9.4 Considering multi-layered vegetation

Since WaSiM-ETH version 7.x the seasonal evolution of vegetation is controlled by a two-part landuse table. Compared to the old landuse table (cf. Chapters 3.5 and 5) the new parametrization scheme allows the parametrization and simulation of multi-layered vegetation. It consists of two parameter tables: (a) the primary **[landuse_table]** containing the parameter values for each vegetation type and (b) the **[multilayer_landuse]** table which links vegetation types provided by the one-layer (primary) [landuse_table] to complex (multi-layered) vegetation structures. The landuse codes within the [multilayer_landuse] table have to correspond to the codes of the landuse grid. The two-part landuse table is not limited with respect to the number of table entries (landuse codes). It is structured as follows:

```
[multilayer_landuse]
4               # count of multilayer landuse codes
1  urban_areas      { Landuse_Layers = 7, -9999, -9999; k_extinct = 0.3; LAI_scale = 10; }
2  mixed_forest     { Landuse_Layers = 8,     4,     3; k_extinct = 0.3; LAI_scale = 10; }
3  decidous_forest  { Landuse_Layers = 9,     2,     1; k_extinct = 0.3; LAI_scale = 10; }
4  pasture          { Landuse_Layers = 1, -9999, -9999; k_extinct = 0.3; LAI_scale = 10; }


[landuse_table]
7               # number of following land-use codes
#co- name of the
#de  land-use type
#-- ---------------
 1   grass_low {method = VariableDayCount;
         RootDistr       = 1.0;
         TReduWet        = 0.95;
         LimitReduWet    = 0.5;
         HReduDry        = 3.45;
         IntercepCap     = 0.75;
         Juldays         = 15    46    74    105   135   166   196   227   258   288   319   349;
         Albedo          = 0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25;
         rsc             = 90    90    75    65    50    55    55    55    60    70    90    90;
         rs_interception = 0.5   0.5   0.5   0.5   0.5   0.5   0.5   0.5   0.5   0.5   0.5   0.5;
         rs_evaporation  = 130   130   130   130   130   130   130   130   130   130   130   130;
         LAI             = 2     2     2     2     3     4     4     4     4     2     2     2;
         z0              = 0.15  0.15  0.15  0.15  0.3   0.4   0.4   0.3   0.3   0.15  0.15  0.15;
         VCF             = 0.95  0.95  0.95  0.95  0.95  0.95  0.95  0.95  0.95  0.95  0.95  0.95;
         RootDepth       = 0.4   0.4   0.4   0.4   0.4   0.4   0.4   0.4   0.4   0.4   0.4   0.4;
         AltDep          = 0.02  0.02  0.02  0.02  0.02  0.02  -0.02 -0.02 -0.02 -0.02 -0.02 -0.02;}
2   grass_high   {method = VariableDayCount; RootDistr = 1.0; ... ; AltDep = 0.025 ... -0.025;}
3   fern         {method = VariableDayCount; RootDistr = 1.0; ... ; AltDep = 0.025 ... -0.025;}
4   shrubbery    {method = VariableDayCount; RootDistr = 1.0; ... ; AltDep = 0.025 ... -0.025;}
7   urban_grass  {method = VariableDayCount; RootDistr = 1.0; ... ; AltDep = 0.025 ... -0.025;}
8   pine         {method = VariableDayCount; RootDistr = 1.0; ... ; AltDep = 0.025 ... -0.025;}
9   birch        {method = VariableDayCount; RootDistr = 1.0; ... ; AltDep = 0.025 ... -0.025;}
```

The parameters denote:

```
k_extinct          : extinction coefficient describing the reduction of radiation in multi-layered vegetation [-]
LAI_scale          : empirical parameter scaling the aerodynamic resistance in multi-layered vegetation [-]

RootDistr          : parameter for root density distribution [-1: konkav, 1: linear, >1: konvex]
TReduWet           : relative theta value for beginning oxygen stress [-]
LimitReduWet      : relative reduction factor of real transpiration for water-saturated soils [-]
HReduDry           : hydraulic head for beginning dryness stress [m]
IntercepCap        : specific thickness of the water layer on the leaves [mm]
Juldays            : Julian days valid for all following rows
Albedo             : albedo (snow free) [0..1]
rsc                : leaf surface resistance [s/m]
rs_interception   : interception surface resistance [s/m]
rs_evaporation    : soil surface resistance (for evaporation only) [s/m]
LAI                : leaf area index [m2/m2]
z0                 : aerodynamic roughness length [m]
VCF                : vegetation covered fraction [0..1]
RootDepth          : root depth [m]
AltDep             : shift in temporal vegetation development per metre altitude [Julian day]
```

9.4.1 [multilayer_landuse] table

Each row in the [multilayer_landuse] table begins with an entry for a landuse (grid) code. Then it follows the name of the landuse type and a certain number of parameters within curly brackets. The first entries within the brackets are the vegetation components or landuse layers. They have to be set in particular order. The uppermost layer (or top layer) is the left entry. Then entries to the underlying vegetation components are following. For all landuse types it has to be set the same number of vegetation components. Missing components get the ignorance parameter "-9999". Apart from the layer code settings, two additional parameters, *k_extinct* and *LAI_scale*, can be defined for each landuse type (cf. COUPMODEL in Jansson und Karlberg, 2001).

k_extinct is the light extinction coefficient which reduces the incoming radiation on its way through the layered vegetation (no consideration of diffuse light components). In conformity with the Lambert-Beer-Law the following relations are used:

$$\begin{aligned} &for\ i=1: \quad R_{use,i} = VCF_i \cdot R_n \cdot (1-e^{-k\_extinct \cdot LAI_i}) \\ &for\ i=2: \quad R_{use,i} = VCF_i \cdot (R_n - R_{use,i-1}) \cdot (1-e^{-k\_extinct \cdot LAI_i}) \\ &for\ i=3: \quad R_{use,i} = VCF_i \cdot (R_n - R_{use,i-2} - R_{use,i-1}) \cdot (1-e^{-k\_extinct \cdot LAI_i}) \end{aligned} \qquad \textbf{(9.2.11)}$$

(analogical procedure for i > 3)

with
- R_{use} available net radiation [Wh/m^2]
- i vegetation component with i=1 as the top level component (e.g. treetop)
- R_n available (total) net radiation (measured or simulated) [Wh/m^2]
- *VCF* vegetation covered fraction [-]
- *LAI* leaf area index [m^2/m^2]

LAI_scale is an empirical parameter used for the calculation of the aerodynamic resistances $r_{a,i>1}$ below the treetop (for the vegetation layers 2..n).

$$r_{a,i>1} = r_{a,i=1} + LAI\_scale \cdot LAI_{kum} \qquad \textbf{(9.2.12)}$$

with
- $r_{a,\,i=1}$ aerodynamic resistance of the top level vegetation component [s/m]
- LAI_{kum} cumulated leaf area index above the actual vegetation component [m^2/m^2]

Default values for *k_extinct* and *LAI_scale* are 0.3 and 10, respectively. These values are also used in the case of parameter absence (in the control file). As the parameters *k_extinct* and *LAI_scale* significantly affect the evapotranspiration of multi-layered vegetation, they should be carefully calibrated. According to values from literature, *k_extinct* can be between 0.25 and 0.85 (e.g. 0.5 for grass), whereas the values for *LAI_scale* can range from 1 to 30.

JANSSON, P.E., KARLBERG, L. (2001): Coupled heat and mass transfer model for soil-plant-atmosphere system. – Division of Land & Water Resources, Depart. of Civil and Environ. Engineering, Royal Institute of Technology, Stockholm. Web document: ftp://www.lwr.kth.se/CoupModel/CoupModel.pdf

9.4.2 [landuse_table]

The primary [landuse_table] has been substantially restructured and extended. In contrast to the old landuse table, the new one is no longer limited to a fixed number of "*Julian day*" entries (so far 4 entries). Now the seasonal evolution of vegetation can be predefined with much higher precision than before. For each "*Julian day*" entry the [landuse_table] requires entries for the following parameters: *albedo*, *rsc*, *rs_interception*, *rs_evaporation*, *LAI*, *z0*, *VCF*, *RootDepth* and *AltDep*. This list of temporally varying parameters contains two new resistance parameters, one for the evaporation of intercepted water (*rs_interception)* and the other for the evaporation of water from the soil surface (*rs_evaporation*). The dependence of plant growth on altitude is controlled by the following approach:

$$Juldays_{i,cor} = Juldays_i + AltDep_i \cdot (h_M - 400) \qquad \textbf{(9.2.13)}$$

with
- $Juldays_i$ actual "Julian day" entry
- *cor* adjusted for altitude
- $AltDep_i$ shift of the actual parameter *Julday* per meter altitude [Julian days]
- h_M altitude above sea level [m]

In addition to the temporally variable parameters, there are also some static parameters which are not linked to the "Julian Day" entries, namely *RootDist*, *TReduWet*, *LimitReduWet*, *HReduDry* and *InterceptCap*.
Apart from the root density distribution function (parameter *RootDist*) and the threshold value for starting dryness stress (*HReduDry*), three new parameters have been added to the [landuse_table]. Two parameters (*TReduWet*, *LimitReduWet*) are defining the reduction potential of real transpiration due to oxygen stress when soil water content reaches saturation (see also Fig. 9.2.4). The third parameter (*InterceptCap*), which is defining the water storage capacity on leaves, is an optional parameter. If this parameter is omitted here, then it is used the default parameter from the [interception_model].

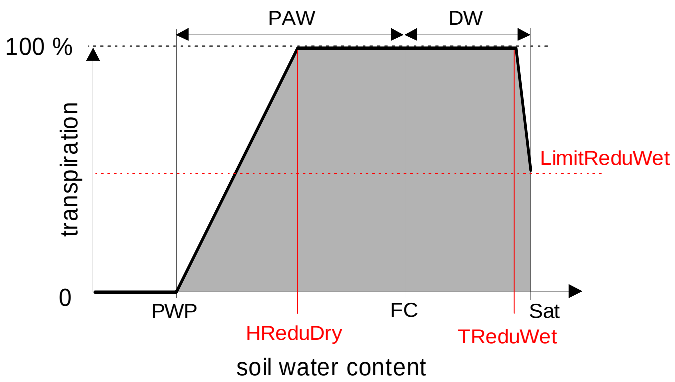

Figure 9.2.4: Interdependence between transpiration and soil water content. PAW: plant-available water, DW: drainable or gravitational water, PWP: permanent wilting point, FC: field capacity, Sat: soil water content at saturation, HReduDry: threshold value for starting dryness stress, TReduWet: threshold value for starting oxygen stress due to (nearly) water saturated soils, LimitReduWet: maximum reduction of transpiration due to oxygen stress

The extended [landuse_table] allows parameter entries in both (i) multi-line and (ii) single-line formats. Each parameter block (containing all parameter entries of one landuse type) is framed by curly brackets. Parameter groups within one block are separated by semicolons. The method identifier "VariableDayCount" signalized WaSiM-ETH that an extended landuse entry has to be read in.

The [landuse_table] can be used in mixed form, i.e. it is possible to use both single-line and multi-line formats within the same table. Moreover, the formats of the old [landuse_table] are furthermore valid. However, for clearity reasons the authors recommend the use of an uniform format of parametrization.

9.5 Upgrading the soil table

The scheme of soil parametrization has been restructured and significantly extended. The new [soil_table] allows a horizon-dependent parametrization of the vertical soil profile including the consideration of macropore runoff. Similar to the scheme of the new [landuse_table] (described in the section before), the parametrization of soil profiles can be done in (i) multi-line or/and (ii) single-line formats. Each parameter block (containing all parameter entries of one soil profile) is framed by curly brackets, whereas parameter groups within one block are separated by semicolons. The method identifier "MultipleHorizons" signalized WaSiM-ETH that an extended table entry has to be read in.

The new soil parametrization scheme is characterized by a high level of structural flexibility. The restructured [soil_table] can generally handle different formats, i.e. individual soil profiles can be defined in both single-line and multi-line formats within the same table. In addition, the compatibility to the format of the older soil table (cf. Chapter 5) is guaranteed.

The extended [soil_table] is structured as follows:

```
 [soil_table]
1              # number of following soil codes
#co- name of the
#de  soil profile
#-- ---------------
 1   profile_1  {method = MultipleHorizons;
         PMacroThresh   = 5.0;
         MacroCapacity  = 4.0;
         CapacityRedu   = 1.0;
         MacroDepth     = 1.5;
         horizon        = 1       2       3;
         Name           = SL      SC      L;
         ksat           = 1.2e-5  3.3e-7  3.0e-6;
         k_recession    = 0.4     0.4     0.8;
         theta_sat      = 0.41    0.38    0.43;
         theta_res      = 0.065   0.10    0.078;
         alpha          = 7.50    2.70    3.60;
         Par_n          = 1.89    1.23    1.56;
         Par_tau        = 0.5     0.3     0.5;
         thickness      = 0.10    0.20    0.40;
         layers         = 3       2       25;    }
```

The parameters denote:

```
PMacroThresh     : precipitation capacity needed to activate macropore runoff [mm/h]
MacroCapacity    : capacity of the macropores [mm/h]
CapacityRedu     : relative reduction of the macropore capacity per meter depth [0..1]
MacroDepth       : maximum depth of the macropores [m]
Horizon          : soil horizon; coding corresponds with the actual horizon sequence from top to down
Name             : name of the horizon
ksat             : saturated hydraulic conductivity [m/s]
k_recession      : ksat recession with depth [-]
theta_sat        : saturated water sontent [0.01 Vol. %]
theta_res        : residual water content [0.01 Vol. %]
alpha            : van Genuchten parameter [1/m]
Par_n            : van Genuchten parameter [-]
Par_tau          : Mualem parameter in the van Genuchten Equ.[-] (default: 0.5)
thickness        : layer thickness [m]
layer            : numerical number of soil layers in the actual horizon
```

9.5.1 Macropore runoff

The macropore approach implemented into WaSiM-ETH follows the „bypass-flow-concept" after Jansson und Karlberg (2001). This approach allows the simulation of macropore runoff in layered soil profiles. The approach describes macropores by three parameters: depth of the macropores, capacity of the macropores and reduction of the macropore capacity per meter soil depth. By means of these parameters a maximum possible macropore flow can be calculated for each soil layer (potential macropore runoff). An additional parameter is given by the precipitation threshold value. Only if this predefined precipitation intensity is reached or exceeded, water can infiltrate into the macropores and macropore runoff can be generated. The real amount of macropore infiltration depends on the actual water content of the adjacent soil layers. Water which exceeds the free capacity of these soil layers, can not infiltrate into the macropores.

The infiltrated macropore water is used to fill up the adjacent soil layers from down to top. When an actual soil layer is saturated then the remaining macropore water is trying to infiltrate into the next upper soil layer. Macropore water is not stored from one simulation time step to another but it has to completely infiltrate into the adjacent soil layers within the actual time step. As the macropore infiltration is strongly dependent on the free water capacity of the soil, the actual macropore runoff can be reduced with respect to the potential runoff.

The parametrization of the macropores is optional. Missing entries are automatically replaced by the following values (i.e. deactivation of the macropore system):

- *PMacroThresh* = 1000
- *MacroCapacity* = 0
- *CapacityRedu* = 1.0
- *MacroDepth* = 1.0

9.5.2 Horizon-dependent soil parametrization

The user can define individual horizon sequences with specific parametrization. For each soil horizon, it can be specified the following parameter entries: saturated hydraulic conductivity (*ksat*), recession of *ksat* with depth (*k_recession*), van Genuchten parameters for defining the soil-water-retention curve (*theta_sat*, *theta_res*, *alpha*, *Par_n*, *Par_tau*), horizon *thickness*, and number of soil layers per horizon. For technical reasons all soil profiles must be divided into the same number of layers but the depth of the soil profiles (column) may vary from one grid cell to another due to different thicknesses of soil layers (horizons). In this context, it is important to note that the depth of the soil profile has to be larger than the thickness of the uppermost (first) groundwater aquifer. Otherwise problems can arise during the use of the WaSiM-ETH groundwater model (groundwater table is falling below the deepest soil layer). For *k_recession* = 1.0 the parameter *ksat* remains constant within the actual soil horizon. In the letter case interflow is only generated at the horizon boundaries (if the actual soil profile uses different horizon-dependent *ksat* values).

9.6 Coupling WaSiM-ETH to an external model

A new model component allowing the online data exchange to an external groundwater model has been integrated into WaSiM-ETH. At the moment the functionality of the coupling module is limited to the data exchange with the groundwater model PCGEOFIM (**P**rogramsystem for **C**omputation of **GEOFI**l-tration and geo**M**igration; see http://www.ibgw-leipzig.de/) but it might be relatively simple to adapt this coupling module to other external models. The WaSiM-ETH coupling module can be run with or without activation of the internal groundwater module.

The online data exchange between WaSiM-ETH and the external model can be carried out at the end of each simulation time step or at predefind simulation intervals. The parametrization scheme of the coupling module is shown below (new section in the WaSiM-ETH control file):

```
[ExternalCoupling]
1
$exchngpath//wasim.inf
100
D
1440
1
$exchngpath//gwtable.grd  GWTableExtern 1 0
#$exchngpath//bh.grd      gw_boundary_fix_h_1 0 0
2
$exchngpath//gwn.grd groundwater_recharge
$exchngpath//balance.grd Balance SumTotal_MY
#$exchngpath//gwstand.grd groundwater_distance
2
$exchngpath//qdir.tab
$exchngpath//qifl.tab
$exchngpath//geofim.inf
geofim
```

The line-by-line entries denote:

```
Line
1       activate / deactivate the external coupling module; 0 = no coupling, 1 = coupling
2       path and name of semaphore (or synchronization) file provided by the external model
3       wait interval for scanning the exchange directory for the new semaphore file [ms]
4       Coupling mode: I = each interval, H = each hour, D = each Day, M = each month, Y = each year
5       time interval used by the external model [min]
6       number of grids provided by the external model; the file names must be available once the semaphore
        file was written. Each following row (1..n) will contain a symbolic name.
7       first parameter: path and file name, second parameter: internal grid name, third parameter: “fillMiss-
        ing” parameter (0 = no fill, 1 = fill with nearest neighbors value), fourth parameter: re-
        name(1)/delete(0) parameter
8       here labelled (#) as comment; in general additional files of the external model could be defined here
        for providing them WaSiM-ETH
9       number of grids provided by WaSiM-ETH before next synchronisation can be done
10      first parameter: path and name of the groundwater recharge grid, second parameter: internal grid name
11      first parameter: path and name of the balance grid (Due to the exchange of groundwater tables WaSiM-
        ETH has to adapt the internally calculated soil water content to the new condition. The cumulated
        amount of adaptation water is balanced by the balance grid.), second parameter: internal grid name,
        third parameter: writecode (D = daily sum grids, M = monthly sum grids, Y = annual sum grids; other
        options e.g. MY = both monthly and annual sum grids)
12      here labelled (#) as comment; in general additional files of WaSiM-ETH could be defined here
13      number of subbasin correlated statistics (mean values) which should be written as table (in ASCII-
        Format)
```

```
14      first parameter: path and name of the file with direct flow per subbasin/zone [mm/Δt]; second parame-
        ter: internal file name
15      first parameter: path and name of the file with interflow per subbasin/zone [mm/Δt]; second parameter:
        internal file name
16      path and name of semaphore file provided by WaSiM-ETH after all of the output above was written
17      content of the semaphore file written by WaSiM-ETH
```

The exchange data containing the routed direct runoff and interflow (per subbasin) are provided by WaSiM-ETH as Ascii tables with the following format:

```
direct discharge [mm per Zone] (QD) unsatzon_model; 4 zones
1       0.128897
2       1.3298
3       4.5257
4       2.14858
```

9.7 Additional WaSiM-ETH outputs

Since WaSiM-ETH version 7.x the number of possible model ouputs has been significantly increased. The actual model version is able to calculate and write out the following additional outputs (cf. Chapters 3.5 and 5):

Flow variables:
- rain (liquid fraction of precipitation) [mm/Δt]
- snow (solid fraction of precipitation) [mm/Δt]
- snow evaporation [mm/Δt]
- snow age [days]
- interception storage outflow for each vegetation component [mm/Δt]
- potential evaporation of intercepted water for each vegetation component [mm/Δt]
- real evaporation of intercepted water for each vegetation component [mm/Δt]
- potential evapotranspiration for each vegetation component [mm/Δt]
- reale transpiration for each vegetation component [mm/Δt]
- infiltration amount into the upper soil layer [mm/Δt]
- potential evaporation from the upper soil layer [mm/Δt]
- real evaporation from the upper soil layer [mm/Δt]
- percolation [mm/Δt]
- capillary rise [mm/Δt]
- withdrawal of soil water due to transpiration for each soil layer [mm/Δt]
- interflow for each soil layer [mm/Δt]
- infiltration amount in macropores [mm/Δt]

Storage variables:
- interception storage for each vegetation component [mm/Δt]
- total snow storage [mm/Δt]
- soil water content over the total soil profil [mm/Δt]
- balance of all changes in soil water content due to coupling with the external model PCGEOFIM (cf. Section 9.6) [mm]