right] + \ln\left[\left(1+x^2\right)/2\right] - 2 \arctan(x) + \pi/2 \quad (4.20)$$

and

$$\psi_H = 2 \ln\left[\left(1+x^2\right)/2\right] \quad (4.21)$$

where

$$x = \left(1 - a_{z/L} (z_{ref} - d) / L_o\right)^{1/4} \quad (4.22)$$

where the non-optional parameter value $a_{z/L}=19$ was taken from Högström (1996).

For *stable conditions* ($(z_{ref}-d)/L_o > 0$) the empirical stability function is instead calculated as:

$$-\psi_M = \alpha \frac{z_{ref} - d}{L_o} + \beta \left(\frac{z_{ref} - d}{L_o} - \frac{\gamma}{\delta} \right) \exp \left(-\delta \frac{z_{ref} - d}{L_o} \right) + \frac{\beta \gamma}{\delta} \quad (4.23)$$

$$-\psi_H = \left(1 + \alpha \frac{2}{3} \frac{z_{ref} - d}{L_o} \right)^{3/2} + \beta \left(\frac{z_{ref} - d}{L_o} - \frac{\gamma}{\delta} \right) \exp \left(-\delta \frac{z_{ref} - d}{L_o} \right) + \frac{\beta \gamma}{\delta} \quad (4.24)$$

following Bejaars and Holtslag (1991), with the non-optional parameter values $\alpha=1$, $\beta=0.667$, $\gamma=5$ and $\delta=0.35$.

Furthermore, an upper limit of the aerodynamic resistance in extreme stable conditions is set by the “windless exchange” coefficient, $r_{a,soil,max}^{-1}$, adopted from Jordan (1991). It is applied in both (I) and (II):

$$r_{aa} = \left(\frac{1}{r_{aa}} + r_{a,max}^{-1} \right)^{-1} \quad (4.25)$$

Empirical approach for soil evaporation

The empirical approach for soil evaporation is based on the Penman combination equation¹ as suggested by Monteith (1965). It uses the available energy at the soil surface, $R_{ns} - q_h$, to calculate latent heat flux from the soil surface, $L_v E_s$, from which the soil surface evaporation, E_s , can be derived:

$$L_v E_s = \frac{\Delta(R_{ns} - q_h) + \rho_a c_p \frac{(e_s - e)}{r_{as}}}{\Delta + \gamma \left(1 + \frac{r_{ss}}{r_{as}} \right)} \quad (4.26)$$

where R_{ns} is the net radiation at the soil surface, q_h is the soil surface heat flux from the previous time step, r_{as} is the aerodynamic resistance, r_{ss} is the surface resistance at the soil surface, e_s is the vapour pressure at saturation in the air, e_a is the actual vapour pressure in the air, and Δ is the slope of saturated vapour pressure versus temperature curve. The density, ρ_a , and heat capacity, c_p , of air, the latent heat of vaporisation, L_v , as well as the psychrometer constant, γ are all considered as physical constants.

The aerodynamic resistance between the soil surface and the reference height, r_{as} , is calculated in the same way as in the physically based approach using Eq. (4.12)- (4.15).

¹ Elsewhere referred to as the “Penman-Monteith equation”.

The surface resistance at the soil surface, r_{ss} , can be estimated by two different empirical functions accounting for moisture conditions at the soil surface and the water tension in the uppermost soil layer. The first approach (“PM-eq, Rs(1Par)”) is based on only one governing parameter:

$$r_{ss} = \begin{cases} r_\psi (\log \psi_s - 1 - \delta_{surf}) & \psi_s > 100 \\ r_\psi (1 - \delta_{surf}) & \psi_s \leq 100 \end{cases} \quad (4.27)$$

where r_ψ is an empirical coefficient and ψ_s is the water tension in the uppermost layer (see viewing function “[Surface Resistance, Penman eq. 1 par](#)”). The δ_{surf} is the mass balance at the soil surface in units mm of water (see eq. 4.9).

The second approach (“PM-eq, Rs(3Par)”) is based on three governing parameters:

$$r_{ss} = \max(0, r_{\psi 1} \max(\psi_s - r_{\psi 2}, 0) - r_{\psi 3} \delta_{surf}) \quad (4.28)$$

where $r_{\psi 1}$, $r_{\psi 2}$ and $r_{\psi 3}$ are empirical coefficients (see viewing function “[Surface Resistance, Penman eq. 3 par](#)”).

Optionally, (“K-function”) the soil evaporation can be estimated as the minimum value of the flow rate that could be supplied from the middle point of the uppermost soil layer and the potential rate according to Eq. (4.26) taking $r_{ss}=0$. The soil surface temperature will also be estimated (for all of the three approaches described above) if the switch “[Surface cover](#)

Value	Meaning
No	No surface cover
Plastic sheet	A plastic sheet covering parts of the soil and thus preventing soil evaporation.

[Surface Temperature](#)” is put to “f(PM-equation)”. This is done by first solving the heat balance equation for the sensible heat flow to the air as:

$$H_s = R_{ns} - LE_s - q_h \quad (4.29)$$

where the soil surface heat flux, q_h , is taken from the preceding time steps. The soil surface temperature is finally given as:

$$T_s = \frac{H_s r_{as}}{\rho_a c_p} + T_a \quad (4.30)$$

Alternatively the soil surface temperature can be set equal to the air temperature except when snow covers the surface (option “Air temperature”).

Restrictions of soil evaporation

Independently of the choice of evaporation method, the estimated soil evaporation is limited to the fraction of snow free ground, for the calculation of the water balance of the uppermost soil layer. If condensation is predicted, the estimated (negative) soil evaporation is also restricted to a maximum rate, $e_{max,cond}$:

$$E_s = \max(-1 \cdot e_{max,cond}, L_v E_s / L_v) \cdot f_{bare} \quad (4.31)$$

where f_{bare} is the fraction of bare soil. The soil evaporation is finally restricted to a limited portion of the soil water content of the upper most soil layer (arbitrarily chosen to 10%), to avoid negative soil moisture contents:

$$E_s = \min(E_s, \max(0, 0.10 \cdot \theta_1 / \Delta t)) \quad (4.32)$$

The numerical restrictions on the mass flux of water have not yet been incorporated in the heat balance.

Partitioning of soil evaporation

Soil evaporation can be calculated separately for two different types of surfaces if the surfaces differ such as in the case of drip irrigation (see switch “[SoilPartitioningArea](#)”). This approach is only applicable when soil evaporation is calculated with the surface energy balance approach. The division of the soil surface into two sections is defined by the parameter s_{frac} , which determines the fraction of the surface belonging to area one. In the case of drip irrigation s_{frac} equals i_{cover} . Soil evaporation is thus calculated with Eqs. [\(4.2\)-\(4.9\)](#) for each section of the soil, and including the irrigation rate, i_{drip} , in Eq. [\(4.9\)](#).

Plants may shadow the two sections of the soil differently, which can optionally be included in the simulation (see switch “[SoilPartitioningArea](#)” third option). In order to calculate the different amounts of radiation to each soil section, the position of the centre point in section one has to be known. In the case of drip irrigation this position is determined by the parameter i_{pos} . Radiation is distributed through the canopy as explained in the section “[Radiation processes](#)”. Different values of net and long wave radiation to the ground, as well as the fraction of radiation absorbed by the canopy are calculated for each section and used separately in eqs. [\(4.2\)-\(4.9\)](#) to calculate soil evaporation (as explained above).

If the partitioned soil evaporation is combined with a plastic sheet, the uncovered soil fraction is assumed to be wet. Only if the uncovered soil fraction is larger than the wetted surface will soil evaporation also take place from the dry area.

Switches

Evaporation Method

Value	Meaning
Not Estimated	Soil evaporation is not accounted for.
PM-eq, Rs(1Par)	Soil evaporation is calculated using the Penman-Monteith equation and a simple function for the surface resistance of the soil using an estimated surface storage and one governing parameter.
PM-eq, Rs(3Par)	Soil evaporation is calculated using the Penman-Monteith equation and a simple function for the surface resistance of the soil using an estimated surface storage and three governing parameters.
Iterative Energy Balance	Soil evaporation is derived from an iterative solution of the soil surface energy balance of the soil surface, using an empirical parameter for estimating the vapour pressure and temperature at the soil surface.
K-function	Soil evaporation is simply taken as the minimum value of the flow rate that could be supplied from the middle point of the uppermost soil layer to the soil surface and the potential rate as calculated by the Penman-Monteith equation with surface resistance set to zero.

SoilPartitioningArea

Value	Meaning
No	Soil evaporation is calculated from the whole surface area.

Based on Drip Irrig	Soil evaporation is calculated separately from the area irrigated by the emitters and the rest of the soil.
Based on Drip Irrig and Radiation	Soil evaporation is calculated separately from the area irrigated by the emitters and the rest of the soil. Radiation interception by the plant canopy is accounted for.

SoilRoughness

Value	Meaning
CommonR	One common roughness value is used for all evaporation surfaces: bare soil, snow, and canopy. That means that the (largest in case of a multiple canopy) canopy roughness is used if there is a canopy present, otherwise the individual bare soil roughness value is used.
IndividualR	Each evaporating surface has its own roughness value

Stability Correction

Value	Meaning
f(Richardson Number)	The aerodynamic resistance is estimated as a function of Richardson number.
f(Monin-Obukhov Length)	The aerodynamic resistance is estimated as a function of the Monin-Obukhov stability parameter $(z_{ref} - d)/L_O$. Richardsons number is transformed into the Monin-Obukhov parameter by an iterative procedure which may slow down the simulations. On the other hand, variations of surface roughness for momentum and heat are treated in a consistent way.

Surface cover

Value	Meaning
No	No surface cover
Plastic sheet	A plastic sheet covering parts of the soil and thus preventing soil evaporation.

Surface Temperature

Value	Meaning
Air Temperature	Assumed to equal air temperature except when snow occurs on the soil.

f(PM-equation)	Estimated from the surface sensible heat flux, which is calculated as the residual of the surface energy balance using the soil evaporation rate as calculated by the P-M equation. The switch “Evaporation Method” must be set to either “PM-Eq, (1Par)”, “PM-Eq., (3Par)” or “K-function” to be able to use this option.
f(E-balance Solution)	Iterative numerical solution also used for estimating the soil evaporation and vapour pressure at the soil surface. The switch “Evaporation Method” must be set to “Iterative Energy Balance” to be able to use this option.

Parameters

EquilAdjustPsi

Factor to account for differences between water tension in the middle of top layer and actual vapour pressure at soil surface.

Default	Unit	Symbol	Equation	Function
1	-	ψ_{eg}	(4.7), (4.8)	“Vapour pressure at the soil surface”

Normal values ranges from 0 to 2. 0 implies that there is no difference in soil moisture between the soil surface and the uppermost soil layer. 1 implies that the surface can be two orders of magnitudes drier and one order of magnitude wetter than the uppermost soil layer, if the “MaxSurf” parameters are set to default values.

KBMinusOne

Difference between the natural logarithm of surface roughness length for momentum and heat (or moisture) respectively. Theoretically the kB^{-1} should increase with the aerodynamic roughness of the surface due to the different mechanisms responsible for transfer of momentum and scalars like heat and moisture. Field measurements indicate that this is the case above low to medium rough surfaces like grass land and crops with $kB^{-1} \approx 2.3$ ($z_{OM}/z_{OH}=10$) (Garrat, 1993). Sparse roughness elements also tend to enlarge the momentum transport compared to heat transport (Beljaars and Holtslag, 1991). However, kB^{-1} can be found to decrease above very rough forest surfaces due to a deep roughness sub-layer, which enhances the heat transport (Mölder et al 1999).

Default	Unit	Symbol	Equation	Function
0	-	kB^{-1}	(4.16)	

MaxSoilCondens

A threshold for the maximal allowed condensation rate that is accounted for in the water budget of the uppermost layer.

Default	Unit	Symbol	Equation	Function
2	mm/day	$e_{max,cond}$	(4.31)	

MaxSurfDeficit

The lowest value allowed for the δ_{surf} variable, which is used in the calculations of soil surface resistance and vapour pressure at the soil surface.

Default	Unit	Symbol	Equation	Function
-2	mm	s_{def}	(4.9)	“Surface Resistance, Penman eq. 1 par” and “Surface Resistance, Penman eq. 3 par”

PsiRs_1p

The highest value allowed for the δ_{surf} variable, which is used in the calculations of soil surface resistance and vapour pressure at the soil surface.

Default	Unit	Symbol	Equation	Function
1	mm	s_{excess}	(4.9)	“Surface Resistance, Penman eq. 1 par” and “Surface Resistance, Penman eq. 3 par”

PsiRs_3pf1

Governs the relationship between the actual surface resistance of the soil surface and the soil water tension of the uppermost layer and the surface gradient of soil moisture.

Default	Unit	Symbol	Equation	Function
200	s/m	r_ψ	(4.27)	“Surface Resistance, Penman eq. 1 par”

PsiRs_3pf1

Governs the relationship between the actual surface resistance of the soil surface and the soil water tension in the uppermost layer and the surface gradient of soil moisture.

Default	Unit	Symbol	Equation	Function
1	s/m	$r_{\psi l}$	(4.28)	“Surface Resistance, Penman eq. 3 par”

PsiRs_3pf2

See PsiRs_3pf1

Default	Unit	Symbol	Equation	Function
300	s/m	$r_{\psi 2}$	(4.28)	“Surface Resistance, Penman eq. 3 par”

PsiRs_3pf3

See [PsiRs_3pf1](#)

Default	Unit	Symbol	Equation	Function
100	s/(m mm)	$r_{\psi 3}$	(4.28)	“ Surface Resistance, Penman eq. 3 par ”

RaincreaseWithLAI

The contribution of LAI to the total aerodynamic resistance from measurement height (reference level) to the soil surface.

Default	Unit	Symbol	Equation	Function
50	s/m	r_{alai}	(4.13)	“ Aerodynamic Resistance below canopy, r_ab ”

RoughLBareSoilMom

Surface roughness length for momentum above bare soil.

Default	Unit	Symbol	Equation	Function
0.001	m	z_{0M}	(4.14), (4.18)	“ Aerodynamic Resistance, r_as ”

SoilCoverEvap

Surface cover fraction when the soil surface is covered by a plastic sheet.

Default	Unit	Symbol	Equation	Function
0	-	$i_{scovevap}$		

StabCoefStableRich

Parameter in the analytical stability correction of the aerodynamic resistance above the soil surface – multiplicative factor in front of the Richardson number during stable conditions. Use the view function to compare the exchange coefficients calculated with the Richardson number formulation and the Monin-Obukhov length formulation.

Default	Unit	Symbol	Equation	Function
16	-	$a_{Ri,I}$	(4.15)	

StabCoefStableExp

Parameter in the analytical stability correction of the aerodynamic resistance above the soil surface – exponent of the Richardson number during stable conditions. Use the view function to compare the exchange coefficients calculated with the Richardson number formulation and the Monin-Obukhov length formulation.

Default	Unit	Symbol	Equation	Function
0.333	-	$b_{Ri,I}$	(4.15)	

StabCoefUnstableRich

Parameter in the analytical stability correction of the aerodynamic resistance above the soil surface – multiplicative factor in front of the Richardson number during unstable conditions. Use the view function to compare the exchange coefficients calculated with the Richardson number formulation and the Monin-Obukhov length formulation.

Default	Unit	Symbol	Equation	Function
16	-	$a_{Ri,2}$	(4.15)	

StabCoefUnstableExp

Parameter in the analytical stability correction of the aerodynamic resistance above the soil surface – exponent of the Richardson number during unstable conditions. Use the view function to compare the exchange coefficients calculated with the Richardson number formulation and the Monin-Obukhov length formulation.

Default	Unit	Symbol	Equation	Function
0.333	-	$b_{Ri,2}$	(4.15)	

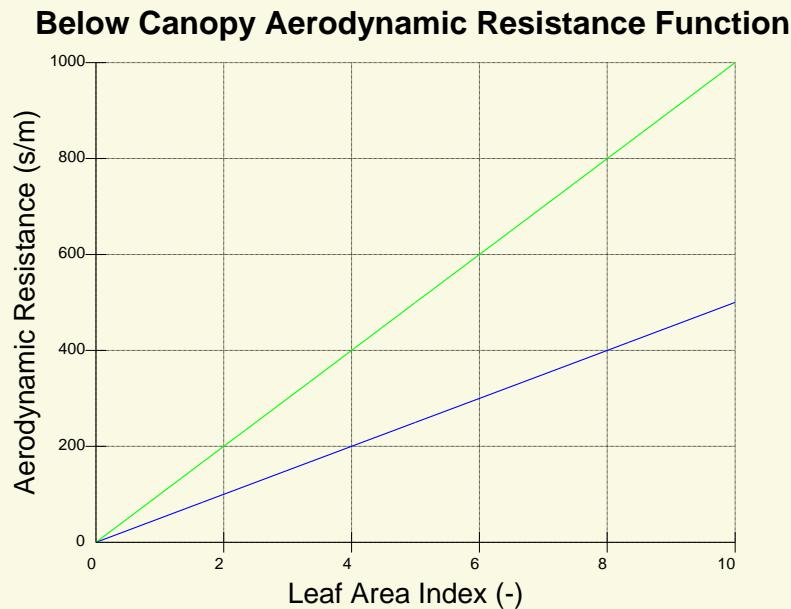
WindLessExchangeSoil

Minimum turbulent exchange coefficient (inverse of maximum allowed aerodynamic resistance) over bare soil. Avoids exaggerated surface cooling in windless conditions or extreme stable stratification.

Default	Unit	Symbol	Equation	Function
0.001	-	$r_{a,soil,max}^{-1}$	(4.25)	

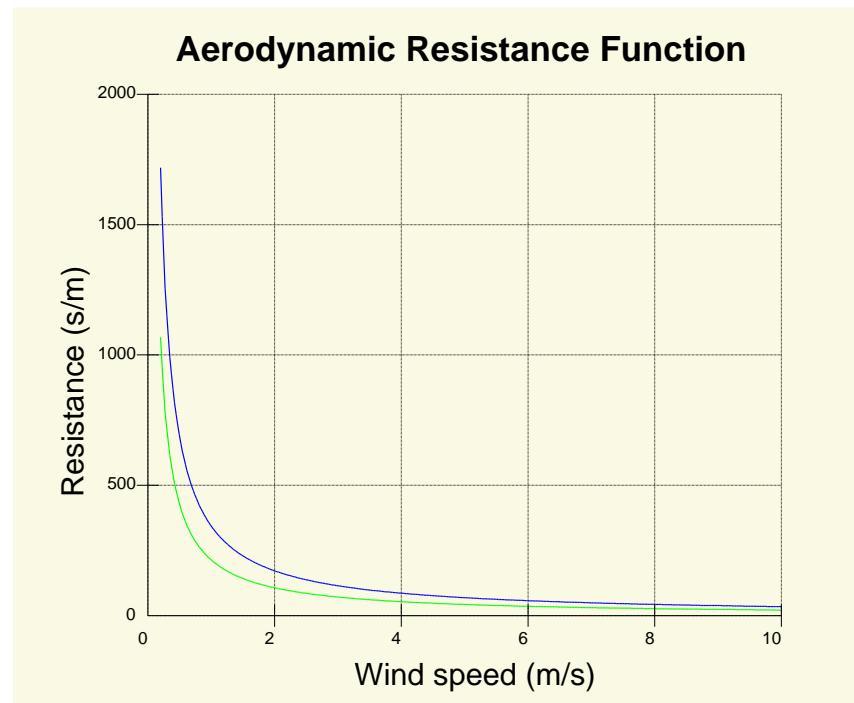
Viewing Functions

Aerodynamic Resistance below canopy, r_{ab}



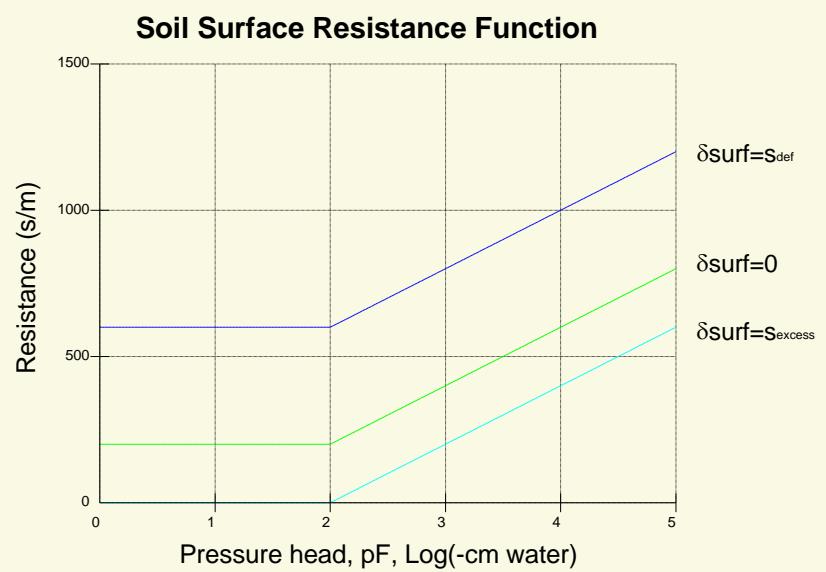
The aerodynamic resistance increases linearly with leaf area index, as determined by the parameter r_{ab} (blue = 50, green = 100).

Aerodynamic Resistance, r_{as}



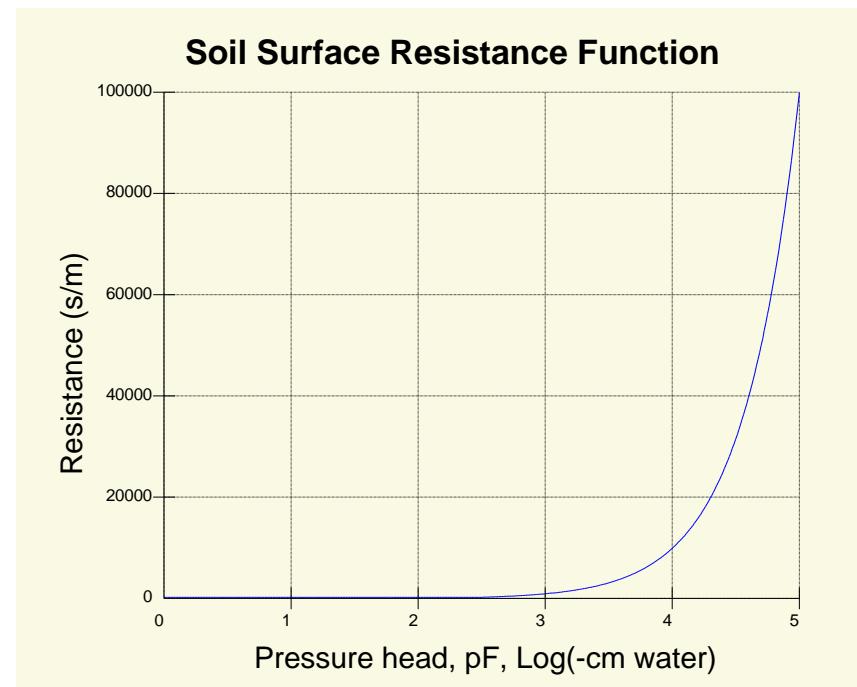
The aerodynamic resistance decreases with increasing wind speed. The plot shows the effect on resistance of different roughness lengths, z_{0M} : blue = 0.001, green = 0.005).

Surface Resistance, Penman eq. 1 par



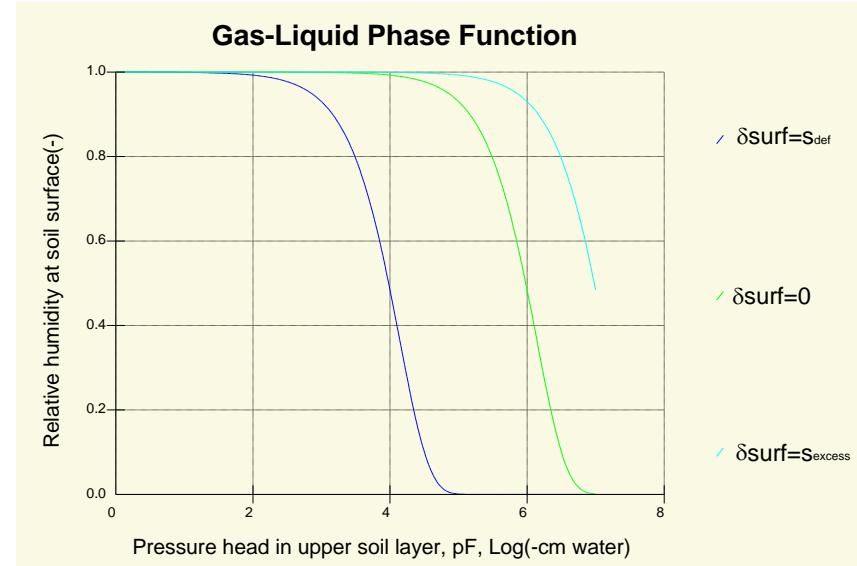
The surface resistance as a function of the water tension (pressure head) in the uppermost soil layer. PsiRs 1p = 200.

Surface Resistance, Penman eq. 3 par



The surface resistance as a function of the water tension (pressure head) in the uppermost soil layer. PsiRs 3pf1 = 1, PsiRs 3pf2 = 300, PsiRs 3pf3 = 100.

Vapour pressure at the soil surface



The relative humidity at the soil surface as a function of the pressure head in the upper soil layer after stability corrections. $\psi_{eg} = 1$.

Flow Variables

SoilEvaporation

The evaporation from the soil surface
mm/day

SoilEvaporation1

The evaporation from section one of the soil surface
mm/day

SoilEvaporation2

The evaporation from section two of the soil surface
mm/day

SurfHeatFlow1

The surface heat flow from section one of the soil surface
 $\text{Jm}^{-2}\text{day}^{-1}$

SurfHeatFlow2

The surface heat flow from section two of the soil surface
 $\text{Jm}^{-2}\text{day}^{-1}$

Auxiliary Variables

EAvailableSurf

Heat flux available for evaporation from the soil surface (Net radiation-Soil surface heat flux) used in the Penman-Monteith estimations of soil evaporation
 $\text{Jm}^{-2}\text{day}^{-1}$

EBalanceClosure

Residual heat flux in the iterative solution of the soil surface energy balance.
 $\text{Jm}^{-2}\text{day}^{-1}$

EBalanceClosure1

Residual heat flux in the iterative solution of the soil surface (section one) energy balance.
 $\text{Jm}^{-2}\text{day}^{-1}$

EBalanceClosure2

Residual heat flux in the iterative solution of the soil surface (section two) energy balance.
 $\text{Jm}^{-2}\text{day}^{-1}$

Fraction of soil Area1

Fraction of the soil that area one is covering.

-

MO-StabParBareSoil

The Monin-Obukhov stability parameter, $\zeta = (z_{ref} - D) / L_O$, estimated over bare soil. The output should be regarded as an auxiliary in the estimation process of the aerodynamic resistance above bare soil.
m

PotEvapGround

The potential evaporation from the soil surface, defined by the Penman-Monteith equation.
 mm day^{-1}

RadNetBareSoil

Net radiation at the bare soil surface, estimated by the iterative solution of the soil surface energy balance equation.
 $\text{J m}^{-2} \text{ day}^{-1}$

RadNetBareSoil1

Net radiation at the bare soil surface (section one), estimated by the iterative solution of the soil surface energy balance equation.
 $\text{J m}^{-2} \text{ day}^{-1}$

RadNetBareSoil2

Net radiation at the bare soil surface (section two), estimated by the iterative solution of the soil surface energy balance equation.
 $\text{J m}^{-2} \text{ day}^{-1}$

ResAirAboveSoil

Aerodynamic resistance (for heat) between the reference height and the bare soil surface.
 sm^{-1}

ResAirAboveSoil1

Aerodynamic resistance (for heat) between the reference height and the bare soil surface (section one).
 sm^{-1}

ResAirAboveSoil2

Aerodynamic resistance (for heat) between the reference height and the bare soil surface (section two).
 sm^{-1}

ResSoilSurface

Estimated surface resistance for bare soil evaporation, used in the Penman-Monteith estimates.
 sm^{-1}

SoilLatentFlow

Latent heat flux between the bare soil surface and the reference height in the atmosphere (*positive direction is upwards*).
 $\text{J m}^{-2} \text{ day}^{-1}$

SoilLatentFlow1

Latent heat flux between the bare soil surface (section one) and the reference height in the atmosphere (*positive direction is upwards*).
 $\text{J m}^{-2} \text{ day}^{-1}$

SoilLatentFlow2

Latent heat flux between the bare soil surface (section two) and the reference height in the atmosphere (*positive direction is upwards*).

Jm⁻²day⁻¹

SoilSensibleFlow

Sensible heat flux between the bare soil surface and the reference height in the atmosphere (*positive direction is upwards*).

Jm⁻²day⁻¹

SoilSensibleFlow1

Sensible heat flux between the bare soil surface (section one) and the reference height in the atmosphere (*positive direction is upwards*).

Jm⁻²day⁻¹

SoilSensibleFlow2

Sensible heat flux between the bare soil surface (section two) and the reference height in the atmosphere (*positive direction is upwards*).

Jm⁻²day⁻¹

SurfmoistureBalance

Mass balance of water at the soil surface.

mm

SurfmoistureBalance1

Mass balance of water at the soil surface (section one).

mm

SurfmoistureBalance2

Mass balance of water at the soil surface (section two).

mm

TempBareSoil

Temperature of the bare soil surface (This temperature may be different from the soil surface temperature *TempSoilSurf*, which is calculated as a weighed mean of *TempBareSoil* and *TempSoilUnderSnow*).

°C

TempBareSoil1

Temperature of the bare soil surface (section one). This temperature may be different from the soil surface temperature *TempSoilSurf*, which is calculated as a weighed mean of *TempBareSoil* and *TempSoilUnderSnow*.

°C

TempBareSoil2

Temperature of the bare soil surface (section two). This temperature may be different from the soil surface temperature *TempSoilSurf*, which is calculated as a weighed mean of *TempBareSoil* and *TempSoilUnderSnow*.

°C

VapourPSurf

Vapour pressure at the bare soil surface.
Pa

WindspeedSoil

The output should be regarded as an auxiliary in the estimation process of the aerodynamic resistance above bare soil.
 ms^{-1}

Snow Dynamics

Snow conditions are considered both as a water storage and boundary condition for soil water flows and as an important factor influencing the soil heat boundary condition. Precipitation is divided into rain and snow, depending on the values assigned to threshold parameters. Melting of snow is based on global radiation, air temperature and the heat flux from the soil. The melting caused by global radiation is to some extent controlled by snow age. Liquid water retained in the snow can also refreeze. The thermal conductivity of snow is estimated from snow density. During melting the soil surface temperature is put to 0. The energy balance calculations of the snow surface are used to estimate snow surface temperature and sensible and latent heat fluxes, but these fluxes are not incorporated in the present mass balance of the model. The heat storage of snow is not explicit in the present snow model

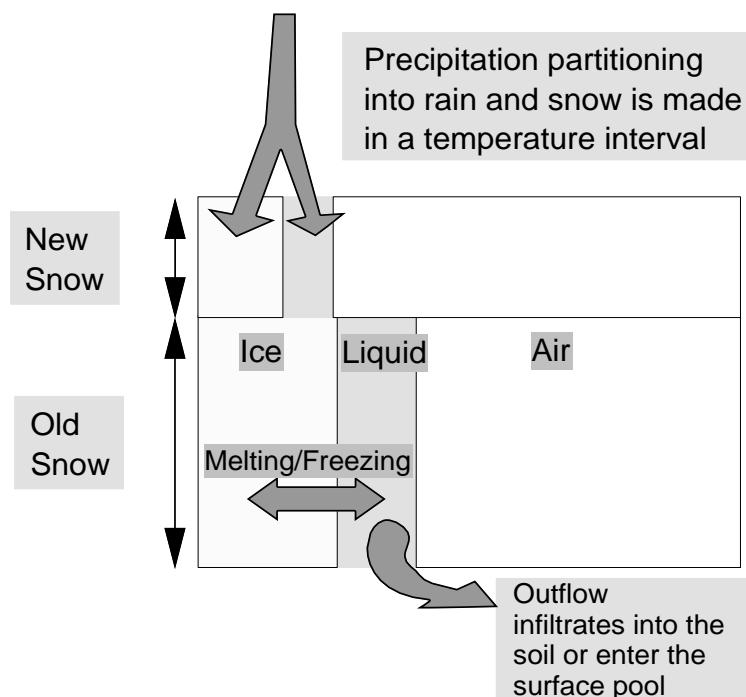


Figure 4.2.
The snow model, subdivision of snow into two compartments and the different water flow paths.

Snow is separated into liquid water and the total water equivalent. The entire snow pack is considered to be homogeneous both horizontally and vertically. The mass balance of the snow pack can be calculated using either an empirical melting/freezing function or an energy balance approach taking the heat balance of the snow pack into account, as determined by the switch “[SnowMeltFunction](#)”. The liquid water will (in both cases) control both the mass balance and the outflow from the snow but also the density and the thermal properties of the snow. This is described below.

Empirical Melting/Freezing Function

The fundamental part of the empirically based snow model is the melting-freezing function, which combines the mass and heat budgets. The amount of snow melt, M , is made up by a temperature function, M_T , a function accounting for influence of solar radiation, M_R , and the soil surface heat flow, $q_h(0)$:

$$M = M_T T_a + M_R R_{is} + \frac{f_{qh} q_h(0)}{L_f} \quad (4.33)$$

where T_a is air temperature, R_{is} is global radiation, f_{qh} is a scaling coefficient and L_f is the latent heat of freezing. Melting will affect the whole snow pack, whereas refreezing will only affect a limited surface layer. Refreezing efficiency is, therefore, inversely proportional to snow depth, Δz_{snow} :

$$\begin{aligned} m_T & \quad T_a \geq 0 \\ M_T = & \frac{m_T}{\Delta z_{snow} m_f} \quad T_a < 0 \end{aligned} \quad (4.34)$$

where T_a is air temperature and m_T and m_f are parameters. See viewing function “[Snow melt-refreeze function, Air Temperature](#)”.

Albedo is markedly reduced with age of snow surface, such that radiation absorption increases with time. This is the reason for making M_R dependent on the age of the surface snow, t_{age} :

$$M_R = m_{Rmin} (1 + s_1 (1 - e^{-s_2 t_{age}})) \quad (4.35)$$

where m_{Rmin} , s_1 and s_2 are parameters. See viewing function “[Snow melt-refreeze function, Global Radiation](#)”.

Age of surface snow, s_{age} , is determined by the number of days since the last snowfall. To reduce the influence of mixed precipitation and minor showers, snowfall is counted in this context only for snow spells larger than a critical value, p_{samin} , and for precipitation with thermal quality, Q_p , above a threshold value w_{samin} :

$$s_{age} = \begin{cases} 0 & P_{snow} > p_{samin} \& Q_p > w_{samin} \\ s_{age} + \Delta t & P_{snow} \leq p_{samin} \text{ or } Q_p \leq w_{samin} \end{cases} \quad (4.36)$$

where the thermal quality of precipitation (its fractional frozen water content) is defined by:

$$Q_p = \begin{cases} \min \left(1, \left(1 - f_{liqmax} \right) + f_{liqmax} \frac{T_a - T_{RainL}}{T_{SnowL} - T_{RainL}} \right) & T_a \leq T_{RainL} \\ 0 & T_a > T_{RainL} \end{cases} \quad (4.37)$$

where f_{liqmax} is a parameter that defines the maximum liquid water content of falling snow and is automatically put to 0.5. T_{RainL} and T_{SnowL} are the temperature range where precipitation is regarded as a mixture of ice and liquid water.

Energy balance Melting/Freezing Function

The energy balance approach for snow melt and refreezing of liquid water within the snow is based on the conservation of heat within the snow pack. The change of heat content in the snow pack due to temperature changes and phase changes is assumed to be equal to the net heat flux to the snow:

$$-(q_{h,sensible} + q_{h,lat}) = q_{h,snow} - q_{h,soil} + q_{h,prec} \quad (4.38)$$

which includes the following heat fluxes:

1) snow temperature change:

$$q_{h,sensible} = C_i S \Delta T_{snow} \quad (4.39)$$

where C_i is the specific heat of ice, S is the snow water equivalent and ΔT_{snow} is the change of temperature.

2) snow melt/refreeze of liquid water:

$$q_{h,lat} = L_f \cdot \frac{\Delta S_{ice->liq}}{\Delta t} \quad (4.40)$$

where L_f is the latent heat of fusion and $\Delta S_{ice->liq}$ is the snow melt.

3) snow surface heat flux:

$$q_{h,surface} = \frac{2 \cdot k_{snow} (T_{snows} - T_{snow})}{z_{snow}} \quad (4.41)$$

where T_{snows} is the snow surface temperature, T_{snow} is the temperature of the snow pack, k_{snow} is the thermal conductivity of the snow and z_{snow} is the snow depth.

4) heat flux between snow and soil:

$$q_{h,soil} = \frac{2k_{snow}k_{h,1}}{(k_{snow}\Delta z_1 + k_{h,1}z_{snow})} (T_{snow} - T_1) \quad (4.42)$$

where $k_{h,1}$, Δz_1 and T_1 is the thermal conductivity, thickness and temperature of the upper most soil layer respectively.

5) heat content in precipitation:

$$q_{h,prec} = T_{prec} (C_i P_{snow} + C_w P_{rain}) \quad (4.43)$$

where P_{snow} and P_{rain} are the precipitation rates of snow and rain respectively, defined by eq. (4.45) and C_w is the specific heat of water. T_{prec} is the temperature of the precipitation, taken as the wet bulb temperature and calculated as a function of air temperature and the saturated vapour pressure above ice/water, limited to a maximum of 0°C for frozen precipitation (cf. below for details).

The temperature of the snow pack is not allowed to be higher than 0°C, and is assumed to be 0°C in the presence of liquid water. The heat flux used for snowmelt/refreezing of liquid water, $q_{h,lat}$, is calculated as the residual of Eq. (4.38) using $T_{snow}=0^\circ\text{C}$, and is thereafter used to calculate the amount of snow melt/refreezing in mm of water following Eq. (4.40).

Mass balance

The total water content of the snow pack (snow water equivalent), S , is calculated as the sum of the snow water equivalent remaining from the previous time step, S_{res} , and the total precipitation:

$$S = S_{res} + P \cdot \Delta t \quad (4.44)$$

The partitioning of precipitation into snow and rain is defined by the thermal quality of the precipitation (see Eq. (4.37)):

$$P_{rain} = P(1 - Q_p) \quad (4.45)$$

The accumulation of free water in the snow pack is calculated as:

$$S_{wl} = S_{wlres} + (P_{rain} + M) \Delta t \quad (4.46)$$

where S_{wlres} is the free water remaining from the previous time step, with the restriction that $0 < S_{wl} < S$, and M is the snow melt. If the free water is above a given retention threshold, S_{wlmax} , it is released for infiltration into the soil:

$$q_w(0) = \max(0, (S_{wl} - S_{wlmax}) / \Delta t) \quad (4.47)$$

such that the remaining amount of free water becomes:

$$S_{wlres} = S_{wl} - q_w(0) \Delta t \quad (4.48)$$

The retention capacity is assumed to be a fixed fraction, f_{ret} , of the snow pack water equivalent:

$$S_{wlmax} = f_{ret} S \quad (4.49)$$

The snow pack not only contributes melt water to infiltration but soil surface temperature is also influenced through snow depth and thermal conductivity (cf. Eqs. 1.5 and 1.6 in “Soil Heat Processes”).

Thermal properties of snow

Snow thermal conductivity, k_{snow} is sensitively related to snow density, ρ_{snow} (Snow Hydrology, 1956):

$$k_{snow} = s_k \rho_{snow}^2 \quad (4.50)$$

where s_k is an empirical parameter. See viewing function “[Thermal Conductivity of Snow](#)”.

Density of snow

Snow density, ρ_{snow} , is a weighted average of the old snow pack (i.e. the density of snow remaining from the previous day ρ_{old}) and precipitation density, ρ_{prec} :

$$\rho_{snow} = \frac{\rho_{prec} \Delta z_{prec} + \rho_{old} \Delta z_{old}}{\Delta z_{snow}} \quad (4.51)$$

where Δz indicates depth and the indices represent old snow pack, precipitation and updated snow pack.

The model has two options to calculate the density of new-fallen snow as a function of air temperature, T_a , which is determined by the switch “[NewSnowDensity](#)”.

Linear model:

$$\rho_{prec} = \rho_{smim} + 181 \cdot (1 - Q_p) / f_{liqmax} \quad (4.52)$$

where ρ_{smin} is the density of new snow, Q_p is the thermal quality of precipitation and f_{liqmax} is a parameter that defines the maximum liquid water content of falling snow that is automatically put to 0.5.

Exponential model:

$$\rho_{prec} = \frac{\rho_{smin}}{119.17 \cdot f_{liqmax}} \left(67.92 + 51.25 \cdot e^{T_a/2.59} \right) \quad (4.53)$$

See viewing function “[Density of New Snow Function](#)”.

Depth of precipitation, Δz_{prec} , is then automatically given as:

$$\Delta z_{prec} = \frac{P}{\rho_{prec}} \quad (4.54)$$

The densification of the snow pack can be estimated in two optional ways in the model, which is determined by the switch “[SnowDensification](#)”:

(I). Densification as a function of ice and liquid water content

Density of the old snow pack increases with the relative amount of free water in the pack and with overburden pressure, i.e., with increasing water equivalent. Density also generally increases with age. The age dependency is accounted for by updating density as the maximum density of the previous time step:

$$\rho_{old} = \rho_{smin} + s_{dl} \frac{S_{wl}}{S_{wlmax}} + s_{dw} S_{res} \quad (4.55)$$

where s_{dl} and s_{dw} are parameters, S_{wlmax} is the retention capacity and S_{res} is the water equivalent of the snow. Depth of old pack is given by definition as:

$$\Delta z_{old} = \frac{S_{res}}{\rho_{old}} \quad (4.56)$$

(II). Densification as a function of compaction rate

Three processes are considered to generate snow layer compaction, following the algorithm of Jordan (1991): (a) destructive metamorphism, (b) overburden pressure, and (c) snow melt:

$$C_R = -\frac{1}{\Delta z_{snow}} \frac{\partial \Delta z_{snow}}{\partial t} = C_{R, Metamorph} + C_{R, Overburden} + C_{R, Melt}$$

where C_R is the compaction rate (day^{-1}). The compaction rate and the snow depth from the previous time step give the depth of the old snow:

$$\Delta z_{old} = \Delta z_{snow} (1 + C_R \Delta t) \quad (4.57)$$

and the snow density of the old snow pack is then calculated as:

$$\rho_{old} = \frac{S_{res}}{\Delta z_{old}} \quad (4.58)$$

where S_{res} is the water equivalent of the snow.

Compaction due to metamorphism is described as a function of snow temperature, T_{snow} (°C), bulk density of ice, γ_{ice} (kg m⁻³), and bulk density of liquid water, γ_{liq} (kg m⁻³):

$$C_{R,Metamorph} = C_{R,Temperature} \cdot C_{R,Density} \cdot C_{R,Liquid} \cdot 86400 \quad (4.59)$$

where bulk density of ice, γ_{ice} , and liquid water, γ_{liq} , is the density of the ice and liquid water in the snow pack respectively i.e. the total amount of ice and water in the snow pack divided by the height of the snow, and:

$$\begin{aligned} C_{R,Temperature} &= c_{mmt1} \cdot e^{c_{mmt2} \cdot T_{snow}} \\ C_{R,Density} &= e^{-c_{mmd} \cdot \max[0, (\gamma_{ice} - \gamma_{lim})]} \quad , \gamma_{lim} = \min(\gamma_{lim,max}, 1.15 \cdot \gamma_{ice,new}) \\ C_{R,Liquid} &= \begin{cases} 1 & \gamma_{liq} = 0 \\ c_{mml} & \gamma_{liq} > 0 \end{cases} \end{aligned} \quad (4.60)$$

with the parameters c_{mmt1} , c_{mmt2} , c_{mmd} and c_{mml} , and a threshold density, γ_{lim} , taken as the minimum of parameter $\gamma_{lim,max}$ and the bulk density of ice in new snow, $\gamma_{ice,new}$.

Compaction due to overburden is calculated as follows:

$$C_{R,Overburden} = \frac{P_s}{\eta_0} \cdot e^{(c_{ot} \cdot T_{snow} - c_{od} \cdot \gamma_{ice})} \quad (4.61)$$

where P_s is pressure of the overlaying snow integrated over the snow pack (thus equal to the mass of the snow pack), η_0 is a parameter representing viscosity at 0°C and $\rho_{snow}=0$, and c_{ot} and c_{od} are parameters representing the temperature and density influence on the compaction rate.

Finally, compaction due to snow melt is given as:

$$C_{R,melt} = \frac{q_{melt}}{\gamma_{ice} \cdot \Delta z_{snow}} \quad (4.62)$$

where q_{melt} (mm) corresponds to the snow water equivalent melted during the previous time step. However, compaction due to snowmelt is neglected if the snow density is above a threshold limit, c_{cmco} , with default value 300 kg m⁻³.

Surface energy balance of snow

The snow surface temperature can be assumed to be equal to the air temperature or it can be estimated by solving the energy balance equation of the snow surface (see switch “[SnowSurfTemperature](#)”):

$$R_{n,snow} = H_{snow} + LE_{snow} + q_{h,snow} \quad (4.63)$$

where $R_{n,snow}$, is the available net radiation at the snow surface, H_{snow} and LE_{snow} are the sensible and latent heat fluxes from the snow surface to the atmosphere and $q_{h,snow}$ is the snow surface heat flux. The heat fluxes in Eq. (4.63) are estimated by an iterative procedure where the snow surface temperature is varied according to a given scheme:

1. The turbulent fluxes of latent and sensible heat are calculated with the same methods as described in the surface energy balance approach for the soil evaporation (Eq. (4.1)-(4.5) and Eq. (4.12)- (4.25)) (see switch “[StabilityCorrection](#)”).

2. A steady state solution is assumed for the heat flux through the snow pack and to the middle of the uppermost soil layer (Eq. 1.4 in “Soil Heat Processes”), implying new heat storage in the snow pack. The influence of water vapour flow on the heat flux through the snow and the soil surface may be included according to Eq. [\(4.5\)-\(4.6\)](#) (see switch “[SoilVapour](#)” in “General Options”).

3. If the estimated snow surface temperature, T_{snows} , is above 0°C it is set to 0°C and the surface fluxes are recalculated. The remaining residual of net radiation, latent heat flux and sensible heat flux is considered as part of the snow surface heat flux, and may thus contribute to snow melt if the heat balance approach for snow melt is used.

Fraction of snow free ground

The fraction of snow free ground is used to estimate the average soil surface temperature, eq. (1.8), and the average surface albedo, eq. [\(4.109\)](#), during conditions of "patchy" snow cover:

$$f_{bare} = \begin{cases} \frac{\Delta z_{snow}}{\Delta z_{cov}} & \Delta z_{snow} < \Delta z_{cov} \\ 0 & \Delta z_{snow} \geq \Delta z_{cov} \end{cases} \quad (4.64)$$

where Δz_{cov} is a threshold parameter.

Fraction of snow free vegetation

The snow free fraction of the vegetation, $f_{SnowReduceLAI}$ is calculated as:

$$f_{SnowReduceLAI} = \max \left[1, 1 - \frac{\Delta z_{snow}}{H_p} \right] \quad (4.65)$$

If the vegetation height, H_p , is not explicitly given, it is estimated as ten times the roughness length.

Adjusting to measured snow depths

The simulated snow depth may be adjusted to measured snow depths, $\Delta z_{snow,meas}$. The correction can be applied either continuously or occasionally (see switch “[SnowAdjustment](#)”). Snow depth observations are then either interpolated to every time step or used as discrete observations.

The amount of water added or subtracted to the snow pack is considered as a precipitation adjustment, $P_{SnowAdjust}$:

$$P_{SnowAdjust} = \frac{(\Delta z_{snow,meas} - \Delta z_{snow}) \rho_{snow,adjust}}{\Delta t} \quad (4.66)$$

where the density of the adjusted snow, $\rho_{snow,adjust}$, is taken as the density of the precipitation if the snow depth correction is positive and greater than ε_{samin} m day⁻¹. Otherwise it is taken as the density of the simulated snow pack.

Snow precipitation temperature

The temperature of snow precipitation is estimated as the minimum of 0 °C and the wetbulb temperature, $T_{wetbulb}$, where the latter is estimated through an iterative solution of equation (6.3).

Switches

NewSnowDensity

Value	Meaning
Linear f(air temp)	The density of totally frozen precipitation has a constant value, ρ_{smin} , and the density of mixed precipitation is given as a linear function of air temperature.
Exponential f(air temp)	The density of totally frozen as well as mixed precipitation is given as an exponential function of air temperature.

SnowAdjustment

Value	Meaning
No correction	The simulated snow depth is used as simulated for calculation of heat flows between soil and atmosphere.
Forced to match continuous	The simulated snow depth is adjusted to match measured data as specified in a separate driving variable file. The measured snow depth is interpolated to correct the simulated snow depth at every timestep.
Forced to match discrete	The simulated snow depth is adjusted to match measured data as specified in a separate driving variable file. The snow depth correction is made at discrete time steps.

SnowDensification

Value	Meaning
f(ice and liq. content)	The density of the snow pack is calculated as a function of the ice and water content of the snow and the snow age.
f(compaction rate)	The snow depth change with time (compaction rate) is estimated as a function of three processes (i) metamorphosis, (ii) overburden pressure, and (iii) snow melt. The new snow depth is used to estimate the snow density.

SnowMeltFunction

Value	Meaning
Empirical	An empirical approach is used for the mass balance of the snow pack.

Heat balance	The snow melt is estimated as part of the heat balance of the snow pack, including net radiation, sensible and latent heat flux to the atmosphere, heat flux in precipitation, snow temperature change and heat flux to the soil.
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SnowRoughness

Value	Meaning
Common roughness	One common roughness value is used for all evaporation surfaces: bare soil, snow, and canopy. That means that the (largest in case of a multiple canopy) canopy roughness is used if there is a canopy present, otherwise the individual snow roughness value is used for the snow surface.
Individual	Each evaporating surface has its own roughness value

SnowSurfTemperature

Value	Meaning
Air Temperature	The snow surface temperature is estimated as the air temperature at the reference height.
f(E-balance Solution)	The snow surface temperature is estimated by using an iterative solution of the snow surface energy balance (estimating net radiation, sensible and latent heat to the air and heat conduction into the snow) except during situations with melting snow when snow surface temperature is assumed to be 0 °C.

StabilityCorrection

Value	Meaning
f(Richardson Number)	The aerodynamic resistance is estimated as a function of Richardson number.
f(Monin-Obukhov Length)	The aerodynamic resistance is estimated as a function of the Monin-Obukhov stability parameter $\zeta = (z_{ref} - d)/L$. Richardsons number is transformed into ζ by an iterative procedure which may slow down the simulations. On the other hand, variations in surface roughness for momentum and heat is treated in a consistent way.

Parameters

AgeUpdatePrec

Snowfall limit for snow age updating.

Default	Unit	Symbol	Equation	Function
5	$\text{kg m}^{-2} \text{ day}^{-1}$	p_{samin}	(4.36)	

When precipitation exceeds this value, the age of snow will be reset to 0 provided that the thermal quality also exceeds the value given of AgeUpdatePrecThQ.

AgeUpdatePrecThQ

Precipitation thermal quality limit for snow age updating.

Default	Unit	Symbol	Equation	Function
0.9	-	w_{samin}	(4.36)	

The normal value 0.9 implies that 90% of precipitation must be as snow if the counter for snow age is to be reset.

AgeUpdateSDepthCorr

If the snow depth correction exceeds this threshold value, the snow surface age is reset to 0 and the density of the added snow is equal to the density of new snow. Otherwise the density of the snow pack is used.

Default	Unit	Symbol	Equation	Function
0.01	m day^{-1}	ε_{samin}	(4.66)	

CRCompMeltCutOff

Coefficient in the calculation of snow density using the compaction rate function: compaction due to snow melt is only considered for snow density below CRCompMeltCutOff.

Default	Unit	Symbol	Equation	Function
300	kg m^{-3}	c_{cmco}	(4.62)	

CRMetaMorphDens

Coefficient in the calculation of snow density using the compaction rate function: exponent in the exponential decrease of compaction rate as a function of snow density.

Default	Unit	Symbol	Equation	Function
0.046	$\text{m}^3 \text{ kg}^{-1}$	c_{mmd}	(4.104)	

CRMetaMorphDensMin

Coefficient in the calculation of snow density using the compaction rate function: minimum snow density used in the exponential function describing the compaction as a function of snow density

Default	Unit	Symbol	Equation	Function
100	kg m^{-3}	$\gamma_{im,max}$	(4.60)	

CRMetaMorphLiq

Coefficient in the calculation of snow density using the compaction rate function: snow liquid water content threshold, above which the compaction rate is assumed to be doubled

Default	Unit	Symbol	Equation	Function
2	-	c_{mml}	(4.60)	

CRMetaMorphTemp1

Coefficient in the calculation of snow density using the compaction rate function: linear increase in the compaction rate as a function of snow temperature.

Default	Unit	Symbol	Equation	Function
$2.777 \cdot 10^{-6}$	s^{-1}	c_{mmt1}	(4.60)	

CRMetaMorphTemp2

Coefficient in the calculation of snow density using the compaction rate function: exponential increase in the compaction rate as a function of snow temperature

Default	Unit	Symbol	Equation	Function
0.04	$^{\circ}\text{C}^{-1}$	c_{mmt2}	(4.60)	

CROverburdenDens

Coefficient in the calculation of snow density using the compaction rate function: reducing the compaction rate due to overburden pressure as a function of snow density

Default	Unit	Symbol	Equation	Function
0.023	$\text{m}^3 \text{kg}^{-1}$	c_{od}	(4.61)	

CROverburdenTemp

Coefficient in the calculation of snow density using the compaction rate function: increasing the compaction rate due to overburden pressure as a function of snow temperature.

Default	Unit	Symbol	Equation	Function
0.04	$^{\circ}\text{C}^{-1}$	c_{ot}	(4.61)	

CROverburdenVisc

Coefficient in the calculation of snow density using the compaction rate function: viscosity parameter, which acts as a linear reduction of the overburden pressure compaction rate.

Default	Unit	Symbol	Equation	Function
$9.0 \cdot 10^5$	kg s m^{-2}	η_0	(4.61)	

CritDepthSnowCover

The thickness of mean snow height that corresponds to a complete cover of the soil.

Default	Unit	Symbol	Equation	Function
0.01	m	Δz_{cov}	(4.64)	

The parameter is used to calculate the mean soil surface temperature from a weighed sum of temperature below the snow and the temperature of bare soil. When the snow height is below this threshold the aerial fraction of snow cover is given by the ratio between the actual height of snow and the value of this parameter.

DensityCoefMass

Mass coefficient in the calculation of snow density as a function of liquid and ice content in the "old" snow pack.

Default	Unit	Symbol	Equation	Function

0.5	m^{-1}	s_{dw}	(4.55)	
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The normal value implies that a snow pack with 200 mm water equivalent will get an increased density of 100 kg m^{-3} .

DensityCoefWater

Liquid water coefficient in the calculation of snow density as a function of liquid and ice content.

Default	Unit	Symbol	Equation	Function
200	kg m^{-3}	s_{dl}	(4.55)	

The snow density increase with this value when the liquid water content in the snow pack becomes equal to the total retention capacity (see WaterRetention).

DensityOfNewSnow

Density of new snow.

Default	Unit	Symbol	Equation	Function
100	kg m^{-3}	ρ_{smin}		“Density of New Snow Function”

MeltCoefAirTemp

Temperature coefficient in the empirical snow melt function.

Default	Unit	Symbol	Equation	Function
2	$\text{kg } ^\circ\text{C}^{-1} \text{ m}^{-2} \text{ day}^{-1}$	m_T	(4.34)	“Snow melt-refreeze function, Air Temperature”

A value of 2 is normal for forests. Similar as for MeltCoefGlobRad a two or three fold increase is expected if adaptation to an open field is to be done.

MeltCoefGlobRad

Global radiation coefficient in the empirical snow melt function.

Default	Unit	Symbol	Equation	Function
1.5E-7	kg J^{-1}	m_{Rmin}	(4.35)	“Snow melt-refreeze function, Global Radiation”

A normal value for forests $1.5\text{E-}7$ implies that a global radiation of 15 MJ m^{-2} during a sunny day in the spring will melt 2.2 mm of new snow or 6.6 mm of old snow with the value MeltCoefGlobRadAge1 put to 2. Values of open fields may be 2-3 times larger.

MeltCoefGlobRadAge1

Radiation melt factor for old snow in the empirical snow melt function.

Default	Unit	Symbol	Equation	Function
2	-	s_I	(4.35)	

A value of 0 implies that the melting of snow is independent of snow age. The normal value 2 implies that melting of old matured snow because of global radiation is 3 times as efficient as the melting of new snow.

MeltCoefGlobRadAge2

Snow age coefficient in radiation melt function, which is a part of the empirical snow melt function.

Default	Unit	Symbol	Equation	Function
0.1	day ⁻¹	s_2	(4.55)	

The coefficient is used in an exponential function, which determines how fast the melting because of global radiation is approaching the value valid for old mature snow. The normal value implies that 63 % of the change from new to old snow takes place after 10 days.

MeltCoefReFreeze

Refreezing efficiency constant in the empirical snow melt function.

Default	Unit	Symbol	Equation	Function
0.1	m ⁻¹	m_f	(4.34)	

During conditions of air temperatures below 0 refreezing of liquid water is calculated with the same temperature coefficient as in the snow melt function (MeltCoefAirTemp) adjusted for the depth of snow pack. The normal value 0.1 (m) implies that refreezing will become successively more inefficient when the snow pack increases above 0.1 m. The double thickness of snow pack will reduce the refreezing efficiency to 50%.

MeltCoefSoilHeatF

Scaling coefficient for the contribution of heat flow from ground on the melting of the snow in the empirical snow melt function.

Default	Unit	Symbol	Equation	Function
0.5	-	f_{qh}	(4.102)	

A value of 1 means that all heat flow from ground may be used for melting of snow.

OnlyRainPrecTemp

Above this temperature all precipitation is rain.

Default	Unit	Symbol	Equation	Function
2	°C	T_{RainL}	(4.37)	“Density of New Snow Function”

OnlySnowPrecTemp

Below this temperature all precipitation is snow.

Default	Unit	Symbol	Equation	Function
0	°C	T_{SnowL}	(4.37)	“Density of New Snow Function”

RoughLMomSnow

Roughness length for momentum above snow. Used as z_{0M} in (4.14) but for snow surface. Used only if the surface energy is calculated by solving the energy balance at the surface. If a canopy is present, the roughness length for snow is only used if the Switch "SnowRoughness" is set to Individual.

Default	Unit	Symbol	Equation	Function
0.001	m	$z_{0M,snow}$	(4.14)	

SThermalCondCoef

Thermal conductivity coefficient for snow.

Default	Unit	Symbol	Equation	Function
2.86E-6	$\text{W m}^5 \text{ }^\circ\text{C}^{-1} \text{ kg}^{-2}$	s_k	(4.50)	" Thermal Conductivity of Snow "

The normal value 2.86E-6 ($\text{W m}^5 \text{ }^\circ\text{C}^{-1} \text{ kg}^{-2}$) implies the thermal conductivity function for snow is valid in a range of density from 100 to 900 kg/m³. The highest density corresponds to pure ice. A square dependence of the snow density is assumed in the whole range.

SnowDepthInitial

Initial depth of snow.

Default	Unit	Symbol	Equation	Function
0	m			

SnowMassInitial

Initial mass of snow.

Default	Unit	Symbol	Equation	Function
0	mm			

WaterRetention

Retention capacity of snow, fraction of total storage.

Default	Unit	Symbol	Equation	Function
0.07	-	f_{ret}	(4.49)	

WindlessExChangeSnow

Minimum turbulent exchange coefficient (inverse of maximum allowed aerodynamic resistance) over bare soil. Avoids exaggerated surface cooling in windless conditions or extreme stable stratification.

Default	Unit	Symbol	Equation	Function
0	s^{-1}	$r_{a,max,snow}^{-1}$	(4.25)	

ZeroTemp_WaterLimit

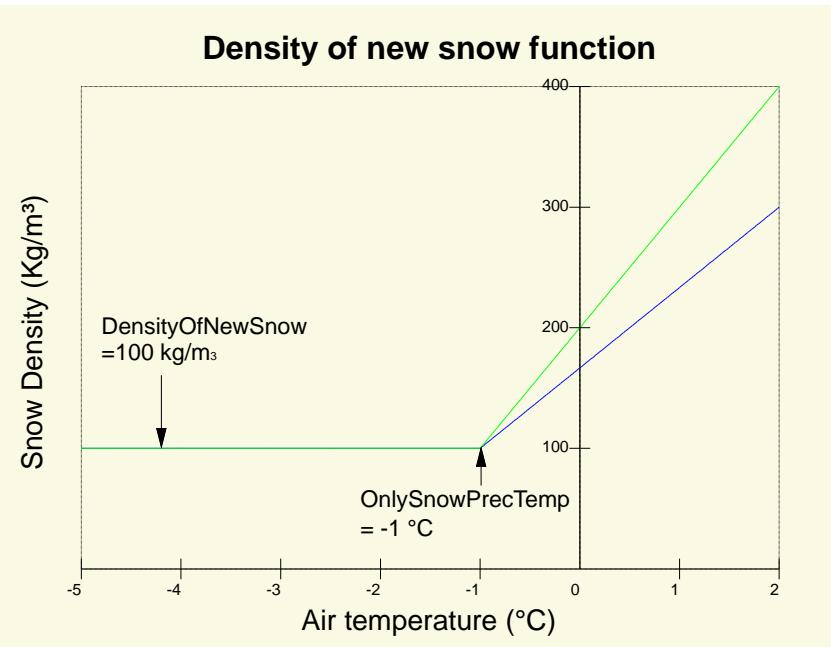
Liquid snow water threshold to put soil surface temperature to 0 °C.

Default	Unit	Symbol	Equation	Function

3	kg m^{-2}	s_{wlmin}	(4.21) see "Soil Heat Processes" eq. (1.5)
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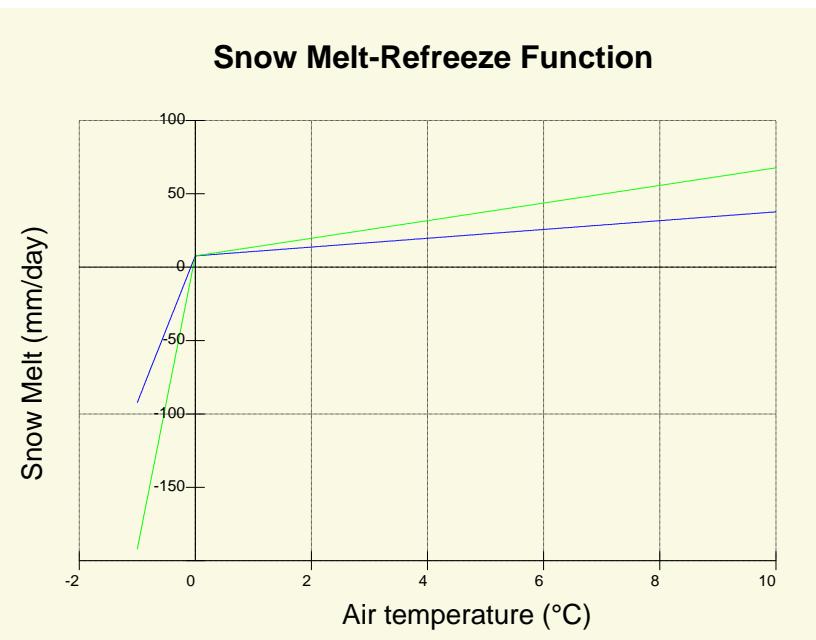
Viewing Functions

Density of New Snow Function



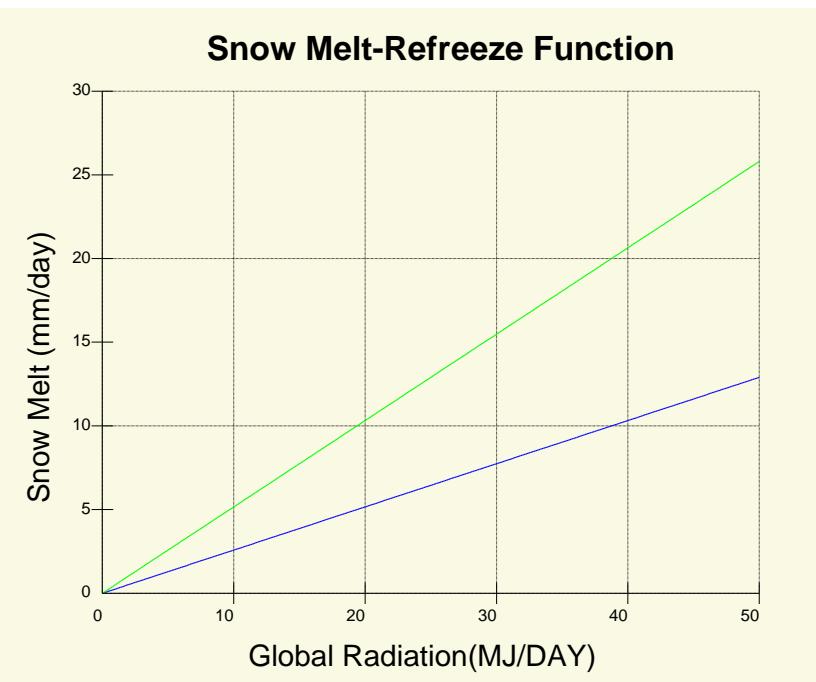
The relationship between snow density and air temperature is dependent on three different parameters. The parameter OnlyRainPrecTemp put to 5 for the blue line and to 3 for the green line. The other two parameters are shown in the plot.

Snow melt-refreeze function, Air Temperature



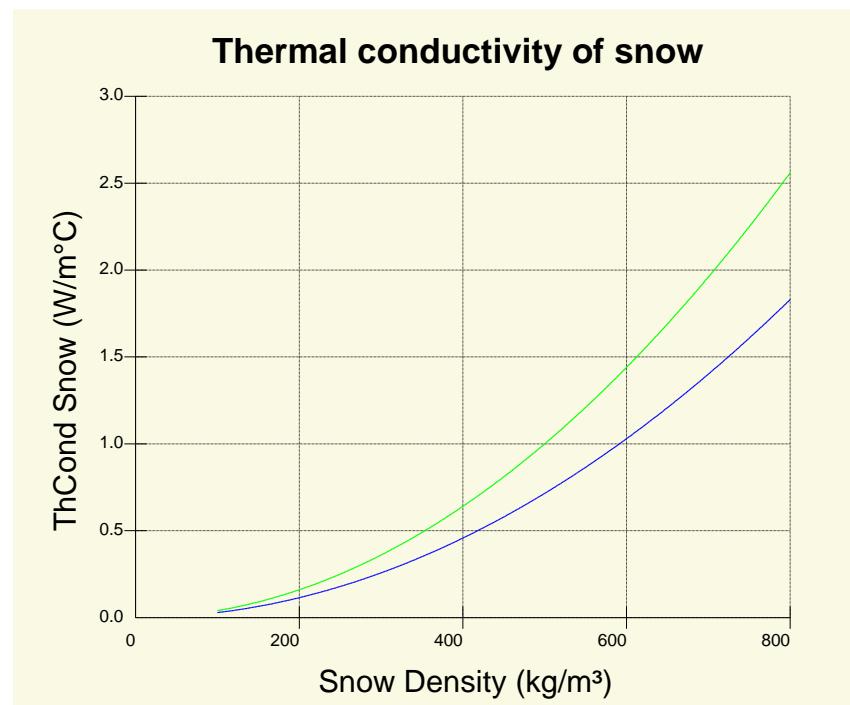
Snow melt/refreeze as a function of air temperature. The relationship is dependent on a parameter MeltCoefAirTemp, which is set to 3 for the blue line and to 6 for the green line. The global radiation is 30 MJ/m²/day.

Snow melt-refreeze function, Global Radiation



Snow melt/refreeze as a function of global radiation. The relationship is dependent on a parameter MeltCoefGlobRad, which is set to 1.0e-7 for the blue line and to 2.0e-7 for the green line. The air temperature is 0 °C.

Thermal Conductivity of Snow



The relationship between snow density and thermal conductivity is dependent on the parameter SthermalCondCoef. This parameter was put to 2.860e-6 for the blue line and to 4.0e-6 for the green line.

State Variables

Snow Depth

Snow depth
m

TotalSnowMass

Snow water equivalent
mm

Auxiliary Variables

FracBareSoil

Fraction of bare soil
-

IceInSnowPack

Mass of ice in the snow pack
mm

MO-StabilityParameter

The Monin-Obukhov stability parameter, z/L, estimated over bare soil.

PrecAdjustSnow

The amount of snow added or reduced by the algorithm that fits simulated snow depth to given observations.
m

QMeltSurface

Snow surface heat flux used for snowmelt. If the solution of the snow surface energy balance results in a surface temperature above 0 °C, heat fluxes are recalculated at the melting point, and the residual (QMeltSurface) is used for snow melt.

Jm⁻²day⁻¹

QSnowSoil

Heat flux at the snow/soil interface
Jm⁻²day⁻¹

RadNetSnowCover

Net radiation over the snow surface
Jm⁻²day⁻¹

ResAirAboveSnow

Aerodynamic resistance above the snow surface
sm⁻¹

Snow Density

Density of snow
kg/m³

SnowEbalClosure

Residual heat flux in the iterative solution of the snow surface energy balance. Note that when the estimated snow surface temperature is above 0 °C, it is reset to 0 °C and the fluxes are recalculated. In this cases the residual heat flux is considerably higher, and is added to the snow surface heat flux, i.e. it is used for snow melt.
Jm⁻²day⁻¹

SnowEvaporation

Evaporation of water from snow pack.
mmday⁻¹

SnowLatentFlow

Latent heat flux from the snow surface to the atmosphere (positive upwards)
Jm⁻²day⁻¹

SnowReduceLAIFactor

The fractional reduction of LAI caused by snow covering the canopy.

SnowSensibleFlow

Sensible heat flux from the snow surface to the atmosphere (positive upwards)
 $\text{J m}^{-2} \text{ day}^{-1}$

SnowSurfHeatFlow

Snow surface heat flux (positive downwards)
 $\text{J m}^{-2} \text{ day}^{-1}$

SnowSurfaceAge

Snow surface age defined as the number of days since the last snow fall event
days

SnowWaterOutflow

Liquid water leaving the snow pack available for infiltration
mm/day

TempSnowSurface

Snow surface temperature
 $^{\circ}\text{C}$

TempSnowPack

Snow pack temperature
 $^{\circ}\text{C}$

TempSnowSurface

Snow surface temperature
 $^{\circ}\text{C}$

TempSoilUnderSnow

Soil surface temperature at the soil-snow interface
 $^{\circ}\text{C}$

ThermQualOfThroughF

Fraction of frozen water of the throughfall

-

VapourPSnowSurface

Saturated vapour pressure at the snow surface
Pa

WaterInSnowPack

Amount of liquid water within the snow pack
 kg/m^3

WindSpeedSnow

If the wind speed is given at another reference height than the air temperature and air humidity, it can be estimated at the reference height of air temperature – if StabilityCorrection is either "Paulsen-1970" or "Beljaars-Holstlag-1991". The

output should be regarded as an auxiliary in the estimation process of the aerodynamic resistance above snow.
 ms^{-1}

Driving variables

SnowMeasured

Measured snow depth.

m

Radiation processes

Partitioning of radiation between plants

When the single big leaf approach is used, the canopy is assumed to completely cover the soil surface. The partitioning of radiation between the plant canopy and the soil is then calculated according to Beer's Law (Eq. (4.1)).

If the multiple leaf approach is used each plant will have one big leaf which is considered to have a rectangular geometry (see [Figure 4.3](#)). The leaf is uniformly distributed within the total height of the canopy. A horizontal area extension and distribution is also assumed, which is described in detail in chapter "Plant water processes". Each plant is considered to cover a fraction of the unit area of soil, distributed in one horizontal dimension around a central point x_j . The horizontal and vertical distribution of plants results in a number of vertical, ΔH_i , and horizontal, Δx_k , zones as described in [Figure 4.3](#).

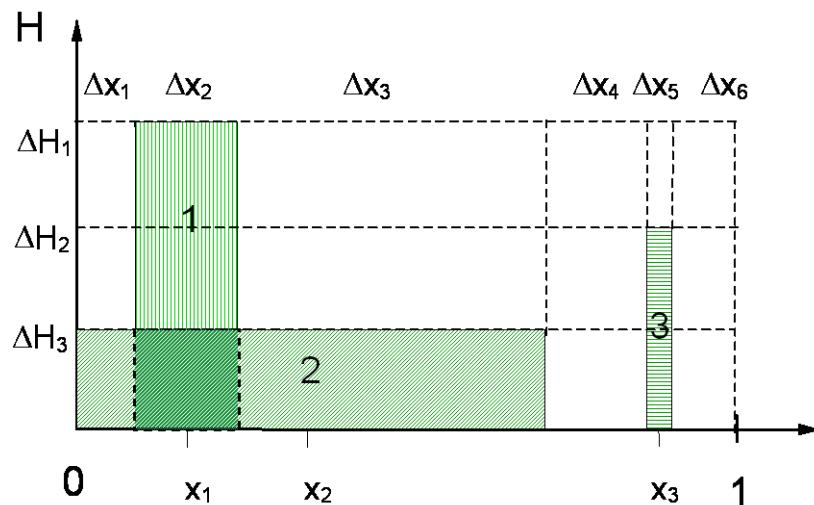


Figure 4.3. Geometric model used for partitioning of light between multiple plants.

The following equations, [\(4.67\)-\(4.71\)](#), can be used for short wave or net radiation. Thus, incoming radiation is denoted R_{in} , symbolising either $R_{n,tot}$ or R_s , and absorbed radiation is denoted R_{abs} . The amount of absorbed radiation, R_{abs} , of a plant j in a height segment ΔH_i in the horizontal zone Δx_k is defined as:

$$R_{abs,i,j,k} = (1 - e^{-k_m \sum_j A_{l,i,j,k}}) \frac{A_{l,i,j,k}}{\sum_j A_{l,i,j,k}} R_{in,i,k} \quad (4.67)$$

where $R_{in,i,k}$ is the radiation intensity above the height segment ΔH_i in the zone Δx_k and k_m is the light use extinction coefficient given as a single parameter common for all plants. $A_{l,i,j,k}$ is the partial leaf area index of plant j in the specific zone, defined as:

$$A_{l,i,j,k} = \frac{A_{l,j}}{f_{cc,j}} \frac{\Delta H_i}{H_i} \quad (4.68)$$

where $A_{l,j}$ is the leaf area index defined as m^2 leaf per unit area of soil, and $f_{cc,j}$ is the degree of surface canopy cover as defined above (cf. Eq. 3.10 in “Plant water processes”). Note that Eq. (4.68) implies that the leaf area index above the soil that is actually covered by the plant will be larger than $A_{l,j}$, if $f_{cc,j} < 1$. See viewing function “[Beer’s Law](#)”.

The radiation intensity above a height segment i will be estimated as:

$$\begin{aligned} R_{in,i,k} &= R_{in,i-1,k} - \sum_j R_{abs,i-1,j,k} & i \neq 1 \\ R_{in,i,k} &= \Delta x_k R_{in} & i = 1 \end{aligned} \quad (4.69)$$

The fraction of light absorbed by vegetation above the unit area of soil, f_{canopy} , is defined by:

$$f_{canopy} = \frac{\sum_{i,j,k} R_{abs,i,j,k}}{R_{in}} \quad , 0 \leq x \leq 1 \quad (4.70)$$

in the multiple plant case, and

$$f_{canopy} = 1 - e^{(-k_m A_l)} \quad (4.71)$$

if a single big leaf is used.

Partitioning of long wave radiation between plants

Net long wave radiation of the canopy is normally considered implicitly through the partitioning of net radiation between plants and soil following equations (4.67) - (4.71). It is also possible to explicitly calculate the long wave radiation balance of the plants taking the plant temperature into account (see Switch “[LongRadCanopy](#)”). This is important when the downward long wave radiation to the surface below the canopy is of special interest, for instance for snow melt in dense forest stands. In this case, short wave and long wave balances are calculated separately, short wave following equations (4.67) - (4.71) and long wave as described below. Plants are assumed to absorb long wave radiation from above and below following Beer’s law, eq.(4.1), and to emit radiation as a function of the plant temperature upwards and downwards.

Single plant

For a single plant, the long wave radiation balance is then:

$$R_{lnet,j} = (R_{il} + R_{ol,ground} - 2 \cdot R_{ol,j}) (1 - e^{-k_m A_{l,j}}) \quad (4.72)$$

where $R_{lnet,j}$ is the long wave net radiation for a plant, $R_{ol,j}$ is the long wave radiation emitted by a plant, and $R_{ol,ground}$ the long wave radiation emitted by the ground (snow and/or soil) surface below the canopy. $A_{l,j}$ is the plant leaf area index and $-k_m$ is the extinction coefficient. The long wave radiation emitted by a plant, $R_{ol,j}$, is calculated as:

$$R_{ol,j} = \sigma(T_j + 273.15)^4 \quad (4.73)$$

where T_j is the plant surface temperature.

The long wave radiation emitted from the ground, $R_{ol,ground}$, is calculated as:

$$R_{ol,ground} = \sigma(T_{ground} + 273.15)^4 \quad (4.74)$$

where T_{ground} is the ground temperature.

Multiple plants

For a canopy of two or more plants the distribution is made following the notation used in equations (4.67) - (4.71). Each plant absorbs and emits long wave radiation in relation to its contribution to the total leaf area index within a height segment ΔH_i in the horizontal zone Δx_k according to:

$$R_{lnet,i,j,k} = \left(1 - e^{-k_m \sum_j A_{l,i,j,k}}\right) \frac{A_{l,i,j,k}}{\sum_j A_{l,i,j,k}} (R_{il,i,k} + R_{ol,i,k} - 2 \cdot R_{ol,j,k}) \quad (4.75)$$

where R_{il} is the downward long wave radiation from the segment above, and R_{ol} is the upward long wave radiation from the segment below. Calculations are made in two steps. First, the downward components are accumulated from the top of the canopy to the ground surface:

$$R_{il,i,k} = R_{il,i-1,k} e^{-k_m \sum_j A_{l,i-1,j,k}} + \sum_j \left(R_{ol,j,k} \left(1 - e^{-k_m \sum_j A_{l,i-1,j,k}}\right) \frac{A_{l,i-1,j,k}}{\sum_j A_{l,i-1,j,k}} \right) \quad (4.76)$$

starting with the downward long wave radiation from the atmosphere for $i=1$. Second, the upward components are added starting with the upward long wave radiation from the surface for the lowest canopy layer.

Estimation of net radiation

Net radiation, $R_{n,tot}$, would ideally be supplied as a measured time-series but in most cases it has to be estimated from other meteorological variables. It can be deduced from global radiation, R_{is} , air temperature, T_a , vapour pressure, e_a , and relative duration of sunshine, n_{sun} , as the sum of net short-wave radiation, R_{snet} , and net long-wave radiation, R_{lnet} given here by Brunt's formula:

$$R_{n,tot} = R_{snet} + R_{lnet} \quad (4.77)$$

where

$$R_{snet} = R_{is} (1 - a_r) \quad (4.78)$$

and

One formula

$$R_{lnet} = 86400 \sigma (T_a + 273.15)^4 (r_1 - r_2 \sqrt{e}) (r_3 + r_4 n_{sun}) \quad (4.79)$$

where a_r is the surface albedo (relative short-wave reflectance), r_1 to r_4 are

Two separate formulas...

empirical parameters and σ is the Stefan-Boltzmann's constant. See viewing function "[Net Long Wave Radiation, One formula approach](#)".

As an alternative formula for the net long-wave radiation (see switch "[LongWaveBalance](#)") the user may also chose:

$$R_{lnet} = 86400\sigma(\varepsilon_s(T_s + 273.15)^4 - \varepsilon_a(T_a + 273.15)^4) \quad (4.81)$$

... with Konzelmann et al

where the temperature of the soil surface (and/or the canopy and snow surface temperatures) T_s is explicitly used. This corresponds to the use of two separate equations for the incoming and outgoing long-wave radiation. The emissivity of the surface, ε_s , is assumed to be equal to 1 and the emissivity of the atmosphere can be calculated from one of [\(4.81\)](#)- [\(4.83\)](#) as determined by the switch "[InLongRad](#)":

... with Brunts

$$\varepsilon_{a,Konzelmann} = \left(r_{k1} + r_{k2} \frac{e_a}{T_a + 273.15} \right)^{\frac{1}{4}} \left(1 - n_c^3 \right) + r_{k3} n_c^3 \quad (4.82)$$

$$\varepsilon_{a,Brunt} = \left(r_{b1} - r_{b2} \sqrt{e_a} \right) \left(1 + r_{b3} n_c^2 \right)$$

(4.82)

$$\varepsilon_{a,Satterlund} = \left(1 - \exp \left(-e_a^{(T_a + 273.15)/r_{s1}} \right) \right) \left(1 + r_{s2} n_c^2 \right) \quad (4.83)$$

where e_a is the vapour pressure in the air, n_c is the fraction of cloud covered sky and r_{k1-3} , r_{b1-3} and r_{s1-2} are parameters. The formula from Konzelmann *et al* (1994) is recommended for most cases (eq [\(4.81\)](#)). The original formulations of Brunt and Satterlund are complemented with a cloud correction term based on a general formula from Monteith "Principles of environmental Physics" (eq [\(4.82\)](#) & [\(4.83\)](#)). See also viewing functions "[Incoming and outgoing long-wave radiation, Brunt's formula](#)", "[Incoming and outgoing long-wave radiation, Konzelmann](#)" and "[Incoming and outgoing long-wave radiation, Satterlund](#)".

Cloudiness and sunshine

Relative cloudiness, n_c , can be used to calculate relative duration of sunshine, n_{sun} :

$$n_{sun} = 1 - n_c \quad (4.84)$$

Duration of bright sunshine, Δt_{sun} , can also be used to estimate relative duration of sunshine:

$$n_{sun} = \frac{\Delta t_{sun}}{\Delta t_{max}} \quad (4.85)$$

Daylength in minutes, Δt_{max} , is calculated as a function of the latitude, l_{at} and day of the year t_{day} :

$$\Delta t_{max} = 1440 - \frac{120}{rad \cdot 15} \arccos(a_1) \quad (4.86)$$

where rad is a conversion factor from degrees to radians ($\pi/180$) and the argument in the arc cosines function a_1 is given as:

$$a_1 = \min(1, \max(-1, \frac{\sin(rad \cdot l_{at}) \cdot \sin(rad \cdot D_{ec})}{\cos(rad \cdot l_{at}) \cdot \cos(rad \cdot D_{ec})})) \quad (4.87)$$

where the declination D_{ec} is given as:

$$D_{ec} = -23.45 \cos\left(\pi \frac{(t_{day} + 10.173)}{182.61}\right) \quad (4.88)$$

where t_{day} is day number of the year.

Estimation of global radiation

Global short wave radiation, R_{is} , is normally supplied as a measured time-series. If not directly measured, it can be deduced from potential global radiation, R_{pris} , and the atmospheric turbidity:

$$R_{is} = R_{pris} \cdot f(turbidity) \quad (4.89)$$

Potential global radiation

Potential global radiation for daily mean values is given as a function of the solar constant, daylength, latitude and declination, D_{ec} :

$$R_{pris} = 1360 \cdot 60 \cdot \Delta t_{max} \cdot a_2 \quad (4.90)$$

where 1360 is the solar constant (Wm^{-2}), 60 is the number of seconds per minute and a_2 is given by:

$$a_2 = \sin(rad \cdot lat) \cdot \sin(rad \cdot D_{ec}) - \frac{\cos(rad \cdot lat) \cdot \cos(rad \cdot D_{ec})}{\Delta t_{max} / 120 \cdot rad \cdot 15} \sin\left(rad \cdot 15 \left(24 - \frac{\Delta t_{max}}{120}\right)\right) \quad (4.91)$$

where lat is latitude. The declination, D_{ec} , is given by Eq. (4.88) and the daylength, Δt_{max} , is given by Eq. (4.86). See viewing function “[Global radiation, potential](#)”.

Within day variation of potential global radiation is estimated as a function of hour of day, day of year and latitude following equation (4.92) -(4.101):

$$R_{pris} = 1360 \cdot 86400 \cdot a_3 \quad (4.92)$$

where 86400 is the number of seconds per day and a_3 is a geometric scaling function given by:

$$a_3 = \frac{p_x \cdot S_X + p_y \cdot S_Y + S_Z}{\sqrt{(p_x^2 + p_y^2 + 1) \cdot (S_X^2 + S_Y^2 + S_Z^2)}} \quad (4.93)$$

where p_x and p_y are parameters defining the slope ($\text{m} \cdot \text{m}^{-1}$) of the surface in the north-south and the west-east direction respectively (see “[Meteorological Data](#)”). This function can also optionally be used for correction of *measured* global

radiation if the ground is sloping and the measured values are representing a horizontal plane (see switch “[SlopeCorrMeasuredGlobal](#)”):

$$R_{is} = R_{is} \cdot \frac{a_3(p_x, p_y)}{a_3(p_x = 0, p_y = 0)} \quad (4.94)$$

S_x , S_y and S_z are geometric functions related to the sun's position at the sky given by:

$$\begin{aligned} S_x &= \sin(\Phi) \cdot \cos(\Lambda) \\ S_y &= \cos(\Phi) \cdot \cos(\Lambda) \\ S_z &= \sin(\Lambda) \end{aligned} \quad (4.95)$$

where Φ is the azimuth angle and Λ is the elevation angle of the sun, which are given by

$$\Phi = \begin{cases} 2\pi - \arctan \Phi & \cos \Phi > 0, \sin \Phi > 0 \\ \pi + \arctan \Phi & \cos \Phi < 0, \sin \Phi > 0 \\ \pi - \arctan \Phi & \cos \Phi < 0, \sin \Phi < 0 \end{cases} \quad (4.96)$$

and

$$\Lambda = \pi/2 - \Theta \quad (4.97)$$

respectively. The $\arctan \Phi$, $\sin \Phi$ and $\cos \Phi$ expressions in equation [\(4.96\)](#) are given by:

$$\arctan \Phi = \arctan \left(\text{abs} \left(\frac{\sin \Phi}{\cos \Phi} \right) \right) \quad (4.98)$$

and

$$\begin{aligned} \sin \Phi &= \frac{\sin(\Omega) \cdot \cos(D_{ec} \cdot rad)}{\sin(\Theta)} \\ \cos \Phi &= \frac{\sin(l_{at} \cdot rad) \cos(\Theta) - \sin(D_{ec} \cdot rad)}{\cos(l_{at} \cdot rad) \cdot \sin(\Theta)} \end{aligned} \quad (4.99)$$

where Θ is the zenith angle and Ω is the hour angle of the sun defined by

$$\begin{aligned} \Theta &= \arccos \left\{ \sin(l_{at} \cdot rad) \cdot \sin(D_{ec} \cdot rad) \right. \\ &\quad \left. + \cos(l_{at} \cdot rad) \cdot \cos(D_{ec} \cdot rad) \cdot \cos(\Omega) \right\} \end{aligned} \quad (4.100)$$

and

$$\Omega = \text{hour} \cdot 15 \cdot \text{rad} \quad (4.101)$$

Turbidity

The potential global radiation is multiplied by a turbidity function to calculate the global radiation (c.f. eq. (4.89)). There are two optional ways of calculating turbidity (see switch “[Turbidity](#)”).

Turbidity can either be a function of the relative duration of sunshine, n_{sun} , (i.e. $1-n_c$), and the global radiation is thus calculated with Ångström's formula as:

$$R_{is} = R_{\text{pris}} (r_5 + r_6 n_{\text{sun}}) \quad (4.102)$$

where r_5 and r_6 are turbidity constants. See viewing function “[Ångströms Short wave equation](#)”.

As an alternative to Eq. (4.102) (only if within day resolution is chosen) the global radiation can be calculated with a flexible atmospheric turbidity, which is calculated as a function of solar inclination, humidity and cloudiness:

$$R_{is} = R_{\text{pris}} \cdot \tau_{\text{Raileigh}} \cdot \tau_{O_3} \cdot \tau_{\text{gas}} \cdot \tau_{\text{vapour}} \cdot \tau_{\text{aerosol}} \cdot \frac{(r_5 + r_6 n_{\text{sun}})}{(r_5 + r_6)} \quad (4.103)$$

where τ_{Raileigh} , τ_{gas} , τ_{vapour} and τ_{aerosol} , are functions describing the transmittance of solar radiation due to:

(1) Raileigh scattering:

$$\tau_{\text{Raileigh}} = e^{\left(-0.0903 \cdot m_a^{0.84} \right) \cdot \left(1 + m_a - m_a^{1.01} \right)} \quad (4.104)$$

(2) Ozone:

$$\tau_{O_3} = 1 - \begin{pmatrix} 0.611 \cdot u_3 \cdot (1 + 139.48 \cdot u_3)^{-0.3035} \\ -0.002715 \cdot u_3 \cdot (1 + 0.044 \cdot u_3 + 0.0003 \cdot u_3^2)^{-1} \end{pmatrix} \quad (4.105)$$

(3) Mixed gases:

$$\tau_{\text{gas}} = e^{\left(-0.0127 \cdot m_a^{0.26} \right)} \quad (4.106)$$

(4) Water vapour:

$$\tau_{\text{vapour}} = 1 - 2.4959 \cdot u_1 \cdot \left\{ (1 + 79.034 \cdot u_1)^{0.683} + 6.385 \cdot u_1 \right\}^{-1} \quad (4.107)$$

(5) Aerosols:

$$\tau_{\text{aerosol}} = e^{\left\{ -k_a^{0.873} \left(1 + k_a - k_a^{0.7088} \right) \cdot m_a^{0.9108} \right\}} \quad (4.108)$$

Unexplained symbols in equation (4.104)-(4.108) are either functions or constants summarized in the table below:

<i>Functions</i>	<i>Meaning</i>
------------------	----------------

$m_r = \left\{ \cos(\Theta) + 0.15 \cdot (93.885 - \Theta/rad) \right\}^{-1}$	optical parameter
$m_a = m_r \cdot P_{air,sim} / 1013.25$	optical parameter
$u_1 = 0.493 \cdot RH \cdot e^{(26.23 - 5416/T_{airK})} \cdot T_{airK}^{-1} \cdot m_r$	used in water vapour function
$k_a = 0.2758 \cdot \beta \cdot 0.38^{-\alpha} + 0.35 \cdot \beta \cdot 0.5^{-\alpha}$	used in aerosol function
$u_3 = \Delta z_{O_3} \cdot m_r$	used in ozone function
$P_{air,sim} = P_{air,met} \cdot e^{(-\Delta elev \cdot g / (287.04 \cdot T_{airK}))}$	Air pressure at the elevation of the simulated profile
Constants	Meaning
$\Delta z_{O_3} = 0.34$	ozone layer thickness (cm)
$\alpha = 1.3, \beta = 0.01$	Angström coefficients
$P_{air,met} = 1013.25$	Air pressure (hPa)

T_{airK} is air temperature in degrees Kelvin and D_{elev} (i.e. $e_{levsim} - e_{levmet}$) is the elevation difference between the meteorological station and the simulated profile.

Albedo of plant, soil and snow

The albedo value will be calculated as a function of the albedo for vegetation, the albedo for bare soil and the albedo for snow as:

$$a_r = (a_{soil} f_{bare} + a_{snow} (1 - f_{bare})) (1 - f_{canopy}) + f_{canopy} a_{veg} \quad (4.109)$$

where f_{bare} is the fraction of snow free ground (see Eq. (4.64)), f_{canopy} is the fraction of the radiation which is absorbed by the vegetation (see Eq. (4.70)-(4.71)). The vegetation albedo a_{veg} is given as parameter values similar to other vegetation characteristics (see chapter “Plant water processes”).

If an implicit plant is simulated the equation above has to be slightly modified:

$$a_r = a_{vegsoil} f_{bare} + a_{snow} (1 - f_{bare}) \quad (4.110)$$

where $a_{vegsoil}$ is the albedo for both the vegetation and the soil given as a parameter.

An empirical correction of a_{veg} is introduced during conditions of precipitation or interception at air temperatures below 0°C, to represent the influence of snow interception on the albedo of the vegetation:

$$a_{veg} = a_{veg} (1 - f_{snowintalb}) + f_{snowintalb} a_{snow} \quad (4.111)$$

where $c_{snowint}$ is an adjustable parameter, which can take values between 0 and 1.

The albedo of the soil surface a_{soil} is calculated as:

$$a_{soil} = a_{dry} + e^{-k_a^{10 \log(\psi)}} (a_{wet} - a_{dry}) \quad (4.112)$$

where k_a is parameter as well as the albedo for a dry, a_{dry} , and wet soil, a_{wet} , respectively. The soil water tension of the uppermost layer, ψ_l , is allowed to vary from 10^1 to 10^7 cm. See viewing function "[Bare Soil Albedo Function](#)".

Snow albedo is calculated as a function of snow surface age, S_{age} , and the sum of daily mean temperatures, $\sum T_a$, since the last snow fall in accordance with the ideas of Plüss (1997):

$$a_{snow} = a_{min} + a_1 e^{a_2 S_{age} + a_3 \sum T_a} \quad (4.113)$$

where a_{min} , a_1 , a_2 and a_3 are parameters. The short-wave radiation not reflected at the surface is assumed to be absorbed at the surface. See viewing function "[Snow Albedo Function](#)".

Switches

InLongRad

Value	Meaning
Konzelmann et al equation	The incoming longwave radiation is estimated with the atmospheric emissivity as a function of air temperature, vapour pressure and cloudiness as suggested by Konzelmann et al 1994 (in a study of the radiation balance over the Greenland ice-sheet) See Eq. (4.81) .
Satterlunds equation	The incoming longwave radiation is estimated with the atmospheric emissivity as a function of air temperature, vapour pressure as suggested by Satterlund for clear-sky irradiance, complemented with a standard formulation of the influence of clouds. See Eq (4.83) .
Brunts equation	The incoming longwave radiation is estimated with the formula by Brunt for clear-sky irradiance, complemented with a standard formulation of the influence of clouds. See Eq (4.82) .

LongRadCanopy

Value	Meaning
implicit	The longwave radiation balance of plants is implicitly considered through the partitioning of net radiation between the canopy and the soil/snow surface below.

explicit f(TempCanopy)	Longwave and shortwave radiation are separately partitioned between the canopy and the soil/snow surface below. The longwave radiation balance of plants is directly governed by the canopy temperature, which also directly influences the longwave radiation to the soil/snow surface.
------------------------	--

LongWaveBalance

Value	Meaning
One formula f(AirTemp)	The net longwave radiation at the surface is estimated by an equation suggested by Brunt, including air temperature
Two separate formulas	The net longwave radiation at the surface is estimated with two separate equations for the incoming and the outgoing radiation. This means that the incoming radiation may be given as an input variable specified in the driving variable file.

SlopeCorrMeasuredGlobal

Value	Meaning
No	No correction of measured global radiation is made due to slope.
Yes	Correction of measured global radiation is made due to slope.

Turbidity

Value	Meaning
Constant	The Ångströms equation is used to estimate the turbidity of the atmosphere as a function of cloudiness only.
Function of solar angle	The turbidity of the atmosphere is given as a function of solar angle and air humidity and cloudiness.

Parameters

AlbLeafSnowCoef

Fraction of snow albedo in the albedo of a snow-covered canopy.

Default	Unit	Symbol	Equation	Function
0.5	-	$f_{snowintalb}$	(4.105)	

AlbSnowMin

Lowest albedo in the albedo function, which accounts for snow age and positive sum of air temperature since latest new snow.

Default	Unit	Symbol	Equation	Function
40	%	a_{min}	(4.113)	“Snow Albedo Function”

Albedo

Albedo of vegetation and soil, used only when vegetation is treated implicitly.

Default	Unit	Symbol	Equation	Function
25	%	$a_{vegsoil}$	(4.110)	

Normal range for coniferous forest are 8-12 and for crops 15-30. The value of this parameter can easily be measured in the field or taken from literature.

AlbedoDry

The albedo of a dry soil

Default	Unit	Symbol	Equation	Function
30	%	a_{dry}	(4.112)	“Bare Soil Albedo Function”

Typical values are found in the range from 20 - 45 %. Normally sandy soils have a higher albedo compared to clay soils.

AlbedoKExp

A rate coefficient that governs the shift of albedo values from wet to dry soils.

Default	Unit	Symbol	Equation	Function
1	-	k_a	(4.112)	“Bare Soil Albedo Function”

AlbedoWet

The albedo of a wet soil.

Default	Unit	Symbol	Equation	Function
15	%	a_{wet}		“Bare Soil Albedo Function”

Typical values are found in the range from 5 - 15 %. The moisture content that represents a totally wet soil has been fixed to a tension of 10 cm water (pF value = 1).

Latitude

Latitude of site, for calculation of day length and global radiation.

Default	Unit	Symbol	Equation	Function
58.5	-	l_{at}	(4.87), (4.91), (4.99) and (4.100)	“Global radiation, potential”

The parameter will be treated as a floating-point variable that means that the minutes must be converted to decimals.

RadFracAng1

The coefficients introduced by Ångström for calculation of global radiation from cloudiness.

Default	Unit	Symbol	Equation	Function
0.22	-	r_5	(4.102)	“Ångströms Short wave equation”

RadFracAng2

The coefficients introduced by Ångström for calculation of global radiation from cloudiness.

Default	Unit	Symbol	Equation	Function
0.50	-	r_6	(4.102)	“Ångströms Short wave equation”

RntLAI

The extinction coefficient in the Beer law used to calculate the partitioning of net radiation between canopy and soil surface.

Default	Unit	Symbol	Equation	Function
0.5	-	k_m	(4.1), (4.67), (4.71)	“Beer’s Law”

Parameter Tables

Brunts incoming long wave Coefficients

Name	Default	Unit	Symbol	Comments/Explanations
BruntCoef 1.	0.605		r_{b1}	Parameters used to calculate the emissivity with the two separate formulas approach.
BruntCoef 2.	0.048		r_{b2}	see above
BruntCoef 3.	0.3		r_{b3}	see above

Brunts Net long wave Coefficients

Name	Default	Unit	Symbol	Comments/Explanations
BruntsAirCoef 1.	0.56		r_1	Parameters used to calculate the incoming net longwave radiation with the one formula approach.
BruntsAirCoef 2.	0.00779		r_2	see above
BruntsAirCoef 3.	0.1		r_3	see above
BruntsAirCoef 4.	0.9		r_4	see above

Konzelmann incoming long wave Coefficients

Name	Default	Unit	Symbol	Comments/Explanations
KonzelmannCoef 1.	0.23		r_{kl}	Parameters used to calculate the emissivity with the two separate formulas approach.
KonzelmannCoef 2.	0.483		r_{k2}	see above

KonzelmannCoef 3.	0.963		r_{k3}	see above
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Satterlunds incoming long wave Coefficients

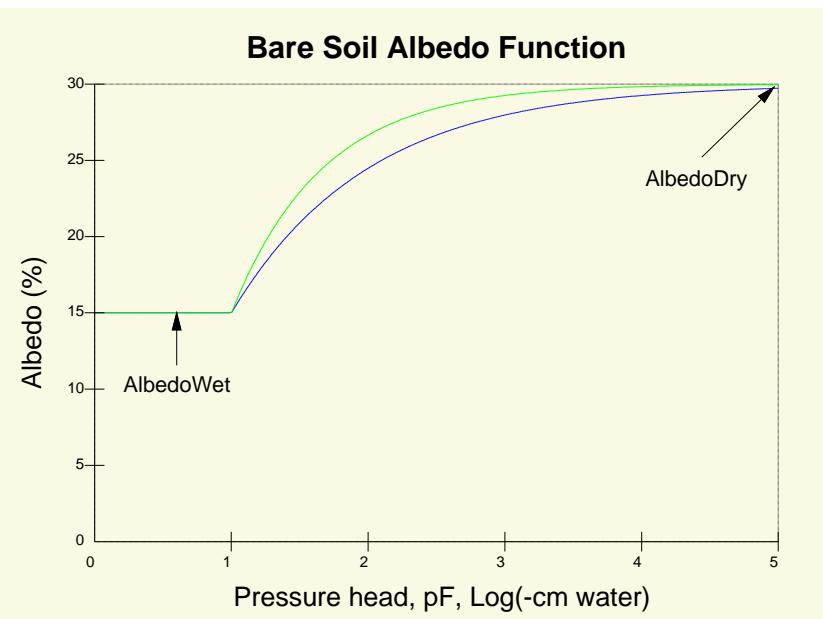
Name	Default	Unit	Symbol	Comments/Explanations
SatterlundCoef 1.	2016		r_{s1}	Parameters used to calculate the emissivity with the two separate formulas approach.
SatterlundCoef 2.	0.3		r_{s2}	see above

Snow Albedo Coefficients

Name	Default	Unit	Symbol	Comments/Explanations
AlbSnowCoef 1.	50		a_1	Parameter used to calculate albedo of snow.
AlbSnowCoef 2.	-0.05		a_2	Parameter used to calculate albedo of snow.
AlbSnowCoef 3.	-0.1		a_3	Parameter used to calculate albedo of snow.

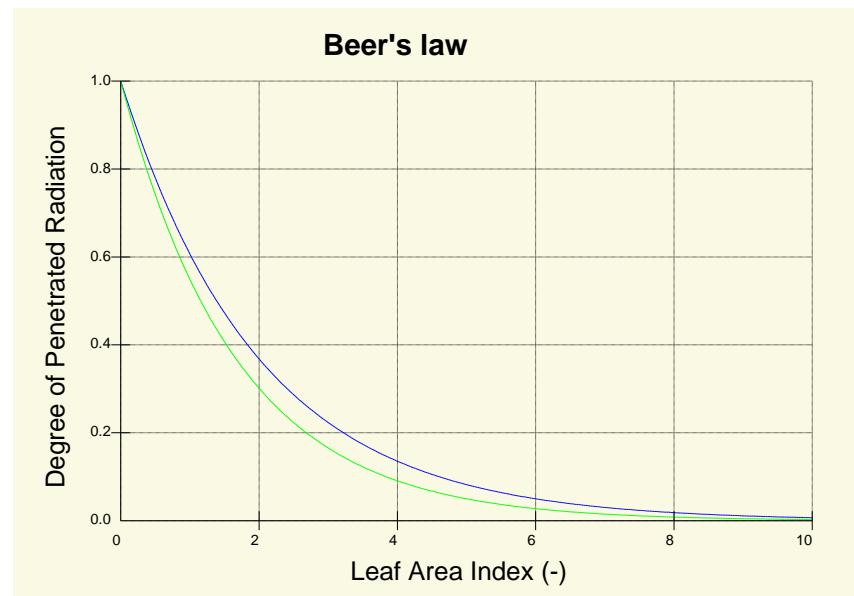
Viewing Functions

Bare Soil Albedo Function



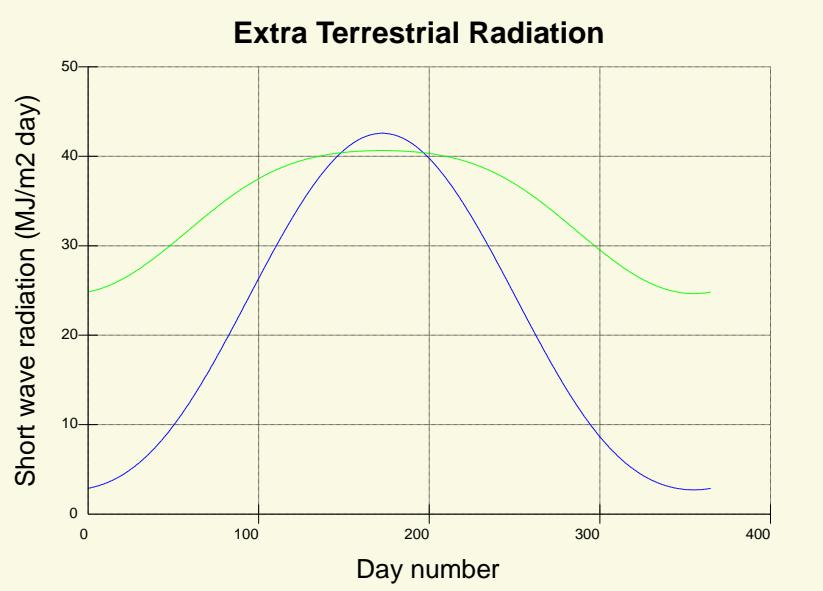
Bare soil albedo as a function of pressure head. k_a is 1 for the blue line and 1.5 for the green line.

Beer's Law



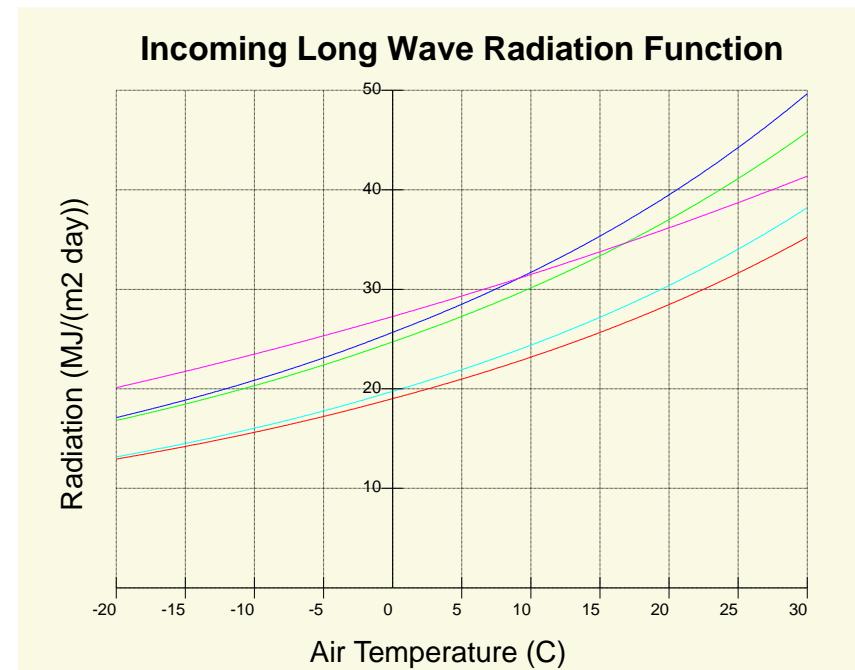
Degree of penetrated radiation through the canopy as a function of leaf area index. The extinction coefficient, k_m , is 0.5 (blue line) and 0.6 (green line).

Global radiation, potential



Potential global radiation (extra terrestrial radiation) as a function of day number for two different latitudes: 58.5 (blue) and 20 (green).

Incoming and outgoing long-wave radiation, Brunt's formula



Incoming long wave radiation as a function of air temperature estimated with Brunt's formula, compared with the outgoing long wave radiation calculated with surface temperature set equal to the air temperature, for four different meteorological situations:

Blue = overcast sky; $h=100\%$.

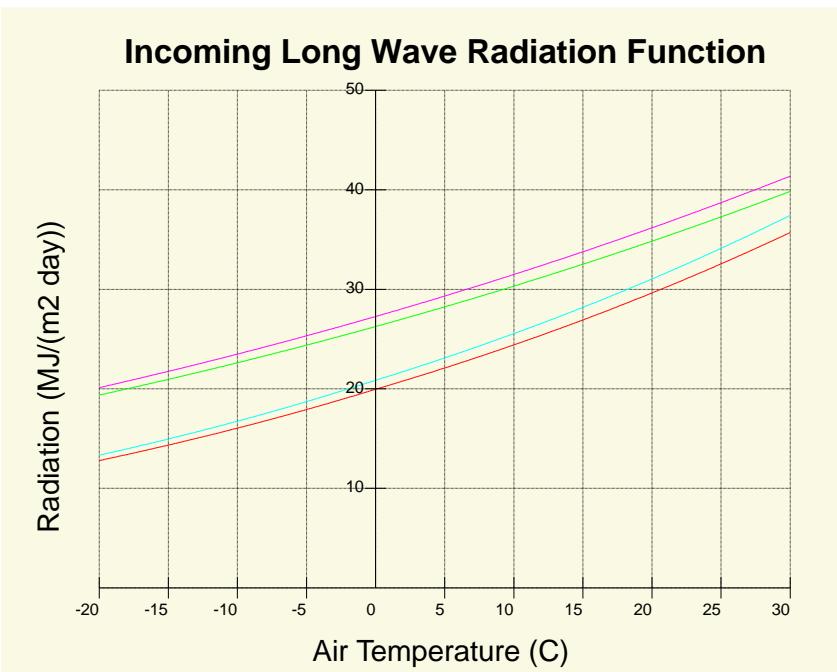
Green = overcast sky; $h = 60\%$.

Turquoise = clear sky; $h = 100\%$.

Red = clear sky; $h = 60\%$.

Violet = *outgoing* radiation.

Incoming and outgoing long-wave radiation, Konzelmann



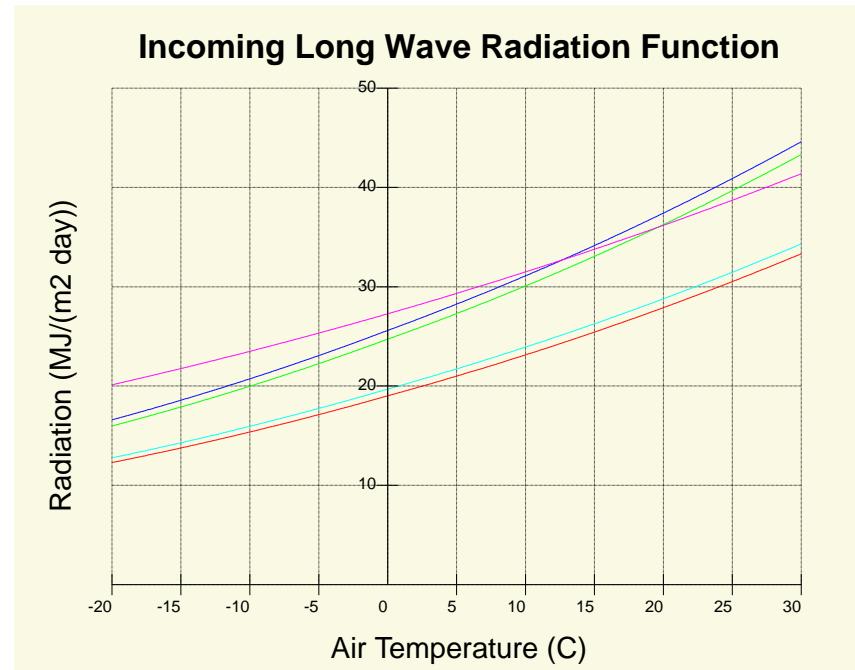
Incoming longwave radiation as a function of air temperature estimated with the Konzelmann-formulation, compared with the outgoing longwave radiation calculated with the surface temperature set equal to the air temperature, for four different meteorological situations:

Blue (same as green) = overcast sky; $h=100\%$. Green = overcast sky; $h = 60\%$.

Turquoise = clear sky; $h = 100\%$. Red = clear sky; $h = 60\%$.

Violet = *outgoing* radiation.

Incoming and outgoing long-wave radiation, Satterlund



Incoming longwave radiation as a function of air temperature estimated with the Satterlund-formulation, compared with the outgoing longwave radiation calculated with the surface temperature set equal to the air temperature, for four different meteorological situations:

Blue = overcast sky; h=100%.

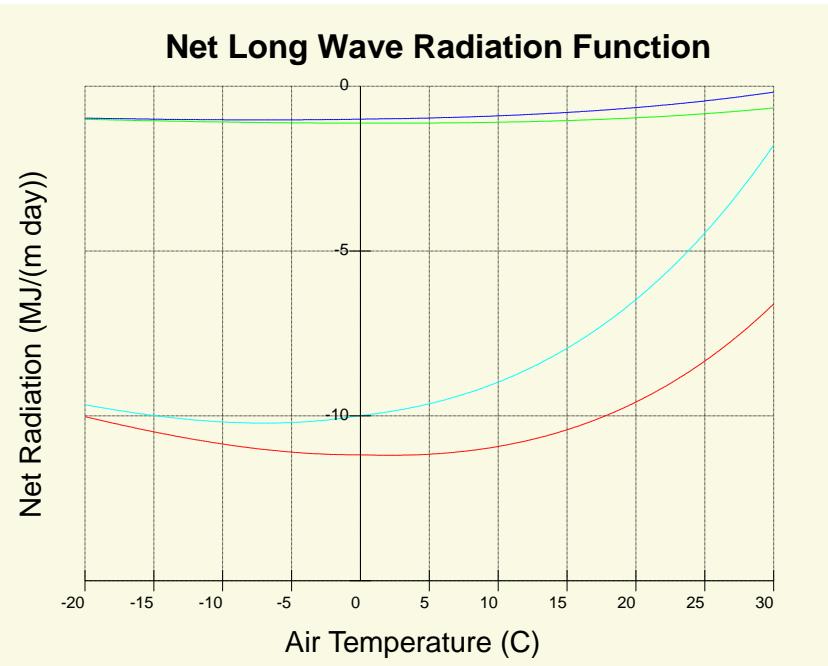
Green = overcast sky; h = 60%.

Turquoise = clear sky; h = 100%.

Red = clear sky; $h = 60\%$.

Violet = *outgoing* radiation.

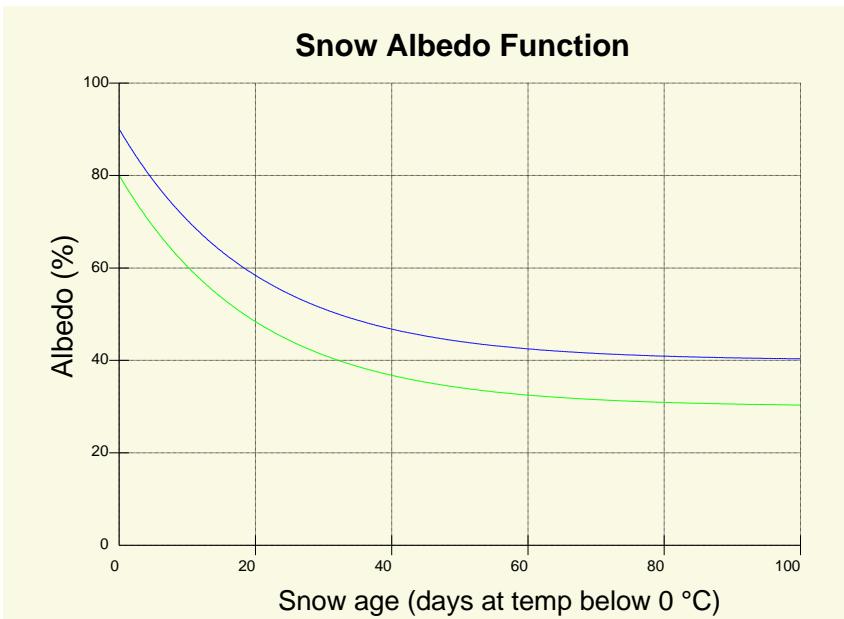
Net Long Wave Radiation, One formula approach



Net long wave radiation as a function of air temperature for four different meteorological situations:

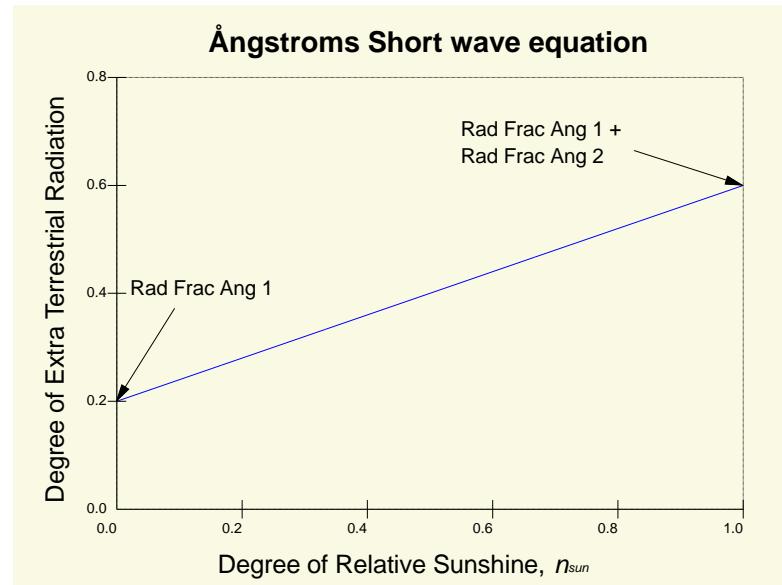
Blue = overcast sky; $h=100\%$. Green = overcast sky; $h=60\%$.
Turquoise = clear sky; $h=100\%$. Red = clear sky; $h=60\%$.

Snow Albedo Function



Snow albedo as a function of snow age. a_{min} is 40 for the blue line and 30 for the green line.

Ångströms Short wave equation



Global radiation at the land surface in fractions of the extraterrestrial solar radiation (potential global radiation), estimated with Ånström's equation as a function of degree of relative sunshine (RadFracAng1: 0.2 and RadFracAng2: 0.4).

Auxiliary Variables

AlbedoVar

Albedo of the surface as seen from the air.
%

CanopyFracRad

The fraction of light absorbed by vegetation above the unit area of soil.

CanopyFracRad1

The fraction of light absorbed by vegetation above the unit area of soil (section one).

CanopyFracRad2

The fraction of light absorbed by vegetation above the unit area of soil (section two).

LAI Above Canopy

The leaf area index above an individual plant in a multiple canopy, calculated as the sum of the partial leaf area indexes of all plants above the specific plant.

Net Radiation Canopy

Net radiation absorbed by individual plants. This variable is only calculated if the multiple plants option is used.
 $\text{Jm}^{-2}\text{day}^{-1}$

RadInLongGround

Long wave radiation below the canopy, i.e. the average net radiation above the snow covered and the snow free fractions of the bare soil.
 $\text{Jm}^{-2}\text{day}^{-1}$

RadInLongGround1

Long wave radiation below the canopy, i.e. the average net radiation above the snow covered and the snow free fractions of the bare soil (section one).
 $\text{Jm}^{-2}\text{day}^{-1}$

RadInLongGround2

Long wave radiation below the canopy, i.e. the average net radiation above the snow covered and the snow free fractions of the bare soil (section two).
 $\text{Jm}^{-2}\text{day}^{-1}$

RadNetGround

Net radiation below the canopy, i.e. the average net radiation above the snow covered and the snow free fractions of the bare soil.
 $\text{Jm}^{-2}\text{day}^{-1}$

RadNetGround1

Net radiation below the canopy, i.e. the average net radiation above the snow covered and the snow free fractions of the bare soil (section one).
 $\text{Jm}^{-2}\text{day}^{-1}$

RadNetGround2

Net radiation below the canopy, i.e. the average net radiation above the snow covered and the snow free fractions of the bare soil (section two).
 $\text{Jm}^{-2}\text{day}^{-1}$

RadNetShort

Net shortwave radiation absorbed by the soil-snow-vegetation system.
 $\text{Jm}^{-2}\text{day}^{-1}$

Nitrogen and Carbon – above ground processes and common functions

Henrik Eckersten, Annemieke Gärdenäs, Karin Blombäck, Per-Erik Jansson & Louise Karlberg

External inputs

There are three possible sources of external inputs of nitrogen to the soil namely [deposition](#), [fertilization](#) and manure (for an overview see “[Structure of Model](#)”). Only one of them, manure, also contains carbon. Deposition enters directly to the uppermost soil compartment and into the pools of mineral nitrogen. Fertilization goes into a special state variable representing undissolved fertilizer that is located on the soil surface. Dissolution into the mineral nitrogen pools is made at continuous rates. Manure is directly mixed into the soil to a specified depth and adds to the litter, faeces or ammonium pools as nitrogen and to the litter and faeces pool as carbon.

Deposition occurs continuously whereas fertilization and manure occur at certain dates that correspond to specified day numbers of the year.

Deposition of nitrogen

Both dry and wet deposition occurs but only mineral N can optionally be accounted for (see “[Deposition](#)”). Ammonium depositions to the soil is given as:

$$N_{Atm \rightarrow NH} = P_{dry} P_{fNH,Dry} + P_{cwet} P_{fNH,Wet} q_{in} \quad (5.1)$$

where P_{dry} , $P_{fNH,Dry}$, P_{cwet} and $P_{fNH,Wet}$ are site-specific parameters and q_{in} is the water infiltration rate. Similarly the nitrate deposition is given as:

$$N_{Atm \rightarrow NO} = P_{dry} (1 - P_{fNH,Dry}) + P_{cwet} (1 - P_{fNH,Wet}) q_{in} \quad (5.2)$$

where the parameters are the same as for the ammonium deposition rate.

A direct uptake of nitrogen by the leaf from the atmosphere may also be specified as:

$$N_{Atm \rightarrow l} = p_{dry,l} A_l \quad (5.3)$$

where $p_{dry,l}$ is the plant specific deposition rate per unit of leaf area and A_l is the leaf area index.

Fertilization

Fertilizer can optionally be added to a soil (see “[N Fertilization](#)”). The fertilization is added at a specified rate, $p_{FertRate}$, to a nitrogen pool, N_{Fert} , located on the soil surface. Dissolution of mineral N from this state variable is made continuously. Ammonium is formed as:

$$N_{Fert \rightarrow NH} = p_{fNH} p_{kFert} N_{Fert} \quad (5.4)$$

where p_{fNH} and p_{kFert} are empirical parameters. Similarly nitrate is given by

$$N_{Fert \rightarrow NO} = (1 - p_{fNH}) p_{kFert} N_{Fert} \quad (5.5)$$

Manure

Manure consists of a mixture of organic matter that can be simulated if the switch “[Faeces pool](#)” (see section “[Soil Organic Processes](#)”) is on. The amount of manure can either be given as parameters of in a PG-file (see switch “[Manure Input](#)”). Manure is mixed as nitrogen into the litter pool, $N_{Litter1}$, the faeces pool, N_{Faeces} , or the ammonium pool, N_{NH} . Carbon is added to the litter pool, $C_{Litter1}$, and the faeces pool, C_{Faeces} , in proportions to specified C-N ratios. Note that an explicit manure pool does not exist. The mixing into the soil is made at a certain depth z_{ma} at the time of application.

Switches

These two switches determine whether or not deposition and fertilizer should be included in the model.

Deposition

Value	Meaning
On	Atmospheric deposition of mineral nitrogen turned on
Off	Atmospheric deposition of mineral nitrogen turned off.

Manure Input

Value	Meaning
Parameters	Manure input is given as parameters
PG-file	Manure input is given in a PG-file.

[N Fertilization](#)

Value	Meaning
On	Application of commercial fertilizer turned on.
Off	Application of commercial fertilizer turned off.

Parameters

Dep N DryRate

Dry deposition of mineral N to the soil surface.

Default	Unit	Symbol	Equation	Function
0.001	g N/m ² /day	p_{dry}	(5.1)	

A value of 0.001 corresponds to 3.65 kg N/ha/year. Normal range for an open field in southern Sweden 0.0005 - 0.002

Dep N WetConc

Concentration of mineral N in surface water that can infiltrate or be lost with surface runoff.

Default	Unit	Symbol	Equation	Function
0.1	mg N /l	p_{cwet}	(5.1)	

This value can be compared to corresponding values for nitrogen concentration in precipitation. During a year with 800 mm infiltration a value of 0.8 corresponds to a wet deposition of 6.4 kg N/ha/year. Normal range for southern Sweden 0.8 - 1.8 mg/l and for central Sweden 0.4 - 1.0.

Dep NH4 FracDry

Fraction of ammonium N in the dry deposition. The rest is nitrate N.

Default	Unit	Symbol	Equation	Function
0.5	-	$p_{fNH4,Dry}$	(5.1)	

Dep NH4 FracWet

Fraction of ammonium N in wet deposition. The rest is nitrate N.

Default	Unit	Symbol	Equation	Function
0.5	-	$p_{fNH,Wet}$	(5.1)	

N Fert Dis k

Specific dissolution rate of commercial fertilizer.

Default	Unit	Symbol	Equation	Function
0.15	/day	p_{kFert}	(5.4)	

A value of 0.15 corresponds to a half time of 5 days and that 90% of the fertilizer is dissolved within 15 days. A higher value results in faster dissolution. Dependent on fertilizer type and moisture conditions. Normal range 0.05-0.5.

N Fert NH4 Frac

Fraction of dissolved solid N fertilizer that is ammonium. The rest is nitrate N.

Default	Unit	Symbol	Equation	Function
0.15	-	p_{fNH}	(5.4)	

Parameter tables

These tables govern how fertilizer and manure are transferred to the soil.

N fertilization

Name	Default	Unit	Symbol	Comments/Explanations
Fert DayNo	121	Day number		Fertilization date (commercial fertilizer)
N Fert Rate	12	gN/m ² /day	$p_{FertRate}$	N-fertilization (commercial fertilizer) 1 g N/m ² \Leftrightarrow 10 kg N/ha. Normal range 0-30 gN/m ² /day

N manure application

Name	Default	Unit	Symbol	Comments/Explanations
Man DayNo	151	Day number		Date of manure application
N Faeces	2	gN/m ² /day		Nitrogen in faeces in manure. Normal range 0-30.
N Litter	2	gN/m ² /day		Nitrogen in litter in manure. Normal range 0-5.
N NH4	6	gN/m ² /day		Nitrogen in ammonium in manure. Normal range 0-30.
CN Litter	30	-		C-N ratio of litter in manure. Normal range 20-80.
CN Faeces	20	-		C-N ratio of faeces in manure. Normal range 10-30.
Man Depth	0.3	m	z_{ma}	Depth to which the applied manure is uniformly mixed into the soil. Normal range 0.05-0.25.

Specific N Deposition uptake leaf

For multiple canopies a value for each plant type is specified in the table below.

Name	Default	Unit	Symbol	Comments/Explanations
Dep N to leaf	$1 \cdot 10^{-5}$	gN/m ² /day	$p_{dry,l}$	Dry deposition of mineral N on canopy per unit of leaf area that is taken up directly by the leaves from the atmosphere.

State Variables

N Fertilizer

Temporary nitrogen pool at the soil surface.
g/m²

Flow Variables

C Manure Faeces Rate

The carbon flux from manure to the faeces pool.
g/m²/day

C Manure Litter Rate

The carbon flux from manure to the litter pool.
g/m²/day

Deposition N Leaf

Deposition of nitrogen to the leaf.
g/m²/day

Deposition NH4 Rate

Deposition rate of ammonium.
g/m²/day

Deposition NO3 Rate

Deposition rate of nitrate.
g/m²/day

N Fert Appl Rate

Nitrogen fertilization application rate.
g/m²/day

N Fert NH4 Dis Rate

Nitrogen fertilization ammonium dissolution rate.
g/m²/day

N Fert NO3 Dis Rate

Nitrogen fertilization nitrate dissolution rate.
g/m²/day

N Manure Faeces Rate

The nitrogen flux from manure to the faeces pool.
g/m²/day

N Manure Litter Rate

The nitrogen flux from manure to the litter pool.
g/m²/day

N Manure NH4 Rate

The nitrogen flux from manure to the soil ammonium pool.
g/m²/day

Auxiliary Variables

Total Deposition N Leaf

The total amount of deposited nitrogen on all plants.
g/m²/day

Files

Manure

This file contains information on manure input. The ID in the table corresponds to the variable name that has to be specified in the PG file.

Name	Unit	ID	Comments/Explanations
N NH4	gN/m ² /day	ManNH	Nitrogen in ammonium in manure. Normal range 0-30.
N Litter	gN/m ² /day	ManNLN	Nitrogen in litter in manure. Normal range 0-5.
CN Litter	-	CNBed	C-N ratio of litter in manure. Normal range 20-80.
N Faeces	gN/m ² /day	ManFN	Nitrogen in faeces in manure. Normal range 0-30.
CN Faeces	-	CNFec	C-N ratio of faeces in manure. Normal range 10-30.
Man Depth	m	ManDepth	Depth to which the applied manure is uniformly mixed into the soil. Normal range 0.05-0.25.

Plant Growth

Biotic and abiotic characteristics of the plant
Simulating growth

When nitrogen and carbon flows are not simulated, the plant exists only as a driving force for heat and water dynamics. In this case the plant can have shape characteristics like height, leaf area index and root depth that are used to estimate transpiration. These characteristics can be given in a table or be read from a file. The resulting plant is therefore only “virtual” and does not consist of any biomass. Simulating carbon and nitrogen flows together with vegetation means that the plant will have a real biomass (i.e. storages of carbon and nitrogen in the plant) that will increase when the plant grows. The shape characteristics of the plant are simulated from this biomass. These simulated values are always used in the biotic section of the model, whereas in the abiotic section the use of simulated values is optional. Hence, it is possible to have for example one leaf area index generated from parameters that determines transpiration and another simulated leaf area index that determines photosynthesis (growth).

Growth and plant development are simulated if the switch “[Growth](#)” is set to any of three alternative options for plant growth (i.e. this switch must not be turned “off”). Subsequently there are three different basic approaches to calculate the plant growth (leaf assimilation) in the CoupModel. The simplest approach is to assume that the plant growth and the nitrogen uptake are described by a logistic growth function (see “[Logistic growth approach](#)”). This means that the potential growth is a function of time (in terms of day-number) and not a function of weather. Another approach estimates the growth from a water use efficiency parameter and from the simulated transpiration (see “[Water use efficiency approach](#)”). Alternatively, light use efficiency can be used to estimate potential growth rate, limited by unfavourable temperature, water and nitrogen conditions (see “[Light use efficiency approach](#)”). A biochemical model after Farquhar et al. (1980) can be used if hourly values of photosynthesis and transpiration is of interest (see “[Farquhar approach](#)”).

This section also describes how the assimilated carbon is allocated to different parts of the plant; see “[Allocation to different parts of the plant](#)”. The carbon uptake gives rise to an uptake demand of nitrogen in the soil, see “”, and the plant also loses some carbon to the atmosphere by respiration, see “[Respiration](#)”.

Leaf Assimilation

Logistic growth approach

In this approach the growth is proportional to the potential uptake of nitrogen. The uptake of carbon in annual plants starts and ends at day numbers specified by the parameters “Up Start” and “Up End”. Note that if the growth starts late one year, for example if an autumn crop is simulated or if the crop is grown on the southern hemisphere, the “Up Start” and “Up End” values should still be given as the calendar day when the growth starts and ends respectively. Perennial plant growth is simulated the whole year. (It can be useful to compare the “Up Start” and “Up End” values with the fixed emergence day number and harvest day number).

The growth, $C_{Atm \rightarrow a}$ (i.e. photosynthesis), is calculated as:

$$C_{Atm \rightarrow a} = cn_p f(E_{ta} / E_{tp}) N_{s \rightarrow pl,p}(t) \quad (5.6)$$

where cn_p is a parameter, E_{ta} is the actual transpiration and E_{tp} is the potential transpiration. The response function for water $f(E_{ta}/E_{tp})$ is simply the ratio itself.

The potential uptake of nitrogen $N_{s \rightarrow pl,p}$ is given as:

$$N_{s \rightarrow pl,p} = \frac{p_{ua} p_{uc} \frac{p_{ua} - p_{ub}}{p_{ub}} e^{-p_{uc}\Delta t}}{\left(1 + \frac{p_{ua} - p_{ub}}{p_{ub}} e^{-p_{uc}\Delta t}\right)^2} \quad (5.7)$$

where p_{ua} , p_{ub} and p_{uc} are parameters and Δt is the time since the start of growth. See viewing function “Potential uptake of nitrogen – logistic growth”.

Water use efficiency approach

Here the only driving force for growth, $C_{Atm \rightarrow a}$, will be the actual transpiration, thus:

$$C_{Atm \rightarrow a} = \varepsilon_w \eta E_{ta} \quad (5.8)$$

where ε_w is the water use efficiency, η is the conversion factor for biomass to carbon and E_{ta} is the actual transpiration.

Light use efficiency approach

Total plant growth, $C_{Atm \rightarrow a}$, is proportional to the global radiation absorbed by canopy, $R_{s,pl}$, (see “Soil evaporation, snow and radiation processes”) but limited by unfavourable temperature $f(T_l)$, nitrogen $f(CN_l)$ and water $f(E_{ta}/E_{tp})$ conditions represented by functions ranging between zero and unity as:

$$C_{Atm \rightarrow a} = \varepsilon_L \eta f(T_l) f(CN_l) f(E_{ta} / E_{tp}) R_{s,pl} \quad (5.9)$$

where ε_L is the radiation use efficiency and η is a conversion factor from biomass to carbon.

Optionally, this equation can be slightly modified to account for radiation saturation at high levels of radiation (see switch “PhoSaturation”) using a non-rectangular hyperbolic function:

$$C_{Atm \rightarrow a} = f(T_l) f(CN_l) f(E_{ta} / E_{tp}) p_{max} \left(1 - e^{-\varepsilon_L R_{s,pl} / p_{max}}\right) \quad (5.10)$$

where p_{max} is the maximum level of photosynthesis given as a parameter.

The leaf temperature response, $f(T_l)$, includes limitations because of too low or too high temperatures:

$$f(T_l) = \begin{cases} 0 & T_l < p_{mn} \\ (T_l - p_{mn}) / (p_{o1} - p_{mn}) & p_{mn} \leq T_l \leq p_{o1} \\ 1 & p_{o1} < T_l < p_{o2} \\ 1 - (T_l - p_{o2}) / (p_{mx} - p_{o2}) & p_{o2} \leq T_l \leq p_{mx} \\ 0 & T_l > p_{mx} \end{cases} \quad (5.11)$$

where p_{mn} , p_{o1} , p_{o2} and p_{mx} are parameters. See viewing function “[Assimilation – air temperature response](#)”.

The leaf nitrogen response, $f(CN_l)$, is made linear as:

$$f(CN_l) = \begin{cases} 1 & CN_{leaf} < p_{CN,Opt} \\ 1 + \frac{CN_{leaf} - p_{CN,Opt}}{p_{CN,Opt} - p_{CN,Th}} & p_{CN,Opt} \leq CN_{leaf} \leq p_{CN,Th} \\ 0 & CN_{leaf} > p_{CN,Th} \end{cases} \quad (5.12)$$

where $p_{CN,Opt}$ and $p_{CN,Th}$ are parameters and CN_{leaf} is the carbon nitrogen ratio in the leaf. See viewing function “[Assimilation – nitrogen content in leaf response](#)”.

The response function for water $f(E_{lg}/E_{tp})$ is simply the ratio itself.

If the plant is developing grain or if the grain is maturing, eq. (5.9) will be slightly modified, because during this period the plants radiation use efficiency is dependent on the development stage. Instead of using the photo radiation use efficiency, ε_L , directly, this parameter is therefore exchanged to a photo radiation response function, $f(\varepsilon_L)$:

$$f(\varepsilon_L) = \varepsilon_L \cdot \left(1 - \frac{\varepsilon_{Lred}}{100} \cdot G_{fill} \right) \quad (5.13)$$

where ε_{Lred} is the percentage reduction of radiation use efficiency due to grain development and G_{fill} is the degree of reduction due to development stage. G_{fill} is low when the plant starts to develop grain, which results in a low reduction of the radiation use efficiency, and it increases gradually towards 1 when the plant is in the grain maturing phase and the radiation use efficiency is then reduced by the whole ε_{Lred} . See viewing function “[Radiation use efficiency response function at grain filling](#)”.

Farquhar approach

The Farquhar biochemical growth model (Farquhar et al., 1980) calculates photosynthesis as a function of demand and supply of CO₂. The advantage with this model is that photosynthesis is regulated not only by radiation and transpiration, but also by air humidity, leaf temperature, CO₂ availability and leaf nitrogen content, and the plant also experience radiation saturation at high levels of radiation. To function properly, driving variables need to be given as input to the simulation at least once an hour. In this module photosynthesis, P , is calculated as mole carbon per leaf area per second. Thus, P has to be converted to g carbon per unit soil area per day, $C_{Atm \rightarrow a}$, at the end of the module:

$$C_{atm \rightarrow a} = M_C \cdot 86400 \cdot P \quad (5.14)$$

where M_C is the molar mass of carbon.

Parameters and variables used in the photosynthesis model are converted in a similar manner.

There are several viewing functions that illustrate the Farquhar photosynthesis model, e.g. “[Farquhar model – Carbon dioxide pressure as a function of time](#)”, “[Farquhar model – Photosynthesis as a function of carbon dioxide pressure in the sub-stomatal cavity](#)”, “[Farquhar model – Photosynthesis as a function of LAI](#)” and “[Farquhar model – Photosynthesis as a function of radiation](#)”.

Demand functions

Three types of photosynthesis are calculated: Rubisco limited photosynthesis,

Rubisco limited rate of assimilation

P_V , and RuBP limited photosynthesis, P_J and TPU limited photosynthesis, P_S . Gross photosynthesis, P , (including photorespiration) will be determined by the most limiting photosynthesis process.

P_V is the Rubisco (leaf enzyme) or carboxylation limited rate of assimilation, which is a function of light, leaf nitrogen, leaf temperature and soil moisture. Photosynthesis as a function of internal CO₂ concentration is calculated according to:

$$P_V = V_m \cdot \frac{c_i - \Gamma^*}{K_c(1+O/K_o) + c_i} \quad C_3$$

$$P_V = V_m \quad C_4$$
(5.15)

where V_m is a function of the maximum activity of Rubisco, c_i is the sub-stomatal cavity concentration of carbon dioxide, Γ^* is the CO₂ compensation point in the light in the absence of mitochondrial respiration, K_c is the Michaelis-Menten constant of Rubisco for CO₂, O is the oxygen concentration (partial pressure) in the atmosphere and K_o is the Michaelis-Menten constant of Rubisco for O₂. The reason for the difference between C₃ and C₄ plants, is that photorespiration occurs in C₃ plants at low levels of CO₂.

The CO₂ compensation point in the absence of mitochondrial respiration, Γ^* , is calculated as:

$$\Gamma^* = \frac{0.5 \cdot O}{2600 \cdot 0.57^{Q_{10}}} \quad (5.16)$$

where the Q₁₀ value is calculated from the leaf temperature, T_l :

$$Q_{10} = (T_l - 298.16)/10 \quad (5.17)$$

The Michaelis-Menten constant of Rubisco for CO₂, K_c , is calculated as:

$$K_c = 30 \cdot 2.1^{Q_{10}} \quad (5.18)$$

and the Michaelis-Menten constant of Rubisco for O₂, K_o , is calculated as:

$$K_o = 30000 \cdot 1.2^{Q_{10}} \quad (5.19)$$

V_m , is a function of the potential maximum capacity of Rubisco, V_{max} and the response functions for leaf temperature, $f(T_l)$, leaf carbon nitrogen ratio, $f(CN_l)$ and soil moisture, $f(E_{ta}/E_{tp})$ described above (Eqs. [\(5.11\)](#) -[\(5.12\)](#)):

$$V_m = V_{max} f(T_l) f(CN_l) f(E_{ta}/E_{tp}) \quad (5.20)$$

RuBP limited rate of assimilation

P_J is the RuBP regeneration limited (i.e. light-limited) rate of photosynthesis calculated as:

$$P_J = J_m \cdot \frac{c_i - \Gamma^*}{c_i + 2\Gamma^*} \quad C_3$$

$$P_J = J_m \quad C_4$$
(5.21)

where J_m is calculated as:

$$J_m = \min(\varepsilon\eta R_{s,pl}, 0.25 \cdot J_{max} \cdot f(T_l) \cdot f(E_{ta}/E_{tp})) \quad (5.22)$$

where ε is the quantum efficiency, η is the conversion factor for biomass to carbon, $R_{s,pl}$ is the absorbed short-wave radiation by the plant and J_{max} is the maximum electron transport rate.

TPU limited rate of assimilation

Finally, the metabolism of end product limited (TPU limited) rate of photosynthesis, P_S , is calculated as:

$$\begin{aligned} P_s &= 0.5 \cdot V_m & C_3 \\ P_s &= \frac{2 \cdot 10^4 \cdot V_m c_i}{p_{atm}} & C_4 \end{aligned} \quad (5.23)$$

where p_{atm} is the atmospheric pressure at the surface.

Scaling from leaf to canopy

The maximum Rubisco capacity for the bulk canopy per leaf area, V_{max} , can be calculated using equations similar to Beer's law:

$$V_{max} = V_{cmax} \left(1 - e^{-k_m A_l}\right) \frac{1}{k_m} \quad (5.24)$$

where V_{cmax} is the maximum Rubisco capacity per leaf area at the top the canopy respectively, k_m is the extinction coefficient for net radiation and A_l is the leaf area index. The relationship between V_{cmax} and the maximum electron transportation rate a the top of the canopy, J_{cmax} , has been investigated by Wohlfahrt et al. (1999). They found that a the ratio between the two was relatively constant ($J_{cmax} / V_{cmax} = 2.1$) for a number of leaves. This relationship is used in the CoupModel to determine the maximum electron transportation rate for the bulk canopy per leaf area, J_{max} .

Smoothing functions

To avoid abrupt transition from one limiting rate to another, we apply two quadratic equations on the assimilation rates that are solved for their smaller roots (Collatz et al., 1991):

$$\begin{aligned} \beta_{vj} P_P^2 - P_P (P_V + P_J) + P_V P_J &= 0 \\ \beta_{ps} P^2 - P (P_P + P_S) + P_P P_S &= 0 \end{aligned} \quad (5.25)$$

where β_{vj} and β_{ps} are empirical constants and P_S is an intermediate variable equal to the minimum of P_V and P_J .

Supply functions

Analogously to Fick's law of gas diffusion, the supply of CO₂ for photosynthesis can be calculated as:

$$P = \frac{c_a - c_i}{p_{atm}} \cdot (g_{sc} + g_{bc} + g_{ac}) \quad (5.26)$$

where c_a is the external carbon dioxide concentration, p_{atm} is the atmospheric pressure at the surface, and g_{sc} is the stomatal , g_{bc} is the boundary layer and g_{ac} is the aerodynamic conductances to CO₂, respectively. The gas diffusion from the atmosphere to the leaf is calculated step-wise, from the atmosphere, c_a , via the canopy air space, c_b , to the surface of the leaf, c_s , and finally into the sub-stomatal cavity, c_i in the following manner:

Carbon concentration in the atmosphere

1) Carbon concentration in the atmosphere, c_a : model input.

2) Carbon concentration in the canopy air space, c_b :

Carbon concentration in the canopy air space

$$c_b = c_{b,t-1} - \left(P_n + R_{soil} + g_{ac} \left(\frac{c_a - c_b}{p_{atm}} \right) \right) \cdot \frac{\Delta t}{k_{CO2cap}} \quad (5.27)$$

where $c_{b,t-1}$ is the carbon concentration in the canopy air space from the previous time step, P_n is the net photosynthesis and R_{soil} is the sum of all respiration fluxes from the soil surface. k_{CO2cap} is the carbon capacity of air ($\text{mol air} / \text{m}^2$), which is basically the mass of air under the top of the canopy, or, to be exact, from ground to displacement height. This factor, together with time, t , converts the flows ($\text{mol CO}_2 / \text{m}^2 / \text{s}$) into concentrations ($\text{mol CO}_2 / \text{mol air}$). The carbon capacity is calculated as:

$$k_{CO2cap} = \max(d, 4) \cdot a_{mol} \cdot \frac{(T_f + T_{abszero}) \cdot (p_{atm} / p_{atmnorm})}{(T_a + T_{abszero})} \quad (5.28)$$

where d is the displacement height, a_{mol} is the amount of gas in one cubic meter of air, T_f is the freezing point, $T_{abszero}$ is the absolute zero temperature, p_{atm} is the atmospheric pressure at the soil surface given as a parameter and $p_{atmnorm}$ is the normal pressure at the soil surface.

Carbon concentration at the leaf surface 3) Carbon concentration in at the leaf surface, c_s :

$$c_s = c_b - \frac{P_n}{g_{bc}} \cdot p_{atm} \quad (5.29)$$

Carbon concentration in the sub-stomatal cavity 4) Carbon concentration in the sub-stomatal cavity, c_i :

$$c_i = c_s - \frac{P_n}{g_{sc}} \cdot p_{atm} \quad (5.30)$$

The functions to derive the equilibrium concentration of carbon dioxide in the sub-stomatal cavity, c_i , from the demand and the supply functions, follows the iterative procedure in the SiB2 model (Sellers et al., 1996).

Conductance of CO₂ from the canopy air space to the atmosphere The conductance from the canopy air space to the free flowing air for carbon dioxide, g_{ac} , is calculated from the aerodynamic resistance to water flow, r_a :

$$g_{ac} = \frac{1.0}{r_a} \quad (5.31)$$

Conductance of CO₂ from the leaf surface to the canopy air space The boundary layer conductance for carbon dioxide, g_{rc} , is calculated from the boundary layer resistance for water flow, r_b , as:

$$g_{rc} = \frac{1.4}{r_b} \quad (5.32)$$

where the boundary layer resistance, r_b , is given as an input to model simulations. 1.4 is the ratio of the diffusivities of CO₂ and H₂O in the leaf boundary layer.

Conductance of CO₂ from the stomata to the leaf The stomatal conductance for carbon dioxide, g_{sc} , is calculated from the resistance to water flow through stomata, r_s , as:

surface

$$g_{sc} = \frac{1.6}{f(E_{ta}/E_{tp}) \cdot r_s} \quad (5.33)$$

where the response function for soil water stress $f(E_{ta}/E_{tp})$ is multiplied with the stomatal resistance to account for stomatal closure due to plant water stress. 1.6 is the ratio of the diffusivities of CO₂ and H₂O in the stomatal pores.

The resistances to water flow are measured in s m⁻¹, and thus corresponding conductance is in m s⁻¹. To convert the conductance from m s⁻¹ to moles m⁻² s⁻¹, which is the unit used in the photosynthesis equations, the following conversion is performed:

$$g_{sc} (\text{mol/m}^2/\text{s}) = g_{sc} (\text{m/s}) \cdot a_{mol} \cdot \frac{(T_f + T_{abszero}) \cdot (p_{atm}/p_{atmnorm})}{(T_a + T_{abszero})} \quad (5.34)$$

Reduction of photosynthesis due to grain development is simulated in the same way as in the light use efficiency approach, by replacing ε_L with ε in Eq.(5.13).

Salinity stress

High concentrations of toxic ions in the soil can lead to decreased photosynthesis and growth, if taken up by the plant. Soil salinity reducing photosynthesis can optionally be simulated (see switch “[Salinity stress](#)”). One option is to simulate salinity stress as a decrease in photosynthesis, such as:

$$C_{Atm \rightarrow a}^* = f(\pi(z)) \cdot C_{Atm \rightarrow a} \quad (5.35)$$

where the salinity reduction function, $f(\pi(z))$ is the same reduction function used for the reduction of plant water uptake, eq. 3.34. The parameters in the function, π_c and p_π can be found in this sections parameter list as well as in the water uptake section.

Alternatively, the salinity reduction function, $f(\pi(z))$ can be used to increase respiration as a response to increased salinity (see eq.X).

Allocation to different parts of the plant

The plant biomass is divided into five compartments of carbon and nitrogen for grain crops (C_{Leaf} , C_{Stem} , C_{Root} , C_{Grain} , C_{Mobile} , N_{Leaf} , N_{Stem} , N_{Root} , N_{Grain} and N_{Mobile}) (see [Figure 5.1](#)). The mobile pools are a kind of luxury storage pools that contain nitrogen and carbon that can be used at special occasions for example at leafing. Three additional compartments exist for perennial plants ($C_{OldLeaf}$, $C_{OldStem}$, $C_{OldRoot}$, $N_{OldLeaf}$, $N_{OldStem}$, $N_{OldRoot}$) for carbon and nitrogen respectively. The “old” compartments for perennial plants consist of biomass assimilated in previous years. Consequently at some time the carbon and nitrogen in the new biomass pools have to be considered as old and therefore have to be allocated from the new to the old pools. This allocation process takes place at the beginning of each year, when all the accumulated carbon and nitrogen in the plant from the previous year is allocated to the “old” biomass pools, unless the plant is less than 180 days old. Consequently the “new” biomass pools are always empty in the beginning of each year in perennial plants (with the exception of very young plants).

Allocation to old biomass pools

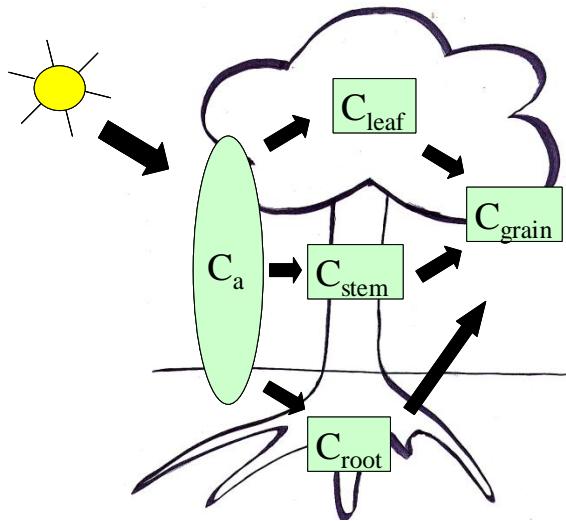


Figure 5.1. Carbon pools in a tree. The grain pool represents all kinds of reproductive organs e.g. fruit, seeds, cones etc. There is also a mobile pool that perennial plants can use at leafing.

Initial conditions

Annuals and perennials

Plant development

The initial amounts of nitrogen in each compartment at the start of the simulation can be specified in the parameter table “[Initial Conditions of plants](#)”. Based on these figures initial amounts of carbon are calculated from the CN-ratios specified in the parameter table “[Initial CN ratios of plants](#)”. In “[Initial Conditions of plants](#)” the plant age must also be specified. If the plant is not yet sown the initial age should be put to zero.

There are no principal differences between annual and perennial plants in the functioning of photosynthesis and many other processes in the model. Instead the main differences in growth rates and structure are caused by differences in allocation patterns, which have to be specified separately for each plant as described in the section “[Allocation of Carbon](#)”.

Allocation to the different compartments is governed by the plant development stage and different environmental responses. The allocation pattern is similar for carbon and nitrogen but some important differences are found.

In the sections below we first describe the different stages of plant development and how they are calculated in the model. Next the allocation flow for carbon and nitrogen to the different compartments will be described.

Plant lifecycle

There are several functions that govern the lifecycle of plants. The total life span is determined by age of the plant and the maximum plant age. A distinction between the growing season and the dormancy period affects leafing and litter fall and finally plant growth stages during the growing season affect allocation patterns. All those functions are represented in [Figure 5.2](#).

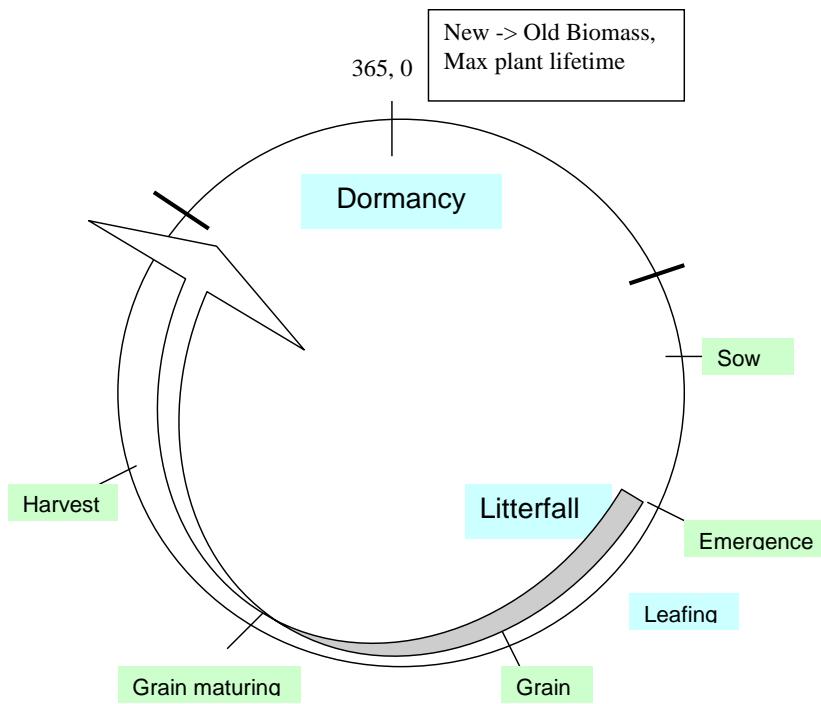


Figure 5.2. Lifecycle of plants on the northern hemisphere (annual and perennial). Growth stage = green, Growing season / dormancy = blue, plant maximum age and old/new biomass allocation = no colour.

Start of growth, initial plant age and plant death

Dormancy

GSI

A plant can either exist from the beginning of the simulation, or it can be sown during the course of the year. As the simulation proceeds the plant age is counted for every existing plant. If the plant existed from the beginning of the simulation, the *initial plant age* is given in the table “[Initial Conditions of plants](#)”, and the age is increased from that value and onwards as time goes by in the simulation. All plants celebrate their birthdays on day 1 i.e. New Years Day (or day 180 for the southern hemisphere) irrespective of whether they were sown the same year or not. When the plant age equals the *maximum plant lifetime* given in table “[Plant Behaviour](#)”, the plant dies. For annual plants it is therefore advisable to choose a maximum plant lifetime of 1. At the year shift (or day 180 for the southern hemisphere) the new biomass from the previous year is transformed into old biomass.

Some perennial plants go into dormancy during the winter. Deciduous plants prepare for the dormancy by losing their leaves. When litter is formed the plant withdraws nutrients from the dying parts and stores them in their remaining tissues. When the growing season starts the stored nitrogen and carbon can be used to build up new leaves during leafing. A dormancy period can optionally be simulated (see switch “[Winter regulation](#)”). The dormancy period begins when the air temperature is less than -5°C for three consecutive days. Similarly, the growing season starts when the difference between the air temperature and the threshold temperature for emergence exceeds 0°C for three consecutive days.

A growth stage is an indicator of where in the lifecycle the plant is at present, and the allocation patterns for carbon and nitrogen are highly dependent on this. The growth stages in the model are labelled 0-4 and are listed in the table below. Each growth stage represents a different allocation pattern.

Index	Description	Governing Variable	Parameters
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-1	No plant exist or dormant season	Temperature Sum or date	T_Thres_Sowing T_Sum_Sowing
0	Sowing	Temperature Sum or date	T_Thres_Emergence T_Sum_Emergence
1	Emergence, Start of vegetative growth	Day Lengths and Temperature sum	GrainSI_StepTemp GrainSI_ThresTemp GrainSI_StepDay GrainSI_ThresDay GrainSI_Step
2	Grain filling start	Temperature sum	T_Thres_GrainFill T_Sum_GrainFill
3	Maturing of grain	Only time	
4	Harvest	Temperature sum	

Plant lifecycles

Start of growth

Temperature sums

Leafing

Grain development

Each simulated plant must have an *initial growth stage*, which is given in the table “[Plant Behaviour](#)”. Annual crops will normally start at a growth stage index (GSI) between -1 to 1 whereas perennial plants such as trees often start at a GSI of 1 i.e. the plant has already emerged. By the passing of time the plant moves from growth stage to growth stage until the *plant maximum GSI* is reached (see “[Plant Behaviour](#)”). A maximum GSI of 2 means that grain will not be developed whereas a maximum GSI of 4, results in grain development. When the plant maximum GSI is reached, the plant retunes to the *plant minimum GSI*. Typical minimum and maximum GSI values for crops are -1 and 4, and for trees 1 and 2 respectively, which means that the GSI will vary for crops but will be constant for trees.

A value of -1 means that no plant exists. Sowing takes place when GSI=0 and the start of growth or emergence occurs when GSI=1. Sowing or emergence day number (if the plant starts at a GSI of -1 or 0) is given for each plant in the parameter tables “[Start of growth](#)”. If 0 is given as day number, the day number will be calculated from temperature sums, whereas values between 1-365 will be interpreted as a fixed date.

The temperature sums as degree-days are calculated by adding the temperature excess over the threshold values. These sums are used for estimating most of the different plant development stages.

The plant is in the leafing phase between GSI 1 and 2. During this period carbon and nitrogen in perennial plants is allocated from the mobile pool to the leaves as an additional source. The mobile pool contains carbon and nitrogen that was retained when the plant lost biomass as litter fall the year before.

Most plants develop grain in order to reproduce themselves. Grains are normally of outmost importance for agricultural crops, but are often not of interest when looking at trees in forest ecosystems, even though these species also develop fruits. Therefore the inclusion of grain development is optional.

The start of grain filling, G_i , is calculated as a function of day-length and temperature:

$$G_i = G_i + \left(1 - \exp \left(-1 \cdot g_{stepday} \cdot \max(0, D / 60 - g_{thresday}) \right) \right) \cdot \left(1 - \exp \left(-1 \cdot g_{steptemp} \cdot \max(0, T_a - g_{threstemp}) \right) \right) \quad (5.36)$$

where $g_{stepday}$, $g_{thresday}$, $g_{steptemp}$ and $g_{threstemp}$, are parameters, D is day length and T_a is the air temperature.

The function for the grain filling start, G_b , is multiplied by a parameter g_{step} , to calculate GSI. The grain filling starts when GSI has reached the value of 2. When GSI has reached 3 the grain filling is finished and the grains will mature before they are ready to be harvested.

Harvest

For plants with a maximum GSI of 4, harvest occurs when the grain has matured (i.e. when GSI = 4) or at a specified harvest day number (see “[Harvest of plants](#)”). Again temperature sums will be used to estimate the harvest day number if the harvest day number is given as 0. If the maximum GSI is less than 4 a harvest day number can still be specified at which harvest will take place, which means that leaves, stems and roots are harvested at that date.

After harvest the GSI for all grain crops (i.e. plants with a maximum GSI of 3 or more) will be put to the minimum GSI specified for the plant.

Death

A plant dies at the year shift the year when the plant age exceeds the maximum plant lifetime, given in the parameter table “[Plant Behaviour](#)”, or after ploughing. When the plant dies the GSI is automatically put to the minimum plant GSI. For plants with a *maximum leaf lifetime* of 1 year i.e. deciduous plants, specified in the parameter tables “[Plant Behaviour](#)”, GSI is also returned to the minimum plant GSI at the year shift.

Allocation of Carbon

Sowing and emergence

At the sowing day the initial carbon content, c_{Seed} , is planted. This does not yet affect any of the plant carbon pools and the seed is not assumed to have any respiration or photosynthesis.

At emergence (for plants starting at GSI < 1) the carbon content of the seed has to be allocated to the roots, stem and the leaves before the assimilation begins. Therefore, at GSI=1, the carbon content in the seed, c_{Seed} , is allocated to the roots, leaves and stem using the same allocation equations as for allocation of assimilates (see eq. (5.37), (5.38) and (5.39)) by assuming that C_a corresponds to the carbon content in the roots, c_{Seed} . If a root already exists at emergence (i.e. remaining from the previous season) no seed is planted. Instead the carbon content in the root is transferred to the seed and thereafter allocated to the stem, leaves and roots as described above.

Vegetative growth

The assimilation starts at GSI=1 for annuals and perennials calculated by any of the equations (5.6), (5.8) or (5.9). The assimilated carbon, $C_{Atm \rightarrow a}$, is moved to a temporary carbon storage pool, C_a . From this pool the assimilates are allocated to the roots, leaves and stem by:

$$C_{a \rightarrow Root} = f_{root} \cdot C_a \quad (5.37)$$

$$C_{a \rightarrow Leaf} = f_{leaf} \cdot C_a \quad (5.38)$$

$$C_{a \rightarrow Stem} = (1 - (f_{root} + f_{leaf})) \cdot C_a \quad (5.39)$$

Root allocation

The allocation fraction to the roots, f_{root} , may be influenced by the shoot mass of plant, $f(M)$, the nitrogen to carbon ratio in the leaf, $f(CN_{leaf})$, and of the water stress, $f(E_{ta}/E_{tp})$, in three different ways (see switch “[Root alloc combination](#)”):

- Average response:

$$f_{root} = (f(M) + f(CN_{leaf}) + f(E_{ta}/E_{tp})) / 3 \quad (5.40)$$

- Maximum response:

$$f_{root} = \max(f(M), f(CN_{leaf}), f(E_{ta}/E_{tp})) \quad (5.41)$$

- Multiplicative response:

$$f_{root} = f(M) \cdot f(CN_{leaf}) \cdot f(E_{ta}/E_{tp}) \quad (5.42)$$

The mass response, $f(M)$, the leaf nitrogen to carbon ratio response, $f(CN_{leaf})$ and the water stress response, $f(E_{ta}/E_{tp})$, can in turn be calculated in three different ways respectively.

Mass response

The mass response, $f(M)$, can be calculated in the following three ways (see switch “[Root allocation mass](#)”):

- Exponential function:

$$f(M) = r_{Mc1} + r_{Mc2} \cdot e^{r_{Mc3} \cdot M} \quad (5.43)$$

- Independent:

$$f(M) = r_{Mc1} \quad (5.44)$$

- Linear function:

$$f(M) = r_{Mc1} + r_{Mc2} \cdot M \quad (5.45)$$

where r_{Mc1} , r_{Mc2} and r_{Mc3} are parameters and M is the carbon content in the leaves and the stem. See viewing functions “[Allocation of carbon – exponential function](#)” and “[Allocation of carbon – linear function](#)”.

Nitrogen response

The nitrogen response, $f(CN_{leaf})$, can be calculated in the following three ways (see switch “[Root allocation N leaf](#)”):

- Exponential function:

$$f(CN_{leaf}) = r_{CNC1} + r_{CNC2} \cdot e^{r_{CNC3} \cdot CN_{leaf}} \quad (5.46)$$

- Independent:

$$f(CN_{leaf}) = r_{CNC1} \quad (5.47)$$

- Linear function:

$$f(CN_{leaf}) = r_{CNC1} + r_{CNC2} \cdot CN_{leaf} \quad (5.48)$$

where r_{CNC1} , r_{CNC2} and r_{CNC3} are parameters and CN_{leaf} is the leaf nitrogen response (see eq. (5.12)). See viewing functions “[Allocation of carbon – exponential function](#)” and “[Allocation of carbon – linear function](#)”.

Water stress response

The water stress response, $f(E_{ta}/E_{tp})$, can be calculated in the following three ways (see switch “[Root allocation water](#)”):

- Exponential function:

$$f(E_{ta}/E_{tp}) = r_{Wc1} + r_{Wc2} \cdot e^{r_{Wc3} \cdot (E_{ta}/E_{tp})} \quad (5.49)$$

- Independent:

$$f\left(E_{ta} / E_{tp}\right) = r_{wc1} \quad (5.50)$$

- Linear function:

$$f\left(E_{ta} / E_{tp}\right) = r_{wc1} + r_{wc2} \cdot \left(E_{ta} / E_{tp}\right) \quad (5.51)$$

where r_{wc1} , r_{wc2} , and r_{wc3} are parameters, E_{ta} is the actual transpiration and E_{tp} is the potential transpiration. See viewing functions “Allocation of carbon – exponential function” and “Allocation of carbon – linear function”.

Leaf allocation

The allocation fraction to the leaves, f_{leaf} , can be calculated in four different ways (see switch “Leaf allocation shoot”):

- Exponential:

$$f_{leaf} = l_{c1} + l_{c2} \cdot e^{l_{c3} \cdot M} \quad (5.52)$$

- Independent:

$$f_{leaf} = l_{c1} \quad (5.53)$$

- Linear function:

$$f_{leaf} = l_{c1} + l_{c2} \cdot M \quad (5.54)$$

- ExpFunc of Stem/Leaf:

$$f_{leaf} = \frac{(C_a - C_{a \rightarrow Root}) (l_{c1} + l_{c2} \cdot e^{l_{c3} \cdot M}) (1 + l_{c3} \cdot M)}{C_a} \quad (5.55)$$

where l_{c1} , l_{c2} , and l_{c3} are parameters and M stands for mass and is the carbon content in the stem and the leaves. See viewing functions “Allocation of carbon – exponential function” and “Allocation of carbon – linear function”.

Grain development

When grain starts to develop, carbon is allocated to the grain pool from the other three pools. The amount of carbon from the root pool to the grain pool are calculated as:

$$C_{Root \rightarrow Grain} = a_{C,rg} \cdot C_{Root} \quad (5.56)$$

where $a_{C,rg}$ is a parameter. Analogously, the allocation of carbon from the leaf and stem pools is calculated with the parameters $a_{C,lg}$ and $a_{C,sq}$ respectively.

Harvest

At harvest some carbon will be harvested and removed from the system. The amounts of carbon that are removed from the leaf pool is calculated as:

$$C_{Leaf \rightarrow Harvest} = f_{leafharvest} \cdot C_{Leaf} \quad (5.57)$$

where $f_{leafharvest}$ is a parameter. Harvest from the grain, stem and root carbon pools is calculated analogously by exchanging $f_{leafharvest}$ with $f_{grainharvest}$, $f_{stemharvest}$ and $f_{rootharvest}$ respectively. These parameters are also used to calculate the harvest fractions from the old stem, leaves and roots in perennials.

At harvest it is possible that some parts of the plant will be removed from the plant, but left on the field as litter. These litter flows are calculated as:

$$C_{Leaf \rightarrow LitterSurface} = f_{leaflithary} \cdot (C_{Leaf} - C_{Leaf \rightarrow Harvest}) \quad (5.58)$$

where $f_{leaflithary}$ is a parameter. Similar flows are calculated for grain, stem and roots by exchanging $f_{leaflithary}$ to $f_{grainlithary}$, $f_{stemlithary}$ and $f_{rootlithary}$ respectively.

Note that it is possible to leave carbon in the plant after harvest. Unless the field is ploughed after harvest or the plant maximum life is equal to one, carbon will remain in the plant to the following growing season i.e. the plant is a perennial.

Litterfall

As a plant grows older some parts of it will eventually die and form litter. In the model this litter fall is an ongoing process that starts as soon as the plant comes to existence and will continue as long as the plant is still alive (Figure 5.3).

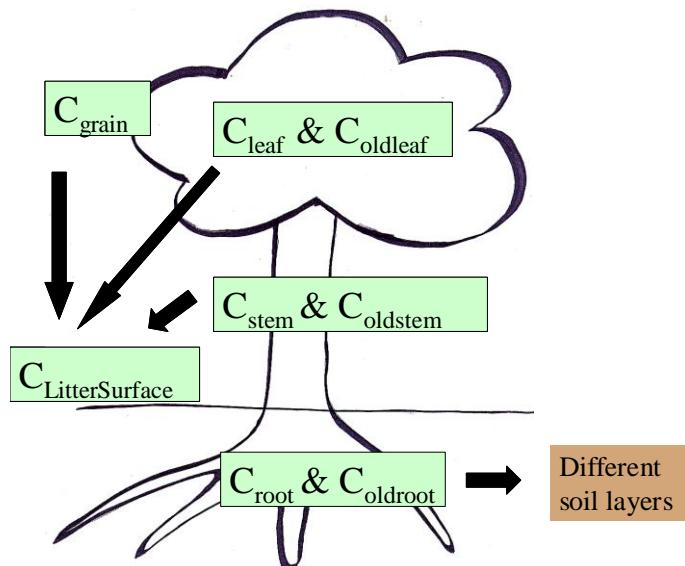


Figure 5.3. Litterfall in a perennial plant.

The leaves fall to the ground at a continuous rate:

$$C_{Leaf \rightarrow LitterSurface} = f(l_{lc}) \cdot C_{Leaf} \quad (5.59)$$

The leaf litter rate function, $f(l_{lc})$, can be calculated in two different ways regulated by the switch “Litter fall dynamics”:

- Static: if “static” is chosen or if $T_{Sum} < t_{L1}$

$$f(l_{lc}) = l_{lc1} \quad (5.60)$$

- F(tempsum): if “f(GrowthTempSum)” or “f(DormingTempSum)” are chosen and $T_{Sum} > t_{L1}$

$$f(l_{lc}) = l_{lc1} + (l_{lc2} - l_{lc1}) \cdot \min(1, \frac{\max(0, T_{Sum} - t_{L1})}{\max(1, t_{L2} - t_{L1})}) \quad (5.61)$$

where t_{L1} , t_{L2} , l_{Lc1} and l_{Lc2} are parameters and T_{Sum} is either the accumulated temperature excess over the temperature threshold value for emergence (the “f(GrowthTempSum)” alternative) or the so called “dorming” temperature sum, $T_{DormSum}$ (the “f(DormingTempSum)” alternative). $T_{DormSum}$ is calculated at the end to the growing season when the air temperature is below +5 °C as the accumulated difference between +5 °C and T_a . The stem and grain litter rate is calculated analogously with the parameters t_{S1} , t_{S2} , l_{Sc1} and l_{Sc2} , and t_{G1} , t_{G2} , l_{Gc1} and l_{Gc2} . See viewing function “[Litter fall](#)”.

Roots also have dying parts that will be lost from the plant and form soil litter. In this case the litter will go straight into the soil litter compartments but is otherwise analogous to the litter fall from leaves:

$$C_{Root \rightarrow Litter} = f(l_{Rc}) \cdot C_{Root} \quad (5.62)$$

The root litter rate function, $f(l_{Rc})$, can be calculated in two ways regulated by the switch “[Litter fall dynamics](#)”, with eq. [\(5.60\)](#) or eq. [\(5.61\)](#) by exchanging the parameters t_{L1} , t_{L2} , l_{Lc1} and l_{Lc2} to t_{R1} , t_{R2} , l_{Rc1} and l_{Rc2} .

Litter fall from roots, leaves and stems in the “old” biomass in perennial plants are calculated similarly to the “new” biomass but with the important exception that some of the old leaves may be retained:

$$C_{OldLeaf \rightarrow LitterSurface} = f(l_{Lc}) \cdot (C_{OldLeaf} - C_{RemainLeaf}) s_{oldleaf} \quad (5.63)$$

where or $s_{oldleaf}$ is a scaling factor. The new leaf litter fall is also multiplied by the scaling factor, $s_{newleaf}$, when litter fall from perennial plants is estimated. The scaling factors can be used as “fractions” in order to determine in what proportions the leaves will fall from the new and the old pools respectively.

$C_{RemainLeaf}$ is the fraction of the whole $C_{OldLeaf}$ pool that will be excluded from the calculation of the litterfall from the old leaves. This fraction is dependent on the maximum leaf lifetime, l_{life} :

$$C_{RemainLeaf} = C_{OldLeaf} \left(1 - \frac{1}{l_{life} - 1} \right) \quad (5.64)$$

The litter fall from perennial plants for stems and roots is calculated analogously.

Mobile pool

When a plant that goes into dormancy is loosing leaves (i.e. litter fall), carbon is retained in a mobile pool that represents an internal storage, C_{Mobile} . At leafing this carbon is used for developing new leaves. The amount of carbon that is allocated to this pool from the C_{Leaf} pool is proportional to the leaf litter fall:

$$C_{Mobile} = (C_{Leaf \rightarrow LitterSurface} + C_{OldLeaf \rightarrow LitterSurface}) \cdot m_{retain} \quad (5.65)$$

where m_{retain} is an allocation coefficient.

At leafing (between GSI 1 and 2) the carbon in the mobile pool is allocated to the plant as an additional supply. This process goes on as long as there is carbon left in the mobile pool:

$$C_{Mobile \rightarrow Leaf} = C_{Mobile} \cdot m_{shoot} \quad (5.66)$$

where m_{shoot} is an allocation coefficient.

Allocation of Nitrogen

Allocation of nitrogen to different components of the plant follows to a large extent the patterns for carbon. At emergence the carbon contents in the stem, leaf and root pools are divided by the parameterised CN ratios $cn_{MinRoot}$, $cn_{MinStem}$ and $cn_{MinLeaf}$ to determine the nitrogen content before the assimilation starts.

As the plant starts to grow the carbon assimilation of the plant generates a nitrogen demand in the plant according to the parameterised CN ratio (see “[Root uptake demand](#)”), which acts as a driving force for uptake of nitrogen from the soil (see “[Root uptake of mineral nitrogen](#)” in “[Mineral N Processes](#)” and “[Root uptake of organic nitrogen](#)” in “[Soil Organic](#)

[Processes](#)"). This uptake is transferred to a mobile nitrogen storage pool, N_a . From this pool the nitrogen is allocated first to roots, secondly, if any nitrogen remains in the mobile pool, to the stem, and finally also to the leaves:

$$N_{a \rightarrow Root} = \min(N_a, C_{a \rightarrow Root} / cn_{MinRoot}) \quad (5.67)$$

$$N_{a \rightarrow Stem} = \min(N_a - N_{a \rightarrow Root}, C_{a \rightarrow Stem} / cn_{MinStem}) \quad (5.68)$$

$$N_{a \rightarrow Leaf} = \min(N_a - N_{a \rightarrow Root} - N_{a \rightarrow Stem}, C_{a \rightarrow Leaf} / cn_{MinLeaf}) \quad (5.69)$$

Allocation to the grain pool during grain development is analogous to the carbon allocation, eq.(5.56). In order to calculate the amounts of nitrogen allocated to grain, $N_{Root \rightarrow Grain}$, $N_{Leaf \rightarrow Grain}$ and $N_{Stem \rightarrow Grain}$, the parameters $a_{C,rg}$, $a_{C,lg}$ and $a_{C,sq}$ are therefore exchanged to $a_{N,rg}$, $a_{N,lg}$ and $a_{N,sq}$ respectively.

The allocation of nitrogen at harvest is handled similarly to carbon using the same equation, i.e. eq.(5.57).

Nitrogen litter fall is analogous to carbon litter fall (see eqs. (5.59) -(5.64)) and allocation to and from the mobile pool is also analogous to carbon allocation (see eqs. (5.65) and (5.66)).

Every run the CN ratios for the leaf, stem, grain and root pools are calculated from the amounts of carbon and nitrogen in each pool. In perennial plants the CN ratios are based on the amounts of carbon and nitrogen in the new and the old pools. If the nitrogen content is less than 0.1 g the CN ratio for that pool is automatically set to 20. CN ratios are used to estimate nitrogen transfer when correspondent carbon transfers or carbon storages are known.

Respiration

Respiration can be included in the simulations either as maintenance respiration only, or as the sum of maintenance and growth respiration as determined by the switch ("[PlantRespiration](#)"). In the former case, maintenance respiration is dependent on the surrounding temperature as:

$$C_{Leaf \rightarrow CO_2} = k_{rc} \cdot f(T_a) \cdot C_{Leaf} \quad (5.70)$$

where k_{rc} is the respiration rate coefficient and $f(T_a)$ is the temperature response (see "[Common abiotic functions](#)"), which can be calculated in several ways as determined by the switch "[Resp Temp Response](#)". Analogously, this equation is used to calculate respiration from stems and roots and also from the old carbon pools in perennial plants, by using the respective carbon pools.

If salinity stress is included in the simulation an increase in respiration, the function is modified into:

$$C_{Leaf \rightarrow CO_2} = k_{rc} \cdot f(T_a) \cdot C_{Leaf} + (1 - f(\pi)) \cdot C_{a \rightarrow Leaf} \quad (5.71)$$

where $f(\pi)$ is the salinity stress response function.

Alternatively, both growth and maintenance respiration can be included in the simulation. Total respiration is in this case calculated as:

$$C_{respleaf} = k_{mrespleaf} \cdot f(T_a) \cdot C_{leaf} + k_{gresp} \cdot C_{a \rightarrow Leaf} \quad (5.72)$$

where $k_{mrespleaf}$ is the maintenance respiration coefficient for leaves, k_{gresp} is the growth respiration coefficient, and $f(T_a)$ is the temperature response (see "[Common abiotic functions](#)"), which can be calculated in several ways as determined by the switch "[Resp Temp Response](#)". The equation calculates respiration from stem, roots and grain by exchanging $k_{mrespleaf}$ to $k_{mrespstem}$, $k_{mresproot}$, $k_{mrespgrain}$, and using the corresponding storage pools. Respiration from the old carbon pools is estimated with the same maintenance respiration coefficients as for respiration from new carbon pools.

If salinity stress is included in the simulation an increase in respiration, the function is modified into:

$$C_{respleaf} = k_{mrespleaf} \cdot f(T_a) \cdot C_{leaf} + k_{gresp} \cdot C_{a \rightarrow Leaf} + (1 - f(\pi)) \cdot C_{a \rightarrow Leaf} \quad (5.73)$$

where $f(\pi)$ is the salinity stress response function.

Root uptake demand

The carbon content in the plant gives rise to a demand of nitrogen. The plant root uptake demand of nitrogen from the soil, N_{Demand} , is calculated as:

$$N_{Demand} = \frac{C_{a \rightarrow Root}}{cn_{MinRoot}} + \frac{C_{a \rightarrow Stem}}{cn_{MinStem}} + \frac{C_{a \rightarrow Leaf}}{cn_{MinLeaf}} \quad (5.74)$$

where $cn_{MinRoot}$, $cn_{MinStem}$ and $cn_{MinLeaf}$ are parameters. The uptake of organic and mineral nitrogen is described in the sections “[Root uptake of organic nitrogen](#)” and “[Root uptake of mineral nitrogen](#)”.

Nitrogen fixation by micro-organisms

If there is still a demand for nitrogen after mineral and organic nitrogen, as well as nitrogen from atmospheric deposition, has been taken up by the plant, nitrogen fixation can optionally take place (see switch “[N fixation](#)”). This uptake, N_{Fix} , is calculated by the function:

$$N_{Fix} = (N_{Demand} - N_{Mineral \rightarrow Plant} - N_{Organic \rightarrow Plant} - N_{Atm \rightarrow l}) \cdot n_{fix} \quad (5.75)$$

where N_{Demand} is the original demand for nitrogen uptake, $N_{Mineral \rightarrow Plant}$ is the uptake of mineral nitrogen, $N_{Organic \rightarrow Plant}$ is the uptake of organic nitrogen, $N_{Atm \rightarrow l}$ is the uptake of nitrogen deposited on the plant leaves, and n_{fix} is a fixation uptake parameter. Nitrogen fixation, N_{Fix} , is added to the total plant nitrogen uptake, N_{TotUpt} .

Switches

The switch “[Growth](#)” governs how the assimilation should be estimated in the simulations and is perhaps the most important of all switches in this section. There are also a few switches determining the start and end of growth and some others that concerns allocation of biomass.

Growth

Value	Meaning
Farquhar	Photosynthesis is calculated as a function of the demand and supply of CO ₂ using a biochemical model developed by Farquhar et al. (1980).
Logistic function	A logistic function for potential nitrogen uptake and carbon is used.
Off	Plant growth is not simulated, i.e. the plant does not assimilate biomass.
Radiation use efficiency	The plant growth is determined by radiation use efficiency and reduced by limiting factors such as unfavourable water, nitrogen and temperature conditions.
Water use efficiency	The plant growth is determined by the water use efficiency only.

Leaf allocation shoot

Value	Meaning

Exponential	The allocation from leaf to shoot during shoot development is an exponential function of the above ground mass. Viewing function " Allocation of carbon – exponential function ".
ExpFunc of Leaf/Stem	The allocation from leaf to shoot during shoot development is an exponential function of the above ground mass and the allocation of carbon to the roots.
Independent	The allocation from leaf to shoot during shoot development is independent of the above ground mass.
Linear function	The allocation from leaf to shoot during shoot development is a linear function of the above ground mass. Viewing function " Allocation of carbon – linear function ".

Litter fall dynamics

Value	Meaning
f(GrowthTempSum)	The litter fall is a function of the accumulated excess air temperature above the threshold temperature for emergence. Viewing function " Litter fall ".
f(DormingTempSum)	The litter fall is a function of the accumulated difference between +5 °C and the air temperature when the temperature is below +5 °C.
Static	The litter fall is independent of air temperature.

N demand dynamics

Dynamic demand of nitrogen is not yet implemented in the model, but will be in later versions. Choosing any of the below stated options will therefore generate a static demand of nitrogen.

Value	Meaning
Dynamic leaf (only)	
Dynamic leaf stem	
Dynamic leaf stem root	
Static	

N fixation

Nitrogen fixation by plants.

Value	Meaning
Off	Nitrogen fixation is simulated.
On	Nitrogen fixation is disregarded

PhoSaturation

Value	Meaning

Off	Radiation use efficiency approach without radiation saturation at high levels of radiation.
On	Radiation use efficiency approach with radiation saturation at high levels of radiation.

PlantRespiration

Value	Meaning
Maintenance Only	Plant respiration is simulated as maintenance respiration.
Growth and Maintenance	Plant respiration is simulated as a combination of growth and maintenance respiration.

Resp Temp Response

Value	Meaning
Common	The temperature response function for respiration is chosen under common abiotic responses.
Q10 threshold	The temperature response function for respiration is a Q10 type of function above a certain threshold temperature. The response is decreases linearly for temperatures below the threshold and is zero below 0° C. Viewing function " Common temperature response function - Q10 threshold ".
Q10 whole range	The temperature response function for respiration is a Q10 type of function for all temperatures. Viewing function " Common temperature response function - Q10 whole range ".

Root alloc combination

Value	Meaning
Average response	The reallocation of new carbon from the leaves to the roots is influenced by the average of the mass-, nitrogen- and water responses.
Maximum value	The reallocation of new carbon from the leaves to the roots is influenced by the maximum value of the mass-, nitrogen- and water responses.
Multiplicative response	The reallocation of new carbon from the leaves to the roots is influenced by the mass-, nitrogen- and water responses multiplied.

Root allocation N leaf

Value	Meaning

Exponential function	The response on leaf nitrogen concentration for the reallocation of new mobile carbon from the leaves to the roots is exponential. Viewing function “ Allocation of carbon – exponential function ”.
Independent	The response for the reallocation of new mobile carbon from the leaves to the roots is independent of the leaf nitrogen concentration.
Linear function	The response on leaf nitrogen concentration for the reallocation of new mobile carbon from the leaves to the roots is linear. Viewing function “ Allocation of carbon – linear function ”.

Root allocation mass

Value	Meaning
Exponential function	The response on the above ground mass for the reallocation of new mobile carbon from the leaves to the roots is exponential. Viewing function “ Allocation of carbon – exponential function ”.
Independent	The response for the reallocation of new mobile carbon from the leaves to the roots is independent of the above ground mass.
Linear function	The response on the above ground mass for the reallocation of new mobile carbon from the leaves to the roots is linear. Viewing function “ Allocation of carbon – linear function ”.

Root allocation water

Value	Meaning
Exponential function	The response on the water stress for the reallocation of new mobile carbon from the leaves to the roots is exponential. Viewing function “ Allocation of carbon – exponential function ”.
Independent	The response for the reallocation of new mobile carbon from the leaves to the roots is independent of the water stress.
Linear function	The response on the water stress for the reallocation of new mobile carbon from the leaves to the roots is linear. Viewing function “ Allocation of carbon – linear function ”.

Salinity stress

Value	Meaning
On	Soil salinity concentration decreases photosynthesis.

Off	Soil salinity concentration does not decrease photosynthesis.
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Winter regulation

Value	Meaning
On	Plant goes into dormancy during winter.
Off	Plant does not go into dormancy during winter.

Parameters

CO2_A

CO2 concentration in the atmosphere.

Default	Unit	Symbol	Equation	Function
$330 \cdot 10^{-6}$	-	c_a	(5.26)	

GrainLitterRate c1

Rate coefficient for the litter fall from grain before the first threshold temperature sum is reached.

Default	Unit	Symbol	Equation	Function
0.001	/day	l_{Gcl}	(5.60), (5.61)	“Litter fall”

GrainLitterRate c2

Rate coefficient for the litter fall from grain after the second threshold temperature sum is reached.

Default	Unit	Symbol	Equation	Function
0.05	/day	l_{Ge2}	(5.60), (5.61)	“Litter fall”

GrainLitterT sum1

Threshold temperature sum for the lower grain litter rate.

Default	Unit	Symbol	Equation	Function
1200	day°C	t_{GI}	(5.60), (5.61)	“Litter fall”

GrainLitterT sum2

Threshold temperature sum for the higher grain litter rate.

Default	Unit	Symbol	Equation	Function
1400	day°C	t_{G2}	(5.60), (5.61)	“Litter fall”

GrainSI_Step

Step length for the index governing the phenological stage from the start of growth until the start of grain fill.

Default	Unit	Symbol	Equation	Function
0.06	-	g_{step}		

GrainSI_StepDay

Coefficient that regulates the shape of the day length part of the grain development function.

Default	Unit	Symbol	Equation	Function
0.5	/hour	$g_{stepday}$	(5.36)	

GrainSI_StepTemp

Coefficient that regulates the shape of the temperature part of the grain development function.

Default	Unit	Symbol	Equation	Function
0.2	/°C	$g_{steptemp}$	(5.36)	

GrainSI_ThresTemp

Threshold temperature for the function for grain development.

Default	Unit	Symbol	Equation	Function
10	°C	$g_{threstemp}$	(5.36)	

GrainSI_ThresDay

Threshold day length for the function for grain development.

Default	Unit	Symbol	Equation	Function
5	hour	$g_{thresday}$	(5.36)	

LeafLitterRate c1

Rate coefficient for the litter fall from leaves before the first threshold temperature sum is reached.

Default	Unit	Symbol	Equation	Function
0.001	/day	l_{Lc1}	(5.60), (5.61)	“Litter fall”

LeafLitterRate c2

Rate coefficient for the litter fall from leaves after the second threshold temperature sum is reached.

Default	Unit	Symbol	Equation	Function
0.05	/day	l_{Lc2}	(5.60), (5.61)	“Litter fall”

LeafLitterT sum1

Threshold temperature sum for the lower leaf litter rate.

Default	Unit	Symbol	Equation	Function
1200	day°C	t_{L1}	(5.60), (5.61)	“Litter fall”

LeafLitterT sum2

Threshold temperature sum for the higher leaf litter rate.

Default	Unit	Symbol	Equation	Function
1400	day°C	t_{L2}	(5.60), (5.61)	“Litter fall”

P_ATheta

Photosynthesis curvature factor in the Farquhar model.

Default	Unit	Symbol	Equation	Function
0.877	-	β_{vj}	(5.25)	

P_BTheta

Photosynthesis curvature factor in the Farquhar model.

Default	Unit	Symbol	Equation	Function
0.99	-	β_{ps}	(5.25)	

P_Surface

Atmospheric pressure at the soil surface.

Default	Unit	Symbol	Equation	Function
10 000	Pa	p_{atm}	(5.26)	

PhoCNLeafOpt

Optimum C-N ratio in leaves for photosynthesis.

Default	Unit	Symbol	Equation	Function
25	-	$p_{CN,Opt}$	(5.12)	“Assimilation – nitrogen content in leaf response”

PhoCNLeafThres

Threshold C-N ratio in leaves. Above this value no photosynthesis occurs.

Default	Unit	Symbol	Equation	Function
80	-	$p_{CN,Th}$	(5.12)	“Assimilation – nitrogen content in leaf response”

PhoMax

Maximum level of photosynthesis.

Default	Unit	Symbol	Equation	Function
40	gC/m ² /day	p_{max}	(5.10)	

PhoRadEff_Reduc

Reduction of radiation use efficiency due to grain development.

Default	Unit	Symbol	Equation	Function
50	%	ε_{Lred}	(5.13)	“Radiation use efficiency response function at grain filling”

PhoRadEfficiency

Radiation use efficiency for photosynthesis at optimum temperature, moisture and C-N ratio. To convert from gDw/MJ PAR to gDw/MJ global radiation, multiply with a factor 0.47. It is also worth noting that at leaf area indexes above 2, basically all global radiation is absorbed by the canopy.

Default	Unit	Symbol	Equation	Function
2	gDw/MJ	ε_L	(5.9), (5.13)	

PhoTempResMax

Maximum mean air temperature for photosynthesis.

Default	Unit	Symbol	Equation	Function
35	°C	p_{mx}	(5.11)	“Assimilation – air temperature response”

PhoTempResMin

Minimum mean air temperature for photosynthesis.

Default	Unit	Symbol	Equation	Function
5	°C	p_{mn}	(5.11)	“Assimilation – air temperature response”

PhoTempResOpt1

Lower limit mean air temperature for optimum photosynthesis.

Default	Unit	Symbol	Equation	Function
15	°C	p_{ol}	(5.11)	“Assimilation – air temperature response”

PhoTempResOpt2

Upper limit mean air temperature for optimum photosynthesis

Default	Unit	Symbol	Equation	Function
25	°C	p_{o2}	(5.11)	“Assimilation – air temperature response”

PhoWaterEfficiency

Water use efficiency for photosynthesis. To convert from $\mu\text{mol CO}_2/\text{mmol H}_2\text{O}$ to gDw/mm, multiply with a factor 1.5. Water use efficiency is quite variable. Literature values range from 2 -14 gDw/mm for different species, but also within each species the variation is large due to for example climatic differences.

Default	Unit	Symbol	Equation	Function
3	gDw/mm	ε_w	(5.8)	

RespGCoef

Growth respiration coefficient.

Default	Unit	Symbol	Equation	Function
0.21	/day	k_{gresp}	(5.72)	

RespMCoefGrain

Maintenance respiration coefficient for grain.

Default	Unit	Symbol	Equation	Function
0.011	/day	$k_{mrespgrain}$	(5.72)	

RespMCoefLeaf

Maintenance respiration coefficient for leaves.

Default	Unit	Symbol	Equation	Function
0.034	/day	$k_{mrespleaf}$	(5.72)	

RespMCoefRoot

Maintenance respiration coefficient for roots.

Default	Unit	Symbol	Equation	Function
0.011	/day	$k_{mresproot}$	(5.72)	

RespMCoefStem

Maintenance respiration coefficient for stem.

Default	Unit	Symbol	Equation	Function
0.017	/day	$k_{mrespstem}$	(5.72)	

RespRateCoef

Coefficient to multiply the maintenance respiration with.

Default	Unit	Symbol	Equation	Function
0.001	/day	k_{rc}	(5.70)	

RespTemQ10

Response to a 10 °C soil temperature change on the maintenance respiration.

Default	Unit	Symbol	Equation	Function
2	-	t_{pQ10}	(5.82)	“Common temperature response function - Q10 whole range”

RespTemQ10Bas

Base temperature for the plant respiration at which the response is 1.

Default	Unit	Symbol	Equation	Function

20	°C	$t_{pQ10bas}$	(5.82)	“Common temperature response function - Q10 whole range”
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RespTemQ10Threshold

Threshold temperature for the microbial activity, plant respiration below which the response is linearly decreasing and ceases at 0 °C.

Default	Unit	Symbol	Equation	Function
5	°C	$t_{pQ10thres}$	(5.82), (5.83)	“Common temperature response function - Q10 threshold”

RootLitterRate c1

Rate coefficient for the litter fall from roots before the first threshold temperature sum is reached.

Default	Unit	Symbol	Equation	Function
0.01	/day	l_{Rc1}	(5.60), (5.61)	“Litter fall”

RootLitterRate c2

Rate coefficient for the litter fall from roots after the second threshold temperature sum is reached.

Default	Unit	Symbol	Equation	Function
0.05	/day	l_{Rc2}	(5.60), (5.61)	“Litter fall”

RootLitterT sum1

Threshold temperature sum for the lower root litter rate.

Default	Unit	Symbol	Equation	Function
1200	°C	t_{RI}	(5.60), (5.61)	“Litter fall”

RootLitterT sum2

Threshold temperature sum for the higher root litter rate.

Default	Unit	Symbol	Equation	Function
1400	°C	t_{R2}	(5.60), (5.61)	“Litter fall”

SaltHalfReductionG

The osmotic water potential at which growth is reduced by 50 %.

Default	Unit	Symbol	Equation	Function
5000	cm	π_c	(3.34)	

SaltPowerCoefG

Power coefficient for soil salinity induced stress on assimilation.

Default	Unit	Symbol	Equation	Function

3	-	p_π	(3.34)	
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StemLitterRate c1

Rate coefficient for the litter fall from the stem before the first threshold temperature sum is reached.

Default	Unit	Symbol	Equation	Function
0.00001	/day	l_{Sc1}	(5.60), (5.61)	“Litter fall”

StemLitterRate c2

Rate coefficient for the litter fall from the stem after the second threshold temperature sum is reached.

Default	Unit	Symbol	Equation	Function
0.00002	/day	l_{Sc2}	(5.60), (5.61)	“Litter fall”

StemLitterT sum1

Threshold temperature sum for the lower stem litter rate.

Default	Unit	Symbol	Equation	Function
1200	°C	t_{SI}	(5.60), (5.61)	“Litter fall”

StemLitterT sum2

Threshold temperature sum for the higher stem litter rate.

Default	Unit	Symbol	Equation	Function
1400	°C	t_{S2}	(5.60), (5.61)	“Litter fall”

T Sum Emerg

The temperature sum at which the plant emerges.

Default	Unit	Symbol	Equation	Function
40	°C		GSI	

T Sum GrainFill

The temperature sum at which the grain filling starts.

Default	Unit	Symbol	Equation	Function
450	°C		GSI	

T Sum Sowing

The temperature sum at which sowing takes place.

Default	Unit	Symbol	Equation	Function
30	°C		GSI	

T Thres Emerg

Threshold temperature for the function for development from seed to emergence.

Default	Unit	Symbol	Equation	Function

5	°C	GSI	
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T Thres GrainFill

Threshold temperature for the function for development during grain filling.

Default	Unit	Symbol	Equation	Function
5	°C		GSI	

T Thres Sowing

Threshold temperature for the function for estimation of the appropriate sowing day.

Default	Unit	Symbol	Equation	Function
3	°C		GSI	

Parameter tables

In these parameter tables some allocation parameters are given as well as initial values for the plant biomass content and also several parameters concerning GSI.

Allocation parameters

Name	Default	Unit	Symbol	Comments/Explanation
Leaf c1	0.2	-	l_{c1}	If <i>Leaf Allocation Shoot is independent</i> : Fraction of the mobile carbon assimilates allocated to the new shoots.
	0.2	-		If <i>Leaf Allocation Shoot is linear function</i> : The constant part of the linear function for the allocation of mobile carbon assimilates to the new shoots. Viewing function " Allocation of carbon – linear function ".
	0.2	-		If <i>Leaf Allocation Shoot is exponential</i> : The constant part of the exponential function for the allocation of mobile carbon assimilates to the new shoots. Viewing function " Allocation of carbon – exponential function ".
Leaf c2	0.2	/g C	l_{c2}	If <i>Leaf Allocation Shoot is linear function</i> : The coefficient for the mass dependence of the linear function for the allocation of mobile carbon assimilates to the new shoots. Viewing function " Allocation of carbon – linear function ".
	0.2	-		If <i>Leaf Allocation Shoot is exponential</i> : The coefficient for the mass dependence of the exponential function for the allocation of mobile carbon assimilates to the new shoots. Viewing function " Allocation of carbon – exponential function ".
Leaf c3	0.2	/g C	l_{c3}	If <i>Leaf Allocation Shoot is exponential</i> : The coefficient for the exponential mass dependence of the exponential function for the allocation of mobile carbon assimilates to the new shoots. Viewing function " Allocation of carbon – exponential function ".

Root Water c1	0.2 0.2 0.2	- - -	r_{Wc1}	If <i>Root Allocation Water</i> is <i>independent</i> : Fraction of the mobile carbon assimilates allocated to the roots in the response function for water stress. If <i>Root Allocation Water</i> is <i>linear function</i> : The constant part of the linear function for the allocation of mobile carbon assimilates to the roots in the response function for water stress. Viewing function " Allocation of carbon – linear function ". If <i>Root Allocation Water</i> is <i>exponential</i> : The constant part of the exponential function for the allocation of mobile carbon assimilates to the roots in the response function for water stress. Viewing function " Allocation of carbon – exponential function ".
Root Water c2	0.2 0.2	- -	r_{Wc2}	If <i>Root Allocation Water</i> is <i>linear function</i> : The coefficient for the water stress dependence of the linear function for the allocation of mobile carbon assimilates to the roots in the response function for water stress. Viewing function " Allocation of carbon – linear function ". If <i>Root Allocation Water</i> is <i>exponential</i> : The coefficient for the water stress dependence of the exponential function for the allocation of mobile carbon assimilates to the roots in the response function for water stress. Viewing function " Allocation of carbon – exponential function ".
Root Water c3	0.2	-	r_{Wc3}	If <i>Root Allocation Water</i> is <i>exponential</i> : The coefficient for the exponential water stress dependence of the exponential function for the allocation of mobile carbon assimilates to the roots in the response function for water stress. Viewing function " Allocation of carbon – exponential function ".
Root CN c1	0.2 0.2 0.2	- - -	r_{CNc1}	If <i>Root allocation N Leaf</i> is <i>independent</i> : Fraction of the mobile carbon assimilates allocated to the roots in the response function for nitrogen concentration in leaves. If <i>Root allocation N Leaf</i> is <i>linear function</i> : The constant part of the linear function for the allocation of mobile carbon assimilates to the roots in the response function for nitrogen concentration in leaves. Viewing function " Allocation of carbon – linear function ". If <i>Root allocation N Leaf</i> is <i>exponential</i> : The constant part of the exponential function for the allocation of mobile carbon assimilates to the roots in the response function for nitrogen concentration in leaves. Viewing function " Allocation of carbon – exponential function ".
Root CN c2	0.2	/g C	r_{CNc2}	If <i>Root allocation N Leaf</i> is <i>linear function</i> : The coefficient for the nitrogen concentration in leaves dependence of the

	0.2	-		linear function for the allocation of mobile carbon assimilate to the roots in the response function for nitrogen concentration in leaves. Viewing function “ Allocation of carbon – linear function ”. If <i>Root allocation N Leaf is exponential</i> : The coefficient for the nitrogen concentration in leaves dependence of the exponential function for the allocation of mobile carbon assimilate to the roots in the response function for nitrogen concentration in leaves. Viewing function “ Allocation of carbon – exponential function ”.
Root CN c3	0.2	/g C	r_{CNc3}	If <i>Root allocation N Leaf is exponential</i> : The coefficient for the exponential nitrogen concentration in leaves dependence of the exponential function for the allocation of mobile carbon assimilate to the roots in the response function for nitrogen concentration in leaves. Viewing function “ Allocation of carbon – exponential function ”.
Root Mass c1	0.2 0.2 0.2	- - -	r_{Mc1}	If <i>Root Allocation Mass is independent</i> : Fraction of the mobile carbon assimilates allocated to the roots in the response function for nitrogen concentration in leaves. If <i>Root Allocation Mass is linear function</i> : The constant part of the linear function for the allocation of mobile carbon assimilates to the roots in the response function for nitrogen concentration in leaves. Viewing function “ Allocation of carbon – linear function ”. If <i>Root Allocation Mass is exponential</i> : The constant part of the exponential function for the allocation of mobile carbon assimilates to the roots in the response function for nitrogen concentration in leaves. Viewing function “ Allocation of carbon – exponential function ”.
Root Mass c2	0.2 0.2	/g C -	r_{Mc2}	If <i>Root Allocation Mass is linear function</i> : The coefficient for the above ground mass dependence of the linear function for the allocation of mobile carbon assimilate to the roots in the response function for the above ground mass. Viewing function “ Allocation of carbon – linear function ”. If <i>Root Allocation Mass is exponential</i> : The coefficient for the above ground mass dependence of the exponential function for the allocation of mobile carbon assimilate to the roots in the response function for above ground mass. Viewing function “ Allocation of carbon – exponential function ”.
Root Mass c3	-0.002	/g C	r_{Mc3}	If <i>Root Allocation Mass is exponential</i> : The coefficient for the exponential above ground mass dependence of the exponential function for the allocation of mobile carbon assimilate to the roots in the response

				function for above ground mass. Viewing function “ Allocation of carbon – exponential function ”.
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Allocation to grain

Name	Default	Unit	Symbol	Comments/Explanations
C Leaf to Grain	0.01	-	$a_{C,lg}$	Fraction of carbon in leaves reallocated to grains during grain development.
C Stem to Grain	0.02	-	$a_{C,sg}$	Fraction of carbon in stem reallocated to grains during grain development.
C Roots to Grain	0.01	-	$a_{C,rg}$	Fraction of carbon in roots reallocated to grains during grain development.
N Leaf to Grain	0.01	-	$a_{N,lg}$	Fraction of nitrogen in leaves reallocated to grains during grain development.
N Stem to Grain	0.02	-	$a_{N,sg}$	Fraction of nitrogen in stem reallocated to grains during grain development.
N Roots to Grain	0.01	-	$a_{N,rg}$	Fraction of nitrogen in roots reallocated to grains during grain development.

Farquhar parameters

Name	Default	Unit	Symbol	Comments/Explanations
C3Type	1	-		If equal to one it represents a C ₃ plant. If equal to zero it represents a C ₄ plant.
QuanEff	8	gDw/MJ	ε	Quantum efficiency.
RBoundary	10	s/m	r_b	Boundary layer resistance.
Vcmax	60	μmol/m ² /s	V_{cmax}	Maximum Rubisco capacity per leaf area at the top of the canopy.
Conduct. Max	0.02	m/s	g_{max}	Maximum conductance of a fully open stomata.

Harvest of plants

Name	Default	Unit	Symbol	Comments/Explanations
Harvest DayNo	280	#		Day number for harvest.
FHarvest Grain	1	-	$f_{grainharvest}$	The fraction of grains that is harvested.
FLitter Grain	0	-	$f_{grainlitharv}$	Fraction of the remaining grain after harvest that enters the litter pool.
FHarvest Leaf	0.1	-	$f_{leafharvest}$	The fraction of leaves that is harvested.
FLitter Leaf	0.1	-	$f_{leaflitharv}$	Fraction of the remaining leaves after harvest that enters the litter pool.
FHarvest Stem	0.1	-	$f_{stemharvest}$	The fraction of the stem that is harvested.
FLitter Stem	0.1	-	$f_{stemlitharv}$	Fraction of the remaining stem after harvest that enters the litter pool.
FHarvest Roots	0	-	$f_{rootharvest}$	The fraction of roots that is harvested.
FLitter Roots	0	-	$f_{rootlitharv}$	Fraction of the remaining roots after harvest that enters the litter pool.

Initial CN ratios of plants

Name	Default	Unit	Symbol	Comments/Explanations
I CN Grain	10	-		Initial C-N ratio of grain.
I CN Leaf	20	-		Initial C-N ratio of leaves.
I CN Stem	50	-		Initial C-N ratio of stem.
I CN Roots	20	-		Initial C-N ratio of roots.
I CN OldLeaf	20	-		Initial C-N ratio of old leaves.
I CN OldStem	50	-		Initial C-N ratio of old stem.
I CN OldRoots	30	-		Initial C-N ratio of old roots.

Initial Conditions of plants

Name	Default	Unit	Symbol	Comments/Explanations
I Plant Age	0	days		Initial plant age
I N Grain	0	g		Initial nitrogen mass in grain.
I N Leaf	0	g		Initial nitrogen mass in leaves.
I N Stem	0	g		Initial nitrogen mass in stem.
I N Roots	0	g		Initial nitrogen mass in roots.
I N OldLeaf	0	g		Initial nitrogen mass in old leaves.
I N OldStem	0	g		Initial nitrogen mass in old stem.
I N OldRoots	0	g		Initial nitrogen mass in old roots.

Minimum CN Ratios of plants

Name	Default	Unit	Symbol	Comments/Explanations
CN Ratio Min Roots	10	-	$cn_{MinRoot}$	Minimum C-N ratio for roots. If the amount of nitrogen in the mobile pool is insufficient to balance carbon according to this C-N ratio, all available mobile nitrogen is allocated to the roots.
CN Ratio Min Stem	10	-	$cn_{MinStem}$	Minimum C-N ratio for stem.
CN Ratio Min Leaf	10	-	$cn_{MinLeaf}$	Minimum C-N ratio for leaves.

N and C uptake (plants)

Parameters for the logistic potential nitrogen uptake function.

Name	Default	Unit	Symbol	Comments/Explanations
Up Start	120	#		Day number for start of plant carbon and nitrogen uptake.
Up End	240	#		Day number for plant uptake of carbon and nitrogen to end.
UpA Coef	20	g N/m ² yr	p_{ua}	Potential nitrogen uptake. A typical value for a grain crop is 20, for a grass layer a typical value is 40. Coefficient governing the plant nitrogen uptake in the logistic growth function. Viewing function " Potential uptake of nitrogen – logistic growth ".

UpB Coef	1	-	p_{ub}	Coefficient governing the plant nitrogen uptake in the logistic growth function. Viewing function “ Potential uptake of nitrogen – logistic growth ”.
UpC Coef	0.12	/day	p_{uc}	Coefficient governing the plant nitrogen uptake in the logistic growth function. Viewing function “ Potential uptake of nitrogen – logistic growth ”.
Up CN Ratio	25	-	cn_p	C-N ratio of the assimilated biomass in the logistic growth function.

Nitrogen fixation

Plant specific parameters for nitrogen fixation.

Name	Default	Unit	Symbol	Comments/Explanations
NFixCoef	0.8	-		

Plant Behaviour

Parameters determining plant development characteristics for each simulated plant.

Name	Default	Unit	Symbol	Comments/Explanations
Initial GSI	0	-		Initial growth stage index when the simulation starts.
Max GSI	4	-		The maximal possible GSI. When this value is reached GSI is put to the minimum value.
Max Leaf Lifetime	1	yr	l_{life}	Maximum leaf lifetime.
Max Plant Lifetime	2	yr		Maximum plant lifetime.
Min GSI	0	-		The minimum GSI.
Mobile Allo Coef	0.5	-	m_{retain}	Coefficient for determining allocation to mobile pool.
Shoot Coef	0.2	-	m_{shoot}	Coefficient for determining allocation from the mobile pool to the leaf at leafing.

Scaling of litter fall

These parameters are used for perennial plants. The actual litter fall is calculated by multiplying the litter fall prior to reduction with these scaling factors, with a reduced litter fall as a result.

Name	Default	Unit	Symbol	Comments/Explanations
Old Leaf	1.0	-	$s_{oldleaf}$	Scaling factor the for litter fall.
New Leaf	1.0	-	$s_{newleaf}$	Scaling factor the for litter fall.
Old Roots	1.0	-	$s_{oldroot}$	Scaling factor the for litter fall.
New Roots	1.0	-	$s_{newroot}$	Scaling factor the for litter fall.
Old Stem	1.0	-	$s_{oldstem}$	Scaling factor the for litter fall.
New Stem	1.0	-	$s_{newstem}$	Scaling factor the for litter fall.

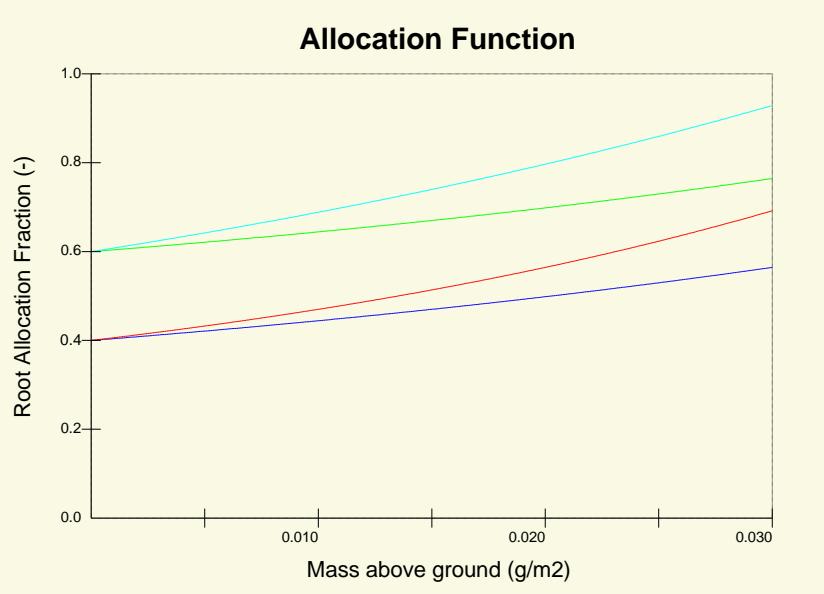
Start of growth

If the user wishes to plant a plant at sowing rather than a small seed, this is accomplished in the model by sowing a very large seed. The carbon content in the seed will be allocated to the stem, leaves and roots at emergence, which thus is equivalent of planting a small plant.

Name	Default	Unit	Symbol	Comments/Explanations
Sowing DayNo	120	#		Day number for sowing.
Day of emergence	135	#		Day number for emergence
C Seed	1	g	c_{Seed}	Initial mass of carbon in seed.

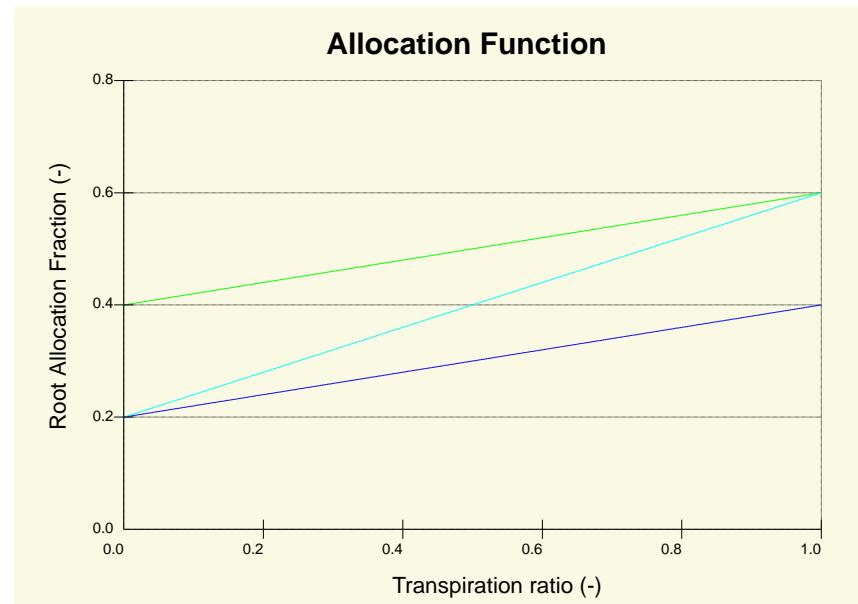
Viewing functions

Allocation of carbon – exponential function



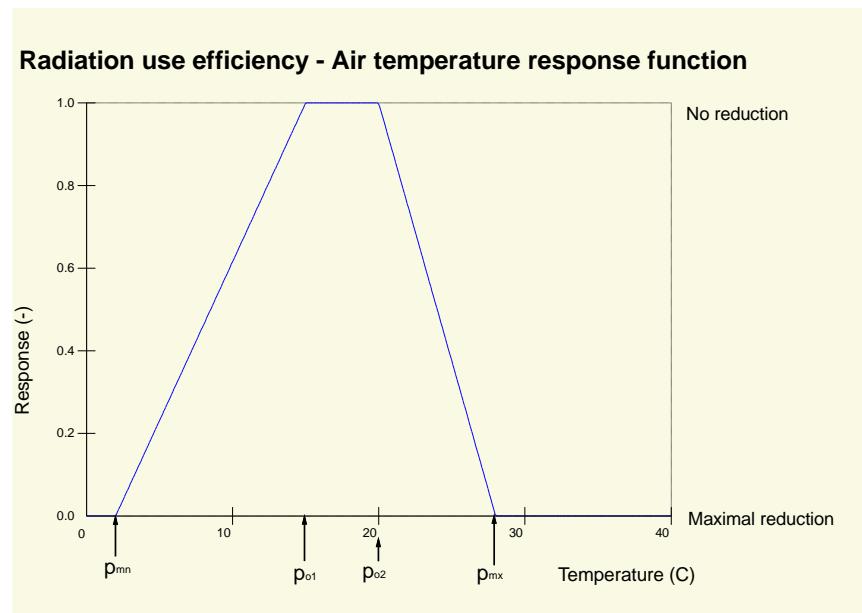
The allocation of carbon as an exponential function, exemplified by the root allocation response function for above ground mass. The dark blue line is the original parameterisation. All the other parameterisations are compared with this one. The green line shows the effect on the allocation function of a doubling of the parameter, r_{Mc1} . A doubling of r_{Mc2} results in the turquoise line and finally a doubling of r_{Mc3} gives the red line. This figure is analogous to the exponential leaf response function and the other exponential root response functions.

Allocation of carbon – linear function



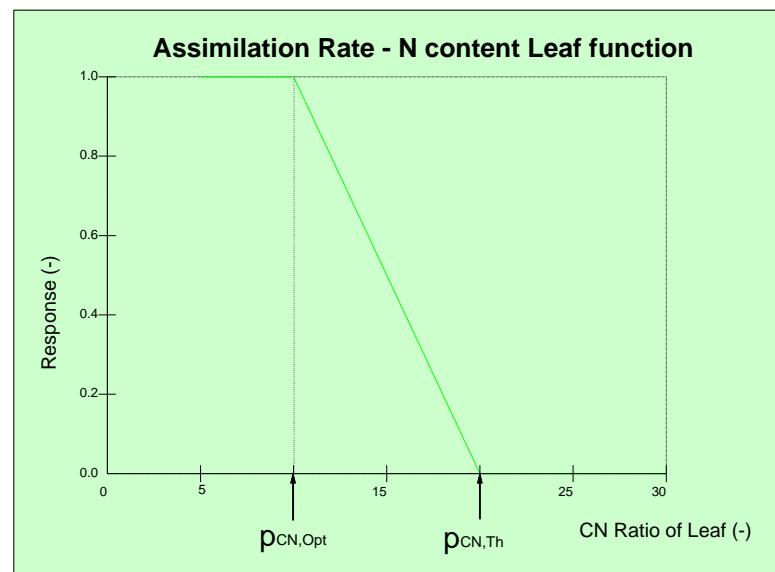
The allocation of carbon as a linear function, exemplified by the root allocation response function for water stress. The dark blue line is the original parameterisation. The other two parameterisations are compared with this one. The green line shows the effect on the allocation function of a doubling of the parameter, r_{Mc1} , and the turquoise line a doubling of r_{Mc2} . This figure is analogous to the linear leaf response function and the other linear root response functions.

Assimilation – air temperature response



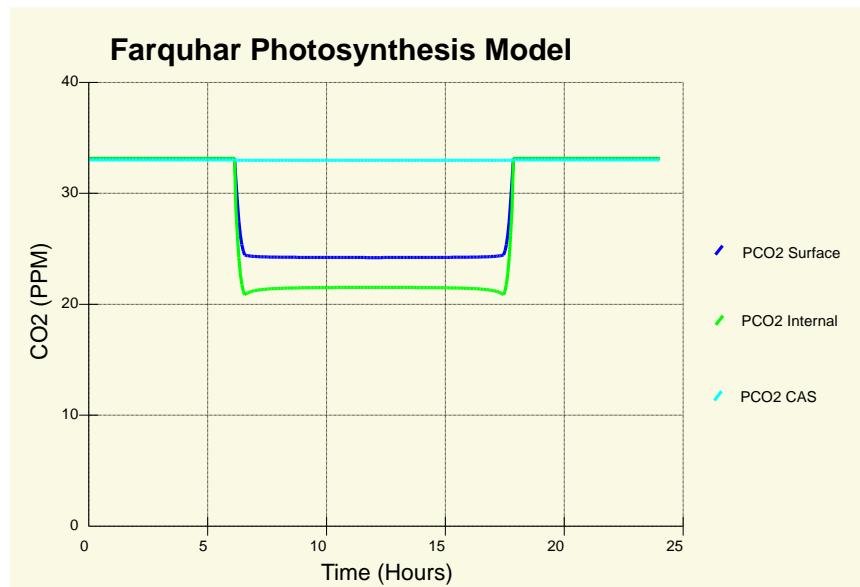
The response function for air temperature on assimilation (radiation use efficiency approach). A response of zero, i.e. at temperatures below p_{mn} or above p_{mx} , leads to a maximum reduction of photosynthesis, whereas if the response function is one, i.e. between p_{o1} and p_{o2} , there is no reduction of assimilation due to temperature.

Assimilation – nitrogen content in leaf response



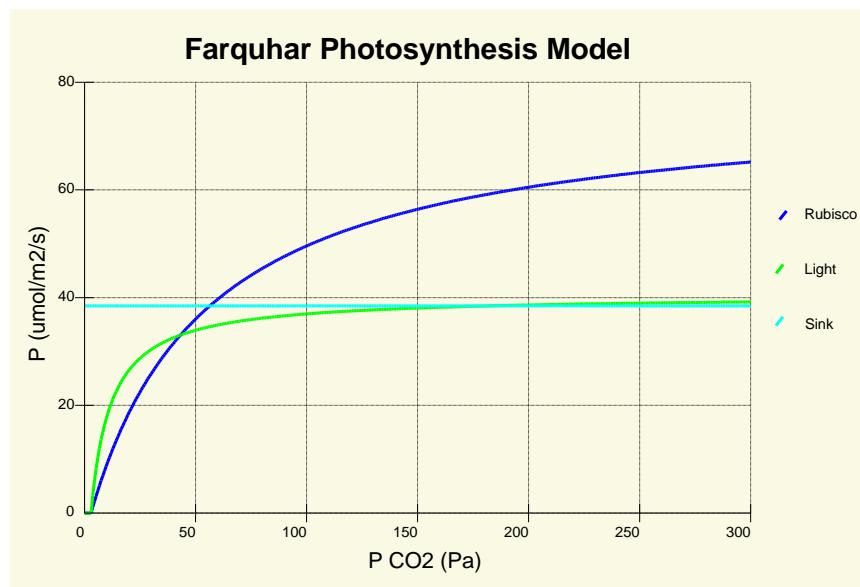
The response function for nitrogen content relative to carbon in the leaf on assimilation (radiation use efficiency approach). A response of zero, i.e. at CN ratios above $p_{QCN,Th}$, leads to a maximum reduction of photosynthesis, whereas if the response function is one, i.e. below $p_{QCN,Opt}$, there is no reduction of assimilation due to the carbon:nitrogen ratio.

Farquhar model – Carbon dioxide pressure as a function of time



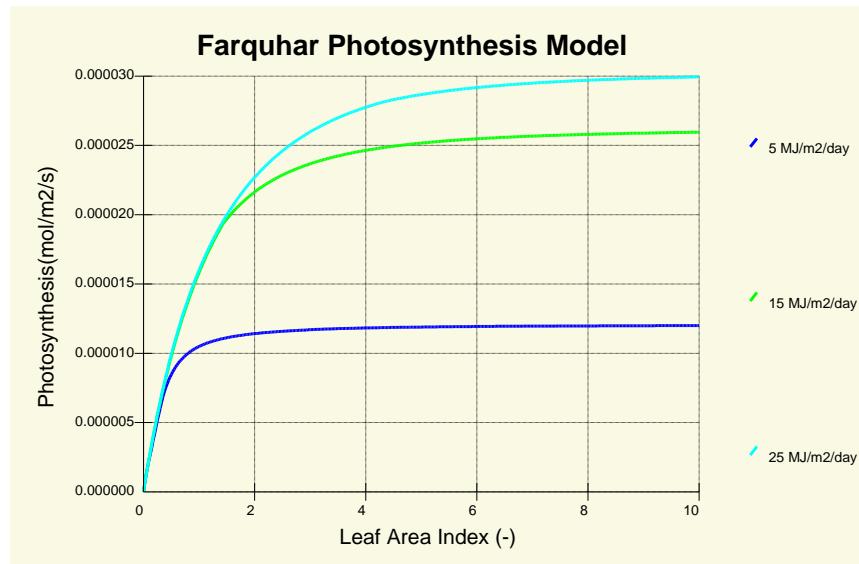
Carbon dioxide pressure inside the stomata, on the leaf surface and in the canopy air space (CAS) a function of time using the Farquhar photosynthesis model.

Farquhar model – Photosynthesis as a function of carbon dioxide pressure in the sub-stomatal cavity



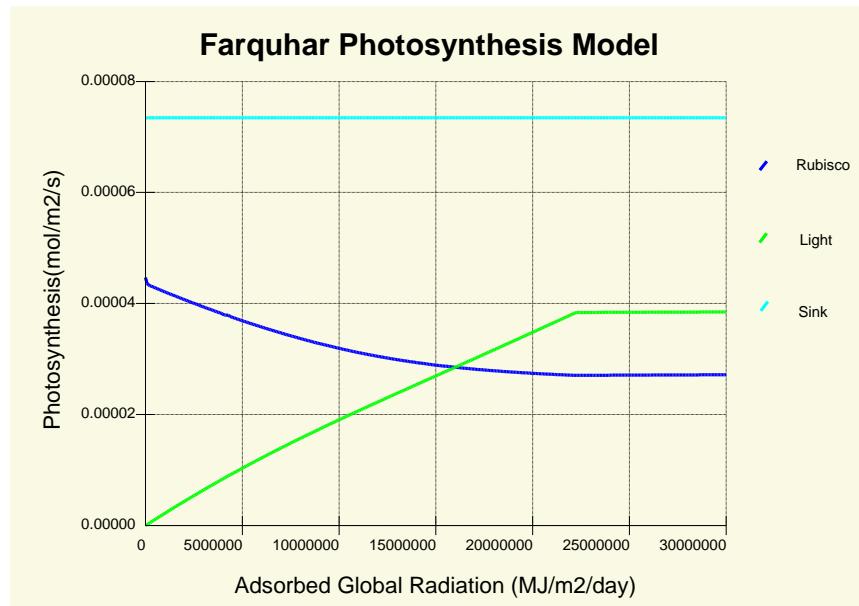
Rate of photosynthesis as a function of carbon dioxide partial pressure in the sub-stomatal cavity calculated for the three rate limiting processes for photosynthesis using the Farquhar model.

Farquhar model – Photosynthesis as a function of LAI



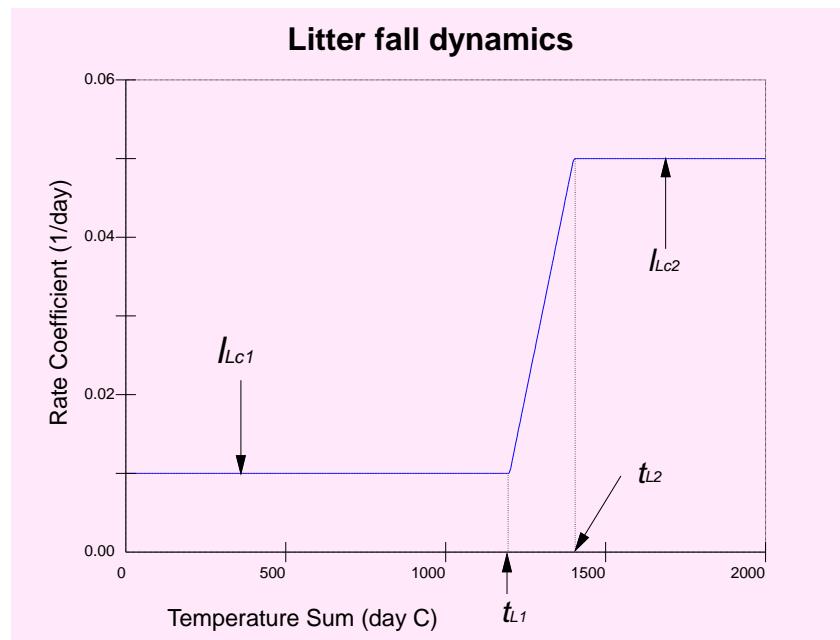
Rate of photosynthesis as a function of LAI calculated for three levels of radiation using the Farquhar model.

Farquhar model – Photosynthesis as a function of radiation



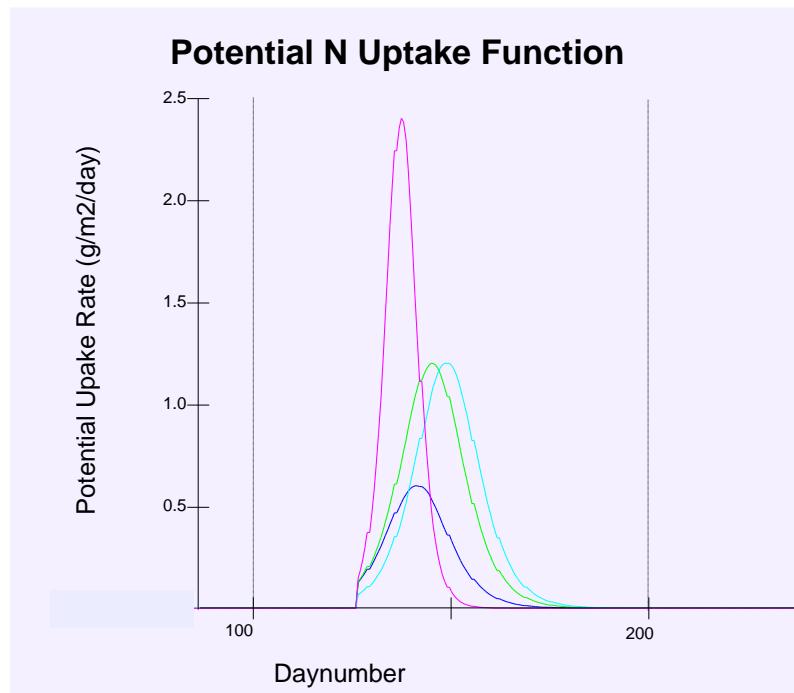
Rate of photosynthesis as a function of absorbed global radiation calculated for the three rate limiting processes for photosynthesis using the Farquhar model.

Litter fall



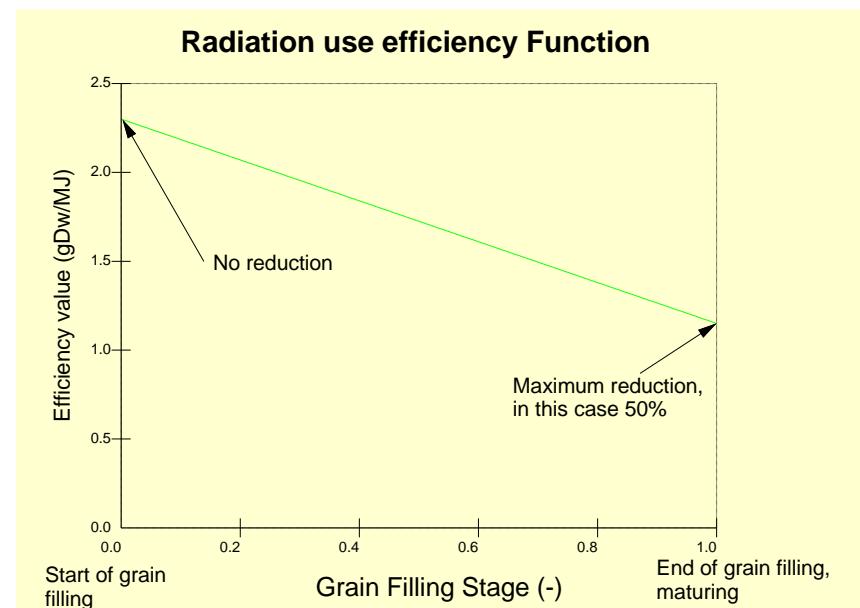
Litter fall dynamics for leaves, $f(l_{Lc})$. The parameters have the following values:
 $t_{L1}=1200$, $t_{L2}=1400$, $l_{Lc1}=0.01$ and $l_{Lc2}=0.05$.

Potential uptake of nitrogen – logistic growth



The potential uptake of nitrogen for logistic growth is determined by the three parameters p_{ua} , p_{ub} and p_{uc} . The blue line was the original simulation. The green line shows what happens if p_{ua} is doubled, the turquoise line corresponds to a value of p_{ub} that is half of the original value. Finally the pink line shows the drastic increase in potential nitrogen uptake due to a doubling of p_{uc} .

Radiation use efficiency response function at grain filling



The reduction of radiation use efficiency due to grain filling. In this case the maximum reduction, ε_{Lred} , is put to 50% and the original, unreduced radiation use efficiency, ε_L , is 2.3 gDW/MJ. At the start of the grain filling there is no reduction of the radiation use efficiency, but during grain development the reduction increases linearly until the end of grain filling where the reduction has reached its maximum value.

State Variables

CGrain

Carbon content in grain.
g/m²

CLeaf

Carbon content in leaf.
g/m²

C Mobile

Carbon content in the mobile allocation pool that the plant uses as an additional reserve source at leafing.
g/m²

CNewMobile

Carbon content in the temporary allocation pool for newly assimilated carbon.
g/m²

COldLeaf

Carbon content in the old leaf.
g/m²

COldRoots

Carbon content in the old roots.
g/m²

COldStem

Carbon content in the old stem.
g/m²

CRoots

Carbon content in roots.
g/m²

CStem

Carbon content in stem.
g/m²

C Surface Litter

Carbon content in the surface litter pool.
g/m²

GrowthStageIndex

The growth stage index that determines development stage.

-

N Grain

Nitrogen content in grain.
g/m²

N Leaf

Nitrogen content in leaf.
g/m²

N Mobile

Nitrogen content in the mobile allocation pool that the plant uses as an additional reserve source at leafing.
g/m²

N NewMobile

Nitrogen content in the temporary allocation pool for newly up taken nitrogen.
g/m²

N OldLeaf

Nitrogen content in the old leaves.
g/m²

N OldRoots

Nitrogen content in the old roots.
g/m²

N OldStem

Nitrogen content in the old stem.
g/m²

N Roots

Nitrogen content in roots.
g/m²

N Stem

Nitrogen content in stem.
g/m²

N Surface Litter

Nitrogen content in the surface litter pool.
g/m²

SimPlantAge

Simulated plant age
days

Flow Variables

C AtmNewMobile

Carbon assimilation. Flow from the atmosphere to the C NewMobile pool.
g/m²/day

C GrainAtm

Grain respiration.
g/m²/day

C GrainHarvest

Fraction of carbon in grain to harvest.
g/m²/day

C GrainSurfaceLitter

Grain litter fall to the surface litter pool.
g/m²/day

C LeafAtm

Leaf respiration.
g/m²/day

C LeafGrain

Carbon flux from leaf to grain.
g/m²/day

C LeafHarvest

Fraction of carbon in leaves to harvest.
g/m²/day

C LeafOldLeaf

Carbon flux from the new leaf pool to the old leaf pool at the end of each growing season.
g/m²/day

C LeafSurfaceLitter

Leaf litter fall to the surface litter pool.
g/m²/day

C MobileLeaf

Flow of carbon between the leaf and the mobile pool.
g/m²/day

C NewMobileLeaf

Fraction of the assimilates to the leaf.
g/m²/day

C NewMobileRoots

Fraction of the assimilates to the roots.
g/m²/day

C NewMobileStem

Fraction of the assimilates to the stem.
g/m²/day

C OldLeafAtm

Old leaf respiration.
g/m²/day

C OldLeafHarvest

Carbon flux from leaf at harvest.
g/m²/day

C OldLeafSurfaceLitter

Carbon flux from the old leaf pool to the surface litter pool at the end of each growing season.
g/m²/day

C OldRootsAtm

Old root respiration.
g/m²/day

C OldRootsHarvest

Carbon flux from roots at harvest.
g/m²/day

C OldRootsLitter

Carbon flux from the old root pool to the soil litter pool at the end of each growing season.
g/m²/day

C OldStemAtm

Old stem respiration.
g/m²/day

C OldStemHarvest

Carbon flux from stem at harvest.
g/m²/day

C OldStemSurfaceLitter

Carbon flux from the old stem pool to the surface litter pool at the end of each growing season.
g/m²/day

C Plant Resp

Plant respiration.
g/m²/day

C RootsAtm

Root respiration.
g/m²/day

C RootsGrain

Carbon flux from roots to grain.
g/m²/day

C RootsHarvest

Fraction of carbon in roots to harvest.
g/m²/day

C RootsLitter

Root litter carbon flow to the soil litter pool.
g/m²/day

C RootsOldRoots

Carbon flux from the new root pool to the old root pool at the end of each growing season.
g/m²/day

C StemAtm

Stem respiration.
g/m²/day

C StemGrain

Carbon flux from stem to grain.
g/m²/day

C StemHarvest

Fraction of carbon in stem to harvest.
g/m²/day

C StemOldStem

Carbon flux from the new stem pool to the old stem pool at the end of each growing season.
g/m²/day

C StemSurfaceLitter

Stem litter fall to the surface litter pool.
g/m²/day

CO₂ flux

Carbon dioxide flux from the canopy air space to the atmosphere (Farquhar growth model only).
mole C/m²/s

N FixationPlant

Nitrogen flow (fixation) from the atmosphere to the plant roots.
g/m²/day

N GrainHarvest

Fraction of nitrogen in grain to harvest.
g/m²/day

N GrainSurfaceLitter

Grain litter fall to the surface litter pool.
g/m²/day

N LeafGrain

Nitrogen flux from leaf to grain.
g/m²/day

N LeafHarvest

Fraction of nitrogen in leaves to harvest.
g/m²/day

N LeafOldLeaf

Nitrogen flux from the new leaf pool to the old leaf pool at the end of each growing season.
g/m²/day

N LeafSurfaceLitter

Leaf litter fall to the surface litter pool.
g/m²/day

N MobileLeaf

Flow of nitrogen between the leaf and the mobile pool.
g/m²/day

N NewMobileLeaf

Fraction of the nitrogen uptake to the leaf.
g/m²/day

N NewMobileRoots

Fraction of the nitrogen uptake to the roots.
g/m²/day

N NewMobileStem

Fraction of the nitrogen uptake to the stem.
g/m²/day

N OldLeafHarvest

Nitrogen flux from leaf at harvest.
g/m²/day

N OldLeafSurfaceLitter

Nitrogen flux from the old leaf pool to the surface litter pool at the end of each growing season.
g/m²/day

N OldRootsHarvest

Nitrogen flux from roots at harvest.
g/m²/day

N OldRootsLitter

Nitrogen flux from the old root pool to the soil litter pool at the end of each growing season.
g/m²/day

N OldStemHarvest

Nitrogen flux from stem at harvest.
g/m²/day

N OldStemSurfaceLitter

Nitrogen flux from the old stem pool to the surface litter pool at the end of each growing season.
g/m²/day

N RootsGrain

Nitrogen flux from roots to grain.
g/m²/day

N RootsHarvest

Fraction of nitrogen in roots to harvest.
g/m²/day

N RootsLitter

Root litter nitrogen flow to the soil litter pool.
g/m²/day

N RootsOldRoots

Nitrogen flux from the new root pool to the old root pool at the end of each growing season.
g/m²/day

N SoilNewMobile

Nitrogen uptake from the soil. Flow of nitrogen from the soil to the N NewMobile pool.
g/m²/day

N StemGrain

Nitrogen flux from stem to grain.
g/m²/day

N StemHarvest

Fraction of nitrogen in stem to harvest.
g/m²/day

N StemOldStem

Nitrogen flux from the new stem pool to the old stem pool at the end of each growing season.
g/m²/day

N StemSurfaceLitter

Stem litter fall to the surface litter pool.
g/m²/day

Auxiliary Variables

C Plant

Carbon content in the new and old plant biomass pools.
g/m²

C Plant AboveG

Carbon content in the new and old plant above ground biomass pools.
g/m²

C Roots

Carbon content in the new and old root pools.
g/m²

C Total Harvest

The total transfer of carbon from the plant(s) to harvest.
g/m²/day

C Total Plant

The total carbon content in the new and old plant biomass pools for all plants (if more than one plant is simulated).
g/m²

C Total PlantAboveG

The total carbon content in the new and old plant above ground biomass pools for all plants (if more than one plant is simulated).

g/m²

C Total PlantLitter

The total transfer of carbon from the plant(s) to litter.

g/m²/day

C Total Roots

The total carbon content in the new and old root pools for all plants (if more than one plant is simulated).

g/m²

CN RatioGrain

The carbon nitrogen ratio in grain.

-

CN RatioLeaf

The carbon nitrogen ratio in the leaf.

-

CN RatioRoots

The carbon nitrogen ratio in the roots.

-

CN RatioStem

The carbon nitrogen ratio in the stem.

-

DormingTempSum

The temperature sum that is used to calculate when the plant goes into dormancy.

°C/day

GrowthTempSum

The temperature sum that is used to calculate GSI.

°C/day

N Plant

Nitrogen content in the new and old plant biomass pools.

g/m²

N Plant AboveG

Nitrogen content in the new and old plant above ground biomass pools.

g/m²

N Plant Demand

Plant demand of nitrogen.

g/m²/day

N Roots

Nitrogen content in the new and old root pools.
g/m²

N Total Harvest

The total transfer of nitrogen from the plant(s) to harvest.
g/m²/day

N Total Plant

The total nitrogen content in the new and old plant biomass pools for all plants (if more than one plant is simulated).
g/m²

N Total PlantAboveG

The total nitrogen content in the new and old plant above ground biomass pools for all plants (if more than one plant is simulated).
g/m²

N Total PlantLitter

The total transfer of nitrogen from the plant(s) to litter.
g/m²/day

N Total Roots

The total nitrogen content in the new and old root pools for all plants (if more than one plant is simulated).
g/m²

N Total PlantDemand

The total plant nitrogen demand (all plants).
g/m²/day

N Total PlantUptake

The total plant uptake of mineral and organic nitrogen from the whole soil profile.
g/m²/day

N Uptake Deficit 1

The difference between total plant demand of nitrogen and the primary uptake of mineral nitrogen.
g/m²/day

N Uptake Deficit 2

The difference between total plant demand of nitrogen and the primary and secondary uptake of mineral and organic nitrogen.
g/m²/day

PCO2 Canopy

CO₂ pressure in the canopy air space (Farquhar model).
Pa

PCO₂ Stomata

CO₂ pressure in the sub-stomatal cavity (Farquhar model).
Pa

PCO₂ Surface

CO₂ pressure at the leaf surface (Farquhar model).
Pa

P Light

RuBP (light) limited rate of photosynthesis (Farquhar model).
μmol/m²/s

P Rubisco

Rubisco (carboxylation) limited rate of photosynthesis (Farquhar model).
μmol/m²/s

P Sink

TPU (sink) limited rate of photosynthesis (Farquhar model).
μmol/m²/s

Radiation adsorbed

Amount of radiation adsorbed by the canopy.
J/m²/day

Response N

Response function for nitrogen stress on assimilation for each plant. Radiation use efficiency only.

-

Response Salt

Response function for soil salinity stress on assimilation for each plant.

-

Response Temp

Response function for temperature stress on assimilation for each plant. Radiation use efficiency only.

-

Response Water

Response function for water stress on assimilation for each plant. Radiation use efficiency only.

-

Total Response N

Response function for nitrogen stress on assimilation for all plants. Radiation use efficiency only.

-

Total Response Temp

Response function for temperature stress on assimilation for all plants. Radiation use efficiency only.

-

Total Response Water

Response function for water stress on assimilation for all plants. Radiation use efficiency only.

Soil Management

Ploughing and surface cultivation can optionally be applied to a soil (see switches “[Deep ploughing](#)” and “[Surface cultivation](#)”). When these events occur (parameters $m_{s,day}$ and $m_{p,day}$) the surface litter is allocated to the litter pool(s) (and humus pool if microbes are explicitly simulated) down to a certain depth determined by the parameters, $m_{s,dep}$ and $m_{p,dep}$, for surface cultivation and deep ploughing respectively. The fractions of the surface litter going to the different pools is calculated by multiplying the carbon and nitrogen content in the surface litter pool with a ratio for each soil organic pool. These ratios are of course depending on the number of receiving pools:

1. Microbes are implicit → only one litter pool:

$$r_l = 1 \quad (5.76)$$

2. Microbes are explicit and only one litter pool is simulated:

$$r_{l1} = \frac{l_{l1}}{l_{l1} + l_h} \quad (5.77)$$

$$r_h = 1 - r_{l1} \quad (5.78)$$

3. Microbes are explicit and two litter pools are simulated:

$$r_{l1} = \frac{l_{l1}}{l_{l1} + l_{l2} + l_{lh}} \quad (5.79)$$

$$r_{l2} = \frac{l_{l2}}{l_{l1} + l_{l2} + l_{lh}} \quad (5.80)$$

$$r_h = 1 - r_{l1} - r_{l2} \quad (5.81)$$

where l_{l1} , l_{l2} and l_h are parameters described in the section “[Soil Organic Processes](#)”.

At ploughing not only the surface litter but also the carbon and nitrogen in the root pool is allocated to litter pool 1 and uniformly distributed in the soil profile.

Switches

Deep ploughing

Value	Meaning
Off	Ploughing is considered.
On	Ploughing is not considered.

Surface cultivation

Value	Meaning

Off	Surface cultivation is considered.
On	Surface cultivation is not considered.

Parameters

PloughingDay

Day number for ploughing.

Default	Unit	Symbol	Equation	Function
0	#	$m_{p,day}$		

PloughingDepth

The depth to which the properties of the soil will be evenly distributed.

Default	Unit	Symbol	Equation	Function
0.3	m	$m_{p,dep}$		

SurfaceCultDay

Day number for surface cultivation.

Default	Unit	Symbol	Equation	Function
0	#	$m_{s,day}$		

SurfaceCultDepth

The depth to which the properties of the soil will be evenly distributed.

Default	Unit	Symbol	Equation	Function
0.1	m	$m_{s,dep}$		

Common abiotic functions

Two response functions are used in many procedures and that is the response function for temperature and the response function for soil moisture. These two functions are described in detail in this section.

Response functions for temperature

Response functions for temperature, $f(T)$, affects processes such as decomposition rate and denitrification. Usually there are several response functions for temperature to choose between, i.e. by switches in different sections of this chapter. Of these options three are standard response functions and the fourth is a general option called “common”. “Common” it self is not a temperature response function. Choosing common means that one of four standard temperature response functions automatically will be used. This choice between the four possible alternatives is made by the switch “[Temp Response](#)” in this section.

The idea behind the option “Common” is that if this option is consequently chosen, it will be easier to remember how all temperature dependent processes respond to temperature responses and the amount of decisions will be fewer. The second reason why a standard temperature response function always has to be chosen is that there are a few processes that always rely on this response function (i.e. the common temperature response function is automatically called for from some processes).

“Q10 threshold” and “Q10 whole range”

If any of these two standard functions are chosen, the temperature response will be calculated as:

$$f(T) = t_{Q10}^{(T-t_{Q10bas})/10} \quad (5.82)$$

where t_{Q10} and t_{Q10bas} are parameters and T is the soil temperature in a certain layer. In the top layer the soil temperature is equal to the surrounding air temperature. See viewing function “[Common Soil Moisture Response Function](#)”.

“Q 10 threshold” only

If the “Q 10 threshold” option is chosen, the response function, $f(T)$, is altered at low temperatures. If the soil temperature is lower than a threshold temperature, $t_{Q10thres}$, the response function will be recalculated as:

$$f(T) = \frac{T}{t_{Q10thres}} \cdot f(T) \quad (5.83)$$

or if the temperature falls below zero the response function, $f(T)$, will be put to zero. See viewing function “[Common temperature response function - Q10 threshold](#)”.

“O’Neill function”

The O’Neill function calculates the temperature response function, $f(T)$, with the help of three parameters:

$$f(T) = \left(\frac{t_{ONmax} - T}{t_{ONmax} - t_{ONopt}} \right)^{n_{ONform}} e^{n_{ONform} \left(\frac{T - t_{ONopt}}{t_{ONmax} - t_{ONopt}} \right)} \quad (5.84)$$

where t_{ONmax} is a maximum temperature, t_{ONopt} is an optimum temperature and n_{ONform} is a form coefficient.

“Ratkowsky function”

Finally if the “Ratkowsky function” is chosen, the temperature response function is calculated differently depending on the temperature:

$$\left. \begin{array}{ll} 1. & T > t_{max} \\ & f(T) = 1 \\ 2. & t_{min} < T < t_{max} \\ & f(T) = \left(\frac{T - t_{min}}{t_{max} - t_{min}} \right)^2 \\ 3. & T < t_{min} \\ & f(T) = 0 \end{array} \right\} \quad (5.85)$$

where t_{min} and t_{max} are parameters. See viewing function “[Common temperature response function - Ratkowsky function](#)”.

Common response function for soil moisture

The common response function for soil moisture is, as opposed to the common response function for temperature, a standard response function in its self. Therefore there is no need for a switch connected to this function. This function is automatically called for in processes such as nitrification, decomposition and respiration.

The common soil moisture response function, $f(\theta)$, looks different depending soil moisture content:

$$1. \quad \theta = \theta_s \\ f(\theta) = p_{\theta satact}$$

$$2. \quad \theta_{wilt} < \theta < \theta_s$$

$$f(\theta) = \min \left(\left(\frac{\theta_s - \theta}{p_{\theta Upp}} \right)^{p_{\theta p}} (1 - p_{\theta satact}) + p_{\theta satact}, \left(\frac{\theta - \theta_{wilt}}{p_{\theta Low}} \right)^{p_{\theta p}} \right)$$

$$3. \quad \theta < \theta_{wilt}$$

$$f(\theta) = 0 \quad (5.86)$$

where $p_{\theta Upp}$, $p_{\theta Low}$, $p_{\theta satact}$, and $p_{\theta p}$ are parameters and the variables, θ_s , θ_{wilt} and θ , are the soil moisture content at saturation, the soil moisture content at the wilting point and the actual soil moisture content respectively, described in the section “Soil Water Processes”. See viewing function “[Common Soil Moisture Response Function](#)”.

Switches

Specific abiotic responses for microbial activity, mineralisation-immobilisation, nitrification and denitrification can also be assigned within each process.

Temp Response

Value	Meaning
Q10 Above Threshold	The temperature response function for microbial activity, mineralisation-immobilisation, nitrification and denitrification is a Q10 type of function above a certain threshold temperature. The response stronger for temperatures below the threshold and diminishes below 0° C.
Q10 Whole range	The temperature response function for microbial activity, mineralisation-immobilisation, nitrification and denitrification is a Q10 type of function for all temperatures.
O Neill function	The temperature response function for microbial activity, mineralisation-immobilisation, nitrification and denitrification is an exponential function of temperature (O'Neill function).
Ratkowsky function	The temperature response function for microbial activity, mineralisation-immobilisation, nitrification and denitrification is a quadratic function

	(Ratkowsky function).
--	-----------------------

Parameters

Neill Form

Shape coefficient in the O'Neill temperature response function.

Default	Unit	Symbol	Equation	Function
4.28	-	n_{ONform}	(5.84)	

Neill Max Temp

Maximum temperature in the O'Neill temperature response function.

Default	Unit	Symbol	Equation	Function
42	°C	t_{ONmax}	(5.84)	

Neill Opt Temp

Optimum temperature in the O'Neill temperature response function.

Default	Unit	Symbol	Equation	Function
27.5	°C	t_{ONopt}	(5.84)	

Saturation Activity

Saturation activity in soil moisture response function.

Default	Unit	Symbol	Equation	Function
0.6	-	$p_{\theta Sact}$	(5.86)	“Common Soil Moisture Response Function”

A value of 1 corresponds to optimum activity at saturation and 0 to no activity

TemQ10

Response to a 10 °C soil temperature change on the microbial activity, mineralisation-immobilisation, nitrification and denitrification.

Default	Unit	Symbol	Equation	Function
2	-	t_{Q10}	(5.82)	“Common temperature response function - Q10 whole range”

TemQ10Bas

Base temperature for the microbial activity, mineralisation-immobilisation, nitrification and denitrification at which the response is 1.

Default	Unit	Symbol	Equation	Function

20	°C	t_{Q10bas}	(5.82)	“Common temperature response function - Q10 whole range”
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TemQ10Threshold

Threshold temperature for the microbial activity, mineralisation-immobilisation, nitrification and denitrification below which the response is more strong than above and ceases at 0 °C.

Default	Unit	Symbol	Equation	Function
5	°C	$t_{Q10thres}$	(5.83)	“Common temperature response function - Q10 threshold”

TempMax

Minimum temperature for the microbial activity, mineralisation-immobilisation, nitrification and denitrification in the Ratkowsky function.

Default	Unit	Symbol	Equation	Function
20	°C	t_{max}	(5.85)	“Common temperature response function - Ratkowsky function”

TempMin

The temperature at which the response on microbial activity, mineralisation-immobilisation, nitrification and denitrification is 1 in the Ratkowsky function.

Default	Unit	Symbol	Equation	Function
-8	°C	t_{min}	(5.85)	“Common temperature response function - Ratkowsky function”

ThetaLowerRange

Water content interval in the soil moisture response function for microbial activity, mineralisation-immobilisation, nitrification and denitrification.

Default	Unit	Symbol	Equation	Function
13	vol %	$p_{\theta Low}$	(5.86)	“Common Soil Moisture Response Function”

The response increases from 0 at the wilting point to optimum at the end of the interval. Normal range 8-15.

ThetaPowerCoef

Coefficient in the soil moisture response function.

Default	Unit	Symbol	Equation	Function
1	-	$p_{\theta p}$	(5.86)	“Common Soil Moisture Response Function”

A linear response corresponds to the value 1. Values between 0-1 results in a convex response and values >1 in a concave response.

ThetaUpperRange

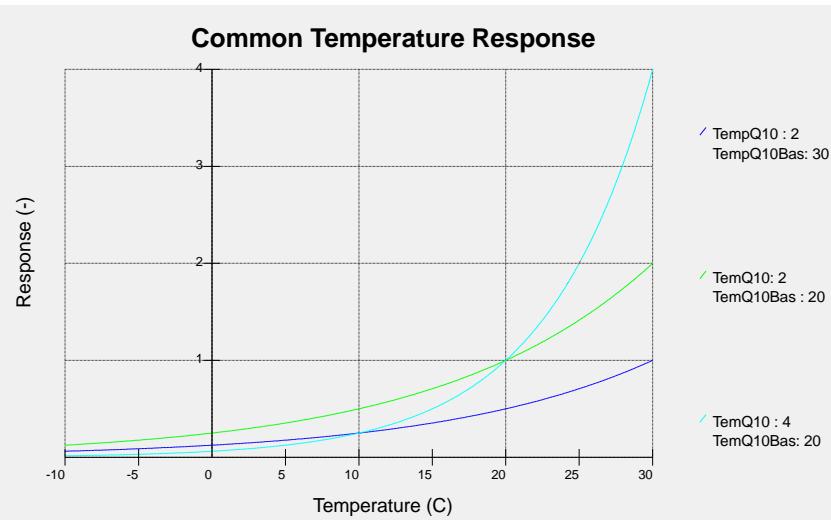
Water content interval in the soil moisture response function for microbial activity, mineralisation-immobilisation, nitrification and denitrification.

Default	Unit	Symbol	Equation	Function
8	vol %	$p_{\theta pp}$	(5.86)	“Common Soil Moisture Response Function”

The response decreases from optimum at the beginning of the interval to saturation activity at saturation. Normal range 1-10.

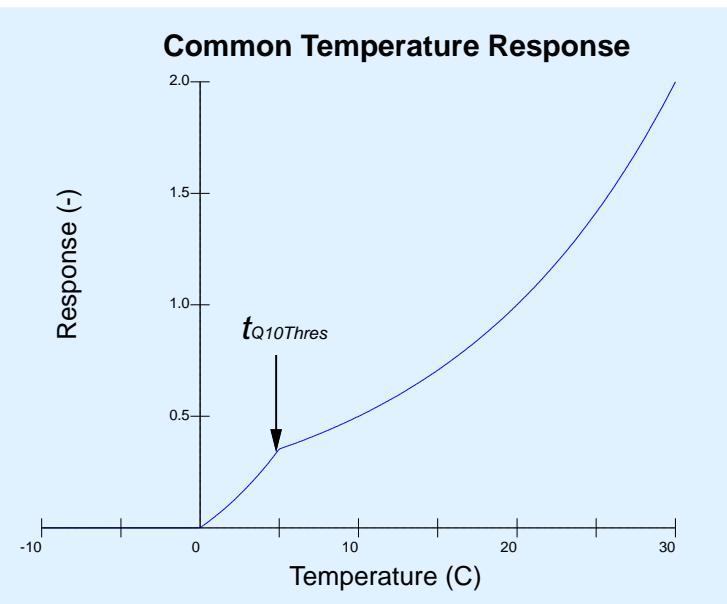
Viewing function

Common temperature response function - Q10 whole range



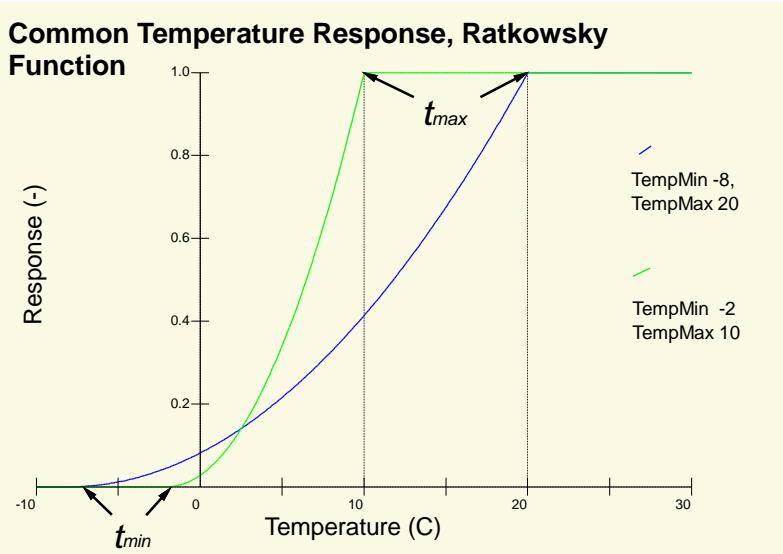
Common temperature response function, Q10 whole range. The plot shows how the parameters TemQ10 and TemQ10Bas affect the temperature response function.

Common temperature response function - Q10 threshold



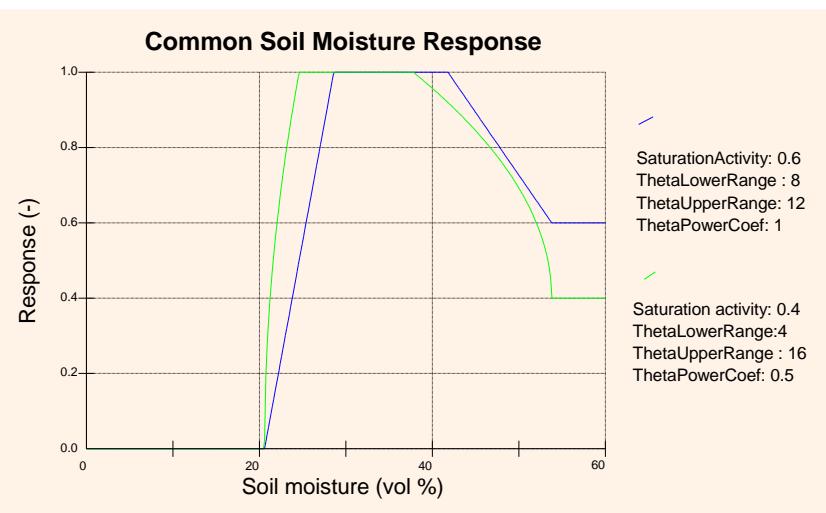
The common Q10 response function for temperature with a threshold value.

Common temperature response function - Ratkowsky function



The Ratkowsky temperature response function for two different parameterisations.

Common Soil Moisture Response Function



The common soil moisture response function used in for example calculations of nitrification. The "Saturation Activity" is the value of the response function when the soil is saturated i.e. to the right in the figure. "Theta Upper and Lower Range" determines the optimum soil moisture content where the response function is equal to one. The "Theta Power Coefficient" determines the slope of the curve below and above the optimum range.

Auxiliary variables

Response(C) Humus

The common response function for temperature and soil moisture weighted for the distribution of humus in the whole soil profile.

Response(C) Litter

The common response function for temperature and soil moisture weighted for the distribution of litter in the whole soil profile.

Response(C) Temp

The common response function for temperature.

Response(C)TempTheta

The common response function for temperature and soil moisture.

Response(C) Theta

The common response function for soil moisture.

Root uptake demand

Nitrogen and Carbon – below ground processes

Per-Erik Jansson, Henrik Eckersten, Annemieke Gärdenäs, Karin Blombäck, Leif Klemedtsson, Marco Ravina, Claudia Wagner-Riddle and Josefine Norman

Soil Organic Processes

Structure

The soil is divided into several organic pools for carbon and nitrogen. Some of these pools are compulsory while others can optionally be switched on or off. The humus pool, C_{Humus} and N_{Humus} , one soil litter pool, $C_{Litter1}$ and $N_{Litter1}$, and the surface litter pool, $C_{LitterSurface}$ and $N_{LitterSurface}$, are always present. If manure is simulated (see section “[External Inputs](#)”) the faeces pool, C_{Faeces} and N_{Faeces} , should be switched on (see switch “[Faeces pool](#)”). Optionally pools for dissolved organic matter may be included in the simulations (see switch “[Dissolved Organics](#)”). This option allows for vertical transport of organic matter of the soil profile.

Soil organisms, microbes, decompose the organic matter and their activity therefore accounts for the fluxes between different compartments in the soil. Microbial biomass can optionally be dynamically interacting with the soil organic matter (i.e. switch “[Microbes](#)” is turned on), and in this case a microbial biomass pool is formed, $C_{Microbes}$ and $N_{Microbes}$. Microbes are decomposing litter, faeces and humus at different rates depending on how many micro organisms that participate in the decomposition process. Therefore different fractions of the microbial biomass are allocated to decompose the litter, faeces and humus pools (see [Figure 5.2](#) below). Subsequently the micro organisms only decompose the carbon in the pool in which they are situated. On the other hand, if the microbial biomass is not explicitly simulated, the biomass is implicitly included in the litter, humus and faeces pools.

The microbial activity can be different in different pools. It is also possible to add an extra litter pool, $C_{Litter2}$ and $N_{Litter2}$, which can differ from litter pool 1 in microbial activity (see switch “[Litter pools](#)”) if the microbial biomass is explicitly simulated.

Initial values

If the soil initial organic content is given as a table (see switch “[Initial soil organic](#)”), the initial nitrogen values for all pools for each soil compartment are given from the parameter tables “[Initial organic Nitrogen](#)”. Initial CN ratios for all pools are then used to calculate the initial carbon contents (see parameter tables “[Initial organic CN ratios](#)”).

Else the soil nitrogen content is calculated from the parameters $i_{II,N}$, $i_{I2,N}$, $i_{f,N}$, $i_{h,N}$, $i_{m,N}$, $i_{II,d}$, $i_{I2,d}$, $i_{f,d}$, $i_{h,d}$, $i_{m,d}$, $i_{II,exp}$, $i_{I2,exp}$, $i_{f,exp}$ and $i_{h,exp}$. Either the nitrogen will be distributed evenly in the soil profile (“Constant”), or it will decrease linearly from the top layer (“Linear”), or finally it will decrease exponentially from the top layer (“Exponential”). From the nitrogen contents in each pool the carbon contents in each pool can be calculated using the initial CN ratios which are given as parameters ($i_{II,CN}$, $i_{I2,CN}$, $i_{f,CN}$, $i_{h,CN}$ and $i_{m,CN}$).

Litter formation

Above soil plant litterfall

When litter falls from the leaves (or sometimes stems or grain) of a plant, $C_{Leaf \rightarrow SurfaceLitter}$ or $N_{Leaf \rightarrow SurfaceLitter}$, it first enters a microbial-inactive pool on soil surface, $C_{LitterSurface}$ and $N_{LitterSurface}$. After that it continues into the litter pool(s), $C_{Litter1(2)}$ and $N_{Litter1(2)}$, and the humus pool, C_{Humus} and N_{Humus} , at continuous rates:

$$C_{LitterSurface \rightarrow Litter1} = l_{l1} \cdot C_{LitterSurface} \quad (6.1)$$

$$N_{LitterSurface \rightarrow Litter1} = l_{l1} \cdot N_{LitterSurface} \quad (6.2)$$

where l_{l1} is a parameter. Similarly the parameters l_{l2} and l_h in the corresponding equation gives the flows to the second litter pool (if selected) and the humus pools.

Root litterfall

Root litterfall is the only input of organics directly to soil layers (i.e. not via the soil surface) except at ploughing when above ground residues are mixed within the ploughing depth (see section “[Soil Management](#)”). The amounts of carbon and nitrogen from the roots to the litter pool, $C_{Root \rightarrow Litter}$ and $N_{Root \rightarrow Litter}$, are calculated in the section “[Plant Growth](#)”. Root litter fall always enters litter pool 1, even if a second litter pool is included in the simulation.

Decomposition and Mineralisation - Soil organisms implicit

When soil organisms are implicit, the soil profile includes a maximum of three organic carbon pools, litter, C_{Litter} , faeces, C_{Faeces} , and humus, C_{Humus} , since microbial biomass is implicit in the litter pool. Decomposition is substrate controlled and follows first-order kinetics: $k_l C_{Litter}$ for litter, $k_f C_{Faeces}$ for faeces and $k_h C_{Humus}$ for humus, where k_l , k_f and k_h are the specific decomposition rates. These three rate constants are affected by common response functions for soil moisture $f(\theta)$ and temperature $f(T)$ described in the section “[Common abiotic functions](#)”. The efficiency parameter, f_e , determines the fraction of carbon mineralised i.e. the fraction that is not released from the soil as CO₂. Of the amount not being mineralised the humification fraction, f_h , determines the carbon flux to humus, whereas the remaining carbon is transferred back to the litter pool as an internal cycling (i.e. the carbon taken up in the microbial biomass). The decomposition rate of the litter pool, $C_{DecompL}$, is calculated as a first order rate process:

$$C_{DecompL} = k_l f(T) f(\theta) C_{Litter} \quad (6.3)$$

where k_l is a parameter. The same first order rate equation is applied for faeces and humus, by using the parameters k_f or k_h and the appropriate state variables, C_{Faeces} and C_{Humus} .

The products of decomposition are CO₂ (respiration), humus and, conceptually, microbial biomass and metabolites. Since the microbes are implicitly included in the litter and faeces pools, the synthesis of microbial biomass and metabolites constitutes an internal cycling i.e. $C_{Litter \rightarrow Litter}$, eq. (6.6). The relative amounts of decomposition products formed from the litter pool decomposition are (see [Figure 5.1](#)):

$$C_{Litter \rightarrow CO_2} = (1 - f_{e,l}) \cdot C_{DecompL} \quad (6.4)$$

$$C_{Litter \rightarrow Humus} = f_{e,l} f_{h,l} C_{DecompL} \quad (6.5)$$

$$C_{Litter \rightarrow Litter} = f_{e,l} (1 - f_{h,l}) \cdot C_{DecompL} \quad (6.6)$$

where $f_{e,l}$ and $f_{h,l}$ are parameters. The relative amounts of decomposition products from the faeces pool i.e. $C_{Faeces \rightarrow CO_2}$, $C_{Faeces \rightarrow Humus}$ and $C_{Faeces \rightarrow Faeces}$ are calculated with the same equations exchanging the parameters to $f_{e,f}$ and $f_{h,f}$ respectively. The only flow from the humus pool is caused by respiration, $C_{Humus \rightarrow CO_2}$, and is calculated with eq. (6.4) with the use of the efficiency parameter, $f_{e,h}$.

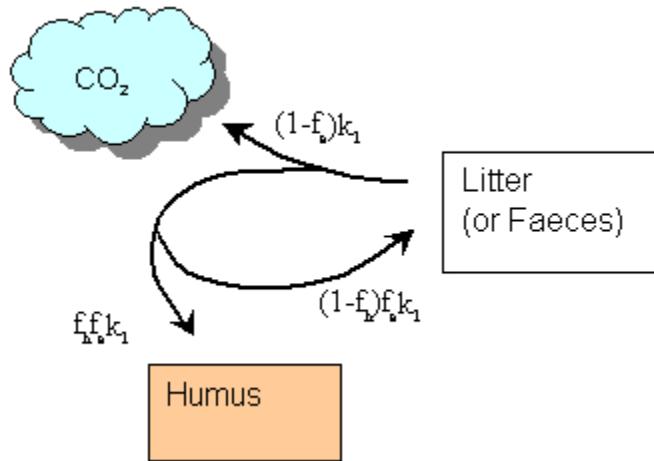


Figure 5.1. Flow diagram showing the relative amounts of decomposition products formed.

The nitrogen fluxes associated with the carbon fluxes from litter and faeces to humus is calculated from a CN ratio representing microbes, which is given as a parameter, cn_m :

$$N_{Litter \rightarrow Humus} = C_{Litter \rightarrow Humus} / cn_m \quad (6.7)$$

The same equation applies to the nitrogen flux from the faeces pool, $N_{Faeces \rightarrow Humus}$, if $C_{Litter \rightarrow Humus}$ is exchanged to $C_{Faeces \rightarrow Humus}$.

When soil organisms are implicit in the simulations the mineralisation/immobilization of nitrogen is dependent on the CN ratio in the source pool. Consequently, the flow from litter pool to the soil ammonium pool, $N_{Litter \rightarrow NH_4}$, is calculated as:

$$N_{Litter \rightarrow NH_4} = C_{DecompL} \left(\frac{1}{CN_{Litter}} - \frac{f_{e,l}}{cn_m} \right) \quad (6.8)$$

where $f_{e,l}$ and cn_m are parameters. Changing the efficiency parameter to $f_{e,f}$ or $f_{e,h}$ in addition to changing the litter CN ratio to the faeces CN ratio or the humus CN ratio, gives the flow from the faeces pool, $N_{Faeces \rightarrow NH_4}$ or the humus pool, $N_{Humus \rightarrow NH_4}$, respectively. A negative value of the flux means that a net immobilisation takes place. This is described in "[Mineralisation / Immobilisation](#)".

Decomposition and Mineralisation - Soil organisms explicit

Microbes can also be treated explicitly i.e. a pool for microbial biomass is included in the simulations. This can be useful for example when simulating forest ecosystems because in forest soils the humified products have an essentially higher CN ratio than the microbes. It is the CN ratio in the microbial biomass that determines the net mobilisation/immobilisation rate and therefore microbial biomass is better expressed explicitly for these soils.

The different organic carbon pools and the carbon flows between them, when soil organisms are explicitly simulated, are illustrated in [Figure 5.2](#). The external inputs have already been described thoroughly in the section “[External inputs](#)” and will therefore not be discussed further.

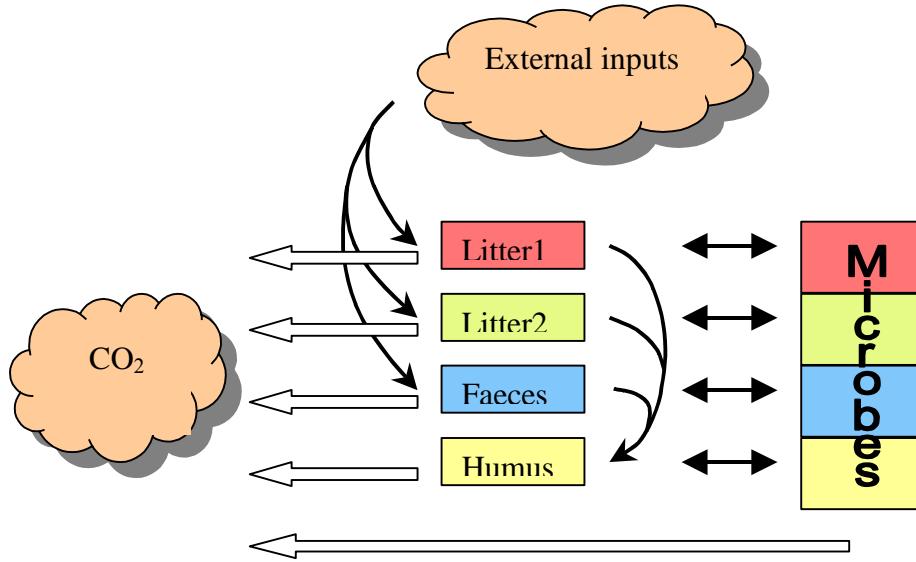


Figure 5.2. The organic carbon pools and carbon flows in the soil. The coloured sections in the microbial pool correspond to the fractions of microbials located in the litter, faeces and humus pools respectively (i.e. the sub pools in the microbial pool).

Fluxes of carbon to the microbial pool from the humus, litter and faeces pools

The size of the microbial pool may vary over time depending on the consumption and mortality of the micro organisms. The net result of these two processes will determine the transfer of carbon to the microbial pool from the humus, litter and faeces pools respectively. These carbon fluxes from the litter, humus and faeces pools to the microbial biomass, $C_{Litter1 \rightarrow Microbe}$, $C_{Humus \rightarrow Microbe}$ and $C_{Faeces \rightarrow Microbe}$ are calculated as:

$$C_{Litter1 \rightarrow Microbe} = f_{e,m} f_{cons,l1} f(CN_{l1}) f(C_{Litter1}) M_{potcons} \\ - k_{m,mort} f_{mort,l1} f(A_{mort}) C_{Microbe} \quad (6.9)$$

where $f_{e,m}$ is an efficiency parameter, $f_{cons,l1}$ is a parameter that gives the fraction of consumption for the litter pool compared to the whole consumption, $f_{mort,l1}$ is a parameter that gives the fraction of mortality for the litter pool compared to the whole mortality and $k_{m,mort}$ is the microbial mortality rate. $f(CN_{l1})$ and $f(C_{Litter1})$ are response functions for the carbon nitrogen ratio and the total carbon content in the litter pool respectively. These response functions are not considered for the humus pool and can also optionally be switched off for the other organic pools (see switch “[CN Ratio Influence](#)”). Finally $f(A_{mort})$ is an abiotic response function on mortality and $M_{potcons}$ is the potential microbial consumption. The equation is used analogously for the faeces, litter 2 and humus pools by the parameters $f_{cons,l2}$, $f_{cons,f}$, $f_{mort,l2}$ and $f_{mort,f}$. For the humus pool the parameters $f_{cons,h}$ and $f_{mort,h}$ are the fractions of the microbial biomass that remains when the rest of the biomass has been allocated to the litter and faeces pools for consumption and mortality respectively.

The potential microbial consumption is calculated as:

$$M_{potcons} = k_{m,cons} f(A_{cons}) C_{dep} \quad (6.10)$$

where $k_{m,cons}$ is the microbial consumption rate and $f(A_{cons})$ is an abiotic response function on consumption (see below). If the consumption is dependent only on the carbon content in the microbes (see switch “[Microbes](#)”) the C_{dep} equals the carbon content in the microbial pool, $C_{Microbe}$. If, on the other hand, the consumption depends of the carbon content in the

substrate, the C_{dep} is the sum of the carbon contents in the litter and faeces pools, when calculating flows from these pools, but from the humus pool, C_{dep} is instead equal to C_{Humus} .

The response function $f(CN_{l1})$ assumes an optimal range when the actual CN ratio is lower than a minimum value, $r_{CN,min}$, and it approaches zero when a maximal CN ratio, $r_{CN,max}$, is reached:

$$f(CN_{l1}) = 1 - \min \left(1, \max \left(0, \frac{CN_{l1} - r_{CN,min}}{r_{CN,max} - r_{CN,min}} \right) \right) \quad (6.11)$$

See viewing function “[Decomposition – Substrate dependence, CN ratio](#)”.

The response because of the total amount of substrate available, $f(C_{Litter1})$, is given by a Michaeli-Menton approach:

$$f(C_{Litter1}) = \frac{(C_{Litter1}/\Delta z)}{(C_{Litter1}/\Delta z) + s_{cons}} \quad (6.12)$$

where s_{cons} is a parameter that corresponds to a 50% reduction of potential consumption rate and Δz is the soil layer thickness. See viewing function “[Decomposition – Substrate dependence, Carbon content](#)”.

The response function for abiotic influence on microbial mortality, $f(A_{mort})$, and consumption, $f(A_{cons})$, can be described together as $f(A_i)$, and are determined by the switches “[Microbial mortality](#)” and “[Microbial consumption](#)”:

- “static”
 $f(A_i) = 1$
 - “F(Temp)”
 $f(A_i) = f(T)$
 - “F(Temp, Moisture)”
 $f(A_i) = f(\theta) \cdot f(T)$
- (6.13)

The response functions for soil moisture and temperature, $f(\theta)$ and $f(T)$, are described in the section “[Common abiotic functions](#)”.

Respiration

The respiration from the litter, faeces and humus pools, $C_{Litter1 \rightarrow CO_2}$, $C_{Faeces \rightarrow CO_2}$ and $C_{Humus \rightarrow CO_2}$ are based on the estimated consumption rate of the microbes with their efficiency explicitly taken into account:

$$C_{Litter1 \rightarrow CO_2} = (1 - f_{e,m}) f_{cons,l1} f(CN_{l1}) f(C_{Litter1}) M_{potcons} \quad (6.14)$$

where $f_{e,m}$ and $f_{cons,l1}$ are the same parameters as in eq. (6.9), $f(CN_{l1})$ and $f(C_{Litter1})$ are response functions and $M_{potcons}$ is the potential microbial consumption as defined above. The response functions equal unity for the respiration flux from the humus pool.

The respiration in the microbial biomass is calculated as:

$$C_{Microbe \rightarrow CO_2} = k_{m,resp} f(A_{cons}) C_{Microbe} \quad (6.15)$$

where $k_{m,resp}$ is a parameter and $f(A_{cons})$ is the response function for abiotic influence on microbial consumption described above.

Humification

What remain of the decomposed litter and faeces material are the humification products that are transferred to the humus pool, $C_{Litter1 \text{ and } 2 \rightarrow Humus}$ and $C_{Faeces \rightarrow Humus}$. These fluxes depend on the humification fraction in the source pools, $f_{h,II}$:

$$C_{Litter1 \rightarrow Humus} = f_{h,II} f_{cons,II} f(CN_{II}) f(C_{Litter1}) M_{potcons} \quad (6.16)$$

where $f_{cons,II}$ is parameter, $f(CN_{II})$ and $f(C_{Litter1})$ are response functions and $M_{potcons}$ is the potential microbial consumption as described above. The parameters $f_{h,I2}$ and $f_{h,f}$, give the fluxes from the litter 2 and faeces pools respectively.

Organic nitrogen fluxes related to the soil organic carbon fluxes

The fluxes of nitrogen are directly related to the carbon flows. When carbon is taken up into the microbial pool there is an associated nitrogen flow, $N_{Litter1 \text{ and } 2 \rightarrow Microbes}$, $N_{Faeces \rightarrow Microbes}$ and $N_{Humus \rightarrow Microbes}$. Also when carbon is transferred to the humus pool there are associated nitrogen fluxes, $N_{Litter1 \text{ and } 2 \rightarrow Humus}$ and $N_{Faeces \rightarrow Humus}$. All these nitrogen fluxes are calculated in the same way: by dividing the carbon flux by the CN ratio of the source.

Mineralisation / Immobilisation

The mineralisation/immobilisation of nitrogen is dependent on the CN ratio in the microbial biomass. This means that the nitrogen flux between the microbes and the soil ammonium pool is calculated as:

$$N_{Microbe \rightarrow NH_4} = \left(1 - \frac{CN_{Microbe}}{cn_m}\right) N_{Microbe} \quad (6.17)$$

If the carbon content in the source pools is high compared to the nitrogen content, the CN ratio becomes large by definition. Studying equations (6.8) and (6.17) one finds that if the CN ratio becomes large enough compared to the parameter cn_m , the flux to the soil ammonium pool becomes negative. This means that instead of having net mineralisation there is a net immobilisation of nitrogen, i.e. the flux of nitrogen is from the soil ammonium pool to the litter, faeces (microbes implicit) or microbial (microbes explicit) pools respectively.

If a net immobilisation takes place the flow from the soil ammonium pool, N_{NH_4} , is:

$$N_{NH_4 \rightarrow Litter} = \max(-i_N N_{NH_4}, N_{Litter \rightarrow NH_4}) \quad (6.18)$$

where i_N is a parameter (note that the term $N_{Litter \rightarrow NH_4}$ is negative). The same formula is used to calculate the flow to the faeces and microbial pools by exchanging the flux-term to the right to the appropriate flux.

Dissolved organic matter

Organic matter in the soil organic pools described above is considered to be vertically immobile. The soil water in the profile normally contains an amount of dissolved organic matter originating from litter, faeces, humus or microbes. Consequently this organic matter can be passively transported vertically by water flows. The dissolved organic matter is generated from the immobile pools and can also be fixed again as humus. These processes are depth dependent, normally resulting in a release of matter to the dissolved organic pools close to the soil surface and a fixation of dissolved organics to the immobile pools at lower depths. It is possible to include such pools for dissolved organic matter for both carbon and nitrogen in the simulation, which then allows for vertical transport of organic matter by advection (see switch “[Dissolved Organics](#)”).

The initial carbon content in the dissolved organics pools is calculated from the initial concentration of dissolved carbon, given as a parameter i_{DOC} , divided by the soil moisture content in the layer and the layer thickness. To calculate the initial dissolved nitrogen content, the dissolved carbon content is divided by the initial CN ratio of the humus pool, given as a parameter $i_{h,CN}$.

The flux from the immobile pools to the dissolved organics pool, C_{DO} , is determined by a rate parameter, d_{DOLI} :

$$C_{Litter1 \rightarrow DO} = d_{DOLI} f(T) f(\theta) C_{Litter1} \quad (6.19)$$

where $f(T)$ and $f(\theta)$ are the common response functions for temperature and soil moisture. The same equation is used analogously for the litter 2, faeces and microbes pools as well as for all correspondent nitrogen pools.

Since dissolved organic material can be both released and fixed to the humus pool, the flux between these two pools is calculated slightly differently:

$$C_{\text{Humus} \rightarrow \text{DO}} = f(T)f(\theta) \cdot (d_{\text{DOH}} C_{\text{Humus}} - d_{\text{DOD}}(z) C_{\text{DO}}) \quad (6.20)$$

where d_{DOH} is the rate parameter for formation of dissolved organic carbon, d_{DOD} is the rate parameter for the fixation of dissolved organic carbon, $f(T)$ and $f(\theta)$ are the common response functions for temperature and soil moisture, $\theta(z)$ is the soil moisture content and Δz is the depth of the soil horizon. The same equation can be used analogously for the correspondent nitrogen flux.

The organic solutes are transported vertically by advection flows:

$$q_{\text{DOC}} = \frac{C_{\text{DO}}(z)}{\theta(z)\Delta z} \cdot q_w \quad (6.21)$$

where q_w is the vertical water flow. The equation is used analogously for nitrogen flows. If drainage and/or deep percolation is considered there will be associated flows of dissolved organic matter out of the soil profile.

Root uptake of organic nitrogen

In some ecosystems e.g. forests, plants are known to be supplemented with nitrogen, with the aid of ectomycorrhiza with proteolytic capacity. In the model this could therefore optionally be considered by including a plant nitrogen uptake directly from an organic source (see switch “[Organic Uptake](#)”). The functioning of mycorrhiza and its symbiosis with plant roots show complexities and uncertainties that concern both basic mechanisms as well as quantities of mass flows. Mycorrhiza takes up both mineral and organic nitrogen. It is assumed that the infected roots always take up mineral nitrogen in preference to organic nitrogen and that the organic nitrogen uptake is in the form of amino acids. The pool of amino acids is never explicitly calculated; instead organic nitrogen is transferred directly from the litter and humus pools to the roots. Hence, mycorrhiza is not explicitly represented but is instead expressed as a part of the infected roots.

When conditions for uptake of nitrogen and carbon directly from the organic pools are favorable (high plant demand and low mineral nitrogen levels), the uptake is limited by a maximum organic nitrogen uptake rate, o_L or o_H . However, organic nitrogen uptake occurs only if the amount taken up from the mineral $N_{\text{Humus} \rightarrow \text{Plant}} = f_{\text{Def}} o_H N_{\text{Humus}}$ pools,

$N_{\text{Mineral} \rightarrow \text{Plant}}$, is lower than the plant demand, N_{Demand} . This is expressed by setting the uptake proportional to the deficiency in supply of mineral, f_{Def} . The uptake, $N_{\text{Litter} \rightarrow \text{Plant}}$ and $N_{\text{Humus} \rightarrow \text{Plant}}$ is then estimated as:

$$N_{\text{Litter} \rightarrow \text{Plant}} = f_{\text{Def}} o_L N_{\text{Litter}} \quad (6.22)$$

$$(6.23)$$

where the deficiency fraction, f_{Def} , is determined by the smallest of two values; the organic nitrogen demand in relation to total potential organic uptake, or the fraction of organic nitrogen from each pool that is available for uptake also in relation to total potential uptake:

$$f_{\text{Def}} = \min \left(\frac{(N_{\text{Demand}} - N_{\text{Mineral} \rightarrow \text{Plant}})}{o_{\text{Def}}}, \frac{N_{\text{Litter}} o_L}{o_{\text{Def}}} \right) \quad (6.24)$$

(and using $N_{\text{Humus}} o_H$ in the second term for humus).

o_{Def} is the maximum uptake of nitrogen from the litter and humus pool:

$$o_{\text{Def}} = N_{\text{Litter}} o_L + N_{\text{Humus}} o_H \quad (6.25)$$

where o_L and o_H are the maximum uptake rates for litter and humus respectively.

If direct nitrogen deposition to the leaf (see section “[External inputs](#)”), this amount of nitrogen is also finally added to the total plant nitrogen uptake.

Switches

The most important switches are the “[Microbes](#)” switch that determines if the micro organisms should be expressed implicitly or explicitly in the model affecting in particular mineralisation / immobilisation of nitrogen, the “[Faeces pool](#)” switch that determines if an external input of manure should be simulated and the “[Initial soil organic](#)” switch that decides how the initial values are given to the model.

CN Ratio Influence

Not yet incorporated in the model.

Value	Meaning
No	The C-N ratio does not influence any microbial activities.
On litter consumption	The C-N ratio influences the microbial litter consumption.

Dissolved Organics

Value	Meaning
On	Dissolved organic nitrogen and carbon are accounted for in the simulation. This option allows vertical transportation of organic matter in the soil profile.
Off	No dissolved organics are accounted for.

Faeces pool

Value	Meaning
One	Manure can be applied and transformation of faeces will be considered.
No	Manure cannot be applied and transformation of faeces will not be considered.

Initial soil organic

Value	Meaning
Constant	The initial soil organic concentrations are the same in all layers of the soil profile.
Exponential	The initial soil organic concentrations decrease exponentially with depth.
Linear decrease	The initial soil organic concentrations decrease linearly with depth.
Table	The initial soil organic concentrations are inserted manually in a table.

Litter pools

Value	Meaning
One	Only one litter pool is simulated.
Two	Two litter pools with different microbial activities are simulated.

Microbes

Value	Meaning
Off	Microbial biomass is not explicitly simulated.
On – substrate dependent	Microbial biomass is dynamically interacting with the soil organic matter. The microbial consumption rate is dependent on the carbon content in the substrate.
On – microbe dependent	Microbial biomass is dynamically interacting with the soil organic matter. The microbial consumption rate is dependent on the carbon content in the microbial biomass only.

Microbial consumption

Value	Meaning
Static	The microbial consumption is not dependent on abiotic response functions.
F(Temp)	The microbial consumption is dependent on soil temperature.
F(Temp, Moisture)	The microbial consumption is dependent on soil temperature and soil moisture.

Microbial mortality

Value	Meaning
Static	The microbial mortality is not dependent on abiotic response functions.
F(Temp)	The microbial mortality is dependent on soil temperature.
F(Temp, Moisture)	The microbial mortality is dependent on soil temperature and soil moisture.

Organic Uptake

Value	Meaning
Off	No uptake of organic nitrogen by mycorrhiza is accounted for.
On	An uptake of organic nitrogen in the form of amino acids by mycorrhiza is included in the simulation.

Q Model

Value	Meaning
Off	Not included in the model yet.
On	Not included in the model yet.

Parameters

CN ratio microbes

A fixed C-N ratio of microbes used for example in the calculations of mineralisation/immobilization.

Default	Unit	Symbol	Equation	Function
10	-	cn_m	(6.7), (6.8) , (6.17)	

Eff Faeces

Efficiency of the decay of faeces

Default	Unit	Symbol	Equation	Function
0.5	/day	$f_{e,f}$	(6.4), (6.5) , (6.6), (6.8)	

Eff Humus

Efficiency of the decay of faeces

Default	Unit	Symbol	Equation	Function
0.5	/day	$f_{e,h}$	(6.4), (6.8)	

Eff Litter1

Efficiency of the decay of litter 1

Default	Unit	Symbol	Equation	Function
0.5	/day	$f_{e,l}$	(6.4), (6.5) , (6.6), (6.8)	

Eff Microbes

Efficiency of the internal synthesis by microbial biomass of organic matter

Default	Unit	Symbol	Equation	Function
0.5	/day	$f_{e,m}$	(6.9)	

HumFracFaeces

Fraction of carbon and nitrogen contained in the faeces pool of the soil that will enter the humus pool.

Default	Unit	Symbol	Equation	Function
0.2	/day	$f_{h,f}$	(6.75), (6.6)	

HumFracLitter1

Fraction of carbon and nitrogen contained in the litter 1 pool of the soil that will enter the humus pool.

Default	Unit	Symbol	Equation	Function
0.2	/day	$f_{h,l}$	(6.5), (6.6)	

Init CDissCons

Initial concentration of carbon in the dissolved organic matter pool.

Default	Unit	Symbol	Equation	Function
1	mg/l	i_{DOC}		

Init F CN tot

Initial C-N ratio in faeces

Default	Unit	Symbol	Equation	Function
15	-	$i_{f,CN}$		

Init F Depth

The initial depth to where the faeces are distributed.

Default	Unit	Symbol	Equation	Function
0.2	m	$i_{f,d}$		

Init F FracExpTail

Fraction of carbon in the faeces pool remaining when the rest has been distributed to the layers above a specified depth by an exponential function. This remaining fraction is evenly distributed among the same layers as the rest of the carbon in the faeces pool.

Default	Unit	Symbol	Equation	Function
0.1	-	$i_{f,exp}$		

Init F N Tot

Initial total amount of nitrogen contained in faeces in the whole soil profile.

Default	Unit	Symbol	Equation	Function
2	gN/m ²	$i_{f,N}$		

Init H CN Tot

Initial C-N ratio in humus.

Default	Unit	Symbol	Equation	Function
10	-	$i_{h,CN}$		

Init H Depth

The initial depth to where the humus is distributed.

Default	Unit	Symbol	Equation	Function
2	m	$i_{h,d}$		

Init H FracExpTail

Fraction of carbon in the humus pool remaining when the rest has been distributed to the layers above a specified depth by an exponential function. This remaining fraction is evenly distributed among the same layers as the rest of the carbon in the faeces pool.

Default	Unit	Symbol	Equation	Function
0.1	-	$i_{h,exp}$		

Init H N Tot

Initial total amount of nitrogen contained in humus in the whole soil profile.

Default	Unit	Symbol	Equation	Function
5000	gN/m ²	$i_{h,N}$		

Init L1 CN Tot

Initial C-N ratio in litter 1.

Default	Unit	Symbol	Equation	Function
25	-	$i_{l1,CN}$		

Init L2 CN Tot

Initial C-N ratio in litter 2.

Default	Unit	Symbol	Equation	Function
15	-	$i_{l2,CN}$		

Init L1 Depth

The initial depth to where the litter 1 is distributed.

Default	Unit	Symbol	Equation	Function
0.5	m	$i_{l1,d}$		

Init L2 Depth

The initial depth to where the litter 2 is distributed.

Default	Unit	Symbol	Equation	Function
0.5	m	$i_{l2,d}$		

Init L1 FracExpTail

Fraction of carbon in the litter pool 1 remaining when the rest has been distributed to the layers above a specified depth by an exponential function. This remaining fraction is evenly distributed among the same layers as the rest of the carbon in the faeces pool.

Default	Unit	Symbol	Equation	Function
0.1	-	$i_{l1,exp}$		

Init L2 FracExpTail

Fraction of carbon in the litter pool 2 remaining when the rest has been distributed to the layers above a specified depth by an exponential function. This remaining fraction is evenly distributed among the same layers as the rest of the carbon in the faeces pool.

Default	Unit	Symbol	Equation	Function
0.1	-	$i_{l2,exp}$		

Init L1 N Tot

Initial amount of nitrogen contained in litter 1 in the whole soil profile.

Default	Unit	Symbol	Equation	Function
10	gN/m ²	$i_{L1,N}$		

Init L2 N Tot

Initial total amount of nitrogen contained in litter 2 in the whole soil profile.

Default	Unit	Symbol	Equation	Function
3	gN/m ²	$i_{L2,N}$		

Init M CN Tot

Initial C-N ratio in microbes.

Default	Unit	Symbol	Equation	Function
8	-	$i_{m,CN}$		

Init M Depth

The initial depth to where the microbes are distributed.

Default	Unit	Symbol	Equation	Function
0.5	m	$i_{m,d}$		

Init M FracExpTail

Fraction of carbon in the microbial pool remaining when the rest has been distributed to the layers above a specified depth by an exponential function. This remaining fraction is evenly distributed among the same layers as the rest of the carbon in the faeces pool.

Default	Unit	Symbol	Equation	Function
0.1	-	$i_{m,exp}$		

Init M N Tot

Initial total amount of nitrogen contained in microbes in the whole soil profile.

Default	Unit	Symbol	Equation	Function
10	gN/m ²	$i_{m,N}$		

Mic Conc Frac Fec

Fraction of the total microbial biomass contained in the faeces fraction of the soil.

Default	Unit	Symbol	Equation	Function
0.1	-	$f_{cons,f}$	(6.9), (6.14), (6.16)	

Mic Conc Frac L1

Fraction of the total microbial biomass contained in the litter 1 fraction of the soil.

Default	Unit	Symbol	Equation	Function
0.5	-	$f_{cons,l1}$	(6.9) , (6.14) , (6.16)	

Mic Conc Frac L2

Fraction of the total microbial biomass contained in the litter 2 fraction of the soil.

Default	Unit	Symbol	Equation	Function
0.1	-	$f_{cons,l2}$	(6.9) , (6.14) , (6.16)	

Mic Hum Frac Fec

Fraction of the faeces pool entering the humus pool during microbial decomposition.

Default	Unit	Symbol	Equation	Function
0.1	-	$f_{h,f}$	(6.16)	

Mic Hum Frac L1

Fraction of the litter 1 pool entering the humus pool during microbial decomposition.

Default	Unit	Symbol	Equation	Function
0.5	-	$f_{h,l1}$	(6.16)	

Mic Hum Frac L2

Fraction of the litter 2 pool entering the humus pool during microbial decomposition.

Default	Unit	Symbol	Equation	Function
0.1	-	$f_{h,l2}$	(6.16)	

Mic Mort Frac Fec

Fraction of the dead microbial biomass that enters the faeces pool.

Default	Unit	Symbol	Equation	Function
0.1	-	$f_{mort,f}$	(6.9)	

Mic Mort Frac L1

Fraction of the dead microbial biomass that enters the litter1 pool.

Default	Unit	Symbol	Equation	Function
0.1	-	$f_{mort,l1}$	(6.9)	

Mic Mort Frac L2

Fraction of the dead microbial biomass that enters the litter 2 pool.

Default	Unit	Symbol	Equation	Function
0.1	-	$f_{mort,l2}$	(6.9)	

N Immob MaxAvailFrac

Fraction of mineral N available for immobilization.

Default	Unit	Symbol	Equation	Function
0.05	-	i_N	(6.18)	

RateCoefFaeces

Rate coefficient for the decay of faeces.

Default	Unit	Symbol	Equation	Function
0.035	/day	k_f	(6.3)	

RateCoefFaecesDis

Diffusion rate for the dissolved organics formation from the faeces pool.

Default	Unit	Symbol	Equation	Function
0.0001	/day	d_{DOF}	(6.19)	

RateCoefHumus

Rate coefficient for the decay of humus.

Default	Unit	Symbol	Equation	Function
$5 \cdot 10^{-5}$	/day	k_h	(6.3)	

RateCoefHumusDis

Diffusion rate for the dissolved organics formation from the humus pool.

Default	Unit	Symbol	Equation	Function
0.00001	/day	d_{DOH}	(6.20)	

RateCoefLitter 1

Rate coefficient for the decay of litter 1.

Default	Unit	Symbol	Equation	Function
0.035	/day	k_l	(6.3)	

RateCoefLitter1Dis

Diffusion rate for the dissolved organics formation from the litter 1 pool.

Default	Unit	Symbol	Equation	Function
0.0001	/day	d_{DOL1}	(6.19)	

RateCoefLitter2Dis

Diffusion rate for the dissolved organics formation from the litter 2 pool.

Default	Unit	Symbol	Equation	Function
0.0001	/day	d_{DOL2}	(6.19)	

RateCoefMic Cons

Rate coefficient for microbial gross consumption at a reference temperature and optimal soil moisture conditions.

Default	Unit	Symbol	Equation	Function
0.01	/day	$k_{m,cons}$	(6.10)	

RateCoefMic Mort

Microbial relative mortality rate

Default	Unit	Symbol	Equation	Function
0.01	/day	$k_{m,mort}$	(6.9)	

RateCoefMic Resp

Fraction of microbial biomass lost by maintenance respiration at a reference temperature.

Default	Unit	Symbol	Equation	Function
0.002	/day	$k_{m,resp}$	(6.15)	

RateCoefMicrobeDis

Diffusion rate for the dissolved organics formation from the microbial pool.

Default	Unit	Symbol	Equation	Function
0.0001	/day	d_{DOM}	(6.19)	

RateCoefSurf Hum

Fraction of the above ground residues that enter the humus pool of the uppermost soil layer.

Default	Unit	Symbol	Equation	Function
0	/day	l_h	(6.1), (6.2)	

RateCoefSurf L1

Fraction of the above ground residues that enter the litter 1 pool of the uppermost soil layer.

Default	Unit	Symbol	Equation	Function
0.005	/day	l_{l1}	(6.57), (6.2)	

RateCoefSurf L2

Fraction of the above ground residues that enter the litter 2 pool of the uppermost soil layer.

Default	Unit	Symbol	Equation	Function
0	/day	l_{l2}	(6.1), (6.2)	

RateResponse CN Max

Maximum C-N ratio of substrate at which optimal decomposition occurs.

Default	Unit	Symbol	Equation	Function

50	/day	$r_{CN,max}$	(6.11)	“ Decomposition – Substrate dependence, CN ratio ”
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RateResponse CN Min

Minimum C-N ratio of substrate at which no decomposition occurs.

Default	Unit	Symbol	Equation	Function
10	/day	$r_{CN,min}$	(6.11)	“ Decomposition – Substrate dependence, CN ratio ”

Substrate HalfRateConc

Substrate amount at which the microbial gross consumption rate is half of its maximum value.

Default	Unit	Symbol	Equation	Function
300	g/m ³	s_{cons}	(6.12)	“ Decomposition – Substrate dependence, Carbon content ”

Upt OrgRateCoef H

The maximum plant uptake rate of organic nitrogen from the humus pool.

Default	Unit	Symbol	Equation	Function
0.0001	-	o_H	(6.23), (6.24), (6.25)	

Upt OrgRateCoef L

The maximum plant uptake rate of organic nitrogen from the litter pool.

Default	Unit	Symbol	Equation	Function
0.01	-	o_L	(6.22), (6.24), (6.25)	

Parameter tables

In these parameter tables initial values for the soil organic contents are given. Also the rate parameters for dissolved organics can be specified.

Initial organic CN ratios

Name	Default	Unit	Symbol	Comments/Explanations
Init L1 CN	25	-		Initial C-N ratio in litter 1 if the initial soil organic content is read from table.
Init L2 CN	15	-		Initial C-N ratio in litter 2 if the initial soil organic content is read from table.
Init F CN	15	-		Initial C-N ratio in faeces if the initial soil organic content is read from table.

Init M CN	8	-		Initial C-N ratio in microbes if the initial soil organic content is read from table.
Init H CN	10	-		Initial C-N ratio in humus if the initial soil organic content is read from table.

Initial organic Nitrogen

Name	Default	Unit	Symbol	Comments/Explanations
Init L1 N	1.0	g		Initial mass of nitrogen in litter 1if the initial soil organic content is read from table.
Init L2 N	0.3	g		Initial mass of nitrogen in litter 2if the initial soil organic content is read from table.
Init F N	0.2	g		Initial mass of nitrogen in faeces if the initial soil organic content is read from table.
Init M N	1.0	g		Initial mass of nitrogen in microbes if the initial soil organic content is read from table.
Init H N	500	g		Initial mass of nitrogen in humus if the initial soil organic content is read from table.

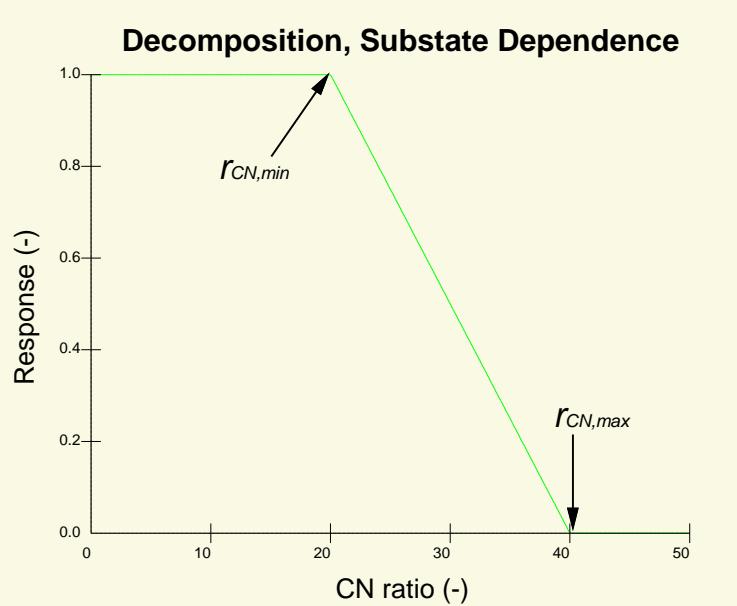
Rate Coefficient Dissolved Organics

Rate coefficient for the fixation of dissolved organics to humus.

Name	Default	Unit	Symbol	Comments/Explanations
RateCoefDissolved	0.01	/day	d_{DOD}	

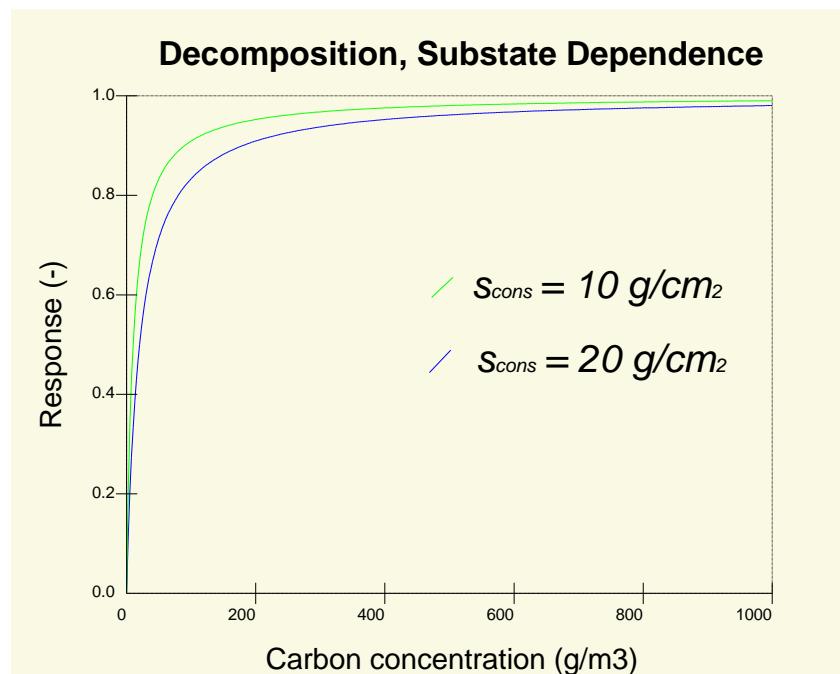
Viewing functions

Decomposition – Substrate dependence, CN ratio



The decomposition response function for the carbon-nitrogen ratio in the litter pool when soil organisms are explicit in the simulation.

Decomposition – Substrate dependence, Carbon content



The decomposition response function for carbon concentration. Two parameterisations with different substrate half rate concentrations.

State Variables

CDissolved

Carbon content in the dissolved organics pool.
g/m²

CFaeces

Carbon content in the faeces pool.
g/m²

CHumus

Carbon content in the humus pool.
g/m²

CLitter1

Carbon content in litter pool 1.
g/m²

CLitter2

Carbon content in litter pool 2.
g/m²

CMicrobes

Carbon content in the microbial pool.
g/m²

NDissolved

Nitrogen content in the dissolved organics pool.
g/m²

NFaeces

Nitrogen content in the faeces pool.
g/m²

NHumus

Nitrogen content in the humus pool.
g/m²

NLitter1

Nitrogen content in litter pool 1.
g/m²

NLitter2

Nitrogen content in litter pool 2.
g/m²

NMicrobes

Nitrogen content in the microbial pool.
g/m²

Flow Variables

CDissolvedDrainage

Drainage of dissolved organic carbon out of the soil profile.
g/m²/day

CDissolvedFlow

Vertical flux of dissolved organic carbon in the soil profile.
g/m²/day

CFaecesDissolved

Carbon flux from the faeces pool to the dissolved organics pool.
g/m²/day

CFaecesHumusRate

Carbon flux from the faeces pool to the humus pool.
g/m²/day

CFaecesMicrobeRate

Carbon flux from the faeces pool to the microbial pool.
g/m²/day

CFaecesRespRate

Respiration from the faeces pool.
g/m²/day

CHumusDissolved

Carbon flux from the humus pool to the dissolved organics pool.
g/m²/day

CHumusMicrobeRate

Carbon flux from the humus pool to the microbial pool.
g/m²/day

CHumusRespRate

Respiration from the humus pool.
g/m²/day

CLitter1Dissolved

Carbon flux from the litter pool 1 to the dissolved organics pool.
g/m²/day

CLitter1HumusRate

Carbon flux from the litter pool 1 to the humus pool.
g/m²/day

CLitter1MicrobeRate

Carbon flux from the litter pool 1 to the microbial pool.
g/m²/day

CLitter1RespRate

Respiration from the litter pool 1.
g/m²/day

CLitter2Dissolved

Carbon flux from the litter pool 2 to the dissolved organics pool.
g/m²/day

CLitter2HumusRate

Carbon flux from the litter pool 2 to the humus pool.
g/m²/day

CLitter2MicrobeRate

Carbon flux from the litter pool 2 to the microbial pool.
g/m²/day

CLitter2RespRate

Respiration from the litter pool 2.
g/m²/day

CMicrobeRespRate

Respiration from the microbial pool.
g/m²/day

CMicrobesDissolved

Carbon flow between the microbial pool and the dissolved organics pool.
g/m²/day

CRootsLitter1

Carbon flux from the roots to the litter pool 1.
g/m²/day

CRootsLitter2

Carbon flux from the roots to the litter pool 2.
g/m²/day

CSurfaceL_Humus

Carbon flux from the surface litter pool to the humus pool.
g/m²/day

CSurfaceL_Litter1

Carbon flux from the surface litter pool to litter pool 1.
g/m²/day

CSurfaceL_Litter2

Carbon flux from the surface litter pool to litter pool 2.
g/m²/day

NDissolvedDrainage

Drainage of dissolved organic nitrogen out of the soil profile.
g/m²/day

NDissolvedFlow

Vertical flux of dissolved organic nitrogen in the soil profile.
g/m²/day

NFaecesDissolved

Nitrogen flux from the faeces pool to the dissolved organics pool.
g/m²/day

NFaecesHumusRate

Nitrogen flux from the faeces pool to the humus pool.
g/m²/day

NFaecesMicrobeRate

Nitrogen flux from the faeces pool to the microbial pool.
g/m²/day

NFaecesNH4Rate

Nitrogen flux from the faeces pool to the soil ammonium pool.
g/m²/day

NHumusDissolved

Nitrogen flux from the humus pool to the dissolved organics pool.
g/m²/day

NHumusMicrobeRate

Nitrogen flux from the humus pool to the microbial pool.
g/m²/day

NHumusNH4Rate

Nitrogen flux from the humus pool to the soil ammonium pool.
g/m²/day

NHumusUpt

Nitrogen flux from the humus pool to the plant.
g/m²/day

NLitter1Dissolved

Nitrogen flux from the litter pool 1 to the dissolved organics pool.
g/m²/day

NLitter1HumusRate

Nitrogen flux from the litter pool 1 to the humus pool.
g/m²/day

NLitter1MicrobeRate

Nitrogen flux from the litter pool 1 to the microbial pool.
g/m²/day

NLitter1NH4Rate

Nitrogen flux from the litter pool 1 to the soil ammonium pool.
g/m²/day

NLitter1Upt

Nitrogen flux from the litter pool 1 to the plant.
g/m²/day

NLitter2Dissolved

Nitrogen flux from the litter pool 2 to the dissolved organics pool.
g/m²/day

NLitter2HumusRate

Nitrogen flux from the litter pool 2 to the humus pool.
g/m²/day

NLitter2MicrobeRate

Nitrogen flux from the litter pool 2 to the microbial pool.
g/m²/day

NLitter2NH4Rate

Nitrogen flux from the litter pool 2 to the soil ammonium pool.
g/m²/day

NMicrobeNH4Rate

Nitrogen flux from the microbial pool to the soil ammonium pool.
g/m²/day

NMicrobesDissolved

Nitrogen flow between the microbial pool and the dissolved organics pool.
g/m²/day

NRootsLitter1

Nitrogen flux from the roots to the litter pool1.
g/m²/day

NRootsLitter2

Nitrogen flux from the roots to the litter pool2.
g/m²/day

NSurfaceL_Humus

Nitrogen flux from the surface litter pool to the humus pool.
g/m²/day

NSurfaceL_Litter1

Nitrogen flux from the surface litter pool to litter pool 1.
g/m²/day

NSurfaceL_Litter2

Nitrogen flux from the surface litter pool to litter pool 2.
g/m²/day

Auxiliary Variables

CFaecesDecomp

Carbon flow from the faeces pool to the decomposition pool when soil organisms are implicit.
g/m²/day

CLitter1Decomp

Carbon flow from the litter pool to the decomposition pool when soil organisms are implicit.
g/m²/day

CN Ratio Faeces

Carbon nitrogen ratio in the faeces pool.

CN Ratio Humus

Carbon nitrogen ratio in the humus pool.

CN Ratio Litter1

Carbon nitrogen ratio in the litter pool1.

CN Ratio Litter2

Carbon nitrogen ratio in the litter pool2.

CN Ratio Microbes

Carbon nitrogen ratio in the microbial pool.

CTotDisOrganics

Carbon content in the dissolved organics pool in the whole soil profile.
g/m²

CTotDisOrgDrainage

Total drainage of carbon from the dissolved organics pool in the whole soil profile.
g/m²/day

CTotFaecesRespRate

Respiration from the faeces pool in the whole soil profile.
g/m²/day

CTotHumusFormation

Total humus formation rate from the litter and faeces pools subtracted by losses of humus to the dissolved pool.
g/m²/day

CTotHumusRespRate

Respiration from the humus pool in the whole soil profile.
g/m²/day

CTotLitter1RespRate

Respiration from the litter pool1 in the whole soil profile.
g/m²/day

CTotLitter2RespRate

Respiration from the litter pool2 in the whole soil profile.
g/m²/day

CTotMicrobeRespRate

Respiration from the microbial pool in the whole soil profile.
g/m²/day

CTotOrg_DisOrg

Carbon flow from the immobile organic pools to the dissolved organic pool in the whole soil profile.
g/m²/day

CTotRootLitter

Total root litter carbon flux to all organic pools in the whole soil profile.
g/m²/day

CTotSoilFaeces

Carbon content in the faeces pool in the whole soil profile.
g/m²

CTotSoilHumus

Carbon content in the humus pool in the whole soil profile.
g/m²

CTotSoilLitter1

Carbon content in the litter pool 1 in the whole soil profile.
g/m²

CTotSoilLitter2

Carbon content in the litter pool 2 in the whole soil profile.
g/m²

CTotSoilMicrobes

Carbon content in the microbial pool in the whole soil profile if microbes are treated explicitly.
g/m²

CTotSoilOrg

Carbon content in all soil organic pools in the whole soil profile.
g/m²

CTotSoilRespRate

Respiration from all organic pools in the whole soil profile.
g/m²/day

DissolvedCConc

Carbon concentration in the dissolved organic pool.
mg/l

DissolvedNConc

Nitrogen concentration in the dissolved organic pool.
mg/l

NTotDisOrganics

Nitrogen content in the dissolved organics pool in the whole soil profile.
g/m²

NTotDisOrgDrainage

Total drainage of nitrogen from the dissolved organics pool in the whole soil profile.
g/m²/day

NTotFaecesNH4Rate

Nitrogen flow from the faeces pool to the soil ammonium pool in the whole soil profile.
g/m²/day

NTotHumusNH4Rate

Nitrogen flow from the humus pool to the soil ammonium pool in the whole soil profile.
g/m²/day

NTotLitter1NH4Rate

Nitrogen flow from the litter pool1 to the soil ammonium pool in the whole soil profile.
g/m²/day

NTotLitter2NH4Rate

Nitrogen flow from the litter pool2 to the soil ammonium pool in the whole soil profile.
g/m²/day

NTotMicrobeNH4Rate

Nitrogen flow from the microbial pool to the soil ammonium pool in the whole soil profile.
g/m²/day

NTotOrg_DisOrg

Nitrogen flow from the immobile organic pools to the dissolved organics pool in the whole soil profile.
g/m²/day

NTotOrgNH4Rate

Nitrogen flow from all soil organic pools to the soil ammonium pool in the whole soil profile.
g/m²/day

N Tot Org Plant Uptake

The total plant uptake of organic nitrogen from the whole soil profile.
g/m²/day

NTotRootLitter

Total root litter nitrogen content in all organic pools in the whole soil profile.
g/m²/day

NTotSoilFaeces

Nitrogen content in the faeces pool in the whole soil profile.
g/m²

NTotSoilHumus

Nitrogen content in the humus pool in the whole soil profile.
g/m²

NTotSoilLitter1

Nitrogen content in the litter pool 1 in the whole soil profile.
g/m²

NTotSoilLitter2

Nitrogen content in the litter pool 2 in the whole soil profile.
g/m²

NTotSoilMicrobes

Nitrogen content in the microbial pool in the whole soil profile if microbes are treated explicitly.
g/m²

NTotSoilOrg

Nitrogen content in all soil organic pools in the whole soil profile.
g/m²

Mineral N Processes

Model Structure

Mineral nitrogen exists in the soil as relatively immobile ammonium, N_{NH4} , and mobile nitrate, N_{NO3} . In agricultural soils, nitrate is normally essentially more abundant than ammonium whereas in forest soils the abundance of ammonium is often higher than that of nitrate due to low pH reducing nitrification. This section describes the fluxes of mineral nitrogen between these two mineral nitrogen pools i.e. nitrification, the plant uptake of mineral nitrogen, denitrification, leaching and vertical redistribution of mineral N.

The initial content of nitrifying microbials (if explicitly simulated) in the soil is given as a parameter, $i_{nitrmicr}$, i.e. a total value for the whole soil profile (see switch “[Initial Nitrifier](#)”). Either the nitrogen will be distributed evenly in the soil profile (“Constant”), or it will decrease linearly from the top layer (“Linear”), or finally it will decrease exponentially from the top layer (“Exponential”). The lowest depth is determined by the parameter i_{ndepth} and the distribution of remaining microbial biomass below i_{ndepth} is determined by the parameter $i_{nexpfrac}$.

Denitrification can optionally be simulated (see switch “[Denitrification](#)”). If denitrifying microbials are simulated explicitly simulated, the initial biomass of the denitrifiers is calculated as:

$$N_{micrDN} = i_{denitmicr} \cdot d_{dist} (\Delta z) \quad (6.26)$$

where $i_{denitmicr}$ is the initial biomass of denitrifiers for the whole soil profile and d_{dist} is a distribution coefficient that varies with depth. This variation is determined by the switch “[Denit depth distribution](#)” Either the denitrification rate can be given as a table (“Table”), it can be distributed evenly in the soil profile (“Constant”), it can decrease linearly from the top layer (“Linear”) or finally it can decrease exponentially from the top layer (“Exponential”). The lowest depth is determined by the parameter d_z and the distribution of remaining microbial biomass below d_z is determined by the parameter d_{exp} . The initial denitrifier activity is equal to zero.

Note that when nitrifiers and denitrifiers are considered explicitly, their nitrogen content is not included in the total nitrogen budget of the soil, and no flows of nitrogen to and from the microbial pools are calculated. The reason for this is the small nitrogen content of the microbes in comparison to the total nitrogen content of the soil.

Vertical redistribution of mineral N

Usually there are vertical flows of water in the soil profile. Nitrate is easily soluble in water and is therefore transported between different layers as long as there is a driving force by water for transportation. Ammonium can either be immobile or mobile, as determined by the switch “[Ammonium mobility](#)”. The vertical nitrate flow from one layer to another is calculated as:

$$q_{NO_3} = q_w \frac{N_{NO_3}}{\theta(z)\Delta z} \quad (6.27)$$

where q_w is the water flow, $\theta(z)$ is the soil moisture content and Δz is the depth of the soil layer.

Since the ammonium ions are rather immobile, the vertical flow of ammonium is calculated slightly differently:

$$q_{NH_4} = q_w \frac{N_{NH_4} (1 - f_{N,ads})}{\theta(z)\Delta z} \quad (6.28)$$

where $f_{N,ads}$ is the adsorption fraction.

Leaching and deep percolation of mineral N

If there is a horizontal drainage of water from the profile, nitrogen in the water solution is leached from the soil profile. The horizontal drainage transport of nitrate, q_{NO3dr} , is calculated as:

$$q_{NO_3dr} = \frac{N_{NO_3}}{\theta(z)\Delta z} \cdot q_{dr} \quad (6.29)$$

where q_{dr} is the total amount of drainage of water, $\theta(z)$ is the soil moisture content and Δz is the depth of the soil layer. The outflow of ammonium is calculated with the same equation but with the amount of ammonium, N_{NH_4} , multiplied by the adsorption correction factor $(1-f_{N,ads})$.

If deep percolation of water, q_{deep} , is included in the simulation, the leaching of nitrate, q_{NO3dp} , is calculated as:

$$q_{NO_3dp} = q_{deep} \frac{N_{NO_3}}{\theta(z)\Delta z} \quad (6.30)$$

The outflow of ammonium is calculated with the same equation but with the amount of ammonium, N_{NH_4} , multiplied by the adsorption correction factor $(1-f_{N,ads})$.

Root uptake of mineral nitrogen

Root uptake of nitrate and ammonium is driven by the plant demand, N_{Demand} . The plant will take up nitrate and ammonium according to their relative abundance in the soil determined by a ratio, r_N , defined as:

$$r_N = \frac{N_{NO_3}}{N_{NO_3} + N_{NH_4}} \quad (6.31)$$

The primary plant uptake of nitrate is calculated as:

$$N_{NO_3 \rightarrow a} = \min(f_{NUpt} N_{NO_3}, r_N \Delta z N_{Demand}) \quad (6.32)$$

where f_{NUpt} is a parameter and Δz is the layer thickness.

The primary plant uptake of ammonium is calculated similarly:

$$N_{NH_4 \rightarrow a} = \min(f_{NUpt} N_{NH_4}, (1 - r_N) \Delta z N_{Demand}) \quad (6.33)$$

If the total uptake of nitrogen is less than the plant demand, a secondary compensatory uptake due to flexible roots takes place. The nitrogen demand of the second uptake is governed by the parameter $n_{Uptflex}$, which is the flexibility degree of the roots:

$$N_{Demand2} = (N_{Demand} - N_{TotUpt}) n_{Uptflex} \quad (6.34)$$

where N_{TotUpt} is the total mineral nitrogen uptake, i.e. primary nitrate and ammonium uptake.

The secondary uptake of nitrate is calculated as:

$$N_{(NO_3 \rightarrow a)2} = \min(f_{NUpt} N_{NO_3}, r_N \Delta z N_{Demand2} r_{compfact}) \quad (6.35)$$

where $r_{compfact}$ is the compensatory root factor i.e. the ratio of the total root system and the fraction of the total root system where a surplus occurred during the primary uptake.

Similarly the secondary uptake of ammonium is calculated as:

$$N_{(NH_4 \rightarrow a)2} = \min(f_{NUpt} N_{NH_4}, (1 - r_N) \Delta z \cdot N_{Demand2} r_{compfact}) \quad (6.36)$$

The total flows of nitrate and ammonium to the plant roots are the sums of the primary and the secondary root uptake for nitrate and ammonium respectively.

If the demand of nitrogen is not satisfied by the uptake of mineral nitrogen, an uptake of organic nitrogen can optionally be included in the simulation (see “[Root uptake of organic nitrogen](#)”). However, if organic nitrogen uptake is not simulated, any nitrogen that has been taken up by the leaf directly from atmospheric deposition (see section “[External inputs](#)”), is also finally added to the total plant nitrogen uptake.

Denitrification

Denitrification can optionally be simulated (see switch “[Denitrification](#)”). In the simplified approach, the denitrification i.e. the conversion of soluble nitrate in the soil to gaseous nitrogen leaving the soil, $N_{NO_3 \rightarrow Denit}$, is calculated as:

$$N_{NO_3 \rightarrow Denit} = f(T) f(\theta) f(N_{NO3Cons}) d_{dist} (\Delta z) d_{pot} \quad (6.37)$$

where d_{pot} is a parameter and $f(T)$, $f(\theta)$ and $f(N_{NO3Cons})$ are response functions for soil temperature, soil moisture and nitrate concentration in the soil. A coefficient, d_{dist} (Δz), adjusts the potential denitrification rate for each soil layer. The variation of d_{dist} (Δz) with depth is determined by the switch “[Denit depth distribution](#)” Either the denitrification rate can be given as a table (“Table”), it can be distributed evenly in the soil profile (“Constant”), it can decrease linearly from the top layer (“Linear”) or finally it can decrease exponentially from the top layer (“Exponential”). The parameters used in these calculations are d_z and d_{exp} .

The switch “[Denit temp response](#)” determines the temperature response, $f(T)$, described in the section “[Common abiotic functions](#)”.

The soil moisture response function, $f(\theta)$, looks different depending soil moisture content:

1. $\theta = \theta_s$
 $f(\theta) = 1$

$$2. \quad \theta_s - \theta < p\theta_{Dp}$$

$$f(\theta) = \left(\frac{\theta - \theta_s - p_{\theta DRage}}{p_{\theta DRage}} \right)^{p_{\theta Dp}}$$

$$3. \quad \theta_s - \theta > p\theta_{Dp}$$

$$f(\theta) = 0 \quad (6.38)$$

where $p\theta_{DRage}$ and $p\theta_{Dp}$ are parameters and the variables, θ_s and θ , are the soil moisture content at saturation and the actual soil moisture content respectively, described in the section “Soil Water Processes”.

The response function for nitrate concentration in the soil, $f(N_{NO3Cons})$, is calculated as:

$$f(N_{NO3Cons}) = \frac{N_{NO_3}/(\theta \cdot \Delta z)}{(N_{NO_3}/(\theta \cdot \Delta z)) + d_{Nhalfsat}} \quad (6.39)$$

where $d_{Nhalfsat}$ is a parameter. See viewing function “[Denitrification Nitrate Response](#)”.

If denitrifying microbes are calculated explicitly the denitrification rate is a function of the amount of denitrifying microbials, N_{micrDN} , and their activity, $M_{activity}$. The whole denitrification process consists of a chain of reactions where nitrogen in the form of nitrate is converted by microbial activity into nitrous gases. In this section processes concerning nitrogen in the forms of NO_3 , NO_2 , NO , N_2O and N_2 formed under anaerobic conditions are described. The following section, “[Gas](#)”, deals with the diffusion of the nitrous gases NO , N_2O and N_2 from the anaerobic fractions of the soil to the aerobic fractions and subsequently the transport through the soil profile into the atmosphere. The amount of nitrogen as nitrate (NO_2) and nitrous gases is not included in the overall nitrogen balance of the soil profile due to the low concentrations in these pools. A schematic image of nitrogen in the different anaerobic nitrogen pools, i.e. N_{NO_3} , N_{AnNO_2} , N_{AnNO} , N_{AnN_2O} and N_{AnN_2} , and the fluxes between these pools is given in [Figure 5.0.3](#).

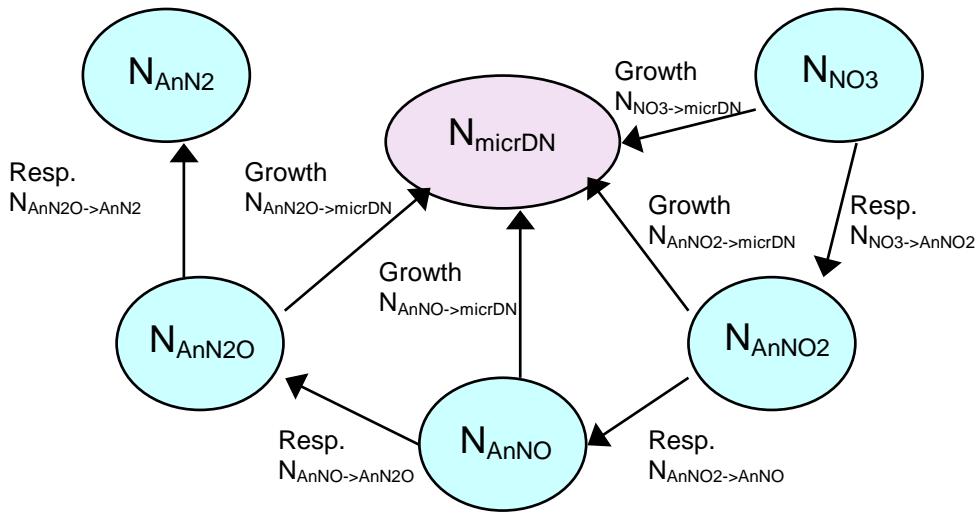


Figure 5.0.3. Denitrification chain when microbes are simulated explicitly.

The concentrations of anaerobic NO_3 , NO_2 , NO and N_2O are used in several calculations. For NO_3 the concentration, $N_{NO3Conc}$, is calculated by dividing the amount of nitrate, N_{NO_3} , by the soil water content for each layer. In the other cases the concentration is calculated by:

$$N_{AnNO_2Conc} = \frac{N_{AnNO_2}}{\theta(z) \cdot f_{Anvol}} \quad (6.40)$$

where $\theta(z)$ is the soil water content and f_{Anvol} is the volumetric anaerobic fraction of each soil layer. This equation is used to calculate $N_{AnNOConc}$ and $N_{AnN2OConc}$ by exchanging N_{AnNO_2} to N_{AnNO} and N_{AnN2O} respectively.

Denitrifying microbes consume nitrogen from all anaerobic nitrogen pools except for N₂. This consumption results in growth and respiration of the microbes, i.e. out flux of nitrogen from the anaerobic nitrogen pools. The losses of nitrogen from the anaerobic nitrogen pools due to microbial growth is calculated as:

$$N_{NO_3 \rightarrow micrDN} = d_{growthNO_3} \cdot f(C_{DO,dnCons}) \cdot f(N_{NxOyConc}) \cdot M_{activity} \cdot N_{micrDN} \quad (6.41)$$

where $d_{growthNO_3}$ is a growth parameter and $f(C_{DO,dnCons})$ and $f(N_{NxOyConc})$ are response functions for dissolved organics and nitrogen concentration respectively. This equation can be used analogously to calculate $N_{NO2 \rightarrow micrDN}$, $N_{NO \rightarrow micrDN}$ and $N_{N2O \rightarrow micrDN}$ by exchanging $d_{growthNO_3}$ to $d_{growthNO_2}$, $d_{growthNO}$ and $d_{growthN2O}$. For $N_{N2O \rightarrow micrDN}$ eq. (6.41) is further modified by multiplying the equation with an inhibition response function for the nitrate content, $f(N_{NO3Concinhib})$, calculated as:

$$f(N_{NO_3Concinhib}) = \frac{d_{inhibitrate}}{d_{inhibitrate} + N_{NO_3Conc}} \quad (6.42)$$

where $d_{inhibitrate}$ is the denitrification inhibition half rate.

The response function for dissolved organics concentration, $f(C_{DO,dnCons})$, is calculated as:

$$f(C_{DO,dnCons}) = \frac{C_{DO}/\theta}{d_{hrateDOC} + (C_{DO}/\theta)} \quad (6.43)$$

where $d_{hrateDOC}$ is the half rate for dissolved organic carbon and θ is the soil moisture content.

The response function for nitrogen concentration is calculated as:

$$f(N_{NxOyConc}) = \frac{N_{NxOyConc}}{d_{hrateNxOy} + N_{NxOyConc}} \quad (6.44)$$

where $d_{hrateNxOy}$ is the half rate for nitrogen concentration. $N_{NxOyConc}$ is the nitrogen concentration, N_{AnNO_3Conc} , N_{AnNO_2Conc} , $N_{AnNOConc}$ or $N_{AnN2OConc}$ for $N_{NO_3 \rightarrow micrDN}$, $N_{NO2 \rightarrow micrDN}$, $N_{NO \rightarrow micrDN}$ and $N_{N2O \rightarrow micrDN}$ respectively.

Each of the nitrogen pools loses nitrogen through microbial maintenance and growth respiration. The respiration loss in one pool will form an input to the next nitrogen pool in the denitrification chain, i.e. the production of N₂, N₂O, NO or NO₂ (see [Figure 5.0.3](#)). These fluxes are calculated as:

$$\begin{aligned} N_{NO_3 \rightarrow AnNO_2} &= \min(AnNO_3 / \Delta t, (N_{rgNO_3} + N_{rmNO_3}) \cdot M_{activity} \cdot N_{micrDN}) \\ N_{AnNO_2 \rightarrow AnNO} &= \min(AnNO_2 / \Delta t, (N_{rgNO_2} + N_{rmNO_2}) \cdot M_{activity} \cdot N_{micrDN}) \\ N_{AnNO \rightarrow AnN_2O} &= \min(AnNO / \Delta t, (N_{rgNO} + N_{rmNO}) \cdot M_{activity} \cdot N_{micrDN}) \\ N_{AnN_2O \rightarrow AnN_2} &= \min(AnN_2O / \Delta t, (N_{rgN_2O} + N_{rmN_2O}) \cdot f(N_{NO_3Conc}) \cdot M_{activity} \cdot N_{micrDN}) \end{aligned} \quad (6.45)$$

where the index rg stands for growth respiration and rm stands for maintenance respiration. Note that the fluxes are either limited by the rate as estimated from the microbial activity or from the amount of gas available in the anaerobic storage.

The total denitrification rate is the sum of the production of N_2 , N_2O and NO , i.e.:

$$N_{NO_3 \rightarrow Denit} = N_{AnNO_2 \rightarrow AnNO} + N_{AnNO \rightarrow AnN_2O} + N_{AnN_2O \rightarrow AnN_2} \quad (6.46)$$

The growth respiration for N_2O , NO , NO_2 and NO_3 is calculated as:

$$N_{rgNO_3} = N_{NO_3 \rightarrow micrDN} / d_{effNO_3} - N_{NO_3 \rightarrow micrDN} \quad (6.47)$$

where d_{effNO_3} is an efficiency parameter. The same equation is used to calculate growth respiration for N_2O , NO and NO_2 by exchanging $N_{NO_3 \rightarrow micrDN}$ to $N_{AnNO_2 \rightarrow micrDN}$, $N_{AnNO \rightarrow micrDN}$ and $N_{AnN_2O \rightarrow micrDN}$, and d_{effNO_3} to d_{effNO_2} , d_{effNO} and d_{effN_2O} respectively.

The maintenance respiration for N_2O , NO , NO_2 and NO_3 is calculated as:

$$N_{rmNO_3} = \frac{d_{rcNO_3} \cdot N_{NO_3}}{N_{AnTot}} \quad (6.48)$$

where d_{rcNO_3} is a respiration coefficient and N_{AnTot} is the total nitrogen content in the N_2O , NO , NO_2 and NO_3 pools. The same equation is used to calculate growth respiration for N_2O , NO and NO_2 by exchanging N_{NO_3} to N_{AnN_2O} , N_{AnNO} and N_{AnNO_2} and d_{rcNO_3} to d_{rcN_2O} , d_{rcNO} and d_{rcNO_2} respectively.

The total biomass of the denitrifiers, N_{micrDN} , is dependent of their growth and their death rates.

$$\frac{\Delta N_{micrDN}}{\Delta t} = M_{growth,DN} - M_{death,DN} \quad (6.49)$$

Microbial growth, $M_{growth,DN}$, is the sum of all the flows from the anaerobic nitrogen pools to the microbial pool as calculated by eq. (6.41). The death rate, $M_{death,DN}$ is calculated as:

$$M_{death,DN} = d_{denitrdie} \cdot M_{activity} \cdot N_{micrDN} \quad (6.50)$$

where $d_{denitrdie}$ is the death rate coefficient.

Microbial activity, $M_{activity}$, is calculated as:

$$M_{activity} = f(T) \cdot f(pH) \cdot f(N_{AnTot}) \cdot f_{Anvol}(z) \cdot d_{actratecoef} \quad (6.51)$$

where $d_{actratecoef}$ is the activity rate coefficient, and $f(pH)$ and $f(N_{AnTot})$ are response functions for soil pH and total nitrogen content in the anaerobic nitrogen pools respectively. The switch “[Denit temp response](#)” determines the temperature response, $f(T)$, described in the section “[Common abiotic functions](#)”.

The response function for soil pH is calculated as:

$$f(pH) = 1 - \frac{1}{1 + e^{(5 - d_{pHrate})/d_{pHshape}}} \quad (6.52)$$

where d_{pHrate} is the pH half rate and $d_{pHshape}$ is a shape coefficient. See viewing function “[Denitrification pH Response](#)”.

The response function for total nitrogen content in the anaerobic nitrogen pools is calculated as:

$$f(N_{AnTot}) = \frac{N_{AnTot}}{d_{hrateNxOy} + N_{AnTot}} \quad (6.53)$$

where $d_{hrateNxOy}$ is a half rate coefficient.

Nitrification processes

The nitrification rate i.e. the flow of nitrogen from the soil ammonium pool to the soil nitrate pool, $N_{NH_4 \rightarrow NO_3}$, can be calculated in two different ways, either by accounting for microbials or without microbials (see switch “[Nitritification](#)”). In the simplified approach the nitrification is calculated as:

$$N_{NH_4 \rightarrow NO_3} = f(T)f(\theta)f(N_{NH_4}, N_{NO_3})n_{pH} \quad (6.54)$$

where n_{pH} is a parameter accounting for pH.

The switch “[Nitritic temp response](#)” determines the temperature response, $f(T)$ and the response function for soil moisture, $f(\theta)$, is the common soil moisture response. These response functions are described in the section “[Common abiotic functions](#)”.

The soil ammonium and nitrate content also affect nitrification. This response function is calculated as:

$$f(N_{NH_4}, N_{NO_3}) = \max\left(0, \frac{N_{NH_4} - N_{NO_3}}{r_{nitr,amm}}\right)n_{rate} \quad (6.55)$$

where $r_{nitr,amm}$ and n_{rate} are parameters. See viewing function “[Nitritification rate under optimal moisture and temperature conditions](#)”.

If microbials are accounted for, eq.(6.54) is modified into:

$$N_{NH_4 \rightarrow NO_3} = n_{micrte}f(T)f(\theta)f(N_{NH_4Cons})n_{pH}N_{micrN} \quad (6.56)$$

where n_{micrte} is a nitrification rate coefficient and N_{micrN} is the biomass of the microbial nitrifiers. The nitrogen in the microbial biomass is not included in the overall nitrogen balance of the soil due to its low nitrogen concentration.

The response function for soil ammonium concentration, $f(N_{NH_4Cons})$, is calculated as:

$$f(N_{NH_4Cons}) = \frac{N_{NH_4}/(\theta \cdot \Delta z)}{(N_{NH_4}/(\theta \cdot \Delta z)) + n_{hrateNH4}} \quad (6.57)$$

where $n_{hrateNH4}$ is the nitrification half rate for ammonium concentration. See viewing function “[Nitritification response function for ammonium content](#)”.

Microbial biomass of nitrifiers is a function of their death, growth and respiration rates:

$$\frac{\Delta N_{micrN}}{\Delta t} = M_{growth,N} - M_{death,N} - M_{respirate} \quad (6.58)$$

Microbial growth rate is calculated as:

$$M_{growth,N} = n_{nitrgrow}f(T_s)f(\theta)f(C_{DO,nCons})f(N_{NO_3,nCons})n_{pH}N_{micrN} \quad (6.59)$$

where $n_{nitrgrow}$ is a growth coefficient for the nitrifiers.

The response function for dissolved organic carbon concentration, $f(C_{DO,nCons})$, is calculated as:

$$f(C_{DO,nCons}) = \frac{C_{DO}/\theta}{n_{hrateDOC} + (C_{DO}/\theta)} \quad (6.60)$$

$$M_{death,N} = n_{nitr死} f(T_s) f(\theta) f(C_{DO,nCons}) n_{pH} N_{micrN}^2$$

where $n_{hrateDOC}$ is the half rate for dissolved organic carbon. See viewing function “[Nitrification response function for dissolved organics](#)”.

The response function for soil nitrate concentration, $f(N_{NO3,nCons})$, is calculated as:

$$f(N_{NO3,nCons}) = \frac{N_{NO_3}/(\theta \cdot \Delta z)}{(N_{NO_3}/(\theta \cdot \Delta z)) + n_{hrateNO3}} \quad (6.61)$$

where $n_{hrateNO3}$ is the half rate for nitrate concentration. See viewing function “[Nitrification response function for nitrate content](#)”.

Microbial death rate is calculated as:

(6.62)

where $n_{nitr死}$ is a death coefficient for the nitrifiers.

Finally, microbial respiration rate is calculated as:

$$M_{respirate} = n_{nitr死} f(T_s) f(\theta) n_{pH} \left(\frac{1}{cn_m} - 1 \right) N_{micrN} \quad (6.63)$$

where cn_m is the carbon nitrogen ratio of the decomposing micro-organisms.

Switches

Ammonia Volatilisation

Value	Meaning
Off	Volatilisation of ammonium is not included in the simulation. Yet to be implemented.
On	Volatilisation of ammonium is included in the simulation. Yet to be implemented.

Ammonium mobility

Value	Meaning
Linear isotherm	The non-adsorbed fraction of ammonium is mobile.
No	All ammonium is adsorbed to the soil.

Denit depth distribution

Value	Meaning
Constant	The denitrification rate is not depth dependent.
Exponential	The denitrification rate decreases exponentially with depth.
Linear decrease	The denitrification rate decreases linearly with depth.
Table	The denitrification rate for each layer is inserted manually in a table.

Denit temp response

Value	Meaning
Common	The temperature response function for denitrification is chosen under common abiotic responses.
Q10 above threshold	The temperature response function for denitrification is a Q10 type of function above a certain threshold temperature. The response is stronger for temperatures below the threshold and diminishes below 0° C.
Q10 whole range	The temperature response function for denitrification is a Q10 type of function for all temperatures.
Ratkowsky function	The temperature response function for denitrification is a quadratic function (Ratkowsky function).

Denitrification

Value	Meaning
Off	Denitrification is not accounted for.
Simplified	Denitrification is accounted for. Denitrifying microbials are not simulated explicitly.
Microbial based	Denitrification is accounted for. Denitrifying microbials are simulated explicitly.

Initial mineral N

Value	Meaning
Concentration(z)	The initial mineral N (nitrate and ammonium) concentrations will be inserted manually in a table.
Uniform concentration	The initial mineral N (nitrate and ammonium) concentrations are uniformly distributed throughout the soil profile.

Initial Nitrifier

Value	Meaning
Linear decrease	Initial nitrifying microbial biomass decreases linearly with depth.
Constant	Initial nitrifying microbial biomass is constant with depth.
Exponential	Initial nitrifying microbial biomass decreases exponentially with depth.

Nitrification

Value	Meaning
Simplified	Nitrifying microbials are not simulated explicitly.
Microbial based	Nitrifying microbials are simulated explicitly.

Nitrific temp response

Value	Meaning
Common	The temperature response function for nitrification is chosen under common abiotic responses.
Q10 above threshold	The temperature response function for nitrification is a Q10 type of function above certain threshold temperature. The response is stronger for temperatures below the threshold and diminishes below 0° C.
Q10 whole range	The temperature response function for nitrification is a Q10 type of function for all temperatures above 0° C.
Ratkowsky function	The temperature response function for nitrification is a Ratkowsky type of function.

Parameters

D InhiHalfRateNO3 N2O

The denitrification inhibition half rate of NO₃ that effect the growth of denitrification microbes during N₂O formation.

Default	Unit	Symbol	Equation	Function
0.3	mg/l	$d_{inhibrate}$	(6.42)	

D pH HalfCoef

The pH half rate in the denitrification process.

Default	Unit	Symbol	Equation	Function

4.25	-	d_{pHrate}	(6.52)	“Denitrification pH Response”
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D pH ShapeCoef

The pH shape coefficient in the denitrification response function.

Default	Unit	Symbol	Equation	Function
0.5	-	$d_{pHshape}$	(6.52)	“Denitrification pH Response”

DeniActivityRateCoef

The denitrification activity rate coefficient in microbial activity function.

Default	Unit	Symbol	Equation	Function
0.5	/day	$d_{actratecoef}$	(6.51)	

DenitDepth

The depth where the denitrification capacity ceases.

Default	Unit	Symbol	Equation	Function
1	m	d_z		

DenitFracExpTail

Fraction of the exponential function remaining below the depth where denitrification ceases.

Default	Unit	Symbol	Equation	Function
0.1	-	d_{exp}		

The remaining fraction is evenly distributed among layers above the denitrification depth..

DenitNitrateHalfSat

Half saturation constant in function for nitrate concentration effect on denitrification.

Default	Unit	Symbol	Equation	Function
10	mg N/l	$d_{Nhalfsat}$	(6.39)	“Denitrification Nitrate Response”

Nitrate concentration at which the activity is half of the activity at optimum nitrate concentrations. Normal range 5-15.

DenitPotentialRate

The potential rate of denitrification is dependent on type of cropping system and soil.

Default	Unit	Symbol	Equation	Function
0.04	g N/m ² day	d_{pot}	(6.37)	

Typical value for a barley crop on a loam soil 0.04 and for a grass ley 0.2.

DenitTemQ10

Response to a 10 °C soil temperature change for the denitrification process.

Default	Unit	Symbol	Equation	Function
2	-	t_{dQ10}		

DenitTemQ10Bas

Base temperature for the denitrification process at which the response is 1.

Default	Unit	Symbol	Equation	Function
20	°C	$t_{dQ10bas}$		

DenitTemQ10Threshold

Threshold temperature for the denitrification process below which the response is linearly decreasing and ceases at 0 °C.

Default	Unit	Symbol	Equation	Function
5	°C	$t_{dQ10thres}$		

DenitTempMax

Minimum temperature for the denitrification process in the Ratkowsky function.

Default	Unit	Symbol	Equation	Function
20	°C	t_{dmax}		

DenitTempMin

The temperature at which the response on denitrification is 1 in the Ratkowsky function.

Default	Unit	Symbol	Equation	Function
-8	°C	t_{dmin}		

DenitThetaPowerC2

Coefficient in the function for soil moisture effect on denitrification.

Default	Unit	Symbol	Equation	Function
10	-	$p_{\theta Dp}$	(6.38)	

A value of 1 corresponds to a linear response whereas a higher value results in a concave response.

DenitThetaRange

Water content range from saturation in the function for soil moisture on denitrification.

Default	Unit	Symbol	Equation	Function
10	vol %	$p_{\theta DRage}$	(6.38)	

Dmic DeathRateCoef

The death rate coefficient.

Default	Unit	Symbol	Equation	Function

0.09	/day	$d_{denitrdie}$	(6.50)	
------	------	-----------------	--------	--

Dmic EffCoef NO

The efficiency parameter in the growth respiration function for NO.

Default	Unit	Symbol	Equation	Function
0.428	-	d_{effNO}	(6.47)	

Dmic EffCoef NO2

The efficiency parameter in the growth respiration function for NO₂.

Default	Unit	Symbol	Equation	Function
0.428	-	d_{effNO2}	(6.47)	

Dmic EffCoef NO3

The efficiency parameter in the growth respiration function for NO₃.

Default	Unit	Symbol	Equation	Function
0.401	-	d_{effNO3}	(6.47)	

Dmic EffCoef N2O

The efficiency parameter in the growth respiration function for N₂O.

Default	Unit	Symbol	Equation	Function
0.151	-	d_{effN2O}	(6.47)	

Dmic GrowthCoef NO

The growth parameter in the denitrification function describing the loss of NO from the anaerobic nitrogen pool due to microbial growth.

Default	Unit	Symbol	Equation	Function
8.2	/day	$d_{growthNO}$	(6.41)	

Dmic GrowthCoef NO2

The growth parameter in the denitrification function describing the loss of NO₂ from the anaerobic nitrogen pool due to microbial growth.

Default	Unit	Symbol	Equation	Function
16	/day	$d_{growthNO2}$	(6.41)	

Dmic GrowthCoef NO3

The growth parameter in the denitrification function describing the loss of NO₃ from the anaerobic nitrogen pool due to microbial growth.

Default	Unit	Symbol	Equation	Function
16	/day	$d_{growthNO3}$	(6.41)	

Dmic GrowthCoef N2O

The growth parameter in the denitrification function describing the loss of N₂O from the anaerobic nitrogen pool due to microbial growth.

Default	Unit	Symbol	Equation	Function
8.2	/day	$d_{growthN2O}$	(6.41)	

Dmic RespCoef NO

The respiration coefficient in the denitrification function describing the maintenance respiration for NO.

Default	Unit	Symbol	Equation	Function
0.84	/day	d_{rcNO}	(6.48)	

Dmic RespCoef NO2

The respiration coefficient in the denitrification function describing the maintenance respiration for NO₂.

Default	Unit	Symbol	Equation	Function
0.84	/day	d_{rcNO2}	(6.48)	

Dmic RespCoef NO3

The respiration coefficient in the denitrification function describing the maintenance respiration for NO₃.

Default	Unit	Symbol	Equation	Function
2.2	/day	d_{rcNO3}	(6.48)	

Dmic RespCoef N2O

The respiration coefficient in the denitrification function describing the maintenance respiration for N₂O.

Default	Unit	Symbol	Equation	Function
1.9	/day	d_{rcN2O}	(6.48)	

InitAmmoniumConc

The initial ammonium concentration that is uniformly distributed throughout the profile.

Default	Unit	Symbol	Equation	Function
10	mgN/l			

InitDenitBiomass

The initial biomass of denitrifying microbials.

Default	Unit	Symbol	Equation	Function
2	gN/m ²	$i_{denitmict}$	(6.26)	

InitNitrateConc

The initial nitrate concentration that is uniformly distributed throughout the profile.

Default	Unit	Symbol	Equation	Function
10	mgN/l			

InitNitrifier

The initial amount of nitrifiers.

Default	Unit	Symbol	Equation	Function
1	gN/m ²	$i_{nitrifcr}$		

InitNtrFracExpTail

The initial amount of nitrifiers below the lowest soil layer with nitrifiers.

Default	Unit	Symbol	Equation	Function
0.1	-	$i_{nexpfrac}$		

NUptFlexibilityDeg

Compensatory N uptake from layers with excess of N.

Default	Unit	Symbol	Equation	Function
0.5	-	$n_{Uptflex}$	(6.34)	

A value of 1 results in the most efficient compensation (i.e., all differences between potential and actual uptake occurring in layers with mineral N deficiency is added to the uptake demand in layers with no deficiency). A value of 0 represents a case where the uptake demand is strictly partitioned between different soil layers according to the soil root distribution.

NUptMaxAvailFrac

Fraction of mineral N available for plant uptake.

Default	Unit	Symbol	Equation	Function
0.08	/day	f_{Nupt}	(6.32), (6.33), (6.35), (6.36)	

For the lowest soil layer with roots the value is decreased in proportion to how large fraction of the layer that is not penetrated by roots. A value of 0.1 means that 10% of the total mineral-N pool is available at one time-step. Normal range 0.05-0.12.

NitrateAmmRatio

Nitrate-ammonium ratio in the nitrification function.

Default	Unit	Symbol	Equation	Function
8	-	$r_{nitr,amm}$	(6.14)	“Nitrification rate under optimal moisture and temperature conditions”

Normal range for agricultural soils 1-15.

NitriDeathCoef

The death coefficient for nitrifiers in the microbial death rate calculation.

Default	Unit	Symbol	Equation	Function
1	/day	$n_{nitrdie}$	(6.62)	

NitrificationRateCoef

The nitrification rate coefficient in nitrification function when microbials are accounted for.

Default	Unit	Symbol	Equation	Function
0.25	mg ha/(day kg)	$n_{micrate}$	(6.56)	

NitrifierDepth

Lowest depth of soil nitrifier distribution.

Default	Unit	Symbol	Equation	Function
-1	m	i_{ndepth}		

NitriGrowthCoef

The growth coefficient for nitrifiers in the calculation of the microbial growth rate.

Default	Unit	Symbol	Equation	Function
2	/day	$n_{nitrgrow}$	(6.59)	

NitriHalfRateDOC

The parameter describing the half rate for dissolved organic carbon in the response function for dissolved organic carbon content.

Default	Unit	Symbol	Equation	Function
5.25	mg N/l	$n_{hrateDOC}$	(6.60)	

NitriHalfRateNH4

The parameter describing the half rate for ammonium in the response function for ammonium concentration.

Default	Unit	Symbol	Equation	Function
6.18	mg N/l	$n_{hrateNH4}$	(6.57)	

NitriHalfRateNO3

The parameter describing the half rate for nitrate in the response function for nitrate concentration.

Default	Unit	Symbol	Equation	Function
1.6	mg N/l	$n_{hrateNO3}$	(6.61)	

NitriTemQ10

Response to a 10 °C soil temperature change for the nitrification process.

Default	Unit	Symbol	Equation	Function
2	-	t_{nQ10}		

NitriTemQ10Bas

Base temperature for the nitrification process at which the response is 1.

Default	Unit	Symbol	Equation	Function
20	°C	$t_{nQ10bas}$		

NitriTemQ10Threshold

Threshold temperature for the nitrification process below which the response is linearly decreasing and ceases at 0 °C.

Default	Unit	Symbol	Equation	Function
5	°C	$t_{nQ10thres}$		

NitriTempMax

Minimum temperature for the nitrification process in the Ratkowsky function.

Default	Unit	Symbol	Equation	Function
20	°C	t_{nmax}		

NitriTempMin

The temperature at which the response on nitrification is 1 in the Ratkowsky function.

Default	Unit	Symbol	Equation	Function
-8	°C	t_{nmin}		

NitrificSpecificRate

Specific nitrification rate in the response function for soil ammonium and nitrate content when microbes are not accounted for.

Default	Unit	Symbol	Equation	Function
0.2	/day	n_{rate}		“Nitrification rate under optimal moisture and temperature conditions”

NXOY DOCHalfRateCoef

The parameter describing the half rate for dissolved organic carbon concentration in the N_xO_y denitrification process.

Default	Unit	Symbol	Equation	Function
17	mg/l	$d_{hrateDOC}$	(6.43)	

NXOY HalfRateCoef

The parameter describing the half rate for nitrogen concentration in the N_xO_y denitrification process.

Default	Unit	Symbol	Equation	Function
87	mg/l	$d_{hrateNxOy}$	(6.44), (6.53)	

Parameter tables

Initial mineral-N concentration

Name	Default	Unit	Symbol	Comments/Explanations
I Nitrate Conc	10	mg N/l		Initial nitrate concentration.
I Ammonium Conc	10	mg N/l		Initial ammonium concentration.

Linear ammonium isotherm

Name	Default	Unit	Symbol	Comments/Explanations
NH4 Ads Frac	0.99	-	$f_{N,ads}$	Fraction of the total ammonium that is adsorbed to particles in the soil.

Nitrification pH-response distribution

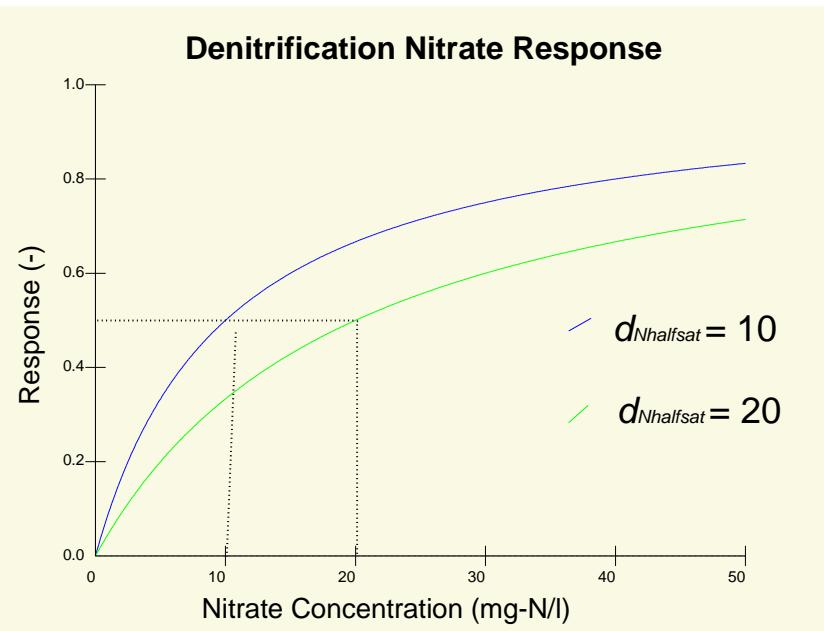
Name	Default	Unit	Symbol	Comments/Explanations
RelScale Response	1	-	n_{pH}	Coefficient for the pH response on nitrification.

Potential denitrification distribution

Name	Default	Unit	Symbol	Comments/Explanations
DenitDistZ	0.1	-	$d_{dist}(\Delta z)$	Coefficient for denitrification.

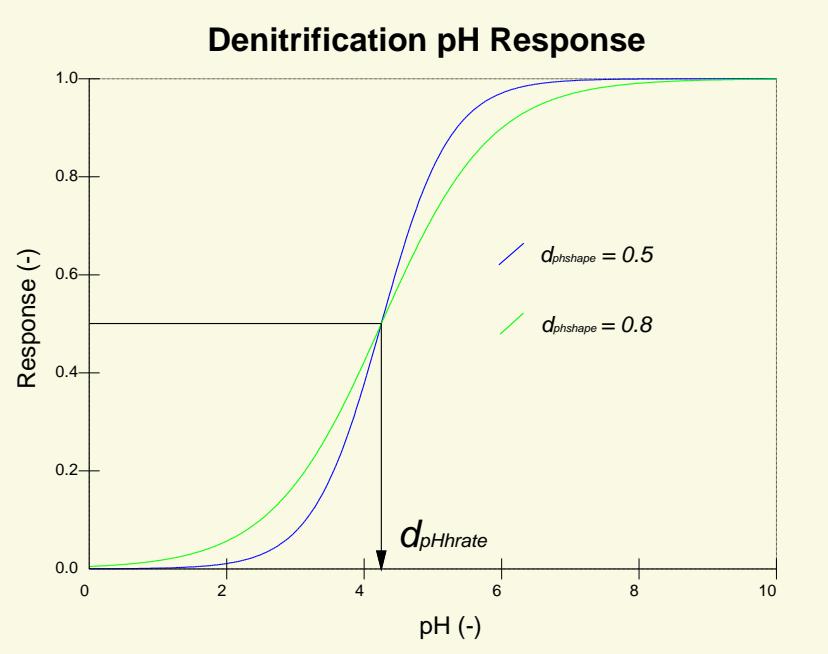
Viewing functions

Denitrification Nitrate Response



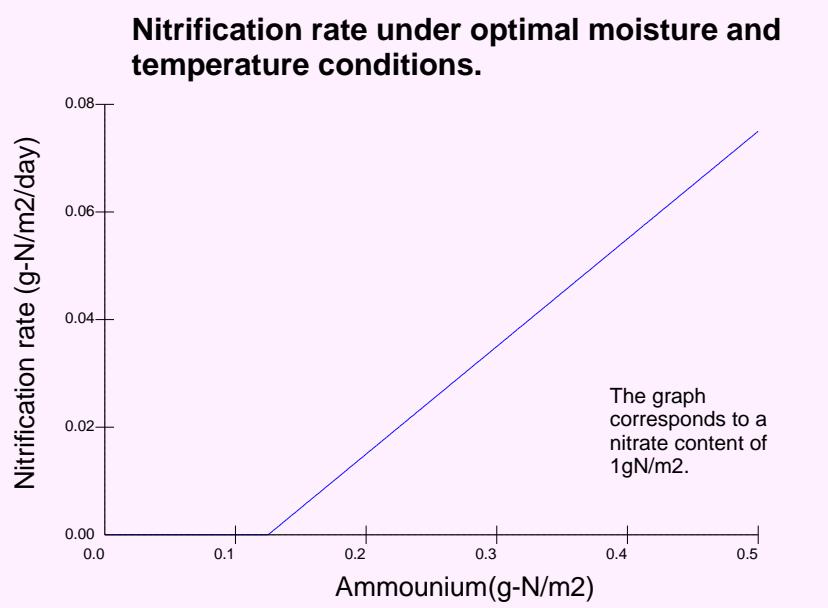
The denitrification response function for nitrate concentration in the soil. Two parameterisations with different denitrification nitrate half rate saturations.

Denitrification pH Response



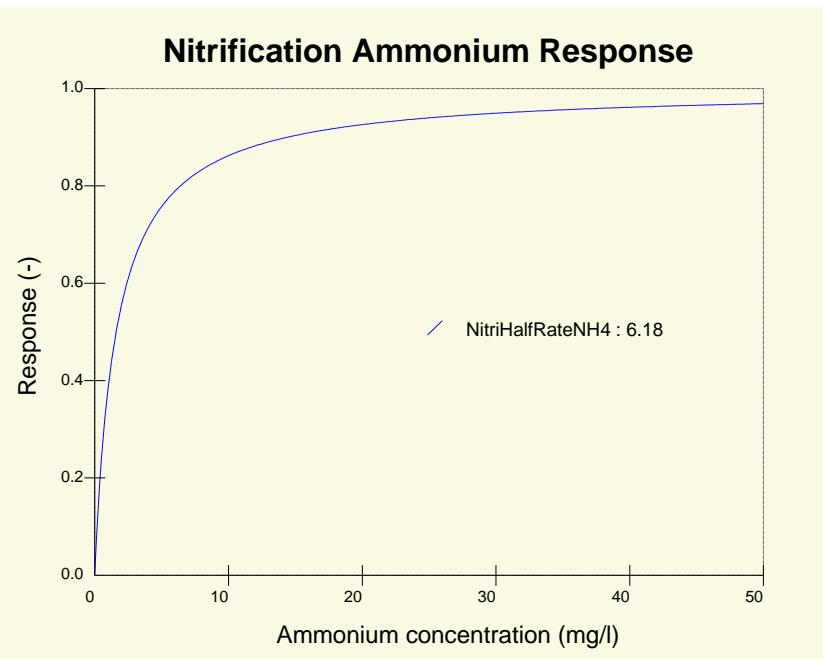
The denitrification response function for soil pH. Two parameterisations with different pH shape coefficients.

Nitrification rate under optimal moisture and temperature conditions



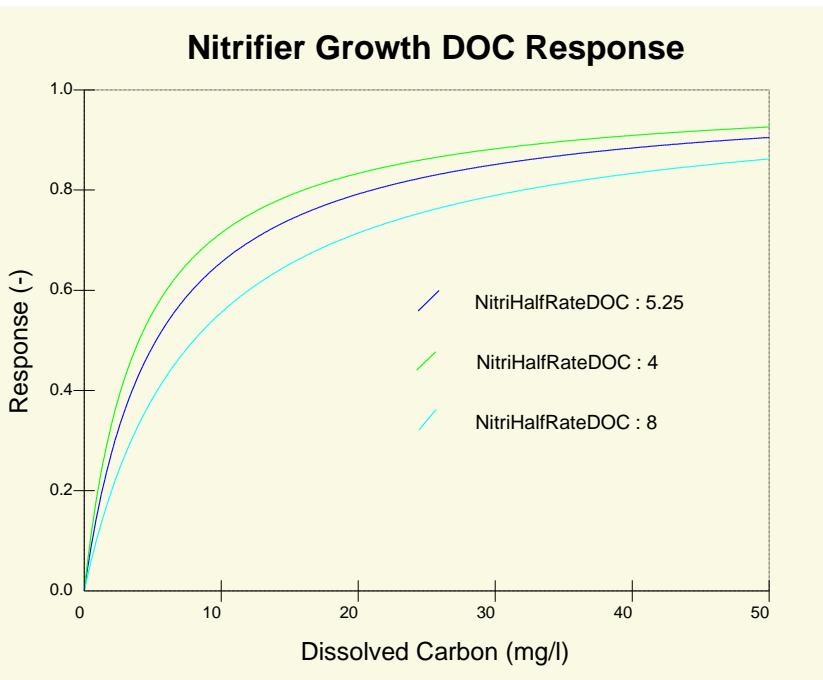
The nitrification rate under optimal temperature and soil moisture conditions, with a fixed soil nitrate content of 1g N/m².

Nitrification response function for ammonium content



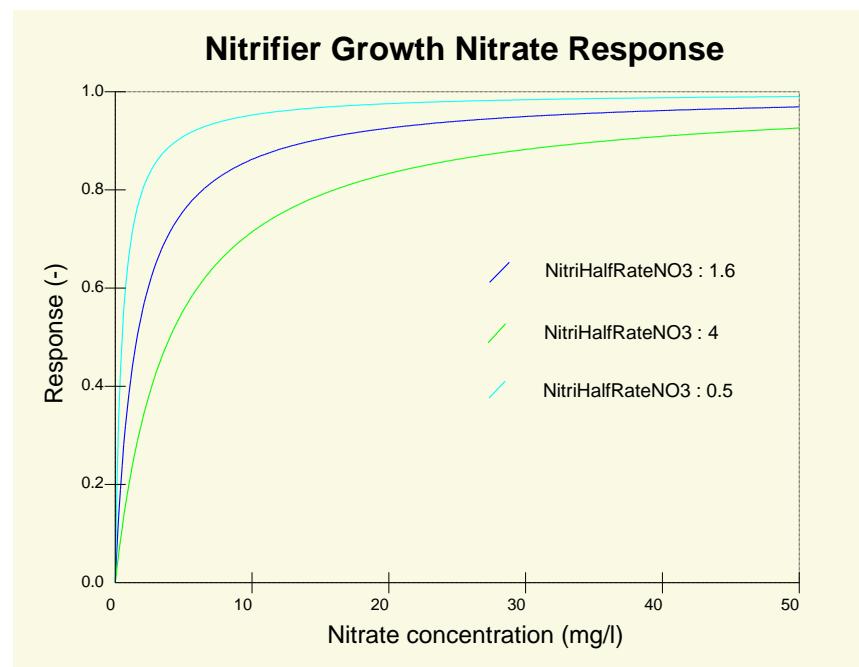
The nitrification response function for a half-rate concentration of ammonium.

Nitrification response function for dissolved organics



The nitrification response function for three different half-rate concentrations of dissolved organic carbon.

Nitrification response function for nitrate content



The nitrification response function for three different half-rate concentrations of nitrate.

State Variables

An NO

Nitrogen content in the anaerobic NO pool.
g/m²

An NO₂

Nitrogen content in the anaerobic NO₂ pool.
g/m²

An NO₃

Nitrogen content in the anaerobic NO₃ pool, i.e. soil nitrate.
g/m²

An N₂

Nitrogen content in the anaerobic N₂ pool.
g/m²

An N₂O

Nitrogen content in the anaerobic N₂O pool.
g/m²

Denitrifier Activity

Activity of denitrifying microbials if simulated explicitly.
g/m²

Denitrifier Biomass

Biomass of denitrifying microbials if simulated explicitly.
g/m²

Nitrifier Biomass

Biomass of nitrifying microbials if simulated explicitly.
g/m²

SoilAmmonium

Nitrogen content in the soil ammonium pool.
g/m²

SoilNitrate

Nitrogen content in the soil nitrate pool.
g/m²

Flow Variables

An Cons NO

Total consumption rate (i.e. microbial growth + respiration) from the anaerobic NO pool.
g/m²/day

An Cons NO2

Total consumption rate (i.e. microbial growth + respiration) from the anaerobic NO₂ pool.
g/m²/day

An Cons NO3

Total consumption rate (i.e. microbial growth + respiration) from the anaerobic NO₃ pool.
g/m²/day

An Cons N2O

Total consumption rate (i.e. microbial growth + respiration) from the anaerobic N₂O pool.
g/m²/day

An Prod NO

Total production rate (i.e. influx of nitrogen due to microbial respiration) to the anaerobic NO pool.
g/m²/day

An Prod NO2

Total production rate (i.e. influx of nitrogen due to microbial respiration) to the anaerobic NO₂ pool.
g/m²/day

An Prod N2

Total production rate (i.e. influx of nitrogen due to microbial respiration) to the anaerobic N₂ pool.
g/m²/day

An Prod N2O

Total production rate (i.e. influx of nitrogen due to microbial respiration) to the anaerobic N₂O pool.
g/m²/day

DenitrificationRate

Denitrification rate.
g/m²/day

Denitrifier Death

Death rate of denitrifiers.
g/m²/day

Denitrifier Growth

Growth rate of denitrifiers.
g/m²/day

NitrificationRate

Nitrification rate.
g/m²/day

Nitrifier DeathRate

Death rate of nitrifiers if simulated explicitly.
g/m²/day

Nitrifier GrowthRate

Growth rate of nitrifiers if simulated explicitly.
g/m²/day

Nitrifier RespRate

Respiration rate of nitrifiers if simulated explicitly.
g/m²/day

SoilAmmoniumDrainage

Horizontal ammonium flow.
g/m²/day

SoilAmmoniumFlow

Vertical ammonium flow between layers and deep percolation.
g/m²/day

SoilAmmoniumUptake

Plant uptake of soil ammonium.
g/m²/day

SoilNitrateDrainage

Horizontal nitrate flow.
g/m²/day

SoilNitrateFlow

Vertical nitrate flow between layers and deep percolation.
g/m²/day

SoilNitrateUptake

Plant uptake of soil nitrate.
g/m²/day

Auxiliary Variables

An NO Cons

Concentration of nitrogen in the anaerobic NO pool.
mg/l

An NO2 Cons

Concentration of nitrogen in the anaerobic NO₂ pool.
mg/l

An NO3 Cons

Concentration of nitrogen in the anaerobic NO₃ pool.
mg/l

An N2 Cons

Concentration of nitrogen in the anaerobic N₂ pool.
mg/l

An N2O Cons

Concentration of nitrogen in the anaerobic N₂O pool.
mg/l

DenitResponse

The multiplied effect from the temperature, soil moisture and nitrate response functions on denitrification.

-

N Conc NO3 Drainage

The concentration of nitrate in drainage water.
mg N/l.

N Conc NH4 Drainage

The concentration of ammonium in drainage water.
mg N/l.

N Conc MinN Drainage

The concentration of mineral N (ammonium and nitrate) in drainage water.
mg N/l.

N Tot Ammonium Soil

Total amount of ammonium in the whole soil profile.
g/m²

N Tot Denitrification

Denitrification from all mineral nitrogen pools in the whole soil profile.
g/m²/day

N Tot MinN Drainage

Horizontal nitrogen flow from all mineral nitrogen pools in the whole soil profile.
g/m²/day

N Tot MinN Soil

Total amount of mineral nitrogen in the whole soil profile.
g/m²

N Tot Nitrate Soil

Total amount of nitrate in the whole soil profile.
g/m²/day

N Tot NH4 Plant Uptake

Total amount of ammonium taken up by the plant from the whole soil profile.
g/m²/day

N Tot Nitrification

Total nitrification rate for the whole soil profile.
g/m²/day

N Tot NO3 Plant Uptake

Total amount of nitrate taken up by the plant from the whole soil profile.
g/m²/day

N Tot NH4 Drainage

Horizontal nitrogen flow from the soil ammonium pool in the whole soil profile.
g/m²/day

N Tot NO3 Drainage

Horizontal nitrogen flow from the nitrate pool in the whole soil profile.
g/m²/day

N Tot Min Plant Uptake

Total plant uptake of mineral nitrogen from the whole soil profile.
g/m²/day

SoilAmmoniumConc

Ammonium concentration in the soil.
mg/l

SoilNitrateConc

Nitrate concentration in the soil.
mg/l

Gas Processes

In this section nitrous and oxygen gas flows from the soil to the atmosphere are described. Trace gas emissions of nitrous gases i.e. NO, N₂O and N₂ can be simulated in two different ways (see switch “[Trace gas emissions of nitrous gases](#)”). Both options require the simulation of denitrifying microbes. The trace gases can either be emitted directly to the atmosphere from the layer in which they were formed or the transportation of the gases through the soil profile can be simulated explicitly. Oxygen flows can optionally be simulated (see switch “[Methane Model](#)”)

Value	Meaning
Off	No Methane flux is considered
Simplified	A simple Methane model is considered
Detailed	A detailed process oriented model is considered

Methane Emission by Plants

Value	Meaning
Off	
On	

Methane Oxidation by Plants

Value	Meaning
Off	
On	

[Oxygen model](#)”). This requires that the emission of nitrous trace gases is simulated as well. Either oxygen is implicit and the consumption of oxygen in lower soil layers is the driving force for vertical oxygen flows in the soil (steady-state approach), or oxygen can be calculated explicitly (dynamic approach). In the latter case the diffusion rate determines the oxygen flux. The initial oxygen concentration is given by the parameter i_{oxygen} .

Trace gas emissions of nitrous gases

Nitrous gases are formed under anaerobic conditions by the activity of denitrifying microbials (see section “[Denitrification](#)”). These gases diffuse from the anaerobic fractions of the soil to the aerobic parts, travel vertically through the soil profile and leave the soilsurface through the uppermost soil layer to the atmosphere. Nitrous gases are also formed when ammonium is nitrified to nitrate. An overview over the trace gas fluxes and associated nitrogen pools is given in [Figure 5.4](#).

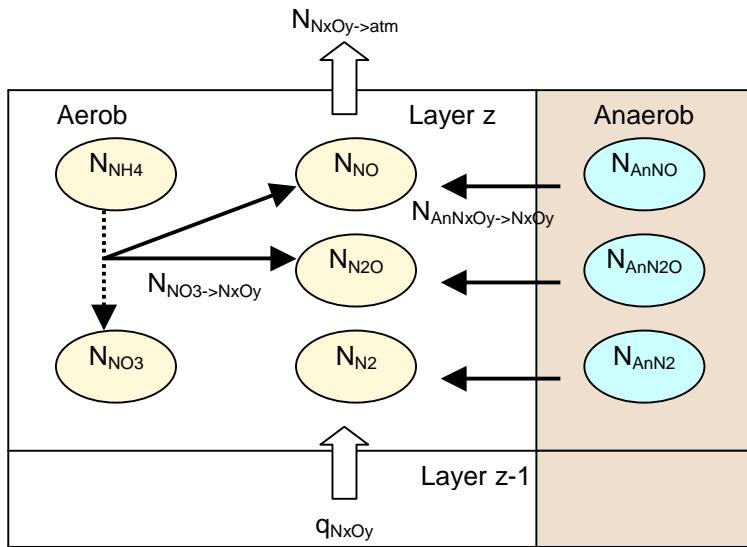


Figure 5.4. Nitrogen trace gas fluxes in the soil profile.

NO and N_2O is formed during the nitrification process. These nitrogen fluxes are calculated as:

$$N_{NO_3 \rightarrow NO} = g_{mfrac{NO}} \cdot f(\theta) \cdot f(T) \cdot f(pH) \cdot N_{NH_4 \rightarrow NO_3} \quad (6.64)$$

where $g_{mfrac{NO}}$ is the maximum NO fraction parameter and $N_{NH_4 \rightarrow NO_3}$ is the nitrification rate. $f(\theta)$, $f(T)$ and $f(pH)$ are the response functions for soil moisture, temperature and soil pH respectively. The formation of N_2O , i.e. $N_{NO_3 \rightarrow N_2O}$, is calculated with the same equation by exchanging $g_{mfrac{NO}}$ to $g_{mfrac{N_2O}}$ and excluding the term $f(pH)$.

The response function for soil moisture is calculated as:

$$f(\theta) = 1 - \frac{1}{1 + e^{(\theta(z)/\theta_s(z) - g_{\theta satcrit{NO}})/g_{\theta satform{NO}}}} \quad (6.65)$$

where $\theta(z)$ is the soil moisture content, $\theta_s(z)$ is the water content at saturation, and $g_{\theta satcrit{NO}}$ and $g_{\theta satform{NO}}$ are parameters. The parameters $g_{\theta satcrit{NO}}$ and $g_{\theta satform{NO}}$ are exchanged to $g_{\theta satcrit{N_2O}}$ and $g_{\theta satform{N_2O}}$ to calculate the response function for the formation of N_2O . See viewing function “[Moisture response function nitrification](#)”.

The response function for soil temperature is calculated by:

$$f(T) = \left(\frac{g_{T max NxO} - T(z)}{g_{T max NxO} - g_{Top{NxO}}} \right)^{g_{T shape NxO}} e^{f(T_{exp})} \quad (6.66)$$

$$f(T_{exp}) = g_{T shape NxO} \cdot \frac{T(z) - g_{Top{NxO}}}{g_{T max NxO} - g_{Top{NxO}}} \quad (6.67)$$

where $g_{T max NxO}$, $g_{Top{NxO}}$ and $g_{T shape NxO}$ are parameters and $T(z)$ is the soil temperature. See viewing function “[Temperature response function nitrification](#)”.

The response function for soil pH is calculated as:

$$f(pH) = g_{pHcoef} - g_{pH}(z) \quad (6.68)$$

where g_{pHcoef} is a pH coefficient and $g_{pH}(z)$ is the soil pH in different soil layers. See viewing function “[pH response function nitrification](#)”.

When the nitrous gases are emitted directly to the atmosphere from the layer in which they were formed, the diffusion of nitrous gases from anaerobic fractions are calculated as:

$$N_{AnNO \rightarrow NO} = \min(f(O_2) \cdot N_{AnNO}, 0.5 \cdot N_{AnNO}) \quad (6.69)$$

and analogously for N₂O and N₂. $f(O_2)$ is an oxygen diffusion exchange function.

This equation is slightly modified when vertical trace gas diffusion through the soil is simulated:

$$N_{AnNO \rightarrow NO} = -f(O_2) \cdot (N_{NO} - N_{AnNO}) \quad (6.70)$$

and analogously for N₂O and N₂. The negative sign indicates that the flow is directed from the anaerobic to the aerobic parts of the soil.

The oxygen diffusion exchange function is calculated as:

$$f(O_2) = o_{diffred} \cdot f_{Anvol} \cdot (1 - f_{Anvol}) \cdot O_{diffrate} \quad (6.71)$$

where f_{Anvol} is the volumetric anaerobic fraction of the soil and $o_{diffred}$ is an oxygen diffusion reduction parameter. See viewing function “[Oxygen diffusion exchange function](#)”.

$O_{diffrate}$ is the oxygen diffusion rate calculated as:

$$O_{diffrate} = d_{O_2} \cdot f_a \cdot o_{O_2diffrate} \cdot D_O \quad (6.72)$$

where d_{O_2} is a tortuosity parameter, $o_{O_2diffrate}$ is the oxygen diffusion rate at 20 °C, D_O is the diffusion coefficient in free air and f_a is the air porosity calculated as:

$$f_a = \theta_s - \theta \quad (6.73)$$

where θ_s and θ are the saturated and actual soil moisture content respectively.

The flux of nitrous trace gases to the atmosphere when transport through the soil is not considered, is equal to the sum of the nitrous gases formed by nitrification and denitrification:

$$N_{NO \rightarrow atm} = N_{AnNO \rightarrow NO} + N_{NO_3 \rightarrow NO} \quad (6.74)$$

and analogously for N₂O and N₂.

Vertical transport of trace gases through the soil, when simulated explicitly, is a function of the oxygen diffusion rate:

$$q_{NO} = -\frac{f(O_2) \cdot \partial N_{NO}}{\partial z} \quad (6.75)$$

and analogously for N₂O and N₂. The negative sign indicates that the gas flow is always directed upwards in the soil.

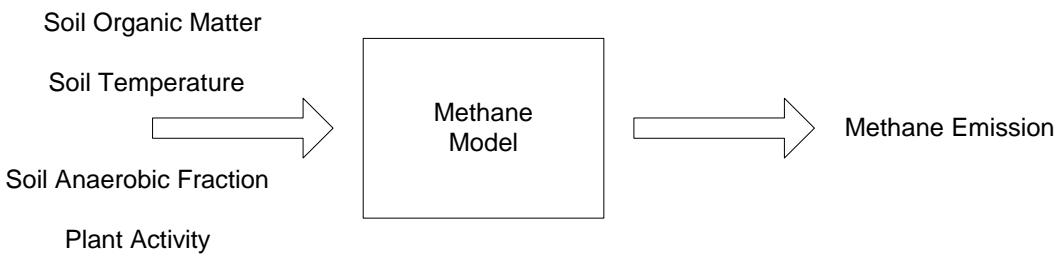
For the uppermost layer eq.(6.75) is modified into:

$$q_{NO} = \frac{f(O_2) \cdot (N_{NO}(z))}{\Delta z / 2} \quad (6.76)$$

where Δz in this case symbolises thickness of layer 1.

Methane gas model

The conceptual model is described in Fig.



5.5. Conceptual scheme of methane model

Figure

Main input variables used in the process are given by the already existing structure. Soil organic matter provides the substrate useful for respiration by microbial biomass, which volumetric content is already calculated by CoupModel. Process rates are regulated by soil temperature and water content, which both influence microbial activity. Plant activity, in particular root water uptake and respiration, influences methane transport and oxidation.

Production, oxidation and transport of methane along the vertical soil column are described, taking into account three different transport mechanisms:

Advection flow and molecular diffusion through the soil pore space;

Transport by ebullition from the depth where bubbles are formed up to the water table and

Transport through plants from the soil region above the rooting depth directly to the atmosphere.

The model calculates methane concentration profiles in the soil and methane emissions to the atmosphere on a daily basis by numerically solving the 1-dimensional continuity equation within the vertical soil profile (Walter, 1996):

$$\frac{\partial C(t, z)}{\partial t} = -\frac{\partial}{\partial z} \left(D \frac{\partial C_{CH_4}(t, z)}{\partial z} \right) + C_{CH_4net}(t, z) \quad (6.77)$$

where $C_{CH_4}(t, z)$ is methane concentration at soil depth z and time t , D is the diffusion coefficient and $C_{CH_4net}(t, z)$ is net methane source at depth z and time t .

The net methane source consists of a methane-production source (C_{CH_4prod}) and sinks by oxidation (C_{CH_4ox}), ebullition (C_{CH_4ebull}) and plant uptake (C_{CH_4plant}).

$$C_{CH_4net}(t, z) = C_{CH_4prod}(t, z) - C_{CH_4ox}(t, z) - C_{CH_4ebull}(t, z) - C_{CH_4plant}(t, z) \quad (6.78)$$

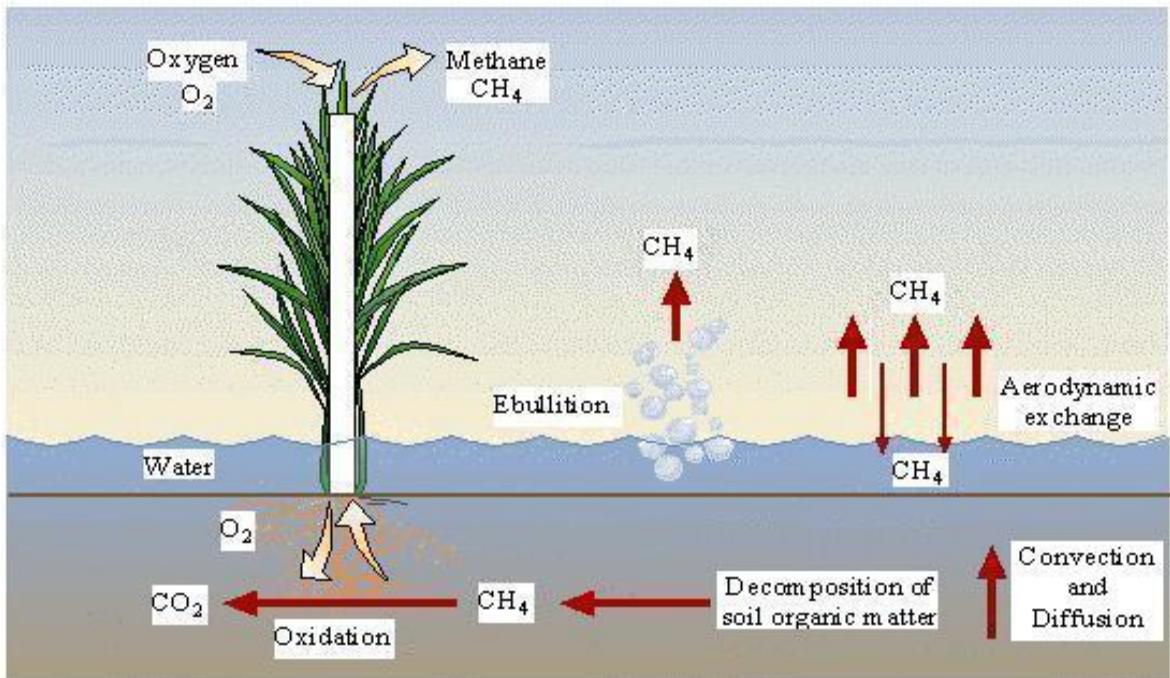


Figure 5.6. Illustration of the different processes involved in the model

Methane Production

The conversion of substrate in the soil to methane leaving the soil, $C_{CH_4\ prod}$, is calculated as a first order decay reaction, depending on the soil organic matter content:

$$C_{CH_4\ prod} = f(T) \cdot f_{Anvol} \cdot d_{m_ratio} \cdot \sum_i (d_{ratecoef_i} \cdot C_i) \quad (6.79)$$

where:

$f(T)$ is the common response function for soil temperature previously introduced in CoupModel. In other existing models, methane production always refers to a Q_{10} function (Van Bodegom, 2001), (Van der Peijl, 1999), with Q_{10} values ranging between 2 (Huang, 1998) and 6 (Yu, 2003). Highest microbial activity is reached between 30 and 40°C, while no production occurs below 0°C (Le Mer, 2001).

f_{Anvol} is the volumetric anaerobic fraction.

d_{m_ratio} (**CH4 HalfRateOxConstant**)

<u>Default</u>	<u>Unit</u>	<u>Symbol</u>	<u>Equation</u>	<u>Function</u>
<u>2.3E-03</u>	-	<u>$K_{p,50}$</u>	<u>(6.81)</u>	

CH4 RateCoefRatio is the methane conversion rate, considered to be a unique value for all the soil. This simplification has been already introduced in some existing models (Bhattacharya, 1994), (Huang, 1998), while others (Van Bodegom, 2001), (Grant, 1998) use different conversion rates for the different soil organic matter pools.

$d_{ratecoef_i}$ is the decomposition rate of each soil carbon content C_i , calculated as a first order rate process. Index i means litter (see k_l RateCoefLitter) and humus (k_h RateCoefHumus) pool respectively.

Methane Oxidation

Methane oxidation rate from a soil layer, $C_{CH4ox}(t, z)$, consists of two parts, C_{CH4ox1} and C_{CH4ox2} .

$$C_{CH4ox} = C_{CH4ox1} + C_{CH4ox2} \quad (6.80)$$

The first term represents oxidation by methanotrophic bacteria at the aerobic interface between the water (or air) and the soil, and is defined as a first order function of the soil methane content and regulated by the Michaelis–Menten kinetics (Bender, 1992):

$$C_{CH4ox1} = k_{o_rate} \frac{C_{CH4w}}{(K_{o_50} + C_{CH4w})} \cdot C_{CH4} \quad (6.81)$$

where C_{CH4w} is the methane concentration in soil water, C_{CH4} is the soil methane content, k_{o_rate} ([CH4 AerobicOxRate](#)) is the maximum reaction rate and K_{o_50} ([CH4 HalfRateOxConstant](#)) is the half rate Michaelis constant.

The second term, C_{CH4ox2} , describes the oxidation of methane by plant-transported oxygen which is calculated as a function of the plant root respiration:

$$C_{CH4ox2} = k_{pox} \cdot f(Root_resp) \quad (6.82)$$

where k_{pox} ([CH4 PlantOxidationRate](#)) is a scaling parameter.

The response function $f(Root_resp)$ is defined as:

$$f(Root_resp) = 1 - e^{p_{oxshape} \cdot C_{rootresp}^2} \quad (6.83)$$

where $C_{rootresp}$ is the total carbon emitted by roots, and $p_{oxshape}$ is a shape parameter.

In the WMEM model (wetland methane emission model) of Cao, Marshall and Gregson (1996) oxidation is calculated as a single term. An empirical equation is introduced and the oxidation rate is thought to depend just from the maximum gross primary production occurring any month.

Methane Ebullition

Following the assumption given by Rothfuss (1994), bubble formation occurs, if the sum of the partial pressures of all gases in the pore water exceeds a threshold value which is the sum of the hydrostatic and the atmospheric pressures plus the pressure required to move the soil particles. The amount of methane removed in the form of bubbles is thus calculated introducing an empirical equation, as suggested by Walter (1996):

$$C_{CH4ebull} = k_{bu} \cdot MAX(c_{CH4w} - c_{bu1}, 0) \quad (6.84)$$

where k_{bu} is a rate constant and c_{bu1} is the threshold methane concentration above which bubbles are formed.

Methane Plant transport

Gas transport through plants is known to operate by molecular diffusion, effusion or active transport due to pressure differences (Whiting, 1992). The rate at which methane is removed from soil by plants depends from the growing status of the plant:

$$C_{CH4plant} = k_{plant} \cdot E_{ta} \cdot f(PlantEff) \cdot c_{CH4w} \quad (6.85)$$

where k_{plant} is a rate constant parameter ([CH4 WaterPlantCoef](#)), E_{ta} is the root water uptake, $f(PlantEff)$ is a function describing plant transport efficiency and c_{CH4w} is the concentration of CH_4 in water:

$$f(PlantEff) = \begin{cases} 1 & E_{ta} \leq 1 \\ \left(\frac{E_{ta_limit}}{E_{ta}} \right)^{p_{CH4_W1}} & E_{ta} \geq E_{ta_limit} \end{cases} \quad (6.86)$$

where p_{CH4_W1} ([CH4_WaterPowerCoefCH4_PlantOxShapeCoef](#)) is a shape coefficient and E_{ta_limit} is the threshold water uptake ([CH4_LimitWaterUptake](#)) above which plant transport efficiency begins to decrease. This means that the methane uptake increases in proportion to the water uptake rate until the water uptake rate exceeds E_{ta_limit} . When the water uptake rate becomes higher than E_{Ta_limit} the efficiency is reduced.

The approach used in the present model gives a simplified description about the real process, which is complex and still not well-known (Le Mer, 2001). To define the influence of plant activity on emission other authors followed similar ways. Yu (2003), for example, connected the emission rate with the GSI of the plant, introducing a function which is constant during winter time and decreases linearly from the time the plants emerge from the peat until maturity, followed by a linear decrease until most of the plant stems are killed by frost. On the other hand, some author tried to introduce more detailed models. Beckett (2001), for example, described a multicylinder model for *Phragmites* that accommodates detailed structure into a cylindrically symmetric set of time-dependant partial differential equations, by regarding the root as a set of coaxial regions, each of which has diffusion and respiration properties that are (on average) appropriate to the local structure and metabolism.

Methane Emission

The total soil methane emission is calculated as the sum of ebullition ($C_{CH4ebull}$), plant transport ($C_{CH4plant}$), diffusive flux through soil air ($C_{CH4airflux}$) and aerodynamic exchange between soil surface and atmosphere ($C_{CH4surface}$):

$$C_{CH4emission} = C_{CH4ebull} + \eta_{plantox} \cdot C_{CH4plant} + C_{CH4airflux} + C_{CH4surface} \quad (6.87)$$

The first three terms are calculated as direct emissions from each soil layer.

Since gas conducting plants are capable of transporting atmospheric oxygen down to the roots, an efficiency parameter $\eta_{plantox}$ ([CH4_PlantOxidationEff](#)) has been introduced to calculate effective methane emission from plants (Gerard, 1993).

The diffusive flux through air is calculated for each layer as:

$$C_{CH4airflux}(I-1) = f(O_2) \cdot \frac{C_{CH4a}(I) - C_{CH4a}(I-1)}{\Delta z} \quad (6.88)$$

where Δz is the distance from the middle depth of one layer (I) to the middle depth in the layer above ($I-1$), C_{CH4a} is the methane concentration in air and $f(O_2)$ is an oxygen diffusion exchange function.

The emission from the uppermost layer is calculated as:

$$C_{CH4surface} = \frac{C_{CH4a}(1) - C_{CH4atm}}{r_{as}} \cdot \rho_{CH4} \quad (6.89)$$

where $C_{CH4a}(1)$ is the methane concentration in air in the uppermost layer, C_{CH4atm} is the concentration in atmosphere ([CH4_AirConc](#)), r_{as} is the aerodynamic resistance above soil surface and ρ_{CH4} is the density of methane.

Oxygen flows

Oxygen flows in the soil profile are treated slightly differently depending on which oxygen flux approach that is used. Oxygen consumption is a result of aerobic plant and microbial respiration in the soil:

$$O_{O_2 \rightarrow CO_2} = o_{ratioC} \cdot \left(C_{Root \rightarrow CO_2} + C_{OldRoot \rightarrow CO_2} + C_{Litter1 \rightarrow CO_2} + C_{Litter2 \rightarrow CO_2} + C_{Humus \rightarrow CO_2} + C_{Faeces \rightarrow CO_2} + C_{Microbe \rightarrow CO_2} \right) \quad (6.90)$$

where o_{ratioC} is the molar ratio between oxygen gas and carbon.

For the steady-state approach the flux of oxygen from one layer (or from the atmosphere) to the layer below, q_{O_2} , is a function of oxygen consumption and oxygen flux in the lower layer:

$$q_{O_2}(z) = \int_{z_b}^z O_{O_2 \rightarrow CO_2} dz \quad (6.91)$$

The concentration of oxygen, O_{O2Conc} , in each layer is calculated as:

$$O_{O_2Conc} = O_{O_2Conc}(z-1) - \frac{q_{O_2}(z-1)/\Delta z}{O_{diffuse}} \quad (6.92)$$

where Δz in this case symbolises the distance from the middle depth of one layer (z) to the middle depth in the layer above ($z-1$). The oxygen concentration of the uppermost soil layer is calculated with the same equation by exchanging $O_{O2Conc}(z-1)$ with the oxygen concentration of the atmosphere, $O_{O2ConcAtm}$, calculated as:

$$O_{O_2ConcAtm} = 0.2095 \cdot o_{ratioair} \cdot \rho_a(T) \quad (6.93)$$

where $o_{ratioair}$ is the molar ratio of oxygen to air and $\rho_a(T)$ is the air density temperature function calculated as:

$$\rho_a(T) = \frac{\rho_a \cdot 293.15}{(273.15 + T)} \quad (6.94)$$

where ρ_a is the density of air at 20°C.

In the dynamic approach oxygen, O_{O2} , is calculated explicitly as:

$$\frac{dO_{O_2}}{dt} = q_{O_2} - O_{O_2 \rightarrow CO_2} \quad (6.95)$$

and the concentration of oxygen, O_{O2Conc} , is calculated as:

$$O_{O_2Conc} = \frac{O_{O_2}}{f_a} \cdot \Delta z \quad (6.96)$$

where Δz is the layer thickness.

The flux of oxygen is calculated as:

$$q_{O_2}(z) = O_{diffuse} \cdot \int_{z_b}^z O_{O_2Conc} dz \quad (6.97)$$

For the uppermost soil layer, this equation is modified into:

$$q_{O_2} = O_{diffuse} \cdot \frac{O_{O_2ConcAtm} - O_{O_2}}{\Delta z/2} \quad (6.98)$$

Volumetric anaerobic soil fraction

The volumetric anaerobic fraction of the soil is calculated as:

$$f_a = e^{-g_{aporshape} \cdot O_{volcons}^2} \quad (6.99)$$

where $g_{aporshape}$ is a shape parameter and $O_{volcons}$ is the volumetric oxygen concentration calculated as:

$$O_{volcons} = \frac{O_{O_2Conc}}{o_{ratioair} \cdot \rho_a(T)} \quad (6.100)$$

where O_{O_2Conc} is the oxygen concentration, $o_{ratioair}$ is the ratio of oxygen to air and $\rho_a(T)$ is the air density temperature function. See viewing function "[Anaerobic volumetric fraction](#)".

Switches

Methane Model

Value	Meaning
Off	No Methane flux is considered
Simplified	A simple Methane model is considered
Detailed	A detailed process oriented model is considered

Methane Emission by Plants

Value	Meaning
Off	
On	

Methane Oxidation by Plants

Value	Meaning
Off	
On	

Oxygen model

Value	Meaning
Steady state	Oxygen is implicit. The consumption of oxygen in lower soil layers is the driving force for vertical oxygen flows in the soil
Dynamic	Oxygen is explicit. The oxygen diffusion rate determines the oxygen flux.

Trace Gas Emissions

Value	Meaning
off	Nitrous trace gas emissions are not simulated.

Direct Loss	Nitrous trace gas emissions are simulated. The gases leave the soil directly when they are formed.
Vertical fluxes in soil	Nitrous trace gas emissions are simulated. The gases are transported through the soil profile to the atmosphere.

Parameters

AnBal ShapeCoef

The shape parameter as a function of oxygen level in the volumetric anaerobic fraction of the soil.

Default	Unit	Symbol	Equation	Function
100	-	$g_{a\text{porshape}}$	(6.99)	“Anaerobic volumetric fraction”

CH4 AerobicOxRate

Default	Unit	Symbol	Equation	Function
4.34	day^{-1}	K_{o_rate}	6.81 (6.81)	

CH4 HalfRateOxConstant

Default	Unit	Symbol	Equation	Function
2.3E-03	-	K_{o_50}	(6.81)	

CH4 RateCoefRatio

Default	Unit	Symbol	Equation	Function
.1	-	d_{m_ratio}	(6.79)	

CH4 AirConc

Default	Unit	Symbol	Equation	Function
1.86E-6		C_{CH4atm}	(6.89)	

CH4 BubbleRateConstant

Default	Unit	Symbol	Equation	Function
0.015	-	k_{bu}	(6.84)	

CH4_EbullThreshold

Default	Unit	Symbol	Equation	Function
8.E-6	-	C_{bul}	(6.84)	

CH4_InitConc

Default	Unit	Symbol	Equation	Function
1.E-4	g/g			

CH4_PlantOxidationRate

Default	Unit	Symbol	Equation	Function
2.2E-03	-	$k_{pox} k_{plant}$	(6.82)	

CH4_PlantOxidationEff

Default	Unit	Symbol	Equation	Function
2.2E-07	-	$\eta_{plantox}$	(6.87)	

CH4_PlantOxShapeCoef

Default	Unit	Symbol	Equation	Function
50.	-	$p_{oxshape}$	(6.83)	3108

CH4_LimitWaterUptake

Default	Unit	Symbol	Equation	Function
1.E-2	-	E_{ta_limit}	(6.86)	3107

CH4_Water_Diff_Coef

Default	Unit	Symbol	Equation	Function
1.29E-4	$m^2 s^{-1}$			

CH4_WaterPlantCoef

Default	Unit	Symbol	Equation	Function
100	-	k_{plant}	(6.85)	3107

CH4_WaterPowerCoef

Default	Unit	Symbol	Equation	Function
2.0	-	p_{CH4_W1}	(6.86)	3107

H_RefTemp

Default	Unit	Symbol	Equation	Function
25	C			3109

HenryCoefTempSens

Default	Unit	Symbol	Equation	Function
-1700	K			3109

HenryStdCoef_cp

Default	Unit	Symbol	Equation	Function
0.0013	Mol/atm			3109

D O2 Tortuosity

The tortuosity parameter in the calculation of oxygen diffusion rate.

Default	Unit	Symbol	Equation	Function
0.66	-	d_{O2}	(6.72)	

IntDiffRedFrac

The oxygen diffusion reduction parameter in the oxygen diffusion exchange function.

Default	Unit	Symbol	Equation	Function
0.01	-	$o_{diffred}$	(6.71)	“ Oxygen diffusion exchange function ”

MaxFracNO

The maximum NO fraction parameter when NO is formed during the nitrification process.

Default	Unit	Symbol	Equation	Function

0.004	-	$g_{mfracNO}$	(6.64)	
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MaxFracN2O

The maximum N₂O fraction parameter when N₂O is formed during the nitrification process.

Default	Unit	Symbol	Equation	Function
0.0006	-	$g_{mfracNO}$	(6.64)	

NO pHCoef

The pH coefficient in the response function for the soil pH in different layer.

Default	Unit	Symbol	Equation	Function
4.7	-	g_{pHcoef}	(6.68)	“pH response function nitrification”

NO RelSatCrit

The relative saturation level in the response function for soil moisture when NO is formed during the nitrification process.

Default	Unit	Symbol	Equation	Function
0.45	-	$g_{\theta satcritNO}$	(6.65)	“Moisture response function nitrification”

NO RelSatForm

The parameter describing the shape of the moisture response function for NO during the nitrification process.

Default	Unit	Symbol	Equation	Function
0.024	-	$g_{\theta satformNO}$	(6.65)	“Moisture response function nitrification”

N2O RelSatCrit

The relative saturation level in the response function for soil moisture when N₂O is formed during the nitrification process.

Default	Unit	Symbol	Equation	Function
0.55	-	$g_{\theta satcritN2O}$	(6.65)	“Moisture response function nitrification”

N2O RelSatForm

The parameter describing the shape of the moisture response function for N₂O during the nitrification process.

Default	Unit	Symbol	Equation	Function

0.24	-	$g_{\theta sat form N2O}$	(6.65)	“Moisture response function nitrification”
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NxO TempMax

The maximum soil temperature for the formation of nitrous trace gases during the nitrification process.

Default	Unit	Symbol	Equation	Function
33.5	°C	$g_{TmaxNxO}$	(6.66),(6.67)	“Temperature response function nitrification”

NxO TempOpt

The soil temperature for the maximum response for the formation of nitrous trace gases during the nitrification process.

Default	Unit	Symbol	Equation	Function
23.5	°C	$g_{ToptNxO}$	(6.66),(6.67)	“Temperature response function nitrification”

NxO TempShape

The parameter describing the shape of the temperature response function during the nitrification process.

Default	Unit	Symbol	Equation	Function
1.5	-	$g_{TshapeNxO}$	(6.66),(6.67)	“Temperature response function nitrification”

NxO TempShape

The parameter describing the shape of the temperature response function during the nitrification process.

Default	Unit	Symbol	Equation	Function
1.5	-	$g_{TshapeNxO}$	(6.66),(6.67)	“Temperature response function nitrification”

Parameter Tables

Initial Gas Concentrations

Name	Default	Unit	Symbol	Comments/Explanations
Init Oxygen Conc	20	-	i_{oxygen}	Initial oxygen concentration.

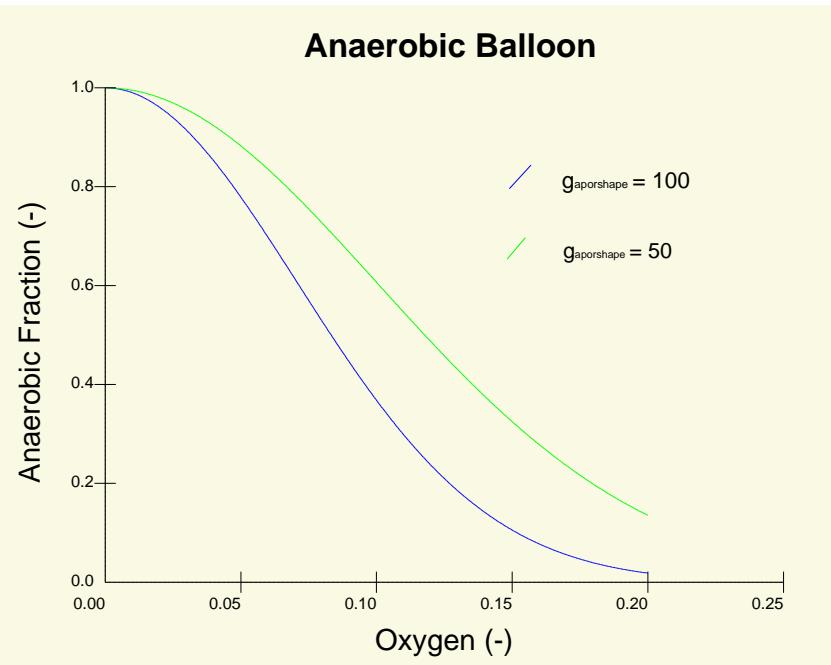
pH Soil Profile

Name	Default	Unit	Symbol	Comments/Explanations

pH value	5	-	$g_{pH}(z)$	Soil pH.
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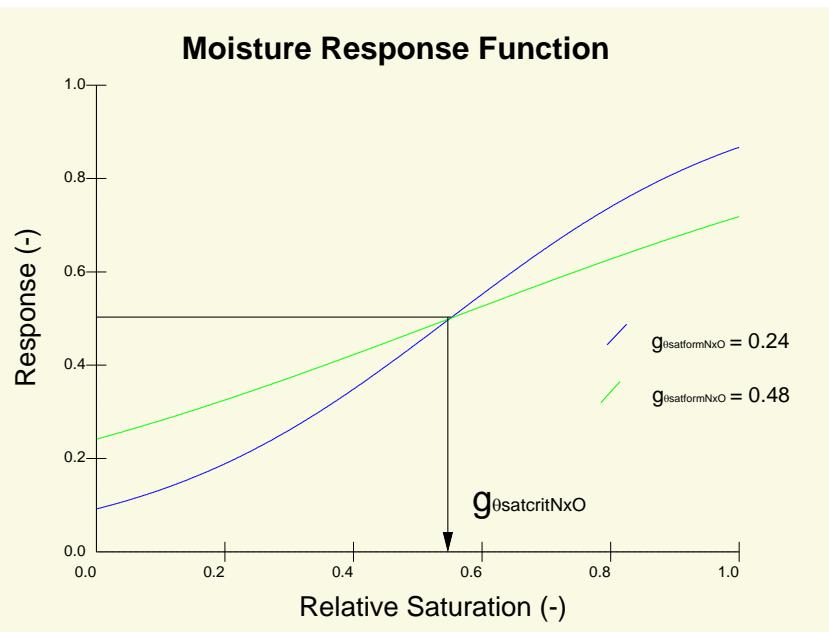
Viewing functions

Anaerobic volumetric fraction



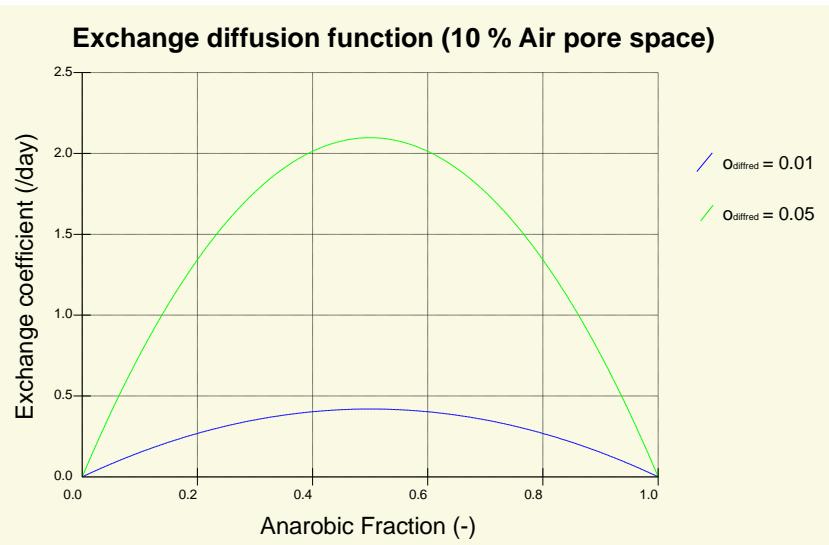
Anaerobic volumetric fraction as a function of oxygen level for two different shape parameter values.

Moisture response function nitrification



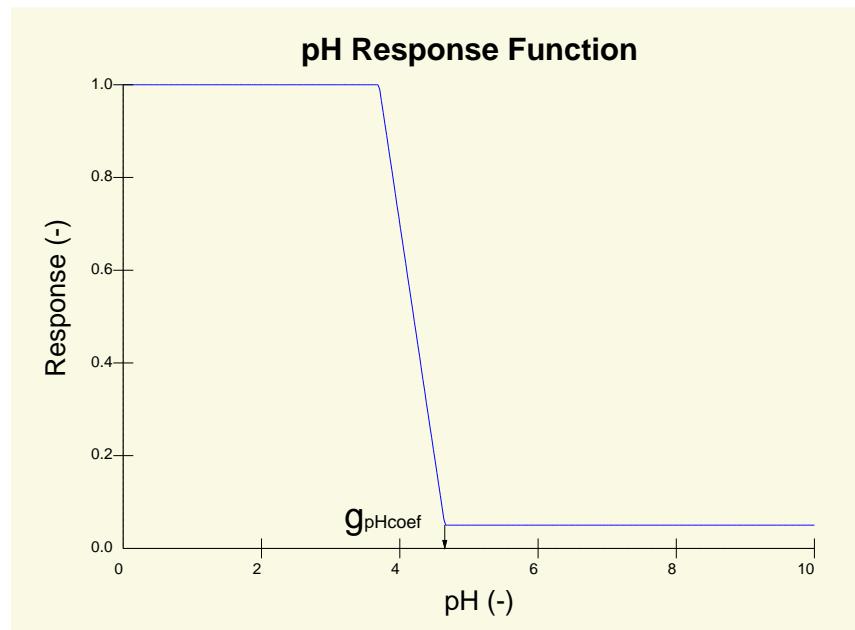
The response function for soil moisture for the formation of nitrous trace gases.
Two different parameter values.

Oxygen diffusion exchange function



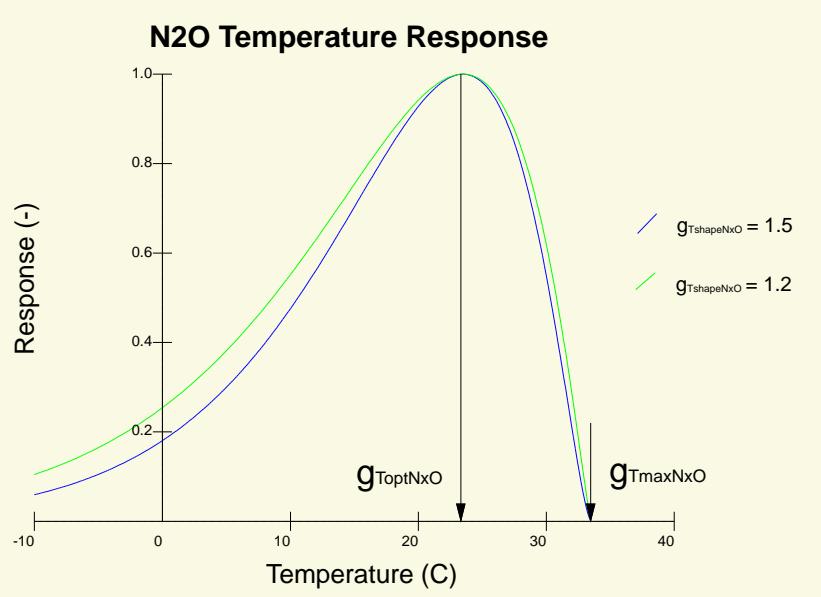
The oxygen diffusion exchange coefficient as a function of anaerobic volumetric fraction for two different diffusion reduction parameter values.

pH response function nitrification



The response function for soil pH for the formation of nitrous trace gases.

Temperature response function nitrification



The response function for soil temperature for the formation of nitrous trace gases. Two different parameter values.

State Variables

Acc CH₄ Bubble Emission

Amount of CH₄ emitted as bubbles from start of simulation.
g/m²

Acc CH4 Plant Emission

Amount of CH₄ emitted from plants from start of simulation.
g/m²

Acc CH4 Emission

Amount of CH₄ emitted from plants from start of simulation.
g/m²

Acc CH4 Production

Amount of CH₄ production from start of simulation.
g/m²

CH4 MassbalanceCheck

Check of mass balance of CH₄ from start of simulation.
g/m²

Diff CH4 Storage

Difference in methane storage from start of simulation.
g/m²

Nitric Oxide

Amount of NO in the aerobic fraction of soil.
g/m²

Nitrogen gas

Amount of N₂ in the aerobic fraction of soil.
g/m²

Nitrous Oxide

Amount of N₂O in the aerobic fraction of soil.
g/m²

Oxygen

Amount of O₂ in the soil.
g/m²

Flow Variables

CH4 source flux

Production of CH₄ from soil layer (i).
g/m²/day

CH4 sink flux

Flux of CH₄ to soil layer (i), the sum of aerobic oxidation and plant oxidation.
g/m²/day

CH4 soil water flux

Water flux of CH4 from soil layer (i) to soil layer (i+1).
g/m²/day

CH4 soil air flux

Air flux of CH4 from soil layer (i) to soil layer (i+1).
g/m²/day

CH4 surface emission

Emission of CH4 from uppermost soil layer to atmosphere.
g/m²/day

CH4 ebullition rate

Flux of CH4 from soil layer (i) as ebullition.
g/m²/day

CH4 plant diffusion

Flux of CH4 from soil layer (i) as diffusion through plants.
g/m²/day

CH4 aerobic oxidation

CH4 aerobic oxidation rate in soil layer (i).
g/m²/day

CH4 plant oxidation

CH4 as plant oxidation rate in soil layer (i).
g/m²/day

Nitric oxide internal exchange

Flux of nitrogen from anaerobic to aerobic NO pools.
g/m²/day

Nitric oxide Nitrification

Flux of nitrogen from NO₃ to NO during nitrification.
g/m²/day

Nitric oxide Soil Flux

Vertical flux of NO through the soil profile.
g/m²/day

Nitrogen internal exchange

Flux of nitrogen from anaerobic to aerobic N₂ pools.
g/m²/day

Nitrogen Soil Flux

Vertical flux of N₂ through the soil profile.
g/m²/day

Nitrous oxide internal exchange

Flux of nitrogen from anaerobic to aerobic N₂O pools.
g/m²/day

Nitrous oxide Nitrification

Flux of nitrogen from NO₃ to N₂O during nitrification.
g/m²/day

Nitrous oxide Soil Flux

Vertical flux of N₂O through the soil profile.g/m²/day

NO emission rate

Emission of NO from the soil to the atmosphere.
g/m²/day

N2 emission rate

Emission of N₂ from the soil to the atmosphere.
g/m²/day

N2O emission rate

Emission of N₂O from the soil to the atmosphere.
g/m²/day

Oxygen Consumption

Oxygen consumption in soil by aerobic respiration processes.
g/m²/day

Oxygen Flux

Vertical flux of oxygen through the soil profile.
g/m²/day

Oxygen Flux Infil

Oxygen input from the atmosphere to the uppermost soil layer.
g/m²/day

Auxiliary Variables

Air Porosity

Percent of air filled pores in the soil.
%

An VolFraction

Volumetric anaerobic fraction of the soil.

-

Oxygen Concentration

Concentration of oxygen in the soil.
%

Common Characteristics

Run Options

Run options are used to specify the time step, the temporal representation of output variables and the period for the simulation.

Run number

May be set to any integer between 1 and 999. The run number is incremented after each run and stored in the register of the computer. If you change the number you will also change the number for next run.

Start date

The start of a simulation is specified by Year, Month, Day, Hour, and Minute.

End date

End of a simulation is specified similar as the start.

Scaling of time period

The simulated time period can be scaled so that a longer time period can be simulated. A scaling factor “Factor to extend period outside above specified” determines how many consecutive times the simulation will be run. Dates and plant age will be counted as if time was passing by normally, and driving variables will be read from beginning to end of the originally determined time period (i.e. as specified by start date and end date) for as many times as have been set by the scaling factor.

Output interval

The output interval determines how frequently the output variables will be written to the output file. The actual representation of the requested output variables can either be a mean value of the whole time interval or the actual value at time of output (see the switches, AVERAGEX, ..T, ..G, ..D). You can specify the output interval as integers with units of days and/or minutes.

No of iterations

The time step must be small enough to avoid numerical problems but still large enough to minimize the total CPU-time consumption. A strong influence of compartment sizes, soil properties and boundary conditions sometimes make the choice difficult. To handle the influence of shifting boundary conditions the default time step may be changed during the simulation according to values specified to parameters in the group [Numerical](#). To avoid truncation errors you should

specify a number of iterations with a number that could be represented exactly in a binary form, e.g. make use of the series 2, 4, 8, 16, 32, 64, 128, ... Remember that the relationship between compartment size and the time step is quadratic, i.e., in case a stable solution exist with 128 iterations and 5 cm thick layers you can reduce the number of iterations to 32 if you increase the thickness to 10 cm. Also remember that you normally can increase the compartment size with increasing depths in your profile because of the slower rates of water and heat flows deeper in the soil. 1. Do not confuse time step with Time resolution (the resolution of model output).

Time Resolution

Value	Meaning
Within day resolution	Driving variables will be read from input file (if defined) at each iteration as specified by the time step of the specific run.
Daily mean values	Driving variables will be read from input file at one occasion only for each day. The input PGraph-structured file is read 00:00 each day and the time point is assumed to be set to 12:00 in the driving variable file. If you have observations once a day, you should chose this setting.
Hourly mean values	Driving variables will be read from input file at one occasion every hour. If you have observations once an hour, you should chose this setting.
10 minute mean values	Driving variables will be read from input file at one occasion every 10 minutes. If you have observations once every 10 minutes, you should chose this setting.

Experience show that “Hourly mean values” reduces the numerical errors on some occasions (e.g. for the water balance during the summer) in comparison to “Within day”. It is also worth noting that “Hourly mean values” resolution reduces the number of eligible options in the simulation.

Run identifier

Any string of characters may be specified to facilitate the identification of your simulation in addition to the run number. The identification given will be written in the variable identification field used by the PGraph program. Be careful when using long strings of characters since the default information for identification of a field may be overwritten in some cases.

Comment

Any string of characters may be specified to facilitate the identification of your simulation in addition to the run number. This string will appear in the View window.

Additional abiotic variables

Theory

This section contains a number of variables related to water and heat processes. Accumulative values of different output variables related to the water balance are listed under state variables. The land surface energy balance is explained, followed by a brief description on how the model can be coupled to a grid application.

Land surface energy balance

The total land surface energy balance, i.e. surface energy balance for the combined soil-snow-plant system, is calculated as additional variables:

$$R_{n,tot} = H_{Total} + L_v E_{Total} + G_{Total} \quad (8.1)$$

where $R_{n,tot}$, H_{Total} , and $L_v E_{Total}$ are the sum of net radiation, sensible heat flux, and latent heat flux for bare soil, snow, and plants, respectively. G_{Total} is the sum of surface heat flux to soil and snow including the latent heat in precipitation. It is not an output in the model yet, but can be calculated as $R_{n,tot} - H_{Total} - L_v E_{Total}$.

Different numerical methods are used to solve the surface energy balance for plants, snow, and bare soil. The dynamic coupling between surface temperature, heat fluxes, and net radiation is only used for the bare soil surface (see section “[Evaporation from the soil surface](#)”) and for the snow surface (see section “[Snow Dynamics](#)”). Evaporation from plants, i.e. transpiration and evaporation of intercepted water, is calculated with the analytical Penman-Monteith equation (see chapter “[Potential transpiration](#)”). Sensible heat flux and corresponding surface temperatures of the vegetation are calculated based on the residual term of the energy balance for the vegetation, assuming that the vegetation has zero heat capacity.

In case of multiple plants, the sensible heat flux from each plant, H_j , is calculated as:

$$H_j = R_{n,j} - L_v E_j \quad (8.2)$$

where $R_{n,j}$ is the net radiation, and $L_v E_j$ is the latent heat flux corresponding to the sum of actual transpiration and interception evaporation (see sections “[Water uptake by roots](#)” and “[Interception](#)”). The corresponding difference between plant and air temperature ΔT_j is calculated by inverting the bulk aerodynamic equation for sensible heat flux:

$$\Delta T_j = \frac{r_{a,j}}{\rho_a c_p} H_j \quad (8.3)$$

where $r_{a,j}$ is the plant aerodynamic resistance and ρ_a and c_p are constants.

The plant surface temperature, T_j , is used for the calculation of net radiation the next time step. To reduce the risk of numerical instability, a recursive filter is applied on the temperature difference before calculating the actual plant temperatures:

$$\Delta T_j^t = 0.8 \cdot \Delta T_j^{t-1} + 0.2 \cdot \Delta T_j^t \quad (8.4)$$

$$T_j = T_a + \Delta T_j \quad (8.5)$$

Coupling the CoupModel to a grid application

When coupling the model to a grid application to do point simulations, it can be useful to keep track of the x, y and z coordinates, as well as the scale of the grid net. The parameters g_x , g_y , g_z and g_{scale} are used for this purpose.

Parameters

These parameters, found under “Abiotic oriented parameters”, are only included to attach simulated results with spatial information. Especially for the use of the multiple run options these parameters are recommended for use.

Spatial_Scale

Default	Unit	Symbol	Equation	Function
0	m	g_{scale}		

X-coordinate

Default	Unit	Symbol	Equation	Function
0	m	g_x		

Y-coordinate

Default	Unit	Symbol	Equation	Function
0	m	g_y		

Z-coordinate

Default	Unit	Symbol	Equation	Function
0	m	g_z		

Parameter tables

This table is found under “Abiotic parameter tables / Soil Profile” in the model.

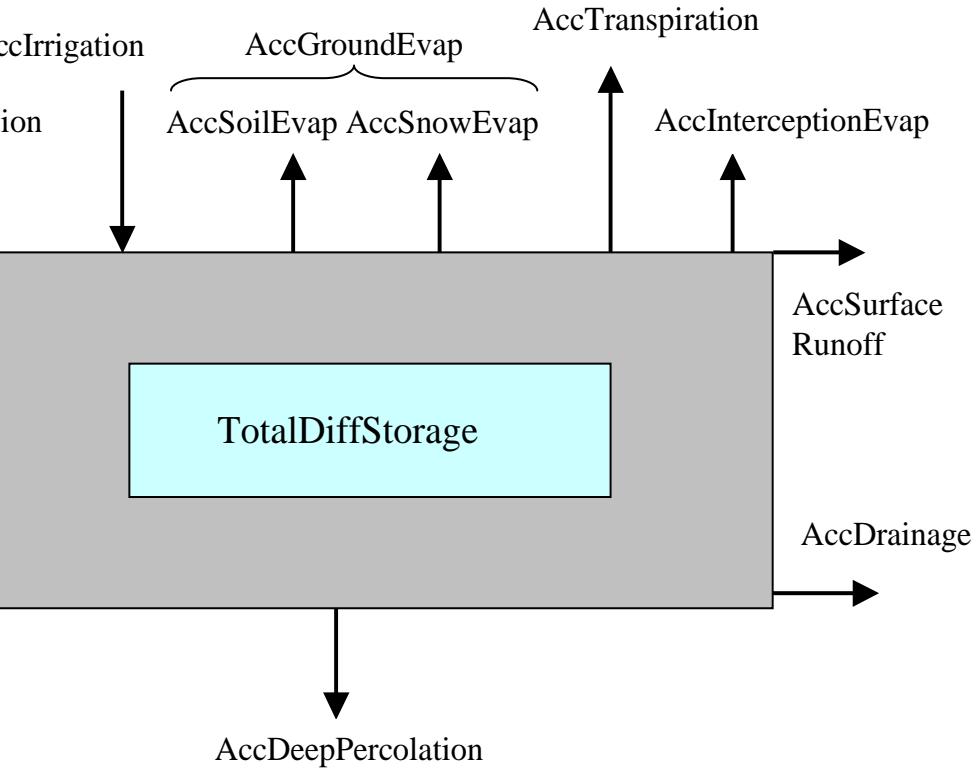
Depths of Sonds

Default No. of elements in Table: 10

Name	Default	Unit	Symbol	Comments/Explanation
Depth	0.2	m	Δz	Thickness of soil depth. The depth is specified from the soil surface down to the value specified for each depth in the table. The Correspondent output variables are: Acc WStorage , Acc Salt Storage , Acc NH4 Storage , Acc NO3 Storage and Acc MinN Storage .

State variables

Of all the additional variables many are accumulated values that can be used to create balances together with the storage differences. Total balance check is the sum of the accumulated inflows and ouflows compared with the storage, and should optimally be zero. [Figure 6.1](#) shows the water balance that can be created from these variables.



WaterBalanceCheck

Figure 6.1. Water balance created from outputs.

AccGroundEvap

The accumulated soil and snow evaporation from the ground. From this variable the accumulated soil evaporation can be estimated.

mm

AccGroundEvapAndTransp

The accumulated ground (soil + snow) evaporation and transpiration. From this variable the accumulated transpiration can be calculated.

mm

AccPrecipitation

The accumulated precipitation to the soil surface including snow adjustment from measured snow depth.
mm

AccPrecandIrrig

The accumulated precipitation and irrigation to the soil surface. Together with the AccPrecipitation the AccIrrigation can be estimated.

mm

AccSoilEvap

The accumulated soil evaporation from the soil surface.
mm

AccSurfaceRunoff

The accumulated surface runoff from the profile. A negativ value indicates a net inflow of water into the soil profile.
mm

AccTotalEvap

The accumulated soil evaporation, snow evaporation, transpiration and interception evaporation. This variable together with the AccGroundEvapAndTransp gives the AccInterceptionEvap.
mm

AccTotalRunoff

The accumulated total runoff from the whole profile. This variable subtracted from acc surface runoff gives the accumulated drainage plus the accumulated deep percolation.
mm

TotalDiffStorage

The total difference in water storage in the soil and the plant (if water storage in the plant is explicitly considered).
mm

WaterBalanceCheck

This value is the sum of the inflows subtracted by the outflows and compared with the difference in water storage.
Ultimately this value should be zero.
mm

Auxiliary Variables

Evapotranspiration

Total evaporation and transpiration (including evaporation from snow).
mm/day

MC_TempCanopy

Temperature of individual canopies when simulating multiple plants.
°C

TempCanopy

Temperature of the canopy if only one plant is simulated.
°C

TotalLatentFlow

The total latent heat flow from the soil, snow and plant.
J/day

TotalSensibleFlow

The total sensible heat flow from the soil, snow and plant.
J/day

Acc_WStorage

The Total amount of water (mm water) from the soil surface down to the depth specified by the parameters in the table [Depths of Sonds](#).

Acc Salt Storage

The Total amount of Salt (g/m^2) from the soil surface down to the depth specified by the parameters in the table [Depths of Sonsds](#).

Acc NO₃ Storage

The Total amount of nitrate (gN/m^2) from the soil surface down to the depth specified by the parameters in the table [Depths of Sonsds](#).

Acc NH₄ Storage

The Total amount of ammonium (gN/m^2) from the soil surface down to the depth specified by the parameters in the table [Depths of Sonsds](#).

Acc MinN Storage

The Total amount of mineral N (nitrate+ammonium) in gN/m^2 from the soil surface down to the depth specified by the parameters in the table [Depths of Sonsds](#).

Additional Biotic Variables

State variables

Of all the additional variables many are accumulated values that can be used to create nitrogen and carbon balances together with the storage differences (see [Figure 6.2](#) and [Figure 6.3](#)). Total balance check is the sum of the accumulated inflows and ouflows compared with the storage, and should optimally be zero.

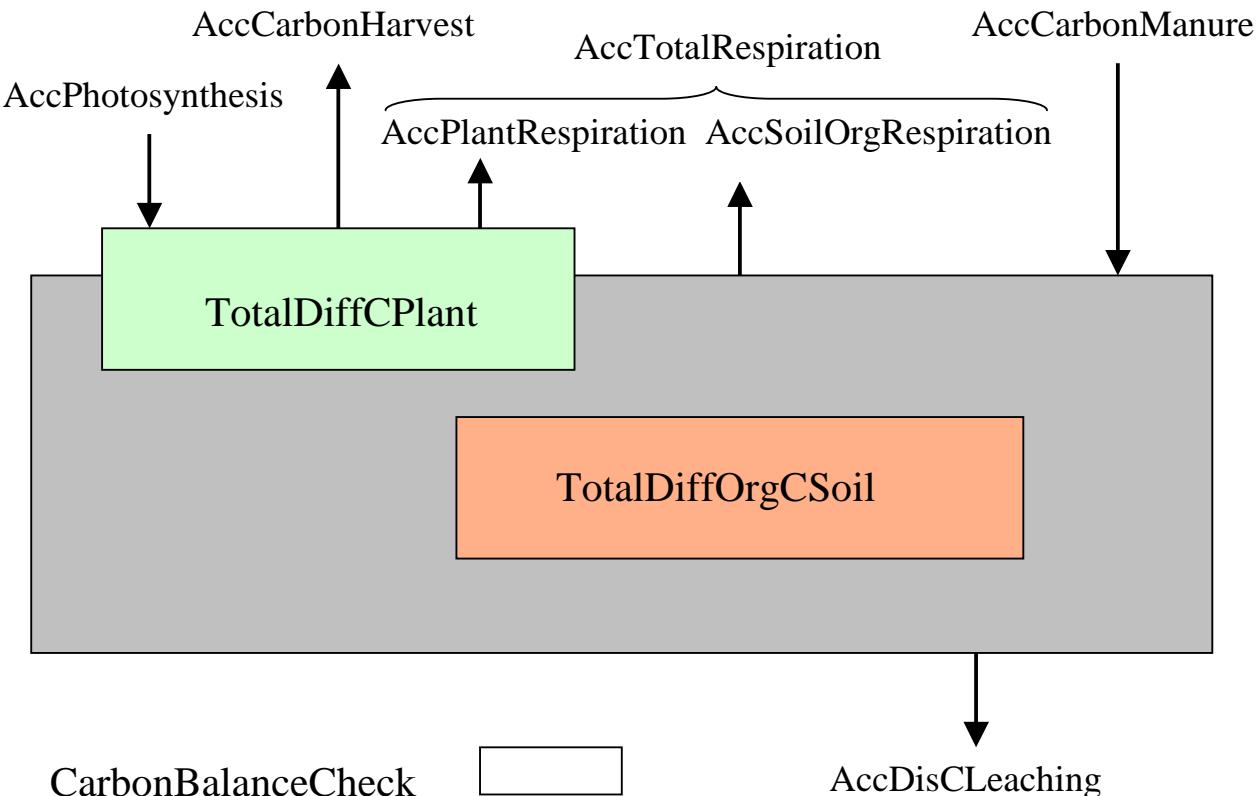


Figure 6.2. Carbon balance created from outputs.

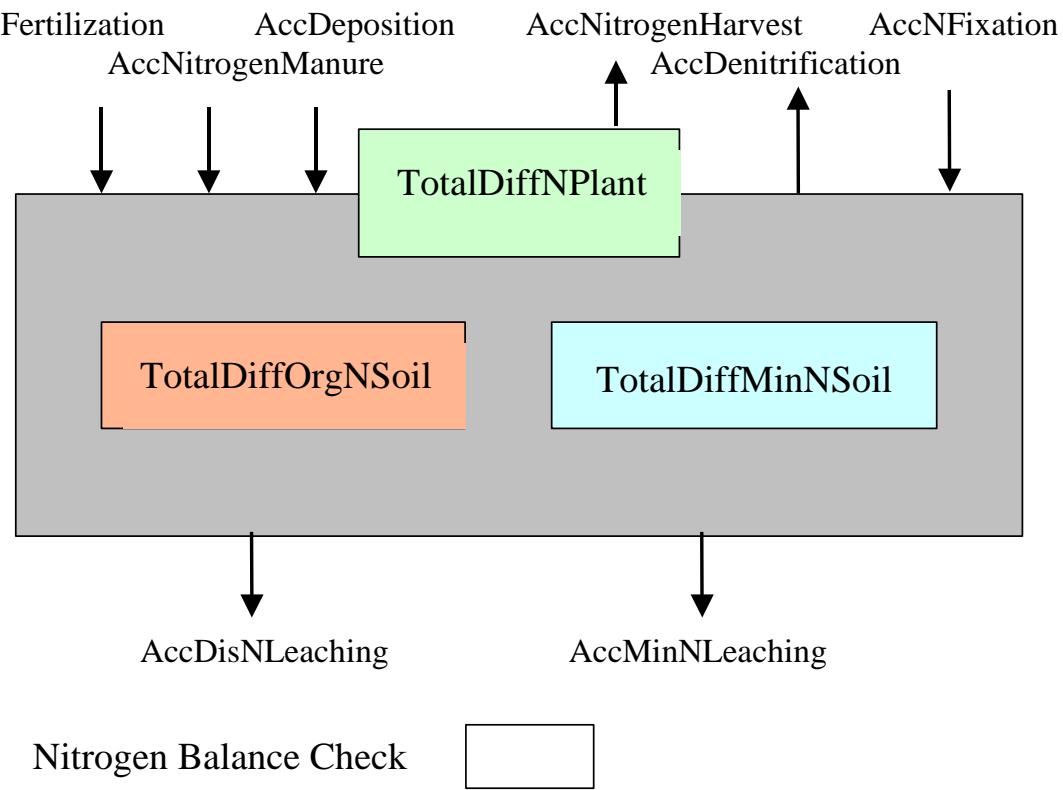


Figure 6.3. Nitrogen balance created from outputs.

AccCarbonBalance

The accumulated amount of carbon in the inflow to the soil profile subtracted by the carbon in the outflow.
gC

AccCarbonHarvest

The accumulated amount of carbon in harvest.
gC

AccCarbonManure

The accumulated amount of carbon in manure, not yet added to the model.
gC

AccDenitrification

The accumulated amount of denitrification of nitrogen.
gN

AccDeposition

The accumulated amount of nitrogen to the profile from deposition.
gN

AccDisCLeaching

The accumulated amount of dissolved organic carbon leaching from the soil profile.
gC

AccDisNLeaching

The accumulated amount of dissolved organic nitrogen leaching from the soil profile.
gN

AccFertilization

The accumulated fertilization to the soil surface.
gN

AccMinNLeaching

The accumulated amount of mineral nitrogen leaching from the soil profile.
gN

AccNFixation

The accumulated amount of nitrogen fixation.
gN

AccNitrogenHarvest

The accumulated amount of nitrogen in harvest.
gN

AccNitrogenManure

The accumulated amount of nitrogen in manure.
gN

AccPhotosyntheses

The accumulated amount of assimilated carbon from photosynthesis.
gC

AccPlantRespiration

The accumulated amount carbon from plant respiration including root respiration.
gC

AccSoilOrgRespiration

The accumulated amount carbon from soil organic respiration excluding root respiration.
gC

AccSoilRespiration

The accumulated amount carbon from soil respiration from the soil organics and the roots.
gC

AccTotalRespiration

The accumulated amount carbon from soil and plant respiration.
gC

CarbonBalanceCheck

This value is the sum of the inputs subtracted by the outputs of carbon to the profile, compared with the difference in carbon storage in the system. Ultimately this value should be zero.

gC

NitrogenBalanceCheck

This value is the sum of the inputs subtracted by the outputs of nitrogen to the profile, compared with the difference in nitrogen storage in the system. Ultimately this value should be zero.

gN

TotalDiffCHumus

The total difference in carbon storage in the humus pool.

gC

TotalDiffCPlant

The total difference in carbon storage in the plant.

gC

TotalDiffMinNSoil

The total difference in mineral nitrogen storage in the soil.

gN

TotalDiffNHumus

The total difference in nitrogen storage in the humus pool.

gN

TotalDiffNPlant

The total difference in nitrogen storage in the plant.

gN

TotalDiffOrgCSoil

The total difference in organic carbon storage in the soil.

gC

TotalDiffOrgNSoil

The total difference in organic nitrogen storage in the soil.

gN

Flow Variables

CarbonBalanceRate

Photosynthesis subtracted by total respiration from the soil and the plant.

gC/day

Meteorological data

Theory

Driving variables are variables that are the driving forces for water, heat, nitrogen and carbon fluxes in the CoupModel. These variables are for example meteorological data that varies over the period that is simulated. The model can be run in several simulation modes depending on the purpose of the simulation. Each mode has its own requirements for driving variables.

The most common simulation mode, thus far, has been to simulate, on an annual basis, both soil heat and water flows in a natural, vegetated soil. This mode requires the input of the following meteorological variables once a day: Precipitation, air temperature, relative humidity, wind speed, net radiation and global, shortwave radiation. Ideally, these variables should be measured at a reference height above vegetation, but being daily sums or averages, it will commonly be sufficient to use data from a nearby standard meteorological network station. If, by chance, a reliable measure of potential transpiration can be given, this measure will substitute relative humidity, wind speed and net radiation.

If, on the other hand, some of the driving variables are not measured, they can be substituted by analytical expressions or they can be deduced from other measurements. Global radiation can be substituted by degree of cloudiness or duration of bright sunshine. Relative humidity, wind speed and cloudiness could each be substituted by parameter values representing average conditions for longer time periods. Net radiation can be substituted by global radiation. The minimum requirement to produce realistic results from simulations of annual heat and water flows is to have only measured precipitation and air temperature.

Precipitation

Precipitation can optionally be given as a series of pulses, with regular frequency and specified pulse height, as determined by the switch “[PrecInput](#)”, (see viewing function “[Precepitation generator](#)”). Normally, however, it is given as a measured timeseries. Measured precipitation, P_m , is almost always less than the ”true” value, P , primarily because of wind losses. These losses are more pronounced for snowfall than for rain. An acceptable long term, average, correction can be given by multiplying the measured value by a constant fraction, different for rain and snowfall:

$$P = (c_{rain} + Q c_{snow}) P_m \quad (8.6)$$

For Swedish conditions, the Swedish Meteorological and Hydrological Institute (SMHI) recommends a rain correction of 7% and a snow correction of 15%, meaning that $c_{rain} = 1.07$ and $c_{snow} = 0.08$.

Air temperature

Air temperature is normally supplied as a measured value, sometimes being the average of a night- and a daytime temperature (see “[TempAirInput](#)”). In this case it is altitude corrected by the parameters “[AltMetStation](#)”, “[AltSimPosition](#)” and “[TairLapseRate](#)” (see viewing function “[Air temperature affected by altitude](#)”). Air temperature can also be given an analytical form:

$$T_a = T_{amean} - T_{aamp} \cos\left(\frac{t - t_{ph}}{y_{cycle}} 2\pi\right) \quad (8.7)$$

which, with correct choices of parameters T_{amean} , T_{aamp} , T_{ph} and y_{cycle} , can properly represent both diurnal and annual variations. y_{cycle} is the air temperature cycle determined by the switch “[TempAirCycle](#)”. See viewing function “[Air temperature day number function](#)”.

Air Humidity

The measured air humidity can either be expressed as relative humidity, h_r , as wet bulb temperature (i.e. the temperature where the relative humidity is 100%), T_{bulb} , or as the actual vapour pressure, e_a (see “[VapourAirInput](#)”). Wet bulb temperature is converted to actual vapour pressure, e_a , by:

$$e_a = e_s(T_{bulb}) - (T_a - T_{bulb}) \cdot \gamma \quad (8.8)$$

where e_s is the saturated vapour pressure, T_a is air temperature and γ is the psychrometric constant.

If the humidity is not supplied as measured time series, a constant value of the relative humidity can be specified as a parameter (see “[HumRelInput](#)”). The vapour pressure, e_a , will be calculated from air temperature if the relative humidity is used and from the vapour pressure, e_a , the vapour pressure deficit, δe , is calculated:

$$e_a = \frac{h_r}{100} e_s(T_a) \quad (8.9)$$

and

$$\delta e = e_s(T_a) - e_a \quad (8.10)$$

The saturated vapour pressure function, $e_s(T_a)$, is defined by:

$$e_s(T_a) = \begin{cases} 10^{\left(12.5553 - \frac{2667}{T_a + 273.15}\right)} & T_a \leq 0 \\ 10^{\left(11.4051 - \frac{2353}{T_a + 273.15}\right)} & T_a > 0 \end{cases} \quad (8.11)$$

where e_s is calculated in (Pa) and T_a in °C.

Wind speed above canopy

Wind speed is normally supplied as a measured time series but it can be substituted by a constant parameter value if it is not available (see switch “[WSpeedInput](#)”). Wind speeds less than 0.1 mm/s are rejected and replaced by this lower limit. If the wind speed is given at another reference height than the air temperature and air humidity, it can be estimated at the reference height of air temperature – if the switch “Stability Correction” is set to *Monin-Obukhov Length*.

Slope

The soil profile is considered flat by default. By giving a value larger than zero to any of the parameters “Slope W-E” or “Slope N-S” will include a slope in the simulation.

SweClim climatic simulations

The CoupModel can be linked to data from SweClim (a Swedish climatic change project) to run climate change scenarios (see switch “[SweClimScenarios](#)”). However, this requires that the data file(s) “RCAO_*.Par”, containing various coefficients, is put in the present working directory. These files can possibly be retrieved on request from SweClim. In addition, a SweClim region should be chosen according to [Figure 6.4](#) (see switch “[SweClimRegions](#)”).

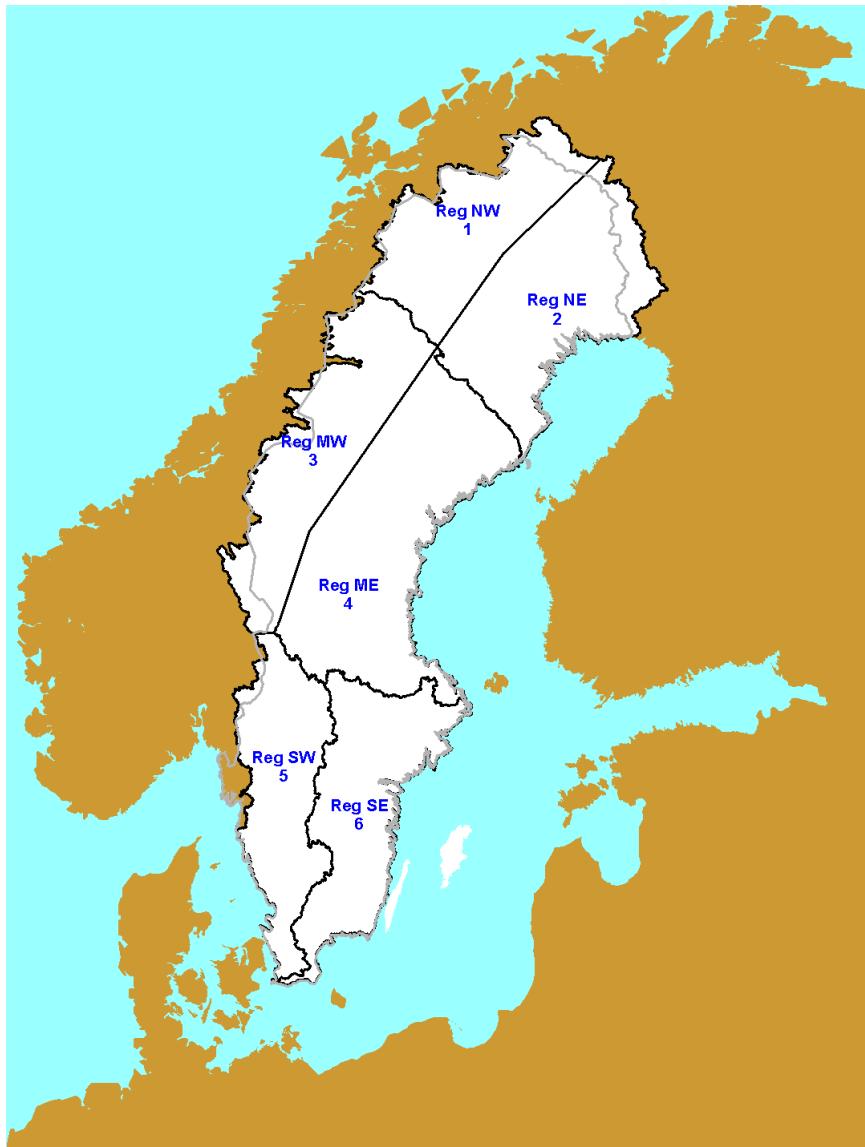


Figure 6.4 SweClim regions..

In these scenarios, it is possible to alter precipitation:

$$P = p_{coef} \cdot P_{SweC} \cdot P_{normal} \quad (8.12)$$

where p_{coef} is a precipitation coefficient retrieved from the SweClim file, P_{SweC} is an optional precipitation correction factor and P_{normal} is the precipitation calculated by equation (8.6).

Similarly, it is possible to alter the air temperature:

$$T_a = t_{coef} + t_{SweC} + T_{normal} \quad (8.13)$$

where t_{coef} is an air temperature coefficient retrieved from the SweClim file, t_{SweC} is an optional air temperature correction factor and T_{normal} is the air temperature calculated by equation (8.7).

Switches

These switches are found under “Technical options / Meteorological data” in the model.

CloudInput

Value	Meaning
Estimated	Estimated from radiation input (global radiation).
Generated by parameters	Cloudiness will be given by the parameter CloudMean.
Read from PG-file	Identified by CLOUD in the PG-Bin File.

CommonRefHeight

Value	Meaning
No	Different measuring heights for temperature/humidity and wind speed are used. See parameter ReferenceHeightWind and ReferenceHeightTemp .
Yes	The same measuring height is used for temperature, humidity and wind speed. See parameter ReferenceHeight .

DBSunInput

Value	Meaning
Not used	Not used in the simulation.
Read from PG-file	Identified by DBS in the PG-Bin File.

HumRelInput

Value	Meaning
Generated by parameters	The relative humidity will be given by the parameter HumRelMean.
Read from PG-file	Identified by HUM or HR in the PG-Bin File. Alternatively, the humidity may be given as a vapour pressure (see VapourAirInput).

PotTranspInput

Value	Meaning
Generated by parameters	Potential transpiration may be defined from the parameters EPMaxRate, EPMaxDay and EPPPeriod. See section “Plant Water Processes”.
Read from PG-file	Identified by POTEN or EPOT in the PG-Bin File. See section “Plant Water Processes”.

PrecInput

Value	Meaning

Generated by parameters	Precipitation may be generated by using the PrecRate and PrecFreq parameters.
Read from PG-file	Identified by PREC in the PG-Bin File.

RadGlobInput

Value	Meaning
Estimated	Will normally be estimated from cloudiness or duration of bright sunshine if not specified.
Read from PG-file	Identified by RIS in the PG-Bin File.

RadInLongInput

Value	Meaning
Estimated	From net radiation and outgoing long wave radiation and net short wave radiation.
Read from PG-file	Identified by RIL in the PG-Bin File.

RadNetInput

Value	Meaning
Estimated	Will normally be estimated from net short wave radiation and a Brunt type of formula for the long wave radiation.
Read from PG-file	Identified by RNT or RAD and NET in the PG-Bin File.

SweClimRegions

Value	Meaning
N-W	SweClim region north-west (see Figure 6.4).
N-E	SweClim region north-east (see Figure 6.4).
M-W	SweClim region middle-west (see Figure 6.4).
M-E	SweClim region middle-east (see Figure 6.4).
S-W	SweClim region south-west (see Figure 6.4).
S-E	SweClim region south-east (see Figure 6.4).

SweClimScenarios

Value	Meaning
No	SweClim scenarios are not included in the simulations.
HadAM3_A2	Scenario HadAM3_A2.

HadAM3_B2	Scenario HadAM3_B2.
ECHAM4_A2	Scenario ECHAM4_A2.
ECHAM4_B2	Scenario ECHAM4_B2.

TempAirCycle

Value	Meaning
Diurnal	A diurnal temperature cycle is assumed when interpreting the input of air temperature parameters that may also be used to estimate the lower boundary condition.
Annual	Note that an annual cycle is the default for cases when the WaterEq switch is turned on.

TempAirInput

Value	Meaning
Generated by parameters	Air temperature may be given from the parameters TempAirMean, TempAirAmpl and TempAirPhase.
Read from PG-file	Identified by TEMPERATURE and AIR in the PG-Bin File.

TempSurfInput

Value	Meaning
Not used	The surface temperature is normally an output variable and is only in some special cases used as an input.
Read from PG-file	Identified by TEMPERATURE' and SURFACE (e.g. 'SURFACE TEMPERATURE' in the PG-Bin File).

VapourAirInput

Value	Meaning
As relative humidity	The vapour pressure will be calculated from the relative humidity (see HumRelInput).
Read as pressure, PG-file	Identified by VAPOUR in the PG-Bin File.
Read as wet bulb, PG-file	Identified by VAPOUR in the PG-Bin File.

WSpeedInput

Value	Meaning
Generated by parameters	The wind speed will be the value of the parameter WindspeedMean.
Read from PG-file	Identified by WIND in the PG-Bin File.

Parameters

These parameters are found under “Abiotic parameters / Meteorological data” in the model.

AltMetStation

Altitude of meteorological station

Default	Unit	Symbol	Equation	Function
0	-	e_{levmet}		“ Air temperature affected by altitude ”

AltSimPosition

Altitude of simulated site

Default	Unit	Symbol	Equation	Function
0	-	e_{levsim}		“ Air temperature affected by altitude ”

CloudFMean

Average cloudiness

Default	Unit	Symbol	Equation	Function
0.7	-	n_c		

HumRelMean

Average relative humidity

Default	Unit	Symbol	Equation	Function
70	%	h_r	(8.9)	

PrecA0Corr

Wind correction for rain precipitation.

Default	Unit	Symbol	Equation	Function
1.07	-	c_{rain}	(8.6)	

The standard value 1.07 takes account for the aerodynamic error in precipitation measurements, it represents a gauge with wind shelter at 1.5 m height. A value of 1.0 should be used if no adjustments are to be done.

PrecA1Corr

Addition wind correction for snow precipitation.

Default	Unit	Symbol	Equation	Function
0.08	-	c_{snow}	(8.6)	

The value will be uncertain because of both aerodynamic problems and representativeness problems with snow precipitation measurements. A typical value will be around 0.08 which means that precipitation is increased with this fraction when snow only .

PrecFreq

Frequency of synthetic precipitation, as the length of a period (days) with one occurrence with precipitation

Default	Unit	Symbol	Equation	Function
7	days			"Preception generator"

PrecRate

The intensity of synthetic generated precipitation.

Default	Unit	Symbol	Equation	Function
20	mm/day			"Preception generator"

PrecScale

Coefficient used in SweClim simulations to scale precipitation.

Default	Unit	Symbol	Equation	Function
1	-	p_{SweC}	(8.12)	

ReferenceHeight

Height above ground which represent the level for air temperature, air humidity and wind speed. Valid only when a common level is used ([CommonRefHeight](#)).

Default	Unit	Symbol	Equation	Function
2	m	z_{ref}		

ReferenceHeightWind

Height above ground which represent the level for wind speed. Valid when the switch ([CommonRefHeight](#)) is put to no.

Default	Unit	Symbol	Equation	Function
2	m	$z_{ref,u}$		

ReferenceHeightTemp

Height above ground which represent the level for air temperature and air humidity. Valid when the switch ([CommonRefHeight](#)) is put to no.

Default	Unit	Symbol	Equation	Function
2	m	$z_{ref,T}$		

Slope N-S

Slope in North-South direction. Positive values are towards south. A value of unity corresponds to 45 °.

Default	Unit	Symbol	Equation	Function
0.	m/m	p_x		

Slope W-E

Slope in West-East direction. Positive values are towards east. A value of unity corresponds to 45 °.

Default	Unit	Symbol	Equation	Function
0.	m/m	p_y		

TAirLapseRate

Change of air temperature with height. Default value correspond to atmospheric pressure and dry lapse rate.

Default	Unit	Symbol	Equation	Function
0.0056	°C/m			“Air temperature affected by altitude”

TempAddCoef

Temperature coefficient used in the SweClim simulations to alter air temperature.

Default	Unit	Symbol	Equation	Function
0	-	t_{SweC}	(8.13)	

TempAirAmpI

Amplitude of analytical air temperature.

Default	Unit	Symbol	Equation	Function
10.	°C	T_{aamp}		“Air temperature day number function”

TempAirMean

Mean value in the analytical air temperature function.

Default	Unit	Symbol	Equation	Function
10.	°C	T_{amean}		“Air temperature day number function”

Note that the air temperature function may also be used to estimate the lower boundary condition.

TempAirPhase

Phase shift of analytical air temperature.

Default	Unit	Symbol	Equation	Function
0.	days	T_{ph}		“Air temperature day number function”

A zero value implies that the minimum air temperature occurs January 1 (when an annual cycle is assumed) and at 2400 (when a diurnal cycle is assumed.). The unit is in days and a positive value will move the air temperature forward in time.

WindspeedMean

Average wind speed at a site.

Default	Unit	Symbol	Equation	Function
2	m/s	<i>u</i>		

Files

Ground water level

Filename	Variable	Unit	Identifier in PG-file
Ground water level	Ground water Level	m	

Heat pump data

Filename	Variable	Unit	Identifier in PG-file
Heat Pump data	Heat extraction Rate	J/m ² day	

Lateral groundwater inflow

Filename	Variable	Unit	Identifier in PG-file
Lateral GroundWater Inflow	Ground water inflow (for each layer)	mm/day	

Meteorological Data

Filename	Variable	Unit	Identifier in PG-file
Meteorological data	Air temperature	°C	Air Temp, Ta
	Surface temperature	°C	Surface Temp
	Relative humidity	%	Hum
	Vapour Pressure	Pa	Vapour
	Wet bulb temperature	°C	Temp and Wet
	Wind Speed	m/s	Wind
	Precipitation	mm/day	Prec
	Irrigation	mm/day	Irrigation
	Global radiation	J/m ² day	Global or Ris
	Cloudiness	-	Cloud
	Duration of Bright Sunshine	minutes	DBS or Dura and Bright
	Potential transpiration	mm/day	Poten or Epot
	Net Radiation	J/m ² day	Rnt or Net Rad (or Rn)
	Incoming Long wave Radiation	J/m ² day	RIL

Pressure head at lower boundary

Filename	Variable	Unit	Identifier in PG-file
Pressured head at Lower boundary	Pressure Head	cm water (positive value)	

Salt concentration

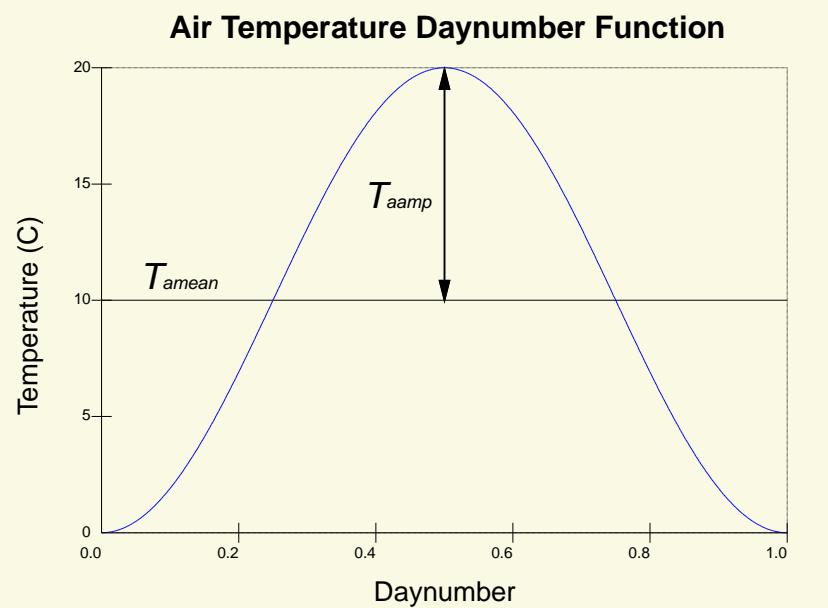
Filename	Variable	Unit	Identifier in PG-file
Salt concentration	Concentration for infiltrating irrigation water or amount of salt for road salt application	mg/l for irrigation mg/m ² for road salt	

Snow depths

Filename	Variable	Unit	Identifier in PG-file
Snow depths	Snow depth	m	

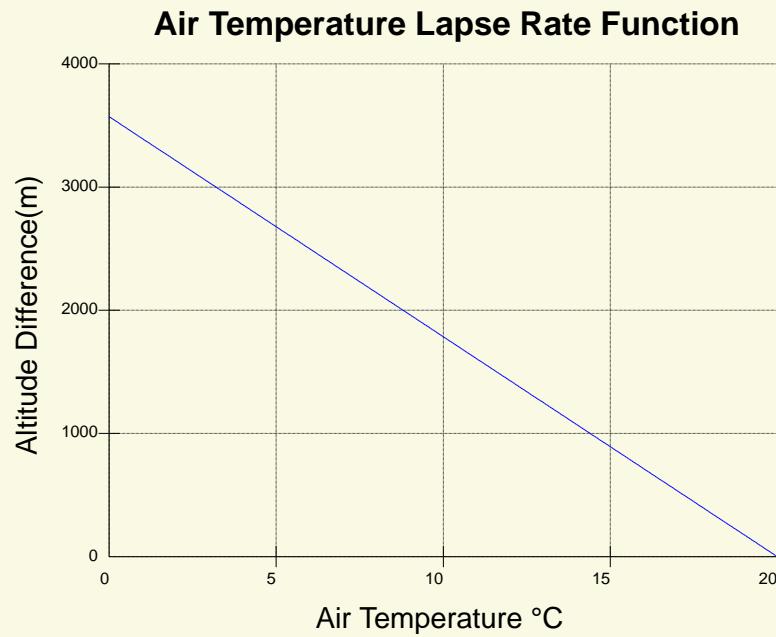
Viewing functions

Air temperature day number function



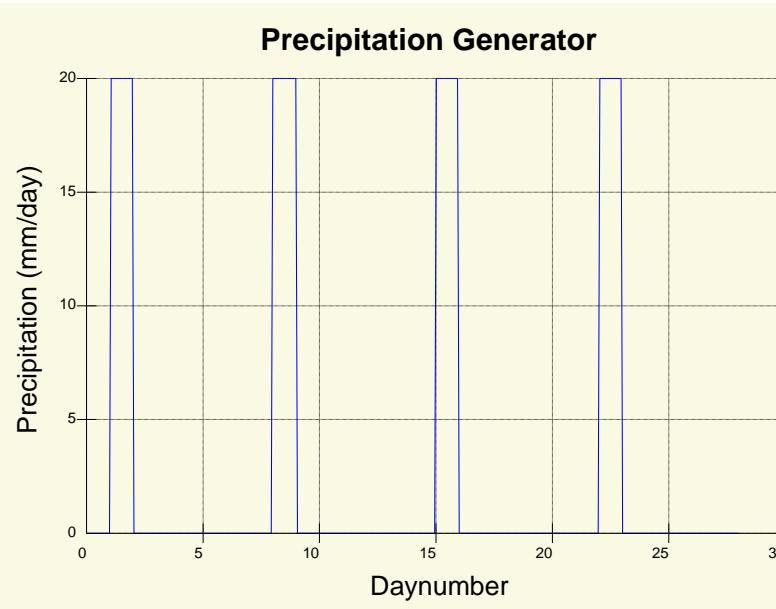
Air temperature as a function of day number. The air temperature phase, T_{ph} , is 0 in the plot.

Air temperature affected by altitude



Air temperature is corrected at high altitudes by a correction parameter “TairLapseRate”, in this case equal to 0.0056.

Precepitation generator



Precipitation generated by parameters as a function of daynumber. The precipitation rate is put to 20 mm/day and the frequency is put to 7 i.e. it will rain every 7th day.

Driving variables

CloudFrac

Cloud fraction.

-

DurBriSunshine

Duration of bright sunshine.
minutes

GlobalRadiation

Global radiation.
J/day

HumidityRelative

Relative humidity.
%

IrrigationRate

Irrigation rate.
mm/day

PotTranspiration

Potential transpiration, implicit single leaf simulations.
mm/day

PrecCorrected

Measured precipitation after corrections.
mm/day

PrecMeasured

Measured precipitation before any corrections are made.
mm/day

RadiationInLong

Incoming long wave radiation.
J/day

RadiationNetTot

Total net radiation.
J/day

TAirDailyMean

Daily mean air temperature after corrections (if any).
°C

TemperatureAir

Air temperature after corrections (if any).
°C

VapourPressureAir

Actual air vapour pressure.
Pa

VapourPressureDef

Air vapour pressure deficit i.e. difference between saturated and actual pressure.
Pa

WindSpeed

Wind speed.
m/s

Wsource

Lateral input of water.
mm/day

Abiotic Driving variables

Theory

The abiotics can optionally be used as driving variables for nitrogen and carbon. This means that there will be no dynamic interaction between abiotics and biotics. There are several switches that regulate if a certain variable should be a driving or not (see below). The default option is “simulated”, which means that the abiotic variable in question will not be a driving variable in the simulation. On the other hand choosing “generated by parameters” or “read from pg-file” makes the abiotic variable a driving, either estimated from parameter values or directly read from a PG bin-file. If all possible abiotic variables are used as drivings the general switch “Nitrogen and Carbon” can be switched to “abiotic driving variables”, which disables a lot of options and parameter settings concerning abiotics that become unnecessary to select or determine when the variables are given elsewhere.

Switches

These switches are found under “Technical Options / Abiotic Driving Variables” in the model.

DeepPercolationInput

Value	Meaning
Generated by parameters	A constant value as given by the parameter DeepPercolation .
Not used	No deep percolation considered.
Read from PG file	Value will be read from file: Abiotic Soil data .
Simulated	Values are simulated.

SoilDrainageInput

Value	Meaning
Generated by parameters	A constant value as given by the parameter SoilDrainage .
Not used	No drainage is considered.
Read from PG file	Value will be read from file: Abiotic Soil data .
Simulated	Values are simulated.

SoilInfillInput

Value	Meaning
Generated by parameters	A constant value as given by the parameter SoilInfiltration .
Read from PG file	Value will be read from file: Abiotic Soil data .
Simulated	Values are simulated.

SoilTempInput

Value	Meaning
Generated by parameters	A constant value as given by the parameter SoilTemperature .
Read from PG file	Value will be read from file: Abiotic Soil data .
Simulated	Values are simulated.

SoilWaterFlowInput

Value	Meaning
Generated by parameters	A constant value as given by the parameter SoilWaterFlow .
Read from PG file	Value will be read from file: Abiotic Soil data .
Simulated	Values are simulated.

SoilWaterInput

Value	Meaning
Generated by parameters	A constant value as given by the parameter SoilWaterContent .
Read from PG file	Value will be read from file: Abiotic Soil data .
Simulated	Values are simulated.

WaterStressInput

Value	Meaning

Generated by parameters	A constant value as given by the parameter PlantWaterStress.
Read from PG file	Value will be read from file: Abiotic Soil data .
Simulated	Values are simulated.

Parameters

These parameters are found under “Abiotic parameters / Abiotic driving variables” in the model. They are all used when the corresponding abiotic variable is “generated from parameters”.

DeepPercolation

A contant value of deep percolation rate (time).

Default	Unit	Symbol	Equation	Function
2	mm/day			

PlantWaterStress

A contant value of soil water stress (time)

Default	Unit	Symbol	Equation	Function
0.7	-			

SoilDrainage

A uniform and constant value of soil drainage (depth and time)

Default	Unit	Symbol	Equation	Function
2	mm/day			

SoilInfiltration

A constant value of soil infiltration (time).

Default	Unit	Symbol	Equation	Function
2	mm/day			

SoilTemperature

A uniform constant value of soil temperature (depth and time).

Default	Unit	Symbol	Equation	Function
10	°C			

SoilWaterContent

A uniform constant value of soil water content (depth and time).

Default	Unit	Symbol	Equation	Function
10	vol %			

SoilWaterFlow

A uniform constant value of vertical soil water flow (depth and time).

Default	Unit	Symbol	Equation	Function
2	mm/day			

Files

Abiotic Soil data

Variables	Unit	ID
Soil water flow(NL)	mm/day	WaterFlow
Soil Drainage flow(NL)	mm/day	Drain
Soil Infiltration	mm/day	SoilInfil
Soil deep percolation	mm/day	DeepPerc
Soil water content(NL)	%	SoilWaterContent
Soil temperature(NL)	°C	SoilTemperature
Water stress on growth/Nitrogen uptake	-	RedCTotal

In addition also global radiation and air temperature may be used as driving variables. These two variables are located in the meteorological data.

Driving Variables

NDrvDeepPercolation

Deep percolation of water as a driving variable for nitrogen and carbon fluxes.
mm/day

NDrvDrainage

Water drainage as a driving variable for nitrogen and carbon fluxes.
mm/day

NDrvInfiltration

Water infiltration as a driving variable for nitrogen and carbon fluxes.
mm/day

NDrvSaltStress

Salinity stress as a driving variable for plant growth calculated by the van Genuchten approach in the section on water uptake.

-

NDrvTemperature

Temperature as a driving variable for nitrogen and carbon fluxes.
°C

NDrvTheta

Soil moisture as a driving variable for nitrogen and carbon fluxes.
vol %

NDrvWaterFlow

Soil water flow as a driving variable for nitrogen and carbon fluxes.
mm/day

NDrvWaterStress

Water stress as a driving variable for nitrogen and carbon fluxes.

-

Numerical

Theory

The two partial differential equations for water and heat are solved with an explicit forward difference method (Euler integration). This solution requires the soil profile to be approximated with a discrete number of internally homogeneous layers.

Slowly changing state variables are bypassed and changes of the integration time step are made during simulation to speed up execution times.

Difference approximation of soil heat and water flow equations

To calculate the flow between two adjacent compartments, a finite difference approximation is made. The governing gradients of temperature and total water potential are calculated linearly between the mid points of consecutive compartments. The flow, q , is given by:

$$q_{i,i+1} = k_{i,i+1}(\theta_{i,i+1}) \frac{\phi_i - \phi_{i+1}}{\Delta z_i + \Delta z_{i+1}} \quad (8.14)$$

where i designates the layer number, ϕ the appropriate potential, Δz the layer thickness and k is conductivity as a function of soil moisture, θ .

For water flow the total potential is the sum of both matric potential and the gravity potential. The gravity potential is directed from the soil surface downwards which justify the use of a single ended approximation of the inter-block conductivity between compartments. Thus the water flow may be given as:

$$q_{i,i+1} = k_{i,i+1}(\theta_{i,i+1}) \frac{\psi_i - \psi_{i+1}}{\Delta z_i + \Delta z_{i+1}} + k_{i,i+1}(\theta_i) \quad (8.15)$$

The numerical solution is sensitive to the choice of inter-block conductivity (Haverkamp & Vauclin, 1979). The solution used by the CoupModel is obtained by defining conductivity at the boundary between two bordering compartments. States, and parameters defining conductivities, are assumed to vary linearly between mid points of compartments. Water content at the boundary between two compartments is, thus, given by:

$$\theta_{i,i+1} = \frac{\Delta z_i \theta_{i+1} + \Delta z_{i+1} \theta_i}{\Delta z_i + \Delta z_{i+1}} \quad (8.16)$$

The only exception to this procedure is the gravity generated flow of water which is using the water content of the upper compartment instead of the boundary water content.

Empirical change of time step

Integration time step must be chosen to avoid numerical instabilities in the simulation. With Euler integration one must normally choose the simulation time step equal to the shortest step necessary for the most variable condition. This may result in inconceivably long execution times, if long term simulations are made, even for a moderate compartmentalisation of the soil. Conditional changes of the time step are made during the simulation to avoid such execution times. A base time step is given initially for the simulation, but during conditions of high infiltration rates the time step is substantially decreased. Water flow rates into the top soil layer and into a layer slightly below top soil are used as tests. The occurrence of frost in the soil also decreases the time step.

In addition to conditional changes in integration time step, conditional bypasses are made to cut down execution times. If the changes in some state variable have been below a prescribed limit no flow recalculation is made. This procedure is used for water and heat flow equations separately. Since frost conditions strongly influence both water and heat flows, recalculation of both are made if any change exceeds the limit for either water or heat. Recalculation is made of flows for a number of the upper soil layers. At regular intervals the whole soil profile is updated.

Three classes of input data may be distinguished. Driving variables are the climatic data which govern the model. Initial values are required to define a starting point at a specific time and physical parameters are constants needed to express relevant properties for the different processes in the model. However, some of these properties may be varied with time and this could either be done by using time dependent functions for some of the parameters or by selecting a new value of a certain parameter to be valid at a specified date (CHange parameter option)

Mathematical estimation of stable time step

Will be written soon.

Switches

These switches are found under “Technical Options” in the model.

FindTimeStep

Value	Meaning
No	The model will run directly without trying to find out the suitable time step.
Yes	The model will make three testruns to make an estimate of the appropriate time step to be used.

NitrogenCarbonStep

Value	Meaning
TimeResolution determined	The same value as the time resolution.
As water and heat	The same as time step as in the calculations of water and heat fluxes.
Independent	A value determined by the user (see parameter “ NC Iteration ”).

NumMethod

Value	Meaning

Central Difference	The finite difference approximation will be made according to (8.15) and (8.16) .
Forward Difference	The second term in eq. (8.15) will be based on the conductivity of the uppermost layer instead of the intercompartment value.

TimeStepOption

Value	Meaning
Empirical	The time step will be adjusted based on the empirical estimated based on flow rate and occurrence of frost and shallow groundwater.
Mathematical	The mathematical requirement for stability is used and the time step is based on a certain fraction of this value. See SaftyPerCent .
Constant	No change of time step will be made during the simulation.

Parameters

These parameters are found under “Abiotic parameters / Numerical” in the model.

Calculations of flows and the correspondent updating of state variables can be adjusted during a simulation depending on how the numerical properties changes with certain conditions as rapid change in some critical flows. The parameters for control of these conditions would be thoroughly examined if you need to reduce CPU-time requirements for a simulation. Remember that since the CoupModel uses a simple explicit method for integration, numerical problems are likely to occur if too few iterations are chosen.

Precision

Default	Unit	Symbol	Equation	Function
2	%			

SaftyPerCent

Default	Unit	Symbol	Equation	Function
80	%			

NC Iteration

Time step used for the calculation of nitrogen and carbon processes if the time step has been chosen to be set by the user.

Default	Unit	Symbol	Equation	Function
8	#			

NXADiv

Division factor for recalculation of integration time step during conditions of frost in the soil, heavy infiltration or a shallow ground water the time step will be shortened.

Default	Unit	Symbol	Equation	Function
4	-			

Normal value will be 2 or 4

XNLev

Number of layers for frequent flow recalculations see Xloop.

Default	Unit	Symbol	Equation	Function
10	#	u		

The number of layers will be chosen to shorten simulation CPU-time in case of deep soil profiles. A too small value on XNLev in combination with a high value of Xloop will cause numeric unstable conditions and erroneous results.

Xloop

Recalculation frequency for flows in the whole soil profile

Default	Unit	Symbol	Equation	Function
1	#			

A value of 1 implies that recalculation of flows at each iteration whereas values greater than 1 implies that recalculations only are made ones during a period of XLOOP iterations. The number of layers is given by XNLEV.

Auxiliary Variables

Timestep

Timestep used in the simulations. The 10 logarithm of number of iterations per day.

- (10Log (n/day))

Technical

Theory

Some of the functions described in this section are closely linked to model processes described in the Win Help in the CoupModel.

The switch “[IndexForValidation](#)” governs how validation is done in the model and enables different variables within a certain category (e.g. snow depth, soil evaporation, above ground biomass) in the validation file to be chosen to match an output variable from the model during a multi-run simulation. This is useful if several localities or treatments are simulated and validation variables are listed in the same file. Thus, there might be several measurements within a category (e.g. several measurements of snow depth, each corresponding to a specific locality). First, an first assignment of validation variables has to be made in the “Validation variables” menu. It is important that all variables are assigned (one value per category), that the variables are repeated in a regular structure within the file, and that they are assigned from the top and downwards. Secondly, a number of parameters are used to govern the assignment of variables in subsequent runs. i_{val} is used to specify the order of the variables within a category that will be used each simulation in the multi-run (use the MR button). The number of values entered into this list should correspond to the number of simulations in the multi-run. i_{cat} specifies the number categories and i_{loop} the number of variables within each category.

An example might clarify the multi-run validation procedure. Let's assume that we have measured transpiration and LAI at four different localities. We have set up a multi-run simulation of four runs, each corresponding to a locality, and we want to use our measured transpiration and LAI to validate the simulation. The validation file looks like this: 1 transpN, 2 transpW, 3 transpE, 4 transpS, 5 LAIN, 6 LAIW, 7 LAIE, 8 LAIS. The suffixes represent four directions: north (N), south(S), east(E) and west(W), and we would also like to simulate the localities in that order. Thus, i_{val} is given as a table

with the following numbers 1, 4, 3, 2, specifying the *order* of the variables within the category. Finally, i_{cath} is set to 2 (two categories, transpiration and LAI) and i_{loop} to 4 (four variables within each category: N, W, E and S).

Switches

These switches are found under “Technical options / Technical” in the model.

Average_Auxiliary

Value	Meaning
off	All requested auxiliary variables will be the current simulated values at the end of each output interval. If all switches (AVERAGE_...) are OFF the date given in the PG-file is also at the end of the interval. Otherwise the date is the middle of each output intervals.
on	All requested auxiliary variables will be mean values representing the whole output interval. The output interval is represented with the date in the middle of each period.

Average_Driving

Value	Meaning
off	See Average_Auxiliary
on	See Average_Auxiliary

Average_Flow

Value	Meaning
off	See Average_Auxiliary
on	See Average_Auxiliary

Average_State

Value	Meaning
off	See Average_Auxiliary
on	See Average_Auxiliary

IndexForValidation

Value	Meaning
From Cursor in Menu	As specified.
From serie	Validation variables can be allowed to vary between simulations in a multi-run simulation.

PressureHeadSign

Value	Meaning

Negative	The matric water potential is expressed according to formal definitions (J/Newton) and is given in cm.
Positive	The matric water potential is expressed as positive values in the unsaturated zone of the soil.

Parameters

Index in val file

Default	Unit	Symbol	Equation	Function
1	#	i_{val}		

No of internal index loop

Default	Unit	Symbol	Equation	Function
1	#	i_{cath}		

Size of internal loop

Default	Unit	Symbol	Equation	Function
1	#	i_{loop}		

Soil Profile

Theory

Soil heat and water characteristics must be defined for each compartment and thermal and unsaturated conductivity must be defined for each boundary between compartments in the soil profile. Available field data representing these properties seldom coincide exactly with the chosen discretization of the soil profile.

Continuous profiles of soil properties are obtained by linear interpolation between, and extrapolation outside of measurement or sampling depths (see [Figure 6.5](#)). From a continuous profile of a parameter, $p(z)$, discrete parameter values are obtained for each compartment by:

$$p_i = \int_{z_i}^{z_{i+1}} \frac{p(z)dz}{(z_{i+1} - z_i)} \quad (8.17)$$

where: z_i and z_{i+1} are the upper and lower boundaries of compartment i . Conductivity parameters are calculated for each boundary between compartments by:

$$p_{i,i+1} = \frac{\Delta z_i p_{i+1} + \Delta z_{i+1} p_i}{\Delta z_i + \Delta z_{i+1}} \quad (8.18)$$

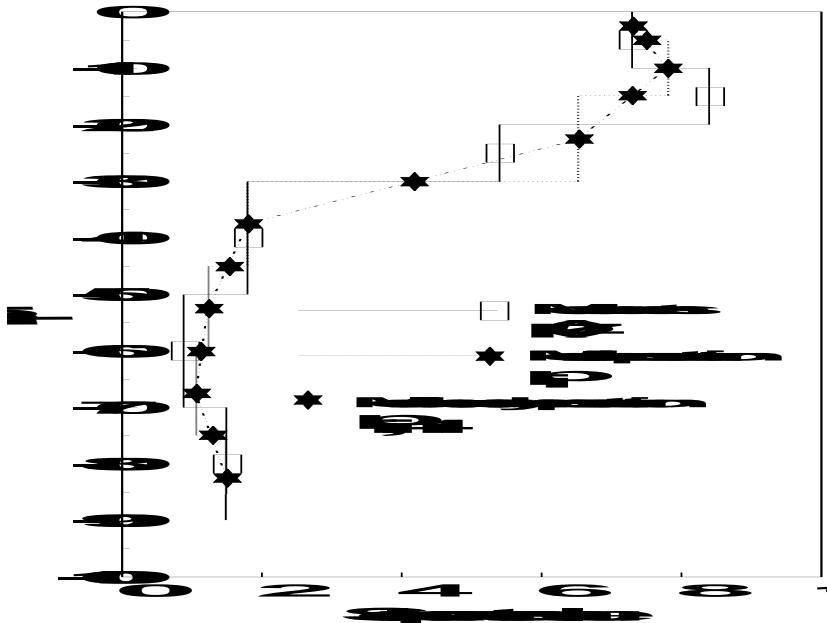


Figure 6.5. Graphical representation of how the model calculates soil parameters to represent a soil profile.

Parameter tables

This table is found under “Abiotic parameter tables / Soil Profile” in the model.

Compartment Sizes

Default No. of elements in Table: 10

Name	Default	Unit	Symbol	Comments/Explanation
ThicknessLayers	0.04	m	Δz	Thickness of each soil layer. Note that the default values will depend on the temporal resolution chosen for the simulation. Also note that a number of soil properties will be influenced by changes in the thickness of layers.

Construction of driving and validation variable files

The normal procedure for construction of input and validation file will be to follow the menus from the PG file tab in the main grid menu. Below you will find details on how to make use of the DOS program to make the same operations. The DOS program is more complicated but may be useful if you have some special format or very big file that does not fit into the clipboard when copying data from other programmes as MS excel.

The DOS program PG is automatically downloaded together with the CoupModel.

To get PG to work on your computer you need to specify the path to the program. This is done in the Control Panel/System/Advanced/Environment Variables. In the “system variables” list, find PATH, and enter the path to the CoupModel/Exe catalogue.

Preparing your data in your data handling program – Time specification

In your data handling program (for example Microsoft Excel) organise your data so that different variables are listed in different columns and time is changing with rows. There are alternative ways of specifying the time.

1. Give time by 12 characters: YEAR-MONTH-DAY-HOUR-MINUTE
Ex. 199501230830 (YYYYMMDDHHMM)
(alternatively only as YYMMDDHHMM)
In the data handling program, list the dates in the first column.
 2. Give time by 8 characters: YEAR-MONTH-DAY
Ex. 19950123 (YYYYMMDD)
(alternatively only as YYMMDD)
In the data handling program, list the dates in the first column.
 3. If your data consists of a number of time points, all separated by the same time interval, or if there is just one time point, you do not need to specify each of them in the file. Instead you can give the first time specification and the time interval when you enter the PG programme (see below). This option is recommended.
 4. An ASCII file derived from the Campbell data logger has normally time specified in three separate variables (year, daynumber and time-of-day). This type of formate is handled separately (see below).

If your time is specified in another way, e.g. as daynumber or minutes you can always read this type of time specification as a separate variable and later, by using a feature in PG (subsection C1 option S13) convert this time to the ordinary time specification as a string of 12 characters. In this case you can request a common time to all your records.

When you have finished structuring your data, save your sheet as a “csv (comma delimited)” or a “Unicode text”-file (accept all the warning messages) and exit the data handling program.

Importing the data in the PG programme

Re-name your newly created file (either *.txt or *.csv) to *.dat. Open the file with Pgraph by right clicking on the file with the mouse and choose “Open with” and selecting PG.

The first thing PG needs to know is how time is specified in your data-file, i.e. option 1-4 described above. Enter your choice on the command line and press enter (note that PG is an old program, so you will not be able to use the mouse to move around). Answer the following questions in the same way.

You will eventually be prompted to enter the format of your data. You can either use free format, fixed format or extended format.

- *Free format*
When you use free format it is not necessary to know the exact position of the variables in your file, as long as they are separated by a space or a comma, and is thus an easy option. The time variable has to be given withing apostrophes (if time is specified in the data-file).

Example: '8502140830' 3 0 2 8 4 5 or: '9805230830' 3 0 2 8 4 5

Choose this option by typing “r” followed by enter

- *Fixed format*
If you use fixed format you have to use a format statement as in FORTRAN (for details on how to write a format statement, please refer to a FORTRAN manual). Remember to give time as A10 or A12 and all other variables in F field descriptions, because all variables, except time, will be dealt with as floating point variables. Make sure you use decimal points if you have decimal values.

Example:
8502140830 3.0 2.8
8502140900 11.8 6.5

For this example you should enter (A10, 2F5.0). Note the parenthesis. This means that you use the first 10 characters for time followed by 2 variables allocating 5 characters each.

Choose this option by typing "f" followed by enter.

- *Extended format*

This is an attempt to make it possible to read data from text files in many formats. The format specifiers are listed in table X (note: in lower case only).

Format	Signifies
y	Year. 2-4 positions. e.g. 80,1987
yy	Year. Exactly 2 pos. e.g. 80,86
m	Month. 1-2 pos. e.g. 01,1,12
mm	Month. Exactly 2 pos. e.g. 01,12
mmm	Month. Exactly 3 letters. e.g. Jan,FEB,Oct
d	Day. 1-2 pos. e.g. 1-31.
dd	Day. Exactly 2 pos.
h	Hour. 1-2 pos.
hh	Hour. Exactly 2 pos
i	Minute. 1-2 pos
ii	Minute. Exactly 2 pos.
v	Data. Delimited of character which is not a digit or one of E, D, +, - .
x	Skip one character.
s	Skip spaces until next non space.

Rules for extended format:

- Characters in the format string which are not format specifier, must correspond exactly to characters in the data file.
- Format specifications, may be repeated e.g.: 10(x) or 4(sxxv) but parentheses cannot be nested.
- Time specifications given using one (1) format specifier letter must be limited by a non-digit e.g. y, m, h.
- Line breaks in the input file are not implemented.
- More than one format may be given, if time specification varies between records. Ex. Month is only given if, change in month.
- The "v" data format need not be specified if data observations are separated only by spaces.
- An expanded format line can not be longer than 132 chars.

Examples of formats to read the following types of data files:

Use: sy-m-d

80-01-01 9.283099 2.377541 8.012897

80-01-01 5.088338 6.233387 8.425648

80-01-10 0.211389 6.818182 5.779749

80-01-11 7.366003 6.043690 7.828479

Use: sy-m-dsh:ii:xx (3 data points) Seconds won't be read.

80-01-01 00:00:00 1.407930 0.340819 4.006003

80-01-06 11:10:22 5.185625 8.431309 6.039198

Use: sy-m-dxh:i:xx

sh:i:xx

80-01-05 05:13:15 5.385658 8.322591 2.693153
 06:09:02 9.312413 9.208962 9.516258
 80-01-12 02:21:50 4.927451 6.841755 8.943993
 80-01-16 20:15:44 5.024314 4.072683 8.386088

Use: s3(x)ddmm8(x)yy16(x)hhii2(sxxv) or
 sxxxddmmxxxxxxxxxxxxxxhhii2(sxxv)
 01+0102. 02+0087. 03+0183. 04+0800. 05+4.845 06-0.589

Use: sdd-mmm-yyyy
 09-May-1987 12.3 13.4...

- *Campbell data logger*

Three types of output formats from the Campbell data logger is supported: comma delimited ASCII, printable ASCII and binary. Normally three different time variables (year, day number and time of day) are needed from the Campbell data file for transfer to the time variable in PG. If the year or the day number is missing in the file, you must specify a common value to be used for all records in the file.

Before you exit the PG program you will be able to enter the names of your variables (or you type G5 at the command prompt, which will take you to the list where variable names can be changed). Make sure you name your input variables according to the standards given in the tables over input files (the “ID”) that you find in this manual (see tables “Crop data” and “Meteorological data”). If you fail to do so the CoupModel will not be able to recognize your variables.

Selecting driving and validation data files in the CoupModel

If you have been successful in creating a data file, you should now have a file with the same name as your *.dat file but with the extension .bin. These files can be imported and read by the CoupModel in the edit menu. Driving variables are specified under “Model files”, whereas validation variables are specified under “Validation Variables”.

General remarks on PG

The PG programme can also be used efficiently to restructure your data, to make graphs and to make various sorts of calculations with your data. If you need help while within PGraph, press F1.

List of constants

Name	Default	Unit	Symbol	Comments/Explanation
Absolute zero	-273.15	°C	$T_{abszero}$	
Biomass to carbon	0.45	mol C/g	η	Conversion of biomass (g dw) to carbon (mol C)
Density of air	1.220	kg/m ³	ρ_a	At 20 °C.
Density of solid soil	2.65	kg/m ³	ρ_s	
Density of water	1000	kg/m ³	ρ_{water}	
Diffusion rate of oxygen	2.6e-5	m ² /s	$oO_2diffrate$	At 20 °C.
Gas constant	8.31	J/K/ mol	R	
Gravitational constant	9.81	m/s ²	g	
Karmans constant	0.41	-	k	Used in the calculation of aerodynamic resistance.
Latent heat of freezing	3.34e5	J/kg	L_f	The energy required to melt 1 kg of ice.
Latent heat of sublimation	2.84e6	J/kg	L_s	The energy required to vapourize 1 kg of ice.

Latent heat of vaporization	2.45e6	J/kg	L_v	The energy required to vapourize 1 kg of liquide water.
Molar Mass, Carbon	12.011	g/mol	M_C	
Molar Mass, Carbondioxide	44.0098	g/mol	M_{CO_2}	
Molar Mass, Dry air	29.0	g/mol	M_{Air}	
Molar Mass, Oxygen	31.998	g/mol	M_{O_2}	
Molar Mass, Salt	35.4527	g/mol	M_{Cl}	
Molar Mass, Water	18.016	g/mol	M_{water}	
Molar ratio, Oxygen to Air	1.10	-	$O_{ratioair}$	
Molar ratio, Oxygen to Carbon	2.664058	-	O_{ratioC}	
Mole air per cubic meter	44.6	mol/m ³	a_{mol}	
Normal atmospheric pressure at soil surface	1.013e5	Pa	$p_{atmnorm}$	
Partial pressure of oxygen in the atmosphere	20.5e3	Pa	O	
Psycrometric constant	66	Pa/°C	γ	Used in the calculation of potential transpiration.
Specific heat of air	1.004	J/g/°C	c_p	At 15 °C. The amount of enegy required to raise the temperature of 1 g of air 1 °C.
Specific heat of ice	2.1	J/g/°C	C_i	The amount of enegy required to raise the temperature of 1 g of ice 1 °C.
Specific heat of water	4.18	J/g/°C	C_w	The amount of enegy required to raise the temperature of 1 g of water 1 °C.
Specific volumetric heat capacity of solid soil	2e6	J/m ³ /°C	C_s	The amount of enegy required to raise the temperature of 1 m ³ of the soil 1 °C.
Stefan-Boltzmann's constant	5.67e-8	W/m ² /K ⁴	σ	
Temperature of a completely frozen soil	-6	°C	T_f	Below this temperature the soil is regarded as completely frozen.

Minteq model

Jon-Petter Gustafsson and David Gustafsson

Minteq sub-model

Theory

Here the theory should be explained.

Switches

MinteqDeposition

Value	Meaning
parameter	Input concentrations of elements estimated by parameters.
vda-file	Input concentrations of element given in a Minteq input file.

MinteqInputUnit

Value	Meaning
mol/lit (water)	Input concentrations of element in Minteq input file.
mol/lit (soil)	Input concentrations of element in Minteq input file.
mol/kg (soil)	Input concentrations of element in Minteq input file.

Parameters

MinteqPeriod

Default	Unit	Symbol	Equation	Function
3	days			

TotalConcDep

Default	Unit	Symbol	Equation	Function
0.001	mol/l			

Parameter tables

Bulk density of input problem

Name	Default	Unit	Symbol	Comments/Explanations
Bulk Density IP	1.2	g/cm ³		

Layer depth of input problem

Name	Default	Unit	Symbol	Comments/Explanations
Upper Depth IP	0	cm		
Lower Depth IP	10	cm		

Flow Variables

TotalFluxInfil

Explain.
mol/day

Auxiliary Variables

DissConcElem01

Concentration of dissolved element no.1.
mol/l

DissConcElem02

Concentration of dissolved element no.2.
mol/l

DissConcElem03

Concentration of dissolved element no.3.
mol/l

DissConcElem04

Concentration of dissolved element no.4.
mol/l

DissConcElem05

Concentration of dissolved element no.5.
mol/l

DissConcElem06

Concentration of dissolved element no.6.
mol/l

DissConcElem07

Concentration of dissolved element no.7.
mol/l

DissConcElem08

Concentration of dissolved element no.8.
mol/l

DissConcElem09

Concentration of dissolved element no.9.
mol/l

DissConcElem10

Concentration of dissolved element no.10.
mol/l

DissConcElem11

Concentration of dissolved element no.11.
mol/l

DissConcElem12

Concentration of dissolved element no.12.
mol/l

DissConcElem13

Concentration of dissolved element no.13.
mol/l

DissConcElem14

Concentration of dissolved element no.14.
mol/l

DissConcElem15

Concentration of dissolved element no.15.
mol/l

DissConcElem16

Concentration of dissolved element no.16.
mol/l

DissConcElem17

Concentration of dissolved element no.17.
mol/l

DissConcElem18

Concentration of dissolved element no.18.
mol/l

DissConcElem19

Concentration of dissolved element no.19.
mol/l

DissConcElem20

Concentration of dissolved element no.20.
mol/l

pH

Soil layer pH.

-

TotalConcElem1

Concentration of both dissolved and solid phases of element no.1.
mol/l

TotalConcElem2

Concentration of both dissolved and solid phases of element no.2.
mol/l

TotalConcElem3

Concentration of both dissolved and solid phases of element no.3.
mol/l

TotalConcElem4

Concentration of both dissolved and solid phases of element no.4.
mol/l

TotalConcElem5

Concentration of both dissolved and solid phases of element no.5.
mol/l

TotalConcElem6

Concentration of both dissolved and solid phases of element no.6.
mol/l

TotalConcElem7

Concentration of both dissolved and solid phases of element no.7.
mol/l

TotalConcElem8

Concentration of both dissolved and solid phases of element no.8.
mol/l

TotalConcElem9

Concentration of both dissolved and solid phases of element no.9.
mol/l

TotalConcElem10

Concentration of both dissolved and solid phases of element no.10.
mol/l

TotalConcElem11

Concentration of both dissolved and solid phases of element no.11.
mol/l

TotalConcElem12

Concentration of both dissolved and solid phases of element no.12.
mol/l

TotalConcElem13

Concentration of both dissolved and solid phases of element no.13.
mol/l

TotalConcElem14

Concentration of both dissolved and solid phases of element no.14.
mol/l

TotalConcElem15

Concentration of both dissolved and solid phases of element no.15.
mol/l

TotalConcElem16

Concentration of both dissolved and solid phases of element no.16.
mol/l

TotalConcElem17

Concentration of both dissolved and solid phases of element no.17.
mol/l

TotalConcElem18

Concentration of both dissolved and solid phases of element no.18.
mol/l

TotalConcElem19

Concentration of both dissolved and solid phases of element no.19.
mol/l

TotalConcElem20

Concentration of both dissolved and solid phases of element no.20.
mol/l

How to understand the menu system

The CoupModel interface has been modified during 2007 and is based on documents and a grid system that have different functions and meaning. Below are the basic features described?

Different modes of a document

A document that is in preparation for making a simulation is very different from a document that represent the results from a completed simulation. A newly empty

document will on the top heading have only one single field named "Make Single Simulation". This means that the document is prepared for only one single option and that is a single run with the model. The different modes are:

- Single run document for editing
- Single run document completed (the model has been run) After the model has been run the option to make a single run is not available, instead the option to make a copy the document exist
- Multiple run document and single run document for editing. The multiple run options for a document will appear as soon as any parameter or data base object has been defined within a dimension of multirun. Such a document that has definition for a multirun can either be activated by as a single run or as a sequence of multiruns.
- Multiple run document completed (the model has been run)

The actual mode of a document could be seen first of all in the RunInfo tab sheet. The top header line will show which option are for the current document. And the text below will give details of the current document. Note also that the right heading of all other tab sheet will indicate the mode by color. If the right heading is green the document represents a completed simulation and could not be changed. A yellow right heading indicates a document that is open for design of a new simulation. The command options for the document will be available for any sheet by making a right click on the right heading.

Grid Menu System for CoupModel

The basic unit for a simulation with the CoupModel will be a document. A Document contains the essential information for making a simulation. The document could be viewed, edited by using the different field of the grids displayed in the document window.

12 different tabs contain information with various use and meaning for design and run of a simulation.

The document will be in different mode and will have different appearances depending on the [Different modes of a document](#).

The fields of the grids have different meanings from

- 1) Provide simple information that could not be edited (readonly)
- 2) Provide editing field where the user can specify any new information (normally require a double click on the field)
- 3) Provide optional controls for selection of choices among differernt option (combon controls)
- 4) Provide command buttons for changing the appearances of the grids or for making specific actions. Many positions have optional command buttons that can be made visible by right click on a specific grid field. A single left click on mouse makes specific actions for many grids that are with yellow color labels.
- 5) Provide options for copy and paste information from the clipboard to facilitate simple export or import of information from various field.
- 6) Many tabs sheets provide information that could be sorted in various ways by clicking on the heading row of the appropriate column
- 7) Different levels of details will be displayed depending on the user level selection withing the User configuration menu and depending on selected or global options.
- 8) Context sensitive help is available for many items by clicking the help F1 button.

The basic functions of the different tabs

Below a brief description of each of the different tab sheets are made. Note that the tabs have different function depending on the [Different modes of a document](#).

RunInfo

This first tab is important for general information about a simulation. The blue fields are open for edition by the user prior a simulation is made. The Top heading is devoted for action that are either to start simulation for documents that are prior the completion of a simulation or for copying to new document if new simulations should be made based on the same information as for the present document. Note that the RunInfo also allows for selection of data base objects from 10 different categories of subsystems for a simulation

Switches

This sheet represents the choice of modules and choice of functionality of the different modules. Not the different modules are linked to each other and that the appearance will shift while the user is modifying the values for the different options. Selection of some options will enable other options to be relevant for your simulation.

By default only options that have been selected to non default values are displayed. A Click on the upper left yellow button will change the appearance so all enabled options are displayed. A right click in the module grid column gives similar options for the specific module.

Note that the switches will enable both Parameters, Parameter Tables, Model Files and Output Variable sheets. Normally the Switches sheet is the first step in the design of a specific simulation. All these sheets have the similar basic classification of entities into different modules that contains the options that could be selected for the simulation

Parameters

Parameters have a unique name in each of the different modules. Note that many parameters represent coefficient in different functions that could be represented also in a graphic format. In such case the plot option will appear after a right click in the parameter value field. The name of the function is displayed in the Function column for this grid.

In addition to changing the value of a parameter the user also have two additional options:

- 1) To allow various type of changes of parameter values between runs by specifying multirun options.
- 2) To allow a parameter value to have different values within a certain run.

If the user select any of these options the parameter will later on be listed in the tabs: [MultiRun](#) or [Dynamic Parameters](#).

Parameter Tables

This sheet is to functionality very similar to the parameter sheet. The important difference is that Parameter Tables are parameters that are represented as arrays rather than single values. The parameters are also put together in different Tables that normally contains related parameters that are sharing some basic information like index and eg. depth for some parameters that are related to soil layers. The number of elements for a table is normally edited prior the specific parameters inside a Parameter Table are edited. Note that many tables are sharing the same indices and by that the number of elements. The two most important elements for the CoupModel is the number of soil layers and the number of plant canopies.

Model Files

This sheet represents the name of the dynamic forcing input to the model. The files have a binary format and the user can either select such files that are already prepared for the simulation or create a new file. The preparation and processing of files can also be done separately in the PG File sheet. Use Help to identify name and units necessary for the driving variables that are selected here. Note that driving variables can be selected in many different ways that is controlled by the switch value selected for various modules. The content of a selected file can be displayed by a single click on the file name and the variables can be viewed on charts by single click on the displayed variable lists.

Output Variables

The CoupModel contains many optional output variables that could be selected in this sheet for a document that is not run. Use the upper left buttons for displaying of the variables and click on the variable name to select as outputs.

A Completed document contains statistic for each selected output variables and allows for creating charts of selected variables. A completed multirun document can be used both for viewing time series of selected variables or to view charts of time series which represent the mean values and variation between the different multiple runs. The statistics for variables can also be viewed as series of the different runs instead of series of time.

Validation

The performance of a simulation can be considered in various ways after selection of simulation variables that are compared with observed variables. The choice of validation is optional but are strongly recommended to evaluate the results from simulations. Normally validation variables are time series and to make comparison with simulated variables the user have to organize the validation variables in one PG-structured time serie file. Make use of options in the PG File sheet to prepare such file. Once the preparation is done the Validation sheet allow the user to select the file and to combine the pairs of variables. In case of bayesian calibration of the model not only time serie variables but also single value variables like the mean value, final value or the accumulated some of any value could be specified for calibration.

A completed document contains the results of the comparison between simulated and observed variables. In addition the results can be view in a similar ways as for the output variable sheet after left och right click on the specific variables in the list.

Messages

This sheet contains messages obtained from the simulation during run. This sheet is only for saving of such information and may be useful if any problems appears during a simulation.

Charts

This sheet contains a list of charts that have been made by the user and also allows for the continued modified design of charts from simulations. Charts may contain information from various files. Note that you can remove all items from this list by clean selection from the draw chart menu that is displayed when you right click above any item that could be used to construct a chart. The Charts can redisplayed or the the table of all the data in the charts can also be displayed as one addition information that is attached to this chart. The attached information is made visible by a click on the upper left button on the heading line. The same button is used to return to the normal appearance of the chart sheet.

Dynamic Parameters

This sheet contains a list of all parameters that have been selected for changes during a simulation. No edition of value could be made here.

Note that not only single parameters could be selected for changes during a run but also data base object can change at a certain time point during a simulation.

MultiRun

This sheet contains a list of all parameters that have been selected for changes during a simulation. No edition of value could be made here.

Note that not only single parameters could be selected for changes during a run but also data base object can change at a certain time point during a simulation.

The MultiRun sheet can be edited prior the multirun is made either from this sheet or from the original entry points in the sheets that reflects the origin of the various parameters in the multirun sheet.

A completed multirun document contains the results of the multirun with information about all the individual multiruns made. By right or left click on the upper left corner different information can be displayed depending on which type of multirun has been made. For a bayesian calibration multirun statistics for the accepted runs can be compared with all the runs. Probability density function (pdf) for all the parameter can be displayed in charts or viewed as tables.

PG File

This sheet contains options for selections of any PG file that could be combined with output results or that could be selected for any processing.

History

A list of all active changes of a document is made in this sheet. Specific list could also be obtained from a single item if right click is made for the active position of that item. The list is made visible/invisible by a left click on the upper right corner button.

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Acknowledgements and comments on this edition

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This edition

Most images are originally in colour and can therefore be difficult to interpret. A colour version of the manual is available on:

<http://www.lwr.kth.se/Vara%20Datorprogram/CoupModel/index.htm>

At present we recommend the internet reference to be used when referring to the contents of this manual / on-line help.

Recent updates

This is a log of various changes made to the program

2010

10-08-20 Viewing the results of Box-Cox Transformed variables on residual or on simulated output

To investigate the possibility to obtain normal distributed residuals by using the Box-Cox transformation a procedure has been implemented that is complementary to the use of the QQ-plot using the checkbox “Versus Normal Distribution” on the Dialog window of an ordinary output chart. After making any QQ plot the transformation can be applied by a click on the button *Redesign Chart*. By opening the tab sheet called Box Cox Transformation the Transformation can be turned on and various values on the coefficient in the transformation can be applied.

10-08-19 New quick update of values in charts

To make quick additional evaluation of results two new check boxes have been introduced in the Window with output charts from the model. The First checkbox *Sorted series of Y values* reorganize the chart to be plotted as a serie from the smallest to the largest value of any time serie. This allow the user to view the continous frequency distribution of any output display. A click on the checkbox could be combined with one additional click on the checkbox *Cumulated Y values* to display the corresponded continuous cumulated frequency distribution of values. The Second new checkbox *Versus Normal Distribution* replace the horizontal axis values of the variable with the estimated values based on the normal distribution function using the estimated std deviation and mean value of the variable. Both axis are showing the cumulated values. The graph corresponds to the QQ-plot since we are plotting quantiles from the cumulative distribution of the variable against the theoretical normal distribution of the variable. A straight line demonstrate that the variable equals a normal distribution function.

10-08-19 New postprocessing of performance after a GLUE based multi run

A new flexibility is introduced to recalculate the results of the log likelihood estimations after a multi run has been completed. The procedure make it possible to compare the results of the used function with any new setting regarding either the error estimation in the log likelihood estimations or in use of Transformation function or Likelihood model. The procedure will be shown in the sheet that are open after selection of the right click option *specify new criterias to define accepted runs* upper left corner of *Validation* sheet. The tab

LogLikelihood option should be activated and the right click options Estimate new loglikelihood values based on new setting should be used after eventually new values are specified in the grids cells that are displayed. The results of the options will be possible to view in the Loglikelihood statistics sheet that display optionally parts of the multirun results.

The upper left corner of the sheet will allow the user to select what to display after right clicking. Make a single click on the left heading to the grid to obtain the results as time series on a chart comparing previous calculation with the latest calculations.

Similar as looking to the estimated likelihood values the residual between simulated and observed can also be viewed in the residual statistics sheet. To display the residual statistics the residuals need to be reorganized in a sorted file that require the user to create the sorted file prior using this option. Right click to obtain the option for this action.

10-08-19 Transformation of variables for likelihood calculation

A new procedure with a Box-Cox transformation (Box&Cox, 1964) have been introduced when calculation log likelihood from validation data. A Technical module switch */Box-Cox transformation/* is used to turn the transformation on. The Box-Cox transformation is using two parameters (*/Box Cox power/* and */Box Cox offset/*) that are part of the parameter table “Scaling of Observed Variables” to filter the observed and simulated data:

Newvalue=((value+offset)**power-1)/power when power>0.00001

and

Newvalue=log(value+offset) when power<0.00001.

The likelihood of the untransformed values are equal to the likelihood based on the transformed values multiplied with the derivative of the transformation. Thus, the log likelihood is calculated as the sum of the loglikelihood of the transformed values plus the log of the transform derivative calculated for the measured value:

The values are calculated as= ((value+offset)**(power-1)))

This procedure was used by Yang et al (2007) for a hydrological application.

References:

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Yang, J., Reichert, P., Abbaspour, K. C., and Yang, H. Hydrological modelling of the Chaohe Basin in China: Statistical model formulation and Bayesian inference. Journal of Hydrology 340, 167– 182, 2007.

10-08-19 New performance indicator

The Nash-Sutcliffe model efficiency coefficient have been introduced as one additional performance indicator that will also be possible to use for selection of output. Note that coefficient is base on the summation of the squared sum of residuals between simulated and measured and the corresponding squared summation of the residual between observed values and the mean of the observations. This means that a simple selection based on RMSE and a selection based on the Nash-Sutcliffe coefficient will give the same results. However, the Nash-Sutcliffe coefficient is normalized with an upper limit of 1 whereas the RMSE will be directly dependent on the units and magnitude of the variable considered.

Statistics of the various performance indicators will be shown after selecting the right click option of the validation sheet of a completed CoupModel multirun document.

10-08-19 HBV model implementation

A new simple conceptual model similar to the original HBV model has been implemented. The Switch *HBV Soil model* (Model structure group) make it possible to run the new model as complementary to the ordinary Richards equation type of soil that is used in the CoupModel. The new switch may also exclude the use of the Richards equation model Note that the model can use any time resolution but it works on the resolution that is specified by the input file time resolution. Normally daily values can be used and only 1 iteration per day is required to get rapid calculations of the runoff using this module.

The module is defined from 1 soil storage and 2 ground water storage.

Note that the HBV model can be used with snow and various evapotranspiration models but with some restrictions if the Richards equation and the soil heat equations are excluded from the CoupModel. For example in such a case no separate soil evaporation will be calculated. The heat storage will not have any interactions on the evaporation calculations and not either on the snow melt.

The follow variables are added:

State Variables:

Base GW Storage

Peak GW Storage

Soil Storage

Flow Variables

Base Flow

HBV Evap

HBV GW Redist

HBV Input GW

HBV Input SOIL

HBV RunOff

HBV_Input

Peak Flow

Parameters:

BetaCoef

Critical Uptake Frac

Discharge Alfa

Discharge K1

Discharge K2

Field Capacity

Initial Base Storage

Initial Peak Storage

Initial Soil Storage

PMaxPerc

10-06-30 New outputs to indicate atmospheric water stress

A new modified Potential Transpiration variable have been introduced disregarding the reduction of canopy resistance that are related to the vapor pressure deficit and the global radiation as calculated by using the Lohammar equation in the CoupModel.

The new variable in the Meteorological data module is named

PotMaxTranspiration and includes all canopies.

For separate canopies we have additional outputs in the Potential Transpiration Module:

Pot MaxTranspiration

Resistance Min Canopy

Response Transp Atm

Note that the atmospheric water stress depends on the parameters in the Lohammar equation

The suggestion to include this is originating from Lorenz Walthert

10-06-02 New flexibility to govern graphic outputs

The new approach with more flexible graphic outputs have been further developed and a number of bugs (minor and major) have been deleted since the first version was introduced Maj 19.

One major new feature is that you can more easily compare different runs by keeping more than one document open. Right click prior making selection of variables for plotting allow you to link all the open documents together. This means that the variable selected from the current open document will also be selected for the other open document.

Another major improvement is that most of the attributes and characteristics of a chart can be modified after it has been created. After clicking Redesign chart you will have options to modify General features, Axis, Variable and parameters for governing Frequency Distribution plots.

Please let me have your comments. The vision is that it should be possible to create charts that could be clear and useful both for typical powerpoint presentations but also for normal scientific formats in journals

10-06-19 New Improved flexible plotting

A major shift have been made in the construction of graphics from CoupModel.

Firstly an option exist already from the entry level when viewing a list of time series in any table within the CoupModel.

For all time serie variable one additional column will give info on Subchart no. By default the number will be 1 and this corresponds to the previous version of the model.

However, by right click options to add more subcharts will be provided, either in the vertical or in the horizontal direction. When making a click in the checkbox we direct selected variables to different subcharts. Change of the subchart no will be made by click on the column directly right of the checkbox. The number will be cycled over then number of subcharts that have been defined.

In this way any number of variables could be directed into a series of subcharts.

Second but equal import.

The layout of the subcharts and the design of the graphics will be flexible by one additional window that can be open by a the "Redesign Chart" button. Note that this window will allow you to modify settings for general aspects, the axis and for the individual variables. The grids with information on present default values can edited by either changing specific numbers, selecting by various provided options or entering any specific text strings. Note that to apply the new setting a creating a new modified chart requires and update. This can be done by an option by the right click method or by a single click on the upper right corner button.

Most charts should normally be created automatically without manual setting. Some new parameters are very important for how to create a good first suggestion.

Note the Tick X size and Tick Y size.

Like all other size related features they are specified in points and represent the minimum distance between ticks on the respectively axis. Make you choice combined with the Font size for scale on axis.

The information is shown in a small window in the ordinary dialog window to the right of the created charts or in the opened separate window. Please note that window open after the Redesign button in clicked need to be closed (OK) button to enable other continuous use of the options above the redesign chart button.

Other interesting options are the color setting also for legend box and for error bands i the charts. Note that colors can be specified with various transparency .

I hope you will enjoy working with the new version and please let me know about any new bugs. I am sure that are some left !!

10-03-03 New visualizations features

The visualization has now been extended for time serie outputs so animations can be done easily from the dialog window that is attached to time serie charts.

A click on the animation button is creating a moving window of the shart. The Window size is the size that i determined by the zoom in function, that should be defined prior the animation starts. The Animation could be stoped or restarted by the repeated clicking on the button. Also note that the resolution (step length) and the speed of updating the window could be modified for you purpose, prior or during the animation process (two combo box button). By default the animation is not producing any output files, however if pressig Save to file button a series of files (png) will be created. Note that a very high number of file are generated if you have small step lengths and this files could be used to create flash animation by popular softwares.

Another new feature that is updated is the New Run (last) and New Run (all) commands that are operating on multi run time serie outputs files only. By using these commands together with also new Curve command your can move between different variables and different runs.

10-03-03 Deleted bug in calculation of Log Likelihood sum

A mistake was discovered in the calculation of the Log Likelihood sum of the CoupModel.

The two possible methods availabe based on the Gaussian distribution or a non Gaussian distribution according to Sivias include both a constant value

-0.5*Log(2*PI)

This constant has not been defined in version of the CoupModel prior March 3th. This mean that the LogLikelihood values that are reported are to high = n*the constant. The good news is that this does not have any direct impact on the calibration. However for comparision with other calculation we have to include this constant number.

10-02-05 Deleted bug with wrong labels in the data base tables for soil properties.

The matric hydraulic conductivity and the total hydraulic conductivity also including macro pore contributions was mixed in the data base table. This is not corrected. Thanks to Rainer Petzold that find the bug.

10-02-05 New Water Pipe model

A submodel to describe the temperature of water pipes that are embedded into the soil has been developed. The model makes it possible to simulated temperature of a water pipe that has a certain water flow and a boundary temperature to the pipe. A full model description will not be presented here. Two swiches in the soil heat flow model controls the model of the new submodel (Insulated water Pipe and Water Pipe Box).

2009

09-12-08 Deleted bug and improved visualization of MultiRun results

Output selected for multirun time serie output was not correctly displayed. The updated version should now allow a right click on the variable to get option to select either mean of all runs or mean of accepted runs with corresponding statistics. The results are also saved in a PG-file "YYY_Mean_Accepted_XXXXX.Bin" or "YYY_Mean_All_XXXXX.BIN". In Addition the outputs of individual runs could be selected by making a click in the check box followed by a single left click on the variable name. The later will initially only output the first run on the chart with correspondent window. However, shifting from various runs or adding additional results from others runs are made by clicking

Improved visualization of multirun results from Bayesian calibrations or from GLUE runs makes it easier to identify the accepted runs compared to all runs. Accepted runs are displayed by line representation in normal chart. The accepted values of variables are shown until they are replaced by new accepted values similar as in MCMC chains.

09-11-26 New regulation of denitrifier death rate function

The denitrifier death rate function has been extended to include a threshold for two different rates. Two new parameters have been introduced: DMic_DeathCDormancy and DMic_DormancyThreshold, representing the rate coefficient during the entire range of microbial biomass and the threshold from which the rate will be determined by the previous rate coefficient DMIC_DeathRateCoef. New default values (0.01) are assigned to the previous DMIC_DeathRateCoef. Note that the new model will not be able to reproduce the previous by using the default values. However, by setting the DMic_DormancyThreshold to 0 and DMic_DeathCDormancy to 0. and previous default value of 0.09 to DMIC_DeathRateCoef the old model will be valid.

09-11-24 New why to specify Harvest dates by PG file option

The *Harvest Day* switch have been extended with a new option allowing the dates for harvest to be specified from table in a PG-file. The options is useful when various irregular harvest dates are applied during many different years. The PG-file should include the exact date for harvest.

09-11-02 Improved bug in the display of output variables in a document prior simulation

The right click menus was not functioning according to the intention. Enabling or disabling of variables for specific groups could be made both after right clicking and selection of choice. Alternatively the display of all variables that are possible for selection could be done by a single click on the grid with the group name. However, hiding of non selected variables are only possible by the right click options.

09-10-28 Deleted bugs causing problems in the denitrification calculations from horizons with a zero microbial biomass

The problem was typical when no denitrification should be from deep horizon and a zero denitrifier microbial biomass assumed. Infinity high fluxes was estimated which caused strange summation of a number of output variables.

09-10-26 Updated Iterative energy balance solution for soil surface

After discover of numerical problems with some parameter combinations causing errors in the energy balance close variable a new default setting have been to estimate fluxes when 40 iterations are not enough to find an energy balance close. Both old and new are based on estimating fluxes from previous periods with a successful energy balance closure. However, new values are also forcing soil temperature and soil vapour at soil surface during such conditions to be equal to air temperature and saturation vapour pressure at air temperature. To trace such conditions when the energy balance is not find by the iterative solution a new auxiliary output : *EBalance Iterations* has been introduces as part of the soil evaporation module. The change of the model is not expected to produce very small deviations from previous version except for rare combinations of soil surface energy balances.

09-10-15 Deleted bug negative values of soil ammonium

Deleted bug that may have been causing negative values of soil ammonium because of to high values of soil nitrifications.

09-10-13 Deleted specific bug to select “Soil Resp (no roots)” variable

The flow variable in the group Additional Biotic Variables was not correctly understood because of the naming with parentheses as part of name. Bug deleted.

09-10-07 New options to plot and process outputs from multiple runs based on the format introduced (09-05-18)

Originally only the mean values or the mean values of accepted runs could be viewed. With the new option the user can select a specific run number to be represented in the chart. Two buttons are shown in the dialog window when a chart has been created. The New Curve (1) button adds a new variable to the current chart with a new run number compared to the last plotted variable. The New Run (2) button change the last variable plotted to represent a new run in the sequence of multiruns.

09-10-07 New Tutorial on permafrost conditions.

An interesting example from Greenland, Zachenberg have been created by Jørgen Hollesen and Christian Juncher Jørgensen from Copenhagen University Denmark. The new tutorial included as pdf-file in the Sample directory created when installing the model. Also all other tutorials are find as pdf-files in the same sample directory of the model. New specific files for each of the tutorials are located in subdirectories of respectively tutorial.

09-09-21 Updated Tutorials

All tutorials have been updated. A number of minor bugs have also been deleted in connection with this. The most important news for the tutorials are that new procedures for multiple runs with various calibration procedures are described. Documents with instructions for using the tutorials can be downloaded from
<ftp://www.lwr.kth.se/vara%datorprogram/CoupModel/Tutorials/>

09-09-21 New Parameter for precipitation generation

To allow a more flexible timing of generated precipitation a parameter PrecStartDay has been introduced. The parameter controls the start of the precipitation in a modulus function.

09-09-21 Timing problem when reading validation files

A short delay of timing between reading the simulated values and comparing with observed values was discovered. The mean value for the duration of the validation variables was overrepresented prior the exact time point in the validation file. This meant that if the duration was specified as 60 minutes and your simulation time step was shorter than one 30 minutes an error occurred. The simulations prior the time specified was overrepresented and the second 30 minutes values was not always considered.

09-09-08 Deleted bugs related to plotting mean values of selected ensambles of simulation

Updating of mean of accepted simulations was not made after definition of new criterias.
All new simulations will be defined as locked until the user has unlocked a document for selection of ensambles of simulations. This is to prevent redefinition of acceptance that are made during multiruns using Bayesian calbrition
Deleted bug in the estimated mean value of performance index for all simulations made within a multirun. This erroneous value may have caused problem when specifying new population of selected runs since it was used as default criteria to accept new populations.

09-08-26 New window for definition of criteria to evaluate Multiruns or viewing results for Bayesian Calibration

To improve the overview when viewing validation results from calibration a new window have been developed complementary to the validation sheets in the main menu. Note that the window is available in two different modes depending if the document is locked or not. A locked document is a document where no changes in criterias for selection of accepted runs can be made. This is recommended for multiruns using Bayesian calibrations and will be the default

after making a multirun with the model. Unlocking will easily be made by right click on the upper left corner on the validation sheet.

A preliminary version was made available of the new window for adding criterias when selecting acceptable runs in June. However, a number of bugs related to the performance of the new model was corrected August 26. Some of these bugs was related to plotting of mean values of accepted runs or the posterior population of the Bayesian calibrations.

09-05-18 Added new output representation during MultiRuns.

The ordinary time serie output variable during multi runs can now be made in two simultaneous categories. An ordinary selection from a previous single run will be considered only for statistics. The additional level of selection will keep all the output data in one single file with name \TestRun\TestRun_Coup_XXXXX.Bin. Selection of variables to this file requires an addition click on the variable name and will result in a new green colour during the selection phase. Note that this variables can then be used for plotting of mean values and uncertainty range in a similar way as for validation variables.

The switches in module (Technical) *TimeSerieOutputs* have been given a partly new meaning. All Variables that have been indicated for time serie outputs will result in an output file for single runs. The differentiated options is only valid for multiruns.

09-05-13 Added new outputs

Three new outputs representing the concentration of nitrate, ammonium and mineral N in drainage water was introduced, *N Conc NO3 Drainage*, *N Conc NH4 Drainage* and *N Conc MinN Drainage*.

The flexibility uptake parameter for all plant *NuptFlexDegree* was corrected to be disabled when the switch *Flexible Uptake* was set to individual plants.

09-05-10 Corrected bug given error in new year update

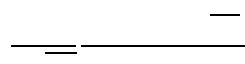
A bug with origin in the conversion between the floating time representation and the date as given for specific year was discovered. The bug caused error during some leap days 29 february that was not correctly converted to a Julian day number. The results was that the 29 of February was considered a one additional year shift. Such additional year shift may have been given serious errors when the counting of years are of importance. Such as the year of harvest when harvest is defined for specific years.

09-04-07 Corrected bug on Residuals in outputs

The new parameters that represent a logarithmic scaling of the measured variables caused and error in the residual output files as generated when using a log scaling coefficient different from default (0.0). With the updated version of the model the correct values will be find. Note however that the measured variables in the output representation will still be the ‘original’ measured values.

09-04-01 New Bayesian Likelihood function

Introduced a new function based on a more robust function than the traditional Gaussian based function. The function (Likelihood) is a switch under the technical module. The function is named Sivias function and can be written as:



Where R is the normalized difference between simulated (sim) and measured values (meas), so R equals

$$R = \frac{sim - meas \cdot E_{sys}}{\sigma}$$

The E_{sys} value is also new in the model compared to previous versions and considered as a parameter in the table *Scaling of observed Variables*. Note that σ is estimated as before based on the smallest value between a relative error estimate and a minimum error as assigned for each validation variable in the model.

09-04-01 Bug in update of Error for Summation variables.

The previous version was not correctly assigning the errors from single value validation variables. Instead they were always from previous run and not the actual run no.

09-03-24 Modification of Microbial based Nitrification model

The microbial biomass growth and death rates are changed to be linked to the Nitrogen mass balance of the system. Previous assumption made microbial biomass as an independent component. The death rate function is changed to be simplified and are now only dependent on a rate coefficient and the square root of the biomass. Previous assumptions also linked the death rate similar as the growth rate to environmental conditions as temperature, moisture and pH. A number of default values have been adjusted for the microbial based function to correspond with robust behavior for the Hogiwald forest in Germany and not to the original DNDC model.

09-03-24 Bug in display of posterior distributions

Changed the display to correctly handle posterior distribution also when not assigned as Bayesian calibration or other functions. Only Data base objects are not excluded from the posterior statistical calculations as performed as post processing in the Validation sheet after multi run simulations.

09-01-12 Extended info about MultiRun

The Validation sheet for selection of accepted runs has been extended with mean values or summation of validation variables for making selection. This means that criteria's could be either or both on single validation variables or on different performance indicators.

09-01-12 Corrected bug for Bayesian Calibration

The Bayesian calibration acceptance was lost when completing multiruns. Only MultiRuns without Bayesian calibration parameters are considered for post evaluation of accepted runs.

09-01-12 Corrected bug for plotting of parameter distributions

Parameter values from multirun using logarithmic distributions was previously plotted as linear function. New feature allow the plotting of distribution function for multirun simulation with both the accepted runs and all runs.

09-01-07 Forcing of document to be considered as completed runs

A non completed document could be forced to be considered as completed by right click in the run info sheet. This features is useful if a multirun has been running for long but has not reaching the final end. After forcing the document to be completed all data from successful runs may be seen as part of the validation results (mbin and xbin files are read). A recent bug making the simulation run number not to be correctly updated when exceeding 99999 runs was deleted. All Sim file should be with a run number lesser than 100 000.

The default multi run method for changing parameter values has been changed from Bayesian calibration to Stochastic linear.

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08-12-18 New parallel processing and features for the Residual files (XBin)

Time serie error file can be added to each other providing that multirun options have exactly the same structure (validation variables and selection of parameters for validation). The feature is available for completed multirun documents in the run info sheet after right click in file information sheet (Output Files from Simulation section). Many runs can be run in parallel on the same computer. Addition of files can be made after completion.

The new version is also improved in plotting and updating of results from multiruns. Also with 30 000 runs it is now a quick estimation of mean values of accepted runs. This means that you can quickly shift between different criterias for updating and looking to new results.

08-11-25 New Index for GW input file name

A new switch *Dynamic indexed GWfile* is introduced to facilitate the use of distributed dynamic drainage levels for simulating many grids within a watershed in combination with a parameter *GWFileNameIndex* to govern which file that should be used as driving variables to each simulation. The file name should include an underscore prior the number. The number after the underscore will be replace by the value of the parameter value give by *GWFileNameIndex*. So *GWInput_234.Bin* will be renamed to *GWInput_6732* if the value of the parameter is 6732. The same system is used to consider a distributed meteorological file using the switch *Dynamic indexed input file* in combination with the parameter *InputFileNameIndex*.

08-11-24 New options for plant development

A dynamic change of the specific leaf area index is introduced as part of the plant module. The switch *Dynamic Specific Leaf Area* allows the user to specify one additional parameter (*Spec LeafArea Begin*) value for the Specific Leaf Area in the Table *Size and shape of growing plant*. Note that the specific leaf area will then be defined by the new parameter at Growth Stage Index 1 and will be changed by linear interpolation towards the ordinary parameter value (*Specific LeafArea*) when reaching Growth Stage Index 2. Note that the growth stage development may need to be changed in connection with introduction of the new parameter to obtain the best timing of the leaf area development. A more flexible dormancy for winter regulated plants is introduced by addition the Temperature Threshold for reaching dormance as a parameter instead of a previous fixed value of +5 ° C. The parameter (*Dormancy Tth*) is located in the *Growth stage* table that is part of the Plant Growth module.

08-11-24 Further development of N-emission model

The Model has been modified to change the source of N for the growth of the microbial biomass from NO_3^- to NH_4^+ or organic N. A new switch *Denitrifier Growth* contains options for distribution between mineral N or organic N as a source.

A number of new output variables have been introduced to represent the summation of fluxes or pools from different layers. The new outputs are consumption and production of N between the different steps of reduction and the exchange between the anaerobic pool and the aerobic environment (*N Tot N2 internal exchange*, *N Tot N2O internal exchange*, *N Tot NO3 internal exchange*). Also the same type of output variables for denitrifier and nitrifier microbial biomass are introduced (*NTotDenitMicDeathRate*, *NTotDenitMicGrowthRate*, *NTotDenitMicGrowth_NOX*, *NTotDenitMicrobe*)

08-11-24 Further Development of GLUE post analysis

The menu for post processing of results from multiruns are developed to enable both for selection of accepted runs and for creating charts that combine plotting from accepted populations, measured values and individual simulations. Selections are automatically saved for further processing after the closing of a document.

08-11-05 New GLUE features as postprocessing of multiruns

To allow for more efficient overview of multiruns some new features are introduced

- 1) New output file that includes all residuals between simulated and observed data (only) This file with extension *XBin* will be place in the subfolder when running a multirun with Validation variables. The switch *Time Serie Error File* has to be adjusted to be on for creating this file. When using this option all other validation outputs can be put off. This means that the *Validation Outputs* switch should be put as: *Statitics Only*.
- 2) The Acceptance of simulated runs could be adjusted from the extended Validation sheet list that will be displayed after pressing the upper corner left button. By default all runs are considered as accepted and the conditions are the actual min and max of validation measures. The user will enter constrains and by that restrict the group of accepted runs to the new limits given. Note that the updating of accepted run groups will be done after activating a command button on the list.

- 3) The plotting of individual run could easily be done by clicking a check button on the extended list of accepted runs.
- 4) The plotting of mean of accepted or mean of all runs are made as before or in the same manner as for the Bayesian calibrations.
- 5) The posterior parameter distributions could be viewed as before with the accepted identified as different from the prior distributions.

Some other minor bugs have also been corrected.

08-10-27 Development of Microbial based Denitrification module

Previous model assumed that N-fluxes to denitrifier to be minor part of overall N-budget for soil and using a small time step allowing correct updating of anaerobic gas pools and Denitrifier biomass. Recently the model was improved to be more robust also for longer integration time steps. The present step of development is in line with previous step attempting to create realistic results also when turnover of pools are very high in relation to estimated fluxes.

The previous step checked for a consistent estimation of production and consumption of the gas for each step in the chain from NO_3^- to N_2 . The present step is also including the exchange from the anaerobic domain to the air filled pore space (or direct emission). When the demand based on the rate functions for each of the transfers exceeds the available storage a common scaling to reduce the flux rate is adapted for each of the transfers are adapted. This allows for a sharing of the available pool.

The time step for estimating fluxes of N gases are recommend to set according to the switch from (Numerical module) to be allow for at least 8 iteration per days. When using daily time resolution of input data we recommend the user to set the switch (NitrogenCarbonStep) to independent of input time resolution.

The Nitrogen balance check is now updated with consideration of both N in microbial biomass and N in the anaerobic gas domain. New auxiliary variables *NTotDenitStorage* and *NTotGasStorage* are introduced as part of the *Soil mineral N module*. The N transfer that represents the death of microbes are assumed to represent a N flux to the Litter1 organic pool.

08-10-20 Correcting bugs

Bug causing error when included an underscore “_” in folder names causing the wrong file names when creating new files deleted.

Bug causing zero transpiration rate when water content reached porosity also when AirMinContent was set to zero is deleted.

Bug causing errors in mass balance of N and C when using a water source flow as external forcing of water to a soil profile.

08-10-20 New colours and interface options

The grid interface have now been complemented with categories of the various modules of the models. Selection of categories to be shown are made by right click on the upper left corner. The various categories have also got a colour coding to enable quick overview.

08-10-06 New options for rerun of MultiRun Simulations

When a multirun result is completed and results are stored in the container file Name_Multi_XXXXXX.MBin the results are possible to view from tables that are shown as part of Validation or MultiRun tab of a completed multiRun document. The previous option is that a specific individual simulation can easily be opened as right click option when you have the cursor on the run no column of this tables. The new option is that the model will also be able to create a new sim file providing that such a file does not exist (typical option for running many simulation without storing the output on the harddisk). The New sim file will be able to rerun the specific multirun.

08-09-29 Change of microbial based denitrification model

The previous microbial based model generated instabilities for certain combination of parameter values and time steps. To make the model more robust a new formulation have been made to the internal fluxes of microbial growth and

respirations. The model has also been changed to represent a proper definition of the efficiency parameters regulating the partitioning between growth and growth respiration of microbes.

The respiration loss in one pool will form an input to the next nitrogen pool in the denitrification chain, i.e. the production of N₂, N₂O, NO or NO₂ (see Figure 5.0.3). These fluxes (eq. 6.45) were calculated as:

$$N_{NO_3 \rightarrow AnNO_2} = (N_{rgNO_3} + N_{rmNO_3}) \cdot M_{activity} \cdot N_{micrDN}$$

Are now replaced by a new equation: $N_{NO_3 \rightarrow AnNO_2} = \min(AnNO_3 / \Delta t, (N_{rgNO_3} + N_{rmNO_3}) \cdot M_{activity} \cdot N_{micrDN})$

To make sure that the fluxes will not exceed the available amount of the source gas given in the above equations as AnNO₃.

The growth respiration for N₂O, NO, NO₂ and NO₃ was before calculated as:

$$N_{rgNO_3} = N_{NO_3 \rightarrow micrDN} / d_{effNO_3} \quad (8.19)$$

And is now estimated as:

$$N_{rgNO_3} = N_{NO_3 \rightarrow micrDN} / d_{effNO_3} - N_{NO_3 \rightarrow micrDN} \quad (8.20)$$

where d_{effNO_3} is an efficiency parameter. Note that the value of the efficiency is now strictly between 0 and 1, a value of .5 implies that half the rate is going to growth and half to respiration. The same value of 0.5 using the previous equation indicated that the respiration loss was twice as big as the growth rate.

08-09-22 Modified Sampling options in Marcov Chain for Bayesian Calibration

The previous procedure was using a fixed step size with a default value of 0.05 based on the suggestion by Marcel Van Oijen. The new procedure is using a change of the step size from an original value to a final value. Scaling of the start step size with the new default value of 0.5 is made based on a new switch in the Technical module. The Switch *Marcov Chain Step* contains 4 options: (1) Constant value, (2) Exponential decrease, (3) linear decrease and (4) a cyclic variation of the step size. New parameters are added to control the change of the step size as a function of number of runs during a multiple run. The *BayesianMinScaling* parameter determines the minimum step size by multiplication of the step size with the value of this parameter. The *MC StepChangePeriod* parameter determines the duration for change from max to min value for option (3) and (4) according to the switch settings of *Marcov Chain Step*. The change of the step size when using option (2) is regulated by the function $f = \exp(-k * \text{no Runs})$ where k is the value of the parameter *BayesianChangeCoef*. A variation of the Marcov Chain step decrease the risk for a calibration to investigate a too small space of the parameter dimensions selected. A decrease of the step size will also increase the number of accepted runs since the search will be made closer the region that has a high probability according to Log Likelihood values.

08-09-22 Improved Real Time monitoring of MultiRuns

The Real time monitoring has been developed to allow for a flexible monitoring of multirun simulation. Previously only the charts for the animation of output variables were possible to design for the user. Now also the monitoring of Bayesian Calibrations is made flexible so the user can decide which parameters and which validation variables should be visualized during the simulation.

08-09-19 Introduced adding heat Source

The Heat Source option has been further developed to include up to two independent heat sources. See Switch *HeatSource* in the *Soil Heat Flow* module. The first heat source is considered to have a chemical origin and the second is controlled by biological processes. Both heat sources have also got a time dependence as controlled by an exponential decay controlled by the new parameters *Source1 Decay Coef* and *Source2 Decay Coef*. The heat source options have been suggested by Bo Elberling and Jorgen Hollesen from Copenhagen University.

08-09-16 Correction – bug in Radiation interception and update of new model from 08-09-03

Bug in call to random number generator deleted eventually causing errors in radiation interception

New view function for the split of diffuse and direct radiation using a new parameter *DiffuseRadCoef*. Also new function connected to the *CanopyChadeCoef* and *ViewScalingMax* parameters to demonstrate the shading and viewing of canopy. The *PlantDiameter* parameter as introduced from 08-09-03 is replaced by a common parameter *DiameterHeightRatio* representing the ratio between the Canopy Height and the Canopy Diameter. The Canopy Height may be specified either as a simulated variable or given from a parameter table.

The Covariance and statistic of Bayesian calibration parameter results was reintroduced after being left out by mistake introduced 08-08-12.

Various minor update of code.

08-09-10 Correction bug in Interception and some other procedures

Deleted bug in new rain and snow interception procedures that caused severe problems when a simulated canopy was without height or leaf area.

Also deleted some old minor bugs that may have caused minor problems or may have some explanations if results are not exactly reproduced from previous runs: (1) Changed demand of N after N-fixation. The remaining demand after N-fixation remained for eventual further N- uptake by .i.e organic uptake that is also related to the demand from the plant.(2) Aerodynamic resistance calculations for heat has been assumed based on a ratio of 10 between distance to reference high and the roughness length. (3) An growth indicator showing the total mean response to N and water was corrected.

08-09-11 Corrected bugs in Calibration procedures

Deleted bug that caused error when more than 600 variables were available in validation file.

08-09-11 New design of plotting procedures from grid

Introduced a new check box for multiple selection of variables when making new charts. In the Output Sheet this option of picking variables will also be optionally linked to other open documents. This means that the same variable can be selected from multiple documents by one single click. The Click to produce the chart is still a single click on any variable name. A single click on a specific variable will not make any chart if not a previous click already have been on the checkbox.

08-09-05 Correcting bug in energy balance procedure

A bug that may eventually have caused serious problems in the energy balance calculation of the soil surface has been detected and corrected. The bug has been when the soil evaporation and soil temperature of the soil surface is calculated for an numerical solution of the energy balance equation of the soil surface. Switch Evaporation method in the Soil evaporation module was set to Iterative Energy balance. The bug may in some cases been causing crashes and infinite values of the energy balance close for the soils surface. However, the bug may also have been hidden and calculations have been made but with a constant thermal conductivity of the uppermost layer instead of a dynamic calculation of the thermal conductivity. The bug has been in the models for the latest 5 years. Improved results may be obtained for soil temperature simulations by using the updated version that allows for dynamic variability of the uppermost layer thermal conductivity.

08-09-05 Correcting bug in new Calibration procedure

Again an error in the correct timing on the combination of simulated and measured variables was detected and deleted. The error was evident when the duration time for estimating mean value of simulated variables was larger or equal to the difference in time between observed values in the validation file. Another error also caused erroneous timing in the output validation file. Hopefully the new procedure makes precise handling of the various new options for finding windows in time for the validation using different temporal representation of simulated and measured variables. In addition some plotting option bugs were deleted. Note that all plotting options still may be instable especially if many charts are made and then automatically stored as objects on the Chart list sheet.

08-09-04 New output option in the PG edit window

When saving files prior or after editing the data simple selection of output variables can now be made by click on check boxes in the Variable list grid. However, by default all variables will be present in output file.

08-09-03 New canopy transmissivity model

Introduced a new **canopy transmissivity model** (activated by the switch *CanopyShade* under *Radiation Properties*), which take into account the influence of solar elevation on the transmissivity of direct solar radiation through the canopy. To do this, the global radiation is firstly splitted into diffuse and direct fractions as a function of cloudiness (following Gryning et el, 1999) (this can be independently activated by another new switch *SplitGlobal* if canopy is not simulated), secondly, a transmissivity coefficient is estimated for direct and diffuse radiation separately, where the transmissivity of direct is dependent on solar elevation following Chen et al (2003), whereas the transmissivity of diffuse radiation (and longwave radiation) is calculated with the standard Beer's Law, independent of solar elevation. In addition, the sky view factor (1-{canopy soil cover fraction}) for direct radiation is also affected by the solar elevation as a consequence of the plant geometry represented by plant height and the (new) parameter *PlantDiameter* (also following Gryning et al, 1999). **Limitations:** the new transmissivity model requires that the longwave radiation balance of the canopy is represented explicitly (see switch *LongRadCanopy*).

In addition, a correction was made on the estimation of cloudiness for sloped surfaces. Previously, the potential radiation was projected onto the slope before comparison with the measured radiation to estimate cloudiness. However, in most cases the measured input is represents Global Radiation of a horizontal surface. Thus, in the new version, the potential radiation (if used as input to the model) is corrected for slope after the cloudiness estimation instead. Thus, simulation of cloudiness, and thereby incoming longwave radiation may change the model results to some extent.

Small differences compared to earlier versions may also occur in PotentialTranspiration and InterceptionEvaporation, due to the introduction of additional checks on the fraction of canopy above snow surface, to avoid any kind of evaporation or interception calculated for snow covered canopies. A new parameter is introduced (*SnowReduceLAIThreshold*), which sets the minimum fraction of canopy above snow surface to allow transpiration or interception evaporation.

08-09-01 Additional changes of new Calibration and new naming convention for MultiRun simulation

Changes made to make sure that file names are correct for multiple simulations. A new file is always created with the correct naming convention using the current runno in the name following the underscore character (Name_XXXXX.Sim). Additional files will be named (Name_Multi_XXXXX.Sim).

08-08-27 Deleted bug on new Calibration

The new calibration was causing mismatch between simulated and measured variables. This should now be corrected.

08-08-26 Deleted bug on index output

Indexex output variables was not correctly identified when writing to the Storage file the array of index started on a value greater than

08-08-19 Modified heat production function

Modified the Heat production function in the module *Soil Heat Flows*. The new function has also the temperature for the maximum heat production as a formal parameter (*HeatProd_Threshold*) instead of the previous fixed value of 30 ° C. The new function is also made available for viewing the function during edition of the parameter values.

08-08-12 New Calibration option – Validation files

Introduction of model version 3.1 that differs from previous mainly in the calibration procedures. The new version is new compared to the previous in two principal ways :(1) The simulated validation variables are selected from the output list independent if they are also selected as output variables, (2) up to 5 different validation files could be specified. In previous version of the model only output variables that were selected as outputs could be used for validation. In the new version any variable could be selected for validation. In previous version of the model validation variables were found in the standard output file (COUP_XXXXX.BIN) together with the ordinary variables. In present version each validation input file will create a separate validation output file with only the selected validation variables together with correspondent simulated variables (VY_COUP_XXXX.BIN) where Y is the validation file number indicator from 1 to 5. The calibration results statistics will as previously be stored in the document file (Name_XXXXX.SIM) or for multiple runs also in the container file (Name_XXXXX.MBIN).

The new validation procedure included the previous useful options as (cumulation of original values) but in addition also log transformation of variables have been included.

A major principal difference with the previous calibration, that was made from the data stored in the output file, is that the new procedure allows differences in time resolution from the simulation variables. If the duration of a variable is specified as 0 (minutes) the most adjacent simulated variable will be picked from the dynamic simulation (momentary value). If instead a value of 30 minutes are specified a mean value of the dynamic simulation will be calculated for the duration specified. The Duration could be specified as any number for each validation variable but less than the intervals between the records in the specific validation file.

A new switch *Time Serie Outputs* in the technical option allows the user to have different type of outputs as the result of the simulation. Default will be both time series and statistics of the selected output variables similar to previous version of model. New options only statics about the selected outputs or no information at all about output variables. The other new switch *Validation Outputs* allow the user to cancel the creation of the validation output files.

08-04-25 New option of Bayesian calibration

Added new option to sample for parameter values in MCMC by using a log distribution between specified min and max values instead of the linear distribution that is normally used. The new log distribution is recommended for parameter values that have very wide ranges from extremely small to huge values, e.g. hydraulic conductivities. The new option is simple one additional option of the multirun options.

08-04-21 Error MultiRun with Changes during Run

Deleted bug that occupied additional non used memory for each new run when including changes during run in a multirun. Depending on internal memory the model crashed after approximately 1000 runs.

08-04-21 Added new outputs for integration of depth

To Allow outputs for the storage of soil Nitrate, soil Ammonium and total Mineral N 3 new variables have been added in the group of *Additional Variables with name Acc_NO3_Storage, Acc_NH4_Storage and Acc_MinN_Storage*. The horizons of these variables are determined by the values specified in the Parameter Table *Depth of Sons*. The will be from the soil surface down to the depth specified in the table by the parameter *Depth*

08-04-17 PG File errors

Deleted bugs that caused errors when creating or editing of PG Bin file. Errors occurred when making editing of a file that previously had been opened.

Deleted bug that omitted updating of file description in the PG dialog menu.

08-04-17 Saving to excel

Changed the save to excel option for time series to allow for saving of more than 255 variables. The first 255 variables are stored in the first sheet and any additional variables are stored in sheets with new numbers.

08-04-12 Growth Stage Index, update

Modified the growth development of by excluding the development of a leaf area index if the maximum growth stage index (*Max GSI*) is set to a value of unity. The GSI parameters are part of the *Plant Behaviour* table in the *Plant Growth module*.

08-03-31 New real time monitoring display

A new real time monitoring for animation of simulation results during the run is included. The real time monitoring enables the user to design any output variable to be display for single runs. The new design will be stored in the register of the computer and will be stored until it is changed by the user of the computer.

A bug in the simulation time (causing errors at day shift) used as introduced 03-18 is also deleted.

08-03-18 New outputs of Simulation time used

The simulation time accuracy have been updated to includes parts of seconds and the simulation time is also separated been the time used to initialize the model prior the run, making the actual run and the post processing of the file. When a simulation is made as part of a multirun simulation the simulation time will be visible from the MultiRun Sheet. For single run the simulation times will be available in the Messages sheet of the document. Note that also the real time monitoring of simulations are changed.

A new Technical switch has been introduced called: *No SingleRunSimFile*. The Switch will allow the use to disable creating Sim file for each single run. The option may be useful when making huge multi run simulations. Only the first and last simulation is then stored completely with SIM files and in addition the result is stored in the multi storage (MBIN) file that include the specific variation of each simulation compared to the base simulation.

08-03-16 New Update of soil DataBase - interface and content

The soil data base has been changed to improve the access to to all data. The inclusion of new data in the soil Database can be entered only from the RunInfo Sheet. Right click on the line with soil properties to enter the main dialog window. Note that a new subdirectory for comments file is created and the old comments stored in file .PFN are moved to a subdirectory called "Comments". This subdirectory has to be present as a subdirectory of Soil Properties. When making a complete update the subdirectory will be created otherwise you have to create this manually.

The Soil data base have been edited and a number of new soil profiles have been included. Of Specific interest are new constructed typical soil that are based on many other sources of data. Annika Lundmark has entered such profiles No 300: 30-36 and 400:1-3.

08-03.12 Improvement of PG file options

New Import and export options have been included. The import options are from simple text file and corresponds to the format that is created by the correspondent export option. Note that for different separators may be valid to separate variable number. The default separator is comma (,), the second is semicolon (;) the third is tab (TAB) and the forth is space (). Numbers could be specified as floating point numbers using the decimal point (.). Records are separated by new lines (CR and NL). The First value on each line could be a date specified as 1985-01-01 12:00. If the data is omitted then it will be estimated from the specified start data and the specified time interval in the dialog window.

08-02-05 New Update of DataBase

The browser of data base objects was updated to improve the visibility of data that have been stored as data base objects. The new preliminary implementation allows for easy edition of key words to classify the objects. The content of the data base objects could either be directly imported from the current document (sim file) or exported from the data base to the current document. The data base object are also possible to use as part of multirun or as changes to be introduced during a simulation period.

08-02-04 Deleted Bug

Deleted bug that caused random type of errors when making multiruns in combination with the use of the Hysteresis option for soil water flows. Re initialization of internal variables was not working properly that caused error after the first run.

08-01-21 New help

Introduced new help file with improved context sensitive feature. The F1 button works from the grid menu system. A new web based on line help was also created

<http://www.lwr.kth.se/Vara%20Datorprogram/CoupModel/Nethelp/default.htm>

PEJ

08-01-16 Bug

Corrected a number of bugs related to the reading and editing of PG-files. The PG file was sometime not closed and blocked for further processing.

PEJ

08-01-08 Bug

Deleted bug that caused run time error when importing data base object from RunInfo sheet.

PEJ

08-01-03 Major changes

1. The multirun options have been extended to incorporate also a watershed approach that makes it possible to make distributed watershed runs by coupling water and salt transfer from higher to lower levels. The new watershed option is connected to the LateralInput option in

module Model structure and the two main parameters need to make the a watershed runs with coupled transport are:Hflow Input index and Hflow Output index that are in the module of Drainage and deep percolation.

2. Charts can easily be combined between different runs by adding to previous charts. The target when adding a variable is made by a focus control of a visible chart window.
3. A PG File (new tab) was introduced and allows for simple and quick management of any PG-structured file. Most of functionality of previous PG-program is now implemented and can be reached in the PG File Sheet by right click within the grid system. Any PG file can also easily be linked with each other by using the options described above (2).
4. A history list of previous editing of a document is also implemented that keeps track of all the changes that have been made for design of a simulation document. Note that the history of individual parameters, switches or basic run instructions (runinfo) also can be view by right click on the specific items.

PEJ

2007

07-09-12 Major changes

Model interface has reached a first B-level of development. Many continuous changes have been made for the first year of 2007.

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07-05-09 Major Changes

New Model Interface. Model Name 3.0

PEJ

2006

06-11-26 Introduced version 2.54

Included new options are export/import to excel from the specification of validation variables (both time series and single output type).

Also deleted bug causing error when using validation on single output type for output types of scalar and using initial values as test variable. PEJ

06-10-30 Bug

Deleted bug from September 2006, that showed non updated values (disabled or enabled) fields in the Model file menu.
PEJ

06-09-26 Bug

Deleted bug that showed non updated values on differences between model output and observations with respect to Summary variables.

06-09-22

Improved the transfer of outputs from model to excel so that more then one spread sheet for each output category could be created when the maximum number of lines for one spreadsheet are exceeded. PEJ

06-09-21

Further updating of Multirun options to allow for more efficient use of excel (import and export) from both the main menu and from the dialog menu of Multirun parameters that now also incorporates database records.

Deleted bug that produced the erroneous covariance matrix as output in previous version of the model. PEJ

06-09-14 Introduced version 2.53

Changed the Bayesian calibration procedure with respect to acceptance criterias to allow more accepted runs when using time serie validations that makes the sum of loglikelihoods to large numbers.

Deleted bug that caused fatal error in the 2D simulation with input from previous runs. In MultiRun mode the new updated version will take the input file for lateral input from a specified name in the first run and for all the consecutive runs the input file will be the output from the previous run no.

Introduced new preliminary option in the Multirun parameter dialog that allows export and import of all setting from an excel file. Note that the format has to be the same as in the export file, including the name of the worksheet (MultiRun).

PEJ

06-08-08 Bayesian calibration

New options for Bayesian calibrations are introduced that makes it possible to add both time serie measurements and other measurements/observations/criterias for the validation.

The options are added by using the menus and all relevant information are added to the sim-files. Also the calibrated parameter values are stored as part of the sim file.

The number of runs of possible number of runs are extended to 9999 and the convention of output file name from individual simulations have changed for the time serie files.

Previous COUP_XXX.BIN are
now named to COUPXXXX.BIN
for numbers greater than 999.

PEJ

06-08-08 Revision of command line

option to handle properly modifications of parameter values, switches and run number. The documentation from 05-09-21 is now complemented with additional optional flags:

[/N] #
/N where # is the intended run number.

[/P] filename_p.txt

/P where filename_p.txt is a list of parameter names followed by their intended values. The list is as below

Groupname;Parametername;Parametervalues;index

where index

0 represents parameter without index
>0 represents indices in parameter tables
-1 represents switches
-2 represents file names

Groupnames have to be specified according to the internal convention that can also be seen when using the optional excel files for output summary.

DG

06-05-31 New Parameter

Introduced new parameter for delay of transport of assimilates from the C_NewMobile pools of plants to the growth of Leaf, Roots and Stem. The new parameter is named AlloRateCoef. A value of 1 (default) corresponds to the previous model. A value lower than 1 will correspond to the fraction of assimilates that are distributed for growth during the period of numerical integration. PEJ

06-05-31 Bayesian calibration

Further development of the MultiRun options have been made. All type of variations except the Bayesian calibration is now working properly and a previous problem with memory allocations during long runs have been minimized.
PEJ

06-04-26 Water Shed approach

New Beta version of distributed watershed approach introduced.

New technical switch DeleteOutBinFile introduced that enables a delete of the ordinary output file COUP_XXX.BIN directly after completion of simulation. PEJ

06-04-17 New Version 2.52 Introduced

Major changes are new dialog menus to facilitate better and more efficient definition of (1) multirun changes or conditions for (2) validations. In addition one new option have been introduced that allow stochastic variation to be uniformly within a range that are either considered as a linear or a logarithmic distribution between selected min or max values.

The new options for multirun changes are on the Edit menu and have made separated for Parameters and Parameter Tables. Within the new dialog windows all parameters could be handled after selection from a tree structure that allow the user to select any of the parameters that are enabled. The user will also be able to view all selected parameters that have been selected for multirun changes and select any of those from a list for any modifications of chosen conditions. By this new menus parameters could easily be introduced, deleted or modified from a single window.

The new options for validation variables makes it easy to select combination of variables from the validation file and from the selected simulation variable list.

PEJ

06-04-04 Precipitation generator

Changed the precipitation generator to make precipitation continuously when having frequency of one day. PEJ

06-03-28 Deleted bug

Deleted bug that caused error on CSurfaceLitter2 (NC Plant module) variable when using two litter pools.

Changed name of variable Soil Resp to Soil Respiration (Organic Module).

Deleted bug that caused error when using stochastic generation of parameter values in multirun option. PEJ

06-02-20 New growth stress response

Implemented new optional combined water and nitrogen stress on plant photosynthesis.

The new option is made available by using the

PlantStess switch and when using Radiation use efficiency as Growth model

A new parameter is named RelW Water that is defined in the parameter table: Photosynthesis Response

The combined response is calculated as

Response=(a*sqrt(ResponseWater)+(1-a)*sqrt(ResponseN))**2 PEJ

06-01-26 Bug

Deleted bug in the viewing function of hydraulic conductivities.

PEJ

06-01-24 Updated and corrected Multirun output feature.

Note that the new Multirun feature require a new excel file to be created if the multirun design have been changed from one multirun to another multirun.

Deleted bug that have caused problem when combining different objects within the same dimension in the multirun. PEJ

06-01-22 Multirun

Introduced outputs of parameter values that are changed during Multiruns in a separate sheet in the Output excel file if selected. The sheet is named Multirun. Note that the parameter values are also located as before in the the parameter value sheets. PEJ

06-01-22 Bug

Deleted bug that caused errors when using N fertilization as input from a parameters in the N external inputs.

Also changed the reading of Manure input PG-file to correctly read only one full day when using irregular input of time points in the input file.

The N Fertilization was also introduced as one additional input in the PG-File.

See the switch N Fertilization. Id Code to identify N fertilization in the file is FERTILIZER.

See also news from 04-09-06. PEJ

06-01-10 Bug

Deleted newly (06-01-02) introduced bug that affected the rate of litterfall from old leaf. PEJ

06-01-09 New Allocation model

Modified the Allocation model to account for the litterfall from oldleaf. Four new variables are introduced: CLeafMobile Ret, COldLeafMobile Ret, NLeafMobile Ret, NOldLeafMobile Ret. The four variables substitute the previous CMobileLeaf and NMobileLeaf using negative values. CMobileLeaf and NMobileLeaf are now only used to represent fluxes from the mobile pool to current year leaf during shooting. PEJ

06-01-04 Allocation model

Changed previous model for allocation to mobile leaf pool. The previous model accounted in a non consistence way to both litter fall from old leaf and from current year leaf when creating the mobile C and N pool. The present version does only account for litter fall from current year leaf and also checks for the N content of leaf to make sure that not more is allocated to the mobile pool than what is available. Previous could cause strange behaviour especially when high litterfall rates. PEJ

06-01-02 Cleaning management

A cleaning operation options is introduced that works in a similar way as the new Harvest option with Tables for Cleaning During Years and Cleaning within Year. Note that Cleaning means that the plants is cut and that the fraction that has been cut will form litter directly at the day of Cleaning. No fraction is harvested, i.e. exported from the system. Also corrected inconsistence PEJ

2005

05-12-27 New version

New version 2.51 introduced that allow for a flexible harvest and biomass removal during development of plant. Two new switch in the Plant Growth models.

Harvest Day and Harvest Range. The Harvest Day switch first and default option (Fixed Single) correspond to the previous model with only one harvest DayNo that is specified the Harvest Plant Table. New options are: Fixed Multiple Days, Estimated GSI, and Estimated LAI. The fixed Multiple Days allow the user to specify both the different years and the different days of the years that are for harvest operations. The values are to be specified in tables (Harvest Within

Years and Harvest During Years) that may include any number of operations. Depending on the value assigned to the Harvest Range Switch the operations may be assigned to specific plants or all defined plants. An index that corresponds to the plant to harvest will be seen in the Tables if only one plant is to be harvest at a time.

The option Estimated GSI means that the harvest is made with the plant has reached the Growth Stage Index of 4. The option Estimated LAI means that the user can specify a LAI value that will trigger the harvest operation. The Harvest LAI value is to be specified in the Harvest Plant Table.

Note that a new auxiliary variable SimPlantYearAge allows displaying the Plant age in year units and is complementary to the SimPlantAge that is specified in days.

PEJ

05-12-27 New Litterfall

New regulation of litter fall as enhanced by higher LAI values are introduced by one new addition parameter LAI Enh Coef that is specified in the Scaling of litter fall table. The scaling enhances higher litter fall rates from leaf by using an exponential function of the coef and the LAI value. Scaling=exp (coef*LAI). The default value 0 means that no effect of LAI is taken into consideration. The scaling is effective on both old and current years of leaf. PEJ

05-12-27 Update

Updating dialog menus for switches to allow for 20 items on a single page. Various minor changes in the source code to improve consistence with new the compiler. PEJ

05-12-23 Bug

Deleted bugs with respect to plotting in Parameter Tables and Hydraulic properties. Also updated the data base function to better function for storing, editing and retrieving data base objects. PEJ

05-12-10 Bug

Deleted bug in newly introduced Nitrogen uptake model from (05-11-29) that caused problem when making repeated number of runs with more than two plants. PEJ

05-12-06 Bug

Deleted bug in the newly introduced Nitrogen uptake model from (05-11-29) that caused problem when more than one plant was competing with another. Large errors when different roots depths were present. DG/PEJ

05-12-02 New option final state variable

Introduced a new method to assign parameter table values to represent final state variable values from previous run. Also introduced two switches to allow for setting initial conditions as Carbon storage instead of N storage and CN ratios. The new switches are Initial Carbon Conditions and Initial Plant Conditions in the soil organic and plant growth section. New values of parameters will re assigned in respectively dialog menus by pressing a new button: Initial State Variables. PEJ

05-12-01 N uptake model

Changed the Nitrogen uptake demand model by accounting for the net carbon production of leaf, roots and stem. In previous version of model the Nitrogen demand was governed by the gross carbon production of respectively plant components. No Switch was connected to the change so users have to change the respectively CN values in the Table: "Minimum CN Ratios of plants" to reproduce old model results. The new model means that the minimum values are related to the values after respiration losses and not prior respiration losses.

A new option in the N Mineral was introduced named Flexible Uptake. This switch allows the use to have either a plant specific compensatory uptake or a common uptake. The parameter for the plant specific flexible uptake is found in a table with the same name. PEJ

05-11-30 N Re Allocation

A new switch "N ReAllocation" was introduced, which provides an option ("on") to calculate a withdrawal of nitrogen from the plant storage pools as a response to low C:N ratios. When this option is chosen, the actual C:N ratios in the plant storage organs are not allowed to be less than the minimum C:N ratios of each organ respectively (the latter are specified by the user). Carbon losses that would result in a lowering of the C:N ratio below these thresholds are instead met by a corresponding allocation of nitrogen to the mobile nitrogen pool. Nitrogen demand by the plant is first met by utilising the nitrogen in the mobile pool, and secondly by withdrawing nitrogen from the soil.

PEJ/LK

05-11-29 Origin of File

Introduced information in each new document (sim-file) about the origin of the file. The origin is shown in the view windows as the full filename of the sim-file from which the current document was created. PEJ

05-11-29 Bug

Deleted new temporary bug in the Validation file. PEJ/DG

05-11-29 N Uptake

Changed N-uptake models to be more consistent for both mineral uptake and for the organic uptake on Nitrogen.

First of all the uptake is related to a root density function for both mineral and organic uptake. See switch "Root Density Influence" and two parameters: NUptRootCoefOrg and NUptRootCoefMin. The parameters are made proportional to the root density in an exponential function that reduce the uptake efficiency from unity to zero depending on the root density.

The mineral uptake model was changed so that the competition between different plants is correctly related to the root distribution for each plant. Previous model was using the relative demand for the entire root system to differentiate the uptake from one single layer. The new model is using the relative demand of the actual plant to the other plants for each specific layer.

The compensatory uptake by plants using the parameter NUptFlexDegree as regulating the degree for all plants in a common way has been complemented by a table "Plant Specific Flexibility Uptake" to specify different values for different plants. A Switch Flexible Uptake is introduced to make choice between the two options.

The Organic uptake was corrected to being independent on soil discretization by removing the relative distribution of roots from the maximum supply function for each layer. The previous model was unfortunately sensitive to number of layers and root distribution. Many layers with roots was an disadvantage for the organic uptake efficiency.

PEJ/DG/LK

05-11-29 Bug

Deleted fatal bug in Database handling of Plant Growth objects. PEJ

05-11-24 New Version

Various changes to make the new version 2.5 correct made.

The directory handling changed so that the .sim document and the output .bin file are always the same.

Also replaced old User option on "Start with values from previous file" with a document related technical switch StartWithPrevious that should be put on if the final state variable values should be used as initial values for the simulation to be done. Parameters that are used to set the initial values when not the switch is set are not still shown and stored in the next document but not used. This allow the use to shift between parameter settings and initial values from previous run without reassigning all parameter values. PEJ/DG

05-11-11 New Version

New First official release of version 2.5 based on new MS VC++ 7.0 combined with Intel Fortran 9.0 and Graphic Server 6.0.

A number of various changes have been made.

Fortran Modules that have been changed are:

Interception, Radiation, Drivings, Drainage, ModelStuc and General. PEJ

05-10-03 Heat source function

Updated Heat source function to allow a uniform heat source to a soil profile.

Added additional auxiliary variables for CN-ratios of

Soil and Plant. New variables represent integrated values for all plant or all soil layers. Part of Plant Growth or Soil Organics. PEJ

05-10-03 Soil Database

Updated Soil Database with profiles from Uganda, Lusta project and Typical Swedish Soils. PEJ

05-10-03 Update

Updated to Graphic Server 6.0 PEJ

05-09-21 Road Salt Application

Updated and changed a number of parameters and switches for the roadsaltapplication (see 050811) PEJ

05-09-21 Command Line option

Introduced a new option that simplifies the use of the command line mode of the model.

Syntax:

coupmodel [/R] [/S] [/Q] [/F] filename

filename Specifies the path to the sim-file to be opened
the optional flags are

/R Run the simulation (a new document with an updated run-number will be created if the sim-file has already been running)

/S Save sim-files after simulation

/Q Exit application after executing command line arguments

/F Indicates the position of the filename in the command line

If no optional flags are present in the command line arguments, the sim-file specified by filename will be opened in the usual way. DG

05-09-11 Winter regulation

Enabled the winter regulation of transpiration also when using multiple leaf options. This means that PlantDevelopment switch in Plant module can be used both in single leaf concept and multiple leaf concept. The multiple leaf concept enable the common WinterCondMax parameter to be used for all canopies. PEJ

05-09-11 New output

Introduced a new set of variables to facilitate the comparison with measured data that are integrated over a number of horizons from the soil surface and downwards. The New output variables that are Auxiliaries in the group Additional Variables are called Acc_WStorage. The depth of the horizons that are to be specified by the user in the parameter table Depths of Sonds. Units for the new variables are mm of water. PEJ

05-09-11 bug

Changed bug in with in Plant module when using the PlantDevelopment switch as governed by Temperature sum. An error in estimation of temperature sum caused winter behaviour for the entire year when the switch was put on. This is only valid when using single big leaf option.

Viewing options for potential transpiration was also updated for the single leaf option. PEJ

05-08-17 Road Salt module

Updated Road Salt module (see below) PEJ

05-08-15 Water Flow Barrier

Introduced a water flow barrier in the soil as an option that might be used to simulate a simplified reduced vertical flow conditions. The Barrier is connected to the soil water flow module and the SoilWaterBarrier switch. The barrier will be located by a certain level

BarrierLevel and by a certain efficiency Barriereficiency. The otherwise vertical water flow will be directed horizontal as a drainage flow when the barrier switch is enabled. PEJ

05-08-12 2D Option

Updated some test runs in the Sample directory.

Created a new folder (Samples\2D_MultiRun) that includes 3 files for simple test of automatic 2D simulation. The example when creating a multiple run document from the Sim-file in the directory a run of 5 vertical columns will be made that are directly linked to each other. Lateral input to the first run will be read from the file COUP_52 but later lateral input will be read from adjacent runs of the models when simulation are made in multirun mode. PEJ

05-08-11 Salt Flux

Introduced lateral Salt GW inflow to allow export of Salt from one run to another simulation in a similar way as made for water. Providing that SaltGWSOURCE switch is enabled the input variables are expected to be defined in the LateralInput File. The input variable are identified by the names SaltDrainflow and they are represented in the run as SaltSourceFlow. The same number of variables as vertical layers should be defined in the input file. PEJ

05-08-11 Road Salt model

Developed connection to Road model.

The input from the output from road in terms of salt emission, snow export or surface runoff are made as possible input to a road side simulation.

SaltRoadStorage switch will be on except for road side simulation when the switch will be off and instead the switch SaltDeposition can be either from parameter or from a PG-file. The variables have the defined in a pg driving variable file Salt Road Deposition. When the application is causing deposition in the road side environment (From Road) 3 variables are expected with naming as give by the output variables: Salt AirEmission, Salt PloughEmission and Salt RunoffEmission.

The Salt emission that will be recalculated to depositions are defined by the SaltRoadApplication switch. When the application is on road the deposition should be specified as mg/m² by one single and unique variable which does not require any specific naming in the file. The Emission rates as simulated by an On Road simulation will be converted from emission rate by road surface to deposition rates by soil surface by scaling coefficients: FracAirEmission, FractPloughEmission and FracRunOffEmission for the respectively origin of the salt.

The Snow export and the surface runoff variable will be located in the Lateral Input File which has been renamed from Lateral Ground Water Input to Lateral Water Input. This file may include Snow Mass Export, surface Runoff and Groundwater inflow. The use is made flexible by the switches: SnowPloughInput, RunOnInput and Lateral GW Source

which are defined in respectively modules for Snow, Surface Water and GroundWater and Drainage. The variables are all identified by the name of the corresponding output variables from an ordinary CoupModel simulation.

PEJ

05-08-10 Road and Salt Tracer

Introduced new preliminary submodel for Roads

In SaltTracer module a new emission model was introduced that estimate the salt emission from the road by 3 different main mechanisms. (1) By particle transport driven by wind and turbulence, (2) by snow ploughing and (3) by surface water flow. The three emissions are represented by the variables:

Salt AirEmission, Salt PloughEmission and

Salt RunoffEmission. New parameters introduced are

SaltRunOffEffCoef and SaltPloughEffCoef.

In Snow module a new ploughing model was introduced to make export of snow by ploughing when the total snow mass exceeds a certain threshold that is set by the parameter PloughSnowMass. The efficiency of ploughing is controlled by a corresponding parameter PloughEffSnow. The exported amount of Snow is represented by the Flow variable SnowExport. PEJ

05-08-10 Introduced version 2.42.

The new feature allow a simple approach to simulate 2D phenomas by making an automatic coupling between a series of runs. The LaterInput option is extended to identify both inflow in the soil profile by variables identified as 'WaterDrainFlow' in a named input file

and by inflow on the soil surface by a single variable indified as 'SpoolRunOff'. The input variables may be estimated from a previous output file from a run with the CoupModel (The same identifiers are used as corresponding outflow).

The Input variables are considered as Driving variables in the current simulations and idenfied as WSource(1:NL) where NL is the number of layers in the profile and as SpoolRunOn.

By Using the Technical switch LateralInputFile the input variables may either be defined by an already existing file or taken from the previous RunNo. The later option can easily be combined with MultipleRuns and in this case all runs in a serie will be taken from previous run except the first multirun which make use of the file name specified. PEJ

05-08-08 Growth temp update

Changed update of Growth Temp Sum so that the sum will be reset also when Winter_Regulation is Off providing that the plant is harvest (Growth Stage Index =4) or when the plant has reached maximum age (PlantAge > Max Plant Age or at sowing day). PEJ

05-08-05 Litter2 Quality

Introduced Litter2 quality also when using the implicit representation of Microbes in the organic soil module.

The partitioning between Litter1 and Litter2 is governed by parameters that can be assigned with different values for Leaf, Stem, Grain, Root and Coarse Roots. The parameters are found in a Table Fraction of Litter2 which is specified in the plant module. Corresponding parameters for turnover of litter2 as for litter1 is found in the soil organic module.

New Flow-variables in Additional Biotic Variable module are Soil Resp and Soil Resp (no roots). PEJ

05-08-05 Coarse roots

Introduced Coarse roots as part of the plant. The Plant is now divided in Leaf, Stem, Grain, Coarse Roots and Roots. The Coarse Roots are described similar as stem but the litter from coarse roots are going into different horizons of the soil instead of to the surface litter pool.

Default allocation to Coarse Roots corresponds to the parameter Fraction R which is part of the parameter Table Coarse Roots versus remaining C. The default value for Fraction R is set to 0 to make the new version similar as the previous model as a default setup. PEJ

05-08-03 New version 2.41

Deleted bug in estimation of soil evaporation when using different reference heights for wind and for heat (CommonRefHeight – No). In this case the common hidden RefHeight parameter was erroneously instead of the reference height that represents heat. PEJ

05-08-03 New version 2.4

New feature with SQL database support is now the new offical version of CoupModel. Version 2.4. A number of parameter names were changed for parameter tables. However the new names should be updated automatically when using old SIM-files from previous versions.

To make use of the SQL-feature you have to install an SQL-server preferable on you local computer.

The essential setup for this are found at:

<ftp://www.lwr.kth.se/CoupModel/mysql-essential-4.1.9-win32.msi>

It might also be of interest to install an additional tools to manage your database. See:

<ftp://www.lwr.kth.se/CoupModel/mysql-administrator-1.0.19-win.msi>

and

<ftp://www.lwr.kth.se/CoupModel/mysql-query-browser-1.1.5-win.msi>

For further information about MySQL and version 4.1 that is used by CoupModel see
of

<http://www.mysql.com>

Various minor updates were also made during the spring with respect to NO emissions and N uptake. PEJ

05-03-04 Gas Flux model update

Change with respect to the NC_GasFlux model.

Introduced new function for the exchange between the anaerobic balloon and the aerobic site in the air pore volume. The previous function was only governed by one parameter IntDiffRedFrac which caused an optimom exchange at 50 % anarabic fraction and with zero exchange both att 100 % and 0 %. The new parameter will add a base level by the value of IntDiffRedFracBase to the previous function. PEJ/JN

05-01-12 Bug

Deleted bug that caused ploblem with the drip irrigation as introduced 04-10-25 together with a salt concentration in the the irrigation water. The water source flow from the container of the dripper is now linked with a SaltSourceFlow to each layer with the water flow rate as given by Wsource. The Totalt input rate of salt by irrigation is summed in the variable TotSaltSourceFlow. The two new variables are enabled only when the Switch Dripper is put to on. PEJ

2004

04-12-21 Surface cover model

Introduced new option by SurfaceCover switch in Soil evaporation module. The SurfaceCover means that the soil can be partly covered by a plastic sheet to prevent evaporation. The degree of cover is governed by the SoilCoverEvap parameter. The Cover is primarily covering the DripIrrigCover if the soil is partitioned because of drip irrigation. Note that SurfaceCover switch will only influence evaporation and not infiltration to soil profile. (See Soilcover parameter in the Surface Water module to prevent infiltration). PEJ/LK

04-12-20 N-Uptake mode

Modified the N-uptake of mineral N to have similar degree of reduction if more than one plant is considered. The previous reduction was based on the demand for each plant in relation to available amount independent of other plants. The present reduction is the based on the total demand of all plants in relation to the available amount in the soil. PEJ

04-12-13 bug

Deleted bug in the Soil Data Base that caused errors when export of data to a local soil database was attempted. PEJ

04-12-08 Update of help file

Updated help file to correspond to changes from July to current day. Also new CoupModel.pdf made available on the web. LK

04-12-06 bug

Updated and corrected bug in the GasFlux processes. The bug used the volumetric water content erroneously instead of the relative saturation in the moisture response function for production of NO and N₂O from nitrification. PEJ

04-11-29 Update

Updated the Summary to excel file with connection to the History button on all parameter menus. The History was previously looking into the opened documents but is now searching for information in the excel summary file. PEJ

04-11-25 aerodynamic resistance

Changed estimation of aerodynamic resistance to include windlessexchange coefficient also when using the Richardson number for estimating stability correction.

Now adding the windlessexchange value in a similar as when using Monin-Obukhov length approach for stability correction. This is appropriate for potential transpiration, snow and soil evaporation.

Also changed to use Monin-Obukhov as default value for snow and soil evaporation. PEJ and DG

04-11-22 excel link

New User Set-up to allow higher flexibility for excel summary file name. Also new flexibility with respect to user defined working directory. The ".Sim" Document file are checked for being in the working directory when opened. The Working directory can be optionally adjusted. Also path for Validation and Driving variable files are checked for multiple locations which is useful when moving files between different computers or directory stuctures. PEJ

04-11-16 New version Minteq

Major revisions in the coupling of CoupModel and VMINTEQ have been undertaken during 2004. The updated code is now included in the latest version of CoupModel (2.33). A complete description will follow as soon as possible in the CoupModel Manual.

Examples of the improvements compared to version 2.29 (2003-11-18) are listed below:

Independent distribution of initial VMinteq problems and CoupModel layers - in other words, the number of initial chemical problems do not have to match the discretization of the soil profile in the hydrological model. The initial VMinteq problems (minteq_input.vda) are distributed on the physical soil layers according to their vertical extent given as parameter values.

Several options for the definition of initial concentrations.

Possibility to input precipitation chemistry via a VMinteq input file.

A correction of the masstransport calculation to allow for both upward and downward water flows between layers. Previously, the model code assumed only downward water flow, which introduced an error for negative (i.e upwards) water flows.

Improved handling of error messages from VMinteq (no more exceptions). The interface recognises when VMinteq fails to converge and identifies the problematic layer when reading the VMinteq result file (vmint.out). An very simple algorithm to achive convergence is implemented, which is based on changing the initial pH guess. The initial guess is increased with 0.5 units to a maximum of 12 until convergence is achieved for the specific layer. However, simulations are stopped after 10 unsuccessful re-runs to avoid infinite loops.

Element names are now written in the Description column in the PG-files

Elimination of several bugs in the interface between CoupModel and VMinteq, mainly concerning the treatment of special cases humic and fulvic acids. DG

04-11-16 Bug

Deleted bugs concerning salt transport when oversaturation occurred and unsaturated flow was assumed. Also introduced an Auxiliary variable "Depth of Front", which represents the lower depth for a certain concentration that is given by the parameter ConcForDepth. PEJ

04-11-15 Introduced version 2.33

New first development of export function to Excel

- 1) The export of information from *.Sim file to an excel file is introduced as optional for each file or regular at the end of each simulation. The File is located in the DataBase Directory and the name can be assigned in the User Defined Configuration.
- 2) The export of the information on time serie data from PG file to excel can in a similar way be optional for each document (see Utility Program menu) or made automatically at end of each simulation (Configuration, user setup).
- 3) The plotting dialog menu (Time serie variables) has been modified with a splitting of variables into separate windows for State, Flows, Auxiliary and Driving variables.

PEJ

04-10-25 Introduced version 2.32

Example of changes:

The Farquhar model tested and developed.

New empirical model for drip irrigation

New switches in Irrigate are:

(1) Dripper that implies that water is applied from a container to the soil when on. The area affected is given by the parameter DrippIrrigCover and the rate of application is given by the parameter DrippIrrigRate. The applied water is distributed to different vertical layers as a source flow (Wsource) input according to the weight coefficients given in the paramter table:Depth Distribution of Irrigation.

The irrigation has also a position (DripIrrigXCenter) that correspond to the same type of positions of multiple plants (XcenterPos).

(2) IrrigationInput that allow either input simulated by water storage in soil or as driving variable file.

(3) IrrigationUnit gives options for unit in the input driving variable file.

In connection to the new drip irrigation a new procedure adapted for the energy balance solutions of soil evaporation has also been developed. The procedure allows for a split of soil evaporation into one are affected by the drip irrigation (DrippIrrigCover) and one are that is not directly influence by the drip irrigation. The new procedure is put on by using the switch SoilPartitioningArea in the Soil Evaporation model. Differences in soil evaporation will occur because of the input irrigation rate to the uppermost compartment in the soil (Wsource(1)) that governs the virtual moisture balance of the soil surface (surfacemoisturebalance). In addition an optional influence of the radiation balance is considered depending on the position of the dripper in relation to the plantcover.

The soil evaporation is changed to be affected by eventual surface pool on the soil surface. This means that the virtual auxillary variable surfacemoisturebalance is sensitive to the storage of water in the surface pool.

Introduced new model for spread of salt from road surface by using the SaltRoadStorage switch in the Salt Tracer model. When the SaltRoadStorage switch is on the driving variable should include the amount of salt as chloride that is applied on the road surface (mg/m²). The salt on the road surface is spread by a first order rate model using the parameter EmissionRateCoef. However only a certain fraction (Fraction of Road) is normally reaching the ground. A bug was also deleted that previously had used the erroneous mole weight for chloride in the estimation of the osmotic water potential.

PEJ/DG/LK

04-09-06 Farquhar model

Introduced New plant growth submodel using the concept of Farquhar for estimation photosynthesis.

New option in Growth Switch in the Plant Growth group. Also introduced new input driving variable file for the manure application in External N inputs. See Switch Manure Input. The Input file are read discrete at time of manuring and have the following variables with Key word need in the PG-file:

MANNH - Nitrogen in NH₄

MANNLN - Nitrogen in litter

CNBED - CN ratio of Litter/bedding

MANFN - Nitrogen in faeces

CNFEC - CN ratio of faeces

MANDEPTH – mixing depth of manure (m)

Deleted various bugs in radiation and aerodynamic exchange.

04-06-16 New output

Introduced estimation of meanTransit time for drainage water from different horizons and an average Transit time for the total drainage from the profile. The estimation is turn on by using the Switch TransitTime. The estimated transit time for a certain layers is in the auxiliary array MeanTransitTime and the flow weighted arage transit time is TotMeanTransitTime.

Deleted bug in a menu on creating new soil properties for the database. PEJ

04-04-14 Scaling retention

Introduced new options for scaling of retention water properties using switch."Scaling retention" using parameters for changing saturation (Saturation Diff) or for residual water content (ScaleCoefResidual). PEJ

04-03-29 Update

Changed name and unit on All previous CTE_Ratio to Be TEC_Ratio with units of g/g.

Also added new auxiliary variable:

TE_TotalStorage (sum of all TE pools) PEJ

04-03-26 New options

Introduced new option for estimation of hydraulic conductivity of matric system as a function of saturated conductivity of total pore system (including macro pores). Switch Matric Conductivity in the hydraulic properties group. Two parameters are connected to switch: Common value and Sensitivity. The Common value define the lowest value of saturated conductivity that corresponds to a value with no influence of macro pores(=The highest value of total conductivity that is originating from matric pores only) The sensitivity corresponds to the increase in the matric conductivity above the common value threshold as a function of the saturated conductivity.

Changed parameters for adsorption of salt/trace_ellement in soil. Previous Ad_Kdv changed to Ad_c. PEJ

04-03-18 New switch

Introduced switch IrrigConcInput to handle different ways of define input concentration of salttracer.

PEJ

04-02-26 Update

Extended string size for path to Working directory and Data base directory from 50 to 150 characters

PEJ

04-02-08 New Version 2.31.

Introduced preliminary N-fixation to plants. The switch N Fixation that also previously is part of Plant Growth. New output variables are “N FixationPlant” (Transfer). The demand for N fixation is controlled by the carbon assimilation by photosynthesis. After mineral N uptake of N all remaining demand may be simulated as N fixation. The degree of uptake in relation to the total demand is controlled by the parameter NFixCoef (0-1) that may be specified for each plant in the parameter table: “Nitrogen Fixation”. An additional state variable “AccNFixation” is defined in the group “Additional Biotic Variables”.

Introduced N uptake from deposition to Leaf in the module “external inputs”. The previous parameter was not used to calculate any actual uptake. The specific plants uptake is related to an uptake rate that is related to the specific LAI of each plant. The parameters “Dep N to Leaf” is in the parameter table “Specific N Deposition uptake leaf”. Note that the rate is made proportional to the LAI of each plant. The uptake to each plant is defined by the transfer variable “Deposition N Leaf” and the total uptake of all plants are defined in the auxiliary variable “Total Deposition N Leaf”. A bug was deleted that caused erroneous N-uptake if more than one plant was defined. PEJ

04-01-20 NewVersion 2.30

Deleted a bug that caused too low rates of N-mineralisation from humus pool after introduced the humus efficiency parameter in version 2.27 from March 2003. The N-mineralisation is now also changed in accordance with the changes by version 2.27. Versions in between have with an efficiency value of 0.5 only calculated a mineralisation of 0.5 of total N-minarilisation.

In addition introduced climate change option according to the Sweclim scenariois in Sweden. However this option requires a file with coefficients, which is not yet distributed with the model. PEJ

2003

03-11-18 Minteq

Updated the Minteq connection. Higher flexibility JPG

03-11-11 New version 2.29

A new procedure to manipulate the input Air temperature (Meteorological Data) so that it corresponds to an urban Island. The procedure is connected to the switch UrbansHeatIsland and the parameter UrbanCoolingCoef. Note that this is an empirical approach and that the parameter value has to be find by calibration. PEJ

03-08-22 New snow interception model

Implemented new version of Interception model to account for snow differences in snow storage capacity (see Switches InterceptionModel and SnowIntUnload) and updated the calculations of canopy temperatures with individual resistances. DG

03-08-21 New Radiation option

Updated and improved calculation of outgoing longwave radiation in case of multiplecanopies and explicit account for the longwaveradiation based on surface temperature estimations. The canopy temperatures are distributed between individual canopies according to the varialbe MC_TempCanopy. The mean canopy temperature is still TempCanopy. The estimated output temperature variables are located in additional variable section of the model. The new version is

more stable than the previous but we still do not recommend to use the explicit estimation of energy balance based on temperatures (See NetLongRad switch) if daily mean values are used as time resolution DG

03-08-20 Photosynthesis model

Introduced preliminary function for Reduction of photosynthesis rate when below saturation rate as an option controlled by switch PhoSaturation and a parameter PhoMax. LK/PEJ

03-08-15 Bug

Deleted bug that caused errors in the waterbalance/ wateruptake function. The error was obvious when the plant water storage was simulated as dynamic and shown as an error in the WaterBalanceCheck. PEJ

03-08-10 Bug

Deleted bug in Multirun section. Table option for parameter values was not working. In addition introduced a new preliminary method to assign flags for validation variables based on parameter values. A new switch "IndexForValidation" in the "Technical" group allows setting of three parameters that will automatically assign variables to be match against simulated variables. However, the Validation variables menu has to be used to make the first assignment of validation variables. All variables have to be assigned except for those that are repeated in a regular structure within the file. The variables should be assign from the top towards. The parameters are named: Index in val file, Size of internal loop and No of internal index loop. PEJ

03-08-10 New version 2.28

Introduced version 2.28 with first preliminary implementation of traceelement turnover between soil solution, plant and organic material in the soil. The trace element is introduced in the Salttracer module. The general switch is TraceElementUptake. In addition to this the ActiveUptake switch regulates an uptake of traceelement that is related to the demand of carbon of the plant. Three parameters ActiveUptEffLeaf, ActiveUptEffRoots, ActiveUptEffStem controls the uptake to the three respectively components of the plants. When the concentrations are below a certain threshold specified with the parameter ActiveUptMaxEffConc a linear reduction of the uptake rate is applied. A passive uptake approach that follows the water flow is associated to the switch PassiveUptake. The demand is proportional to the water uptake by the plants and scaled by the parameter PassiveUptScaling. The allocation to leaf, stem and roots is related to the respectively parameters: PassiveUptAlloLeaf and PassiveUptAlloStem.

In the plant and in the soil the traceElement is following the carbon fluxes, except that no volatilisation is allowed. Another exception is that no harvest is applied to the traceelement. A number of state variables, fluxes and auxiliary variables are introduced.

A new switch InitialSaltConcentrations allows for uniform or distributed initial conditions of salt in the soil. PEJ

03-05-06 Bug

Deleted bug that caused errors in the wateruptake when using more than one plant (MultipleBigLeaves) and assuming the less root layers for any of the plants that was not the last specified in an array of plants. Thanks to Jörg Scherzer, UDATA, Germany that find the bug ! PEJ

03-04-30 New output

Introduced new variable TotalSaltDrainFlow as the sum of all SaltDrainFlow(i). Changed Eff_humus to Eff_Humus to make consistent with Eff_Litter1 PEJ/LK

03-04-03 Parameter value range

Changed introduced error limits for parameters in Soil Water Flow group. PEJ

03-03-26 New version 2.27

4 major changes.

- (1) Introduced new switch (AtmosphericDep) in the Salt modul. The old SaltTracer switch remains in general options but have now only on/off. Instead the AtmosphericDep switch have overtaken previous options SaltTracer.
- (2) Changed the mineralisation model from Humuspool to consider an efficiency (new parameter Eff_humus and the actual C-N ratio of the humus pool Previous model assumed the HumusRateCoefficient to be 100 % losses of carbon to atmosphere and N-mineralisation according to CN-ratio of microbes. With the default value of Eff_humus (0.5) the RateCoefHumus has to be doubled. Eff_humus =0. corresponds to previous model.
- (3) Deleted bug and changed meaning of the parameters for allocation to root when using the exponential function for mass dependence.
- (4) New Height function taking not only age and biomass into account but also grain. Two new parameters i Table : Size and shape of growing plant (Height GrainCoef and Height MaxGrain). The first is the sensitivity of Carbon of grain and the second is the maximal fractional influence of grain on height.

PEJ/LK

03-03-19 New options

Introduced new parameter (SaltIrrigationconc) to allow different concentration of irrigation water compared to precipitation. Also corrected bug to make sure that annual crops does not make reallocation to old-biomass storages.

PEJ/LK

03-03-14 New options

Introduced new parameter (SurfPoolInit) to make initialization of surface pool stable. Also changed error limits for max condensation and made some preliminary adjustments to avoid unrealistic melting of snow. PEJ

03-02-16 New version 2.26

An improved data base functionality and deleted bug that caused problem when running Nitrogen/Carbon dynamics without plant cover. PEJ

03-01-28 New version 2.25.

Updates in Interception. Introduced a simplified approach for snow interception, where the interception capacity is set to the unfrozen value at air temperatures above 0°C, and equal to the maximum capacity of frozen precipitation below 0°C (see switch SnowIntUnload).

Preliminary updates in Radiation to explicitly account for interception of long wave radiation (see switch LongRadCanopy) . DG

03-01-28 Update

Estimation of water retention curve changed to exclude zero value on water content as missing values. PEJ

03-01-28 Bug

Deleted bug in the estimate of total net radiation from canopy covered snow surfaces DG

03-01-21 Bug

Deleted bug that caused error when using estimated depth distribution of soil temperatures as initial conditions for the soil heat equation. PEJ/DG

2002

02-10-27 New version 2.24.

Updates in Plant behaviour and in the data base utilities.

Changed format for Sim-file to be more robust.

Updating of html-help file. PEJ/LK

02-10-02 New version 2.23.

Introduced a parameter "Roughness Max" to constrain the roughness length to an upper limit when using Shaw & Perreria or linear function to estimated roughness from plant height. The parameter is defined in parameter tables in the potential transpiration submodel.

Modified the organic uptake model for nitrogen to make sure that litter and humus pools always remains positive. PEJ

02-09-28 new options

Introduced new options for estimating roughness and displacement when using multiple plants. New switches are Roughnessfunc and MultiRoughness. The allow alternative to Shaw & Perrieria functions and the make it possible to treat individual canopies separated or based on the highest canopy only.

Also deleted bug that made emergence before harvest impossible. After this change all plants with an initial GSI of 1 or more are considered emerged from the beginning of the simulation"

PEJ/LK

02-09-16 New version 2.22.

Corrected error that made document with Carbon/Nitrogen options enabled from files prior 08-28 impossible to read.

PEJ

02-09-04 Bug

Deleted bug that caused error when reading plant input from PG-file using "Explicit Single Leaf "option.

Added new input (RootLength) to plant file to be used when using Darcy based water uptake approach.

ID-Code for RootLength is LROOT in PG-file. PEJ

02-08-28 Bug

Deleted bugs related to harvest and emergence of plants. PEJ/LK

02-08-09 Bug

Deleted bug that made Nitrogen/Carbon simulations incorrect when using a time step that corresponded to the one for the Water and Heat. See Switch NitrogenCarbonStep in the numerical Section.

Updated the wateruptake dynamic water uptake approach.

Also updated part of the GasFlux model but this is still in developing stage. PEJ

02-06-27 Minteq

Introduced button to start Visual Minteq from the tools menu. Deleted bug that caused a possible negative value on transpiration corresponding to negative flows (condensation) of interception on plant surface.

Introduced a reduction of interception evaporation when canopy not fully saturated. New options (roughness related) for snow, potential transpiration and soil evaporation. PEJ/DG

02-06-03 Bug

Deleted bug that caused wrong values on the water reduction factor for photosynthesis (introduced May 15) PEJ

02-05-29 Bug

Deleted bug that caused simulations with invalid input file name (driving variables) to crash.

PEJ

02-05-27 New version 2.21.

New options for running the model for longer period by using the TimeScaleFactor in the run option dialog menu. A value to start with initial values from previous runs have also been introduced as an option in the "user setup menu".

In addition the estimation of net radiation for a system with both vegetation and ground have been changed to a more consistent scheme. The net radiation for the canopy is based on temperature from previous days whereas the net radiation for the ground is based on the temperature of the current day. PEJ

02-05-24 Bug

Deleted bug introduced with SalinityStress option 02-05-08. The bug made Photosynthesis flux zero,

PEJ

02-05-15 New version 2.2

An updated corrected SalinityStress option in Plant Growth and a number of minor debuggings. Full documentation is delayed.

New option for running together with the VisualMinteq program also introduced but not documented and tested.

New control of litterfall dynamics based on a dorming temperature sum. PEJ

02-05-08 New options

Introduced new features of SalinityStress option in plant growth.

PEJ/LK

02-04-01 New options

Introduced new export facility suitable for processing of the parameter and results pages from simulations. The new options (Save data as a text file) will replace previous option on saving of parameters to a par-file on the file menu. Deleted bugs and improved the data base options for the nitrogen and carbon related parts. Note that the plant growth now also include the physical characteristics of plant. Delete old file in the directory: SoilProperties/Plant growth.

Introduced new output variables:

State variables -Additional biotic variables: TotalDiffCHumus and TotalDiffNHumus

Auxiliary variables – Soil organic processes : NTotHumusformation and CTotHumusformation PEJ

02-03-25 Winter regulation update

Introduced new switch to make sure that reallocation from leaf to mobile pool works correctly during spring and autumn. The regulation is now proportional to both the fall of leaf and OldLeaf and if the new switch "Winter regulation" is put on the mobile pool is delayed in reallocation to leaf in the coming spring. PEJ

02-03-20 Bug

Deleted bug that made estimation of fluxes from Humus to Dissolved Organic erroneous in previous version.

PEJ

02-03-19 Bug

A new switch for a more flexible control of integration time step was introduced March 13. A bug in the switch (see numerical – NitrogenCarbonStep) was deleted with this version. A updated help- documentation file is included with this version. PEJ/LK

02-03-13 Gas Flux model

First preliminary introduction of Gas flux model. New chapter still not documented nor tested.

Deleted bug on Dissolved organics, error in previous initial values.

Introduced litter fall from grains at harvest.

Made emergence to the day of root development. This means that roots, stem and leaf start to develop at this date.
Corrected calculations of C-N ratios for perennial plants. PEJ/LK

02-02-27 Road Salt model

Introduced road salt application option. The Option is governed by the Switch "RoadSaltApplication" and has three parameters: Salt Application Rate, Temp Salt Low Limit and Temp Salt High Limit. PEJ

02-02-17 CN ration leaf update

Changed estimation of CN-ratio for leaf to make sure that not reaching to high values after emergence from seed.
Deleted bug when using Root distribution as table function in nitrogen uptake
Change default value for radiation use efficiency from 0.01 to 0.5 gDw/MJ. PEJ

02-02-12 Bug

Removed a bug which was introduced 02-02-06. The vapour pressure at the snow surface was 2 orders of magnitude too low (hPa instead of Pa) - as a result of this bug, snow evaporation was always below zero. DG

02-02-06 Bug

Some minor bugs in the snow routine related to some special situations when the snowmelt exceeds the snow mass: in such cases the snow-adjustment routine was erroneously skipped. DG

02-01-31 New options

Introduced options for the water uptake response to soil temperatures. These are preliminary suggestions and may be changed later. The documentation is not updated, so the present formulations are explained here:

Temperature response

"None"

"Double-exponential" (default)

"Single-exponential"

"Polynomial"

where the triggering temperature Ttrig can be a static parameter or a function of the accumulated daily average air temperatures above a threshold temperature (5°C default):

The switch "PlantDevelopment" must be set to "start=f(TempSum)" in order to use this function.

Temperature response parameters:

Name Symbol Function

TempCoefA	tA	Double-exp.
TempCoefB	tB	Double-exp.
TempCoefC	tC	static Ttrig
TempCoefD	T98% and T100%	Single, Polynom.
TempCoefE	tE	Polynomial
TempCoefF	tF	dynamic Ttrig

DG

02-01-31 New options

Introduced a 24 hr running mean of air temperature, TairDailyMean. TairDailyMean is now used to calculate the temperature sum that is used to trig PlantDevelopment. Previously, this temperature sum was calculated incorrectly except for daily average time resolution.

DG

02-01-31 Bug

Corrected bug that accumulated error in water balance check during winter - the melt water outflow from the snow was not treated correctly. The option to adjust simulated snow depth to measurements also caused errors in the water budget, which hopefully is corrected now.

Please note that the "Precipitation-adjustment" made during snow depth adjustments is not added to the Precipitation variables. The new variable "AccPrecSnowAdjust" must be added to make the waterbudget complete.

Please note that using "Hourly time resolution" reduces the numerical errors in the water balance during summer compared to "Within-day".

DG

02-01-25 Bug

Deleted bug that made snow surface temperature equal to max(0°C, air temperature) instead of min(0°C, air temperature) when using the 'Equal to Air temperature' option.

Corrected bug that caused a heat leakage at the snow/soil interface when using the iterative energy balance for the snow surface temperature. The heat lost from the soil was larger than the heat supplied at the snow surface, which caused too low soil temperatures. DG

02-01-21 Bug

Corrected bug that made time-scale erroneous when plotting periods longer than 10 years.

Corrected also bug that made simulations with explicit water storage erroneous, especially when linked to a dynamic plant growth. The stomatal closure function and the uptake for individual layers was substantially wrong when plant was exposed to stress. PEJ

2001

01-12-12 Update

Changed threshold value of N-amount for making the CN-ratio of leaf to 20. Value changed from 0.1 to 0.001 g/m² PEJ

01-12-03 Bug

Deleted bug that caused problem with snow and interception when using withinday resolution of 10-minuter or 1 hour. Also adjusted upperboundary for heat flow to avoid some unstable numerical behaviour. DG/PEJ

01-11-20 Bug

Deleted bug that made it impossible to have only Canopy Height as input in "Crop data" driving variable file. PEJ

01-10-19 Bug

Nitrogen and Carbon:Deleted bug so that the new mobile pool is also transformed into surface litter after harvest for grain crops and for perennial crops that have reached their maximum age.

Deleted bug so that all parameters regarding plant development is valid also for the WUE approach.

Introduced grain litterfall.

Deleted bug so that sowing also takes place with the WUE approach.

Deleted bug so that litterfall after harvest is calculated from the remaining biomass and not from the original biomass before harvest, which generated negative biomass pools in the plants after harvest.

In growth model: Deleted bug so that all parameters in "Size and shape of growing plant" are activated when the physical characteristics are simulated. LK

01-10-19 Bug

Deleted bug that made the increase of displacement height (d) due to snow depth (hsnow) to large (now $d=f(\text{canopy height}-\text{hsnow})+\text{hsnow}$, instead of previously $d=f(\text{canopy height})+\text{hsnow}$). If displacement height is chosen as a parameter or a prescribed function of time, it will not be influenced by snow depth.

For simulations of forest stands with large amount of snow beneath, this will have a large effect on the wintertime evapotranspiration.

DG

01-09-26 Bug

Deleted bug that made the option of estimation of surface resistance of vegetation restricted in the group of potential transpiration. The RSMethod option "Loh.Eq (T>DayNum)" – is now corrected.

A new parameter CondMaxWinter is used when the temperature sum model is selected (Se PlantDevelopment switch in Plant Group). Note that the CondMaxWinter parameter is used both for a single plant canopy and as a common values of multiple plant canopies. Also note that the PlantDevelopment switch will be forced to the dynamic development with RSMethod is selected as "Loh.Eq (T>DayNum)".

The new parameter CondMaxWinter corresponds to the CondMax parameter that is applied within the growing season.

PEJ

01-09-03 Bug

Deleted bug that made the water use efficiency option for plant growth unusable.

PEJ

01-08-27 Bug

Deleted bug that forced LAI-Input switch to be set to parameters instead of simulated by the growth model.

Also introduced a condition that makes the automatic calculated irrigation to 0 when air temperature is below 5 °C. PEJ

01-08-08 New Interception model

Introduced new parameter "WaterCapacityBase" to improve precipitation interception storage function. The new parameter adds a storage capacity that is not related to the leaf area. It may be used for especially deciduous trees.

Deleted bug on File menu for SnowAdjustment switch. PEJ

01-06-27 Update

New export feature for soil properties database. An Ascii-file with a selection of properties may be created from utility option on main menu. PEJ

01-06-05 Bug

New correction relevant to option of unrestricted area and albedo calculations (01-05-31). DG

01-05-31 Bug

Changed estimation of total albedo to avoid possible errors when canopy cover exceeds unity. DG

01-05-30 Bug

Deleted bug that made radiation interception erroneous when using multiple canopies. Error introduced 04-18. The radiation interception now also changed conceptually for options with and without shading. No exact reproduction of old model is possible. PEJ/DG

01-05-28 New version 2.11.

Deleted bug that made reading of old sim-file impossible. Changed name of output-variables for common abiotic responses from "Response.." to "Response (c)..". PEJ

01-05-17 Bug

Deleted bug that caused overestimation of netradiation at soil surface. The bug was introduced 04-18. PEJ

01-04-28 Bug

Update of Snow and update of soil heat flow during frozen soil conditions. Corrected inconsistent damping of heat flow when partial cover of snow. DG, PEJ

01-04-25 New version 2.1

A preliminary approach for Dissolved organic matter. New Switch: DissolvedOrganics.
General Update of documentation PEJ, DG, MS, MF

01-04-18 New Snow option

Introduced new approach for snow melt estimation based on heat balance of snow cover (new switch: snow melting).
DG

01-04-21 New Snow options

Snow Interception model on the way. Suggestions below:
Introduced preliminary model for snow interception on vegetation. New switch in interception group, "Snow
Interception") New output variable: Interceptedwater_TQ. New parameters: AlbedoSnowCover DG

01-04-18 New outputs

Introduced new output for Radiation, CanopyFracRad.
General update of radiation interception for multiple plants (deleted bug that made error in radiation balance.
Update of aerodynamic resistances estimates both for bare soil, snow and vegetation surfaces. DG

01-04-09 New viewing functions

Introduced viewing function to the Soil heat pump module PEJ

01-03-06 Update

Changed lowest valid wind speed from 0.5 to 0.1 m per second. PEJ

01-02-13 New viewing functions

Introduced 2 new viewing functions in the water retention parameter table PEJ

01-02-07 New check

A check introduced to make sure that uptake of N to plant is always a positive number. PEJ

01-02-01 Bug

Corrected the equations for water uptake using the Darcy-based approach to correspond with the documentation and being consistent with the Dynamic leaf water potential approach (see also updated documentation). PEJ/LK

01-01-30 New outputs

Introduced some new auxiliary variables for Plant Growth. Bug that made table "Start of Growth" hidden is deleted. PEJ

01-01-20 Update

Changed some scales on plant-animation. Update of Soil data base. PEJ

01-01-11 Update

Changed valid range for macropore volume to 0.001-30 PEJ

01-01-10 Update

Introduced a trace of the exact time when the simulation was successfully completed. Please note that the modified date of a SIM file are changed if you open a SIM file and are making a new copy for a new run. This happen also when the file represents a completed simulation. However no changes are made. PEJ

01-01-08 Update

Introduced a new detailed animation of plant development that is optional, see User setup. PEJ

01-01-03 Update

Introduced a new document viewer that allows differentiated view of more than one document. Also some new animation of relevance for Carbon and Nitrogen dynamics. PEJ

2000

00-12-22 Update and Bug

Introduced a trace for the version number and date of exe-file in the parameter window of Sim-documents. Deleted bug that causes erroneous hydraulic conductivities in the macro-pore range when Van Genuchten equation was used together with the Mualem equation. The error became very big when in model layers of higher index than the number of measured layers. PEJ

00-12-13 New output

Introduced new auxiliary variables for organic pool and corrected error in validation procedure that made erroneous mixing of variables. PEJ

00-12-06 New output

Introduced new auxiliary variable NTot_Nitrification.PEJ

00-12-01 Bug

Deleted bug on updating state variables: ammonium flow between layers and deep percolation of both ammonium and nitrate. PEJ

00-11-30 Update

Introduction of new animation, first attempt to show multiple plants and nitrogen in the soil.
Also a general update of all help files. PEJ

00-11-21 Bug

Deleted second bug that caused error in Carbon and Nitrogen budget when using multiple plants PEJ

00-11-20 Bug

Deleted bug that caused errors in calculated rootlitter formation when using multiple plants PEJ

00-11-14 Bug

Deleted bug that mismatched the first table on a second sheet in the parameter table menu. PEJ

00-11-13 Bug

Corrected spelling mistakes and changed upper error level for CONDRIS parameter in Lohammar equation. The new high upper limit is put very high to allow also a different interpretation of CONDMAX parameter
Added Driving variable vDriveDrainLevel and added additional bug for root uptake beneath ground water level. PEJ

00-11-09 Update

The Html-based Help is substantially updated and also possible to access from the main menu.
The Plant growth part is further developed with a table on Plant Behaviour where basic features of each plant can be specified. The general Switches like Perennial_Plant and Grain_Development are deleted. PEJ/LK

00-11-01 Bug

Deleted bug that was introduced 12 Oct when introduced account for root uptake beneath ground water level. Deeper drainage levels were erroneously handled from October 12. PEJ

00-10-30 Bug

Corrected boundary condition for salt infiltration when using daily mean values as time resolution for input PEJ

00-10-12 Update

Changed calculation scheme below ground water level to account for water uptake of roots in a similar way as has previously only been done for the horizontal drainage flow. PEJ

00-10-11 Bug

Corrected error for multiple year plotting that occasionally cut the last year from the time series plotting. Corrected argument to PG program when plotting simulated time series. Changed the profile identity from CoupModel – SLU to CoupModel – KTH. This will require new assignments of UserSetup. PEJ

00-10-09 New outputs

Added a number of variables to make nitrogen and Carbon balance consistent. Added possible uptake of organic N (Organic uptake switch). Also corrected an error in the throughfall variable during conditions with Snow on the ground, PEJ

00-09-06 Bug

Corrected bug that identified wrong Table in Edit Parameter Table dialogues on second page if more than 8 tables existed in one group. PEJ

00-08-30 New options

Introduced new fluxes and procedures appropriate for the perennial plant simulation. Introduced new dynamics for litter fall scaling of both old and current year leaf and roots. Also started to make a new group "Additional BioticVariables" containing budget variables for C and N. Preliminary set of new variables that may change. PEJ

00-08-18 Bug

Deleted bug that made Growth rate =0 when vegetation without grain development was simulated. Introduced a new switch and clarified documentation on the use of a Reference Heights for meteorological data. See CommonRefHeight switch. PEJ

00-08-07 Update

A consistent change of the WinSoil name to CoupModel has been implemented. The former ASCII-file calla *.SUM has been deleted. PEJ

00-03-28 Bug

One bug causing erroneous results when using the Van Genuchten retention curve in combination with the Mualem approach for estimating unsaturated conductivity and a macro pore region larger than 0 is corrected. PEJ

00-03-27 Bug

Some bugs have been corrected. Erroneous calculation of heat flow between layers. Previous version was enhancing heat flow between layer 1 and 2 making the variation to large in the subsoil. A new analytical solution is now an option in the soil heat flow module PEJ

00-03-12 New version CoupModel

Many major changes and updates have been made of the first version of CoupModel, that correspond to WinSoil 2.0. The previous WinSoil 1.61 will not be more updated in details. Instead all updates will be done based on CoupModel (WinSoil 2.0).PEJ

1999

99-06-22 Bug

Deleted bug with respect to selection of soil profiles from database. The selected profile is now updated after a selection of a new list. PEJ

99-06-21 Bug

Deleted bug in the estimation procedure for hydraulic properties. Adjustment procedure when total mass of soil organic matter and fractions of texture exceeded 100 % is now corrected. PEJ

99-06-21 Update

Updating and correction of help. Especially the tutorial with the simple example. DM

99-05-12 NewVersion 1.61

Introduced PEJ

99-05-12 Bug

Deleted bug which produced errors when multiples of the output interval did not matched the end and start data of simulation period exactly. PEJ

99-05-11 Update

Introduced a common aggregated file named MultiRun.Bin to gather results from multiple runs. The new MultiRun.Bin-file contains all the outputs of the individual runs as well as the correspondent parameter values that have been changed with the multi run options Note that if a previous MultiRun.Bin file exist in the same working directory they will be overwritten. Users have to rename the an old file manually. PEJ

99-05-11 New options

Introduced new possible adjustment of radiation estimates as function of altitude and slope. A new Turbidity switch in radiation group enables an account of the solar angle for more precise estimates of incoming global radiation. New parameters are in the group of meteorological data: Slope N-S and Slope W-E represent relative slope in units of (length/length). The parameters for altitude are AltMetStation and AltSimPosition. TairLapseRate represents the mean change of temperature with height. The radiation functions were provided by Dr. Plüss, ETZ, Switzerland. DG

99-05-04 Update snow model

Introduced new interpolation method for forced adjustments of simulated snow depth. The SnowAdjustment switch has now 3 options, no adjustment, or adjustments continuously or discrete.

In addition a parameter (AgeUpdateSnowDeptCorr) for control of age updating in connection to the use of snowadjustment was introduced. PEJ/DG

99-04-29 Bug

Debugging of oversaturation check and introduction of variable OutFlowSurface which is the excess of water from the uppermost layer directed to the surface pool. Over-saturation that occurs in other layers is directed to the adjacent layer above the over-saturated layer. PEJ

99-04-20 Bug

Introduced check to avoid over-saturation in the soil profile which occurred in connection with lateral inflow to a soil profile PEJ

99-03-09 Bug

Assertion error - when clicking to a new dialog page (in edit menu) while putting the focus on the tab prior to the click to a new tab. PEJ

99-03-09 Bug

The plant properties still remained in the menus also if they were specified for driving variable file PEJ

99-03-09 Update

The Validation procedure did not accept more than 400 time points. Now updated to 10 000. PEJ

Glossary of Terms

Demand rate

The potential rate of water uptake from the soil. Normally the same as the potential transpiration rate.

Pedofunction

Soil function.

Resistance

A resistance is defined as the ratio between the difference in potential between two points and the flux between the same points. A resistance may also be expressed as the integral of inverse of the conductivity over the distance between the two points.

Saturation

Water saturation is the degree to which the pore system is saturated with water. The saturation can also be different forms of effective saturations defined for limited ranges.

Soil rhizosphere

The volume of the soil that is influenced by the roots. This volume is supposed to be different from the bulk soil which is the total soil volume.

Suction

The force used by plants to extract water from soil. The suction is normally expressed in positive figures as opposite to the water potential in the unsaturated soil which is always a negative number.

Unit horizontal area

The simulated horizontal area in the model is always 1m².

Wilting point

The wilting point is the water potential that corresponds to conditions when the plant is unable to extract more water from the soil. It can be expressed either as volume or as water potential

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