## AgroEcoSystem-Watershed (AgES-W)

## Model Technical Documentation

## Climate Data Regionalization

The climate regionalization module considers the vertical and horizontal variation of spatial climate value distributions in a catchment or watershed. The vertical variability is estimated by linear regression between station elevation (X) and climate values (Y). The regression is calculated for each time step to determine the gradient (b) of the linear relation and its coefficient of determination (r²).

Horizontal variability is estimated by an inverse distance weighted approach based on *n* nearest climate stations for which weights W(i) are calculated as:

where wDist(i) is the weighted distance of climate station i from the model hydrologic response unit (HRU) for which the regionalization is done. The weighting of the distance is done by applying a user-defined value (pIDW) as power to the distance in m.

The final calculation of the climate value (Climateval) for each HRU is done depending on the r² value of the elevation regression. If r² is larger than a user-defined threshold, the elevation effect is incorporated for the regionalization using:

where*:*

(i) = elevation difference between climate station i and the model spatial entity;

bH = gradient of the linear regression; and

V(i) = climate value (e.g., precipitation, temperature) at station i.

If the r² value is below the user-defined threshold or the elevation correction has been switched off, the HRU climate value is calculated using only the horizontal variability weights from the inverse distance weighting process:

Regionalization of relative humidity is not done directly with the data values because it is a relative value. In AgES-W, first absolute humidity is calculated from relative humidity and mean air temperature, then these two variables are regionalized and spatially-distributed values of relative humidity are calculated from regionalized absolute humidity and mean air temperature. The following steps are performed:

Saturated vapor pressure es(T) (kPa) is calculated from mean air temperature T:

Maximum humidity A(T) (g/cm³) is calculated from es(T) in hPa and *T*:

Absolute humidity a (g/cm³) is calculated from A(T) and relative humidity RH (%):

## Partitioning of Precipitation into Rain and Snow

Partitioning of measured precipitation into rain and snow is computed from average air temperature (T) and two user-defined calibration parameters. The first calibration parameter (TRS) indicates the air temperature in °C at which 50% of the precipitation falls as rain and 50% falls as snow. The second calibration parameter (TRANS) defines an interval around TRS in such a way that at TRS+TRANS the entire amount of precipitation falls as rain and at TRS-TRANS the entire amount of precipitation falls as snow. Between these values, mixed events with both snow and rain components are computed. The snow component p(S) is calculated with the two calibration parameters and the air temperature (T) as:

Using p(S), the snow (PS) and rain (PR) parts of the precipitation event (P) are calculated as:

## Potential Evapotranspiration (Penman-Monteith Method)

Potential evapotranspiration (PET) is calculated according to the approach of Penman-Monteith, following primarily the approach of Allen et al. 1998 (http://www.fao.org/docrep/x0490e/x0490e06.htm). The main equation is:

where:

L = latent heat of vaporization [MJ/kg];

slope of the saturation vapor pressure temperature relationship [kPa/°C];

RN = net radiation [MJ/m²];

G = soil heat flux [MJ/m²];

mean air density at constant pressure [kg/m³];

cp = specific heat of the air [= 1.013E-3 MJ/kg°C];

es = saturation vapor pressure of the air [kPa];

ea = actual vapor pressure of the air [kPa];

= psychrometer constant [kPa/°C];

rs = bulk surface resistance [s/m]; and

ra = aerodynamic resistance [s/m]

Latent heat of vaporization is calculated from air temperature (T) as:

The slope of the saturation vapor pressure temperature relationship is calculated from air temperature (T) as:

Air density at constant pressure is calculated from atmospheric pressure (P) and the virtual temperature (Tv) as:

Virtual temperature (Tv) is calculated from absolute air temperature (Tabs), atmospheric pressure at given elevation (pz) and actual saturation pressure (ea) as:

Saturation vapor pressure (es) is calculated from air temperature (T) as:

Actual vapor pressure (ea) is calculated from saturation vapor pressure (es) and relative humidity RH (%) as:

The psychrometer constant () is calculated from the air pressure (pz) and the latent heat of vaporization (L) as:

using the relationships of mol weights of wet and dry air (VM = 0.622) and the specific heat capacity of the air (cp = 1.013E-3 MJ/kg°C).

Bulk surface or stomata resistance (rs) is calculated from the leaf area index (LAI) of the current land cover, a monthly specific rsc0 value, and the bulk surface resistance of bare ground (rss = 150 s/m) as:

Aerodynamic resistance (ra) is calculated from wind speed (v) and the effective height (eH) of the current land cover as:

## Solar Radiation

For the energy term of the Penman-Monteith equation, either measured solar radiation or measured sunshine duration has to be available. If solar radiation (Rs) is not available as a measured value, it can be calculated from measured sunshine duration. Extraterrestrial radiation (Ra) is calculated from the geographical latitude and the day in year:

where:

Gsc = solar constant [MJ/m²min];

dr = inverse relative distance between Earth and Sun [rad];

= sunset hour angle [rad];

= latitude [rad]; and

solar declination (insolation angle of the sun) [rad]

The solar constant is calculated using the Julian day (jd) as:

The inverse relative distance between Earth and Sun is calculated using the Julian day (jd) as:

The solar declination () is calculated using the Julian day (jd) as:

The sunset hour angle is calculated from the latitude () and the solar declination () as:

The solar radiation (Rs) is calculated from the extraterrestrial radiation (Ra), the measured sunshine duration (S) and the maximum possible sunshine duration (S0) with the Angstrom formula as:

The maximum possible sunshine duration is calculated from the sunset hour angle () as:

The net radiation (RN) for the ET computation is calculated from the net shortwave radiation (RNS) and the net outgoing long wave radiation (RNL) as:

The net shortwave radiation (RNS) is calculated from the solar radiation (RS) and the albedo of the current land cover as:

The net long wave radiation (RNL) is calculated from the absolute air temperature (Tabs), the actual vapor pressure (ea), the solar radiation (RS) and the clear sky solar radiation (RS0) as:

where the Boltzmann constant = 4.903E-9 MJ/K4m²d.

The clear sky solar radiation (RS0) is calculated from the extraterrestrial radiation (Ra) and the elevation (elev) as:

The soil heat flux (G) is calculated from the net radiation (RN) as:

Tables 1 and 2 show the land use parameters currently used in AgES-W for ET calculation. Table 1 contains the albedo and stomata resistance values rsc0 for January to December (rsc0\_1 to rsc0\_12). Table 2 contains the leaf area index for specific days in the year (d1 = day 110; d2 = day 150; d3 = day 250; d4 = day 280), effective plant heights for the same four points in time, the effective rooting depth of the vegetation, and the relative amount of impervious areas. The four points in time for the LAI and effective height values represent the development of the vegetation in an elevation of 400 m a.s.l. (and mark specific points of vegetation development). During model initialization these values are adapted to the elevation (z) of the model HRUs using the following equation:

To account for the influence of slope and aspect of the HRUs on the energy input, a slope aspect correction factor is calculated for each Julian day (jd) using the latitude (radians), slope (radians), and aspect *asp* (radians) as:

The slope aspect factor of the model spatial entity is then:

## Precipitation Correction

AgES-W implements correction methods to account for the systematic error of precipitation measurements. The implemented method follows the approach of Richter (1995) which was developed for the standard measurement equipment of the German Weather Agency (Deutscher Wetterdienst DWD). The agency uses the standard Hellmann precipitation gauge in 1 m elevation above ground. The correction methods described in Richter (1995) were derived from the comparison of daily readings from the standard equipment with mostly error free readings observed in parallel. The measurement errors depending on precipitation amount were tabulated in the publication separately for initial loss and evaporation on one hand and error by wind drift on the other. For the precipitation correction inside AgES-W, continuous correction functions have been derived from the tabulated values for summer and winter conditions and rain or snow precipitation. The correction function for the wind error of rainfall (R) is:

The correction function for the wind error of snowfall (S):

The correction of initial loss and loss due to evaporation is computed for the summer (April to September) as:

and for winter (October to March) as:

The total precipitation correction is finally calculated using the two loss terms as:

## Canopy Interception

The implementation of the interception process follows the approach of Dickinson (1984) which computes a maximum interception capacity as a function of the leaf area index of the land cover class and a dimensionless calibration parameter . This parameter has two different values: one used for snow interception and one for rain interception. The maximum storage is calculated as:

Any precipitation on the HRU is first stored as interception until the maximum interception capacity is reached. Then, any additional precipitation is treated as throughfall and passed to the next module. Interception storage can be depleted evaporation.

## Snow Processes

The AgES-W snow module considers three snow pack states: accumulation, metamorphosis, and melt. The snow module considers the following state variables: snow depth, snow density, liquid/frozen snow water content, and snow albedo. These state variables are continuously calculated during the presence of a snow pack. For the calculation of snow processes, two temperatures (accumulation and melt) are computed from the minimum, average, and maximum air temperatures. An accumulation temperature is calculated as:

In addition, a melt temperature is calculated as:

Based on these temperatures and a user defined base Temperature (Tbase) the snow pack states are determined. New snow density is calculated for temperatures greater than -15°C after Kuchment et al. (1983) and Vehviläinen et al. (1992) with the air temperature T as:

For temperatures below -15°C, new snow density is set to 0.02875. Using the snow density and the amount of snow (S), the change of the snow pack depth () is computed as:

The amount of snow ( ) is then added to the dry snow water equivalent of the snow pack.

When a precipitation event contains a rain part, the rain on snow causes snow pack settlement and an increase of the liquid snow water content. Snow pack settlement is computed according to Bertle (1966). First, the rainfall is added to snow pack total snow water equivalent. From the ratio between dry snow water equivalent ) and total snow water equivalent ), a settlement factor is then calculated as:

[%]

With this factor, the relative depth change of the snow pack is computed as:

This relative depth change is then used to calculate snow pack final depth after settlement as:

The change of depth leads to an increase of snow density. Potential (maximum possible) snow melt is calculated using the following equation that takes energy input from temperature, rainfall, and ground-heat-flux into account:

[mm]

where:

tf = a temperature melt factor (mm/°C);

Tmelt = melt temperature (°C);

rf = a rainfall-temperature melt factor (1/°C);

R = rainfall (mm); and

gmelt = constant melt rate from ground-heat flux (mm).

The potential snow melt rate is used to melt the frozen part of the snow water equivalent (SWEdry) and convert it to the liquid part (SWEliq). The fact that a snow cover can store a specific amount of liquid water without producing snow melt runoff is considered with a user-defined critical density (). Using the critical density and the snow depth (SD), the maximum water holding capacity of the snowpack is computed as:

[mm]

If the actual density of the snowpack is greater than the critical density snow melt, snow melt runoff (SM) is calculated using the maximum water holding capacity and the total snow water equivalent as:

[mm]

## Soil Water

The soil-water module computes infiltration, evapotranspiration, and soil water balance processes. The module produces up to three runoff components (surface runoff, interflow, percolation). The soil is conceptualized by two storage capacities that are derived from physical soil parameters: the middle pore storage and the large pore storage. The middle pore storage (MPS) represents the water holding capacity of the middle pores (pore diameter between 0.2 – 50 µm) of the soil in which water is held against gravity and can only be extracted by an active suction. This storage capacity corresponds to the useable field capacity of the soil. The large pore storage (LPS) represents the water holding capacity of the large pores (pore diameter greater 50 µm) of the soil in which water cannot be held against gravity and which is considered to be the source of all subsurface flow processes of AgES-W. The storage capacity of the LPS corresponds to the air capacity of the soil.

Infiltration is the first process calculated by the module, defined by a maximum possible infiltration rate (Infmax) for either summer (May – October), winter (November – April) or a snow-covered HRU. The actual infiltration is computed from the maximum rate and the actual soil water saturation (soil) as:

[mm/d]

If the actual water amount is larger than the maximum infiltration rate the surplus is stored as depression storage at the surface and/or routed as surface runoff to the next HRU. The infiltration rate (Inf) is distributed among the two soil water storages MPS and LPS as:

[mm/d]

[mm/d]

The MPS is emptied by evapotranspiration (ET) only. The daily rate depends on the PET and the actual saturation of the storage (MPS). With this information a maximum actual transpiration rate is calculated with either a linear or a non-linear function. The linear function is computed with a user-defined parameter (linRed) as:

[mm/d]

The non-linear function is computed with another user-defined parameter (polRed) as:

[mm/d]

Outflow from LPS is calculated from the actual LPS storage content (actLPS), the water saturation of the soil, and a calibration factor LPSout as:

[mm/d]

The outflow is separated into lateral (lat) and vertical (vert) components depending on the slope () of the HRU and a calibration parameter (latVertDist):

[mm/d]

[mm/d]

To account for water retention in larger HRUs, the surface runoff (RD1) and interflow (RD2) components are stored in two concentration storages (RD1conc and RD2conc) and can be temporarily delayed by a linear storage approach with retention coefficients kRD1 and kRD2:

[mm/d]

## Groundwater

The groundwater domain is conceptualized by two storages (RG1 and RG2) for each HRU. RG1 represents the water movement in the withering zone of the bedrock, RG2 the water movement in the deeper aquifer and/or in fractures. Both storages are parameterized by a maximum storage capacity (maxRGx) and a recession coefficient (kRGx). These parameters are specified for each hydrogeological unit in the catchment and saved in the hydrogeological parameter file. The water input (perc) into the groundwater module is distributed among the two storages (inRGx) based on slope () and calibration parameter (distRG1RG2):

[mm/d]

Outflow from the two RG storages is calculated from the actual storage content (RGxact), the recession coefficient kRGx, and a calibration factor gwRGxfact as:

[mm/d]

## Topological Routing Module

Water flow from one modeling unit to either another modeling unit or a river reach is determined by the topological routing module. The topological connections of the single HRUs have to be determined a priori and are read in via the HRU parameter file. The routing module is transfers the output runoff components RD1 (surface runoff), RD2 (subsurface runoff from the soil zone), RG1 (subsurface runoff from the withered bedrock surface) and RG2 (baseflow) from the source HRU to a receiving HRU where inputs are added to the respective storages and/or fluxes. For example, RD1 is added to the input water at the surface, RD2 is added to the infiltration water, RG1 is added to the RG1 (shallow groundwater) storage and RG2 is added to the RG2 (base flow) storage. If an HRU unit is connected to a river segment, the above four runoff components are added to the respective reach storages.

## Reach Routing

The reach routing module conceptualizes stream flow processes with a simplified kinematic wave approach. For each reach segment, the width, slope, and roughness have to be specified in the reach parameter file. Additionally, this file contains the necessary information to establish the reach connectivity (topology) inside the model. Internally, the flow velocity is calculated for a simple rectangular cross-section with the Manning-Strickler equation. The module contains only one calibration parameter (TA) that can be used to influence the overall stream routing velocity.

**References**

Need to add.

**List of Tables**

Table 1. Values for albedo and monthly stomata resistance (rsc0) by land cover class.

Table 2. Leaf area index for specific days in the year (d1 = day 110; d2 = day 150; d3 = day 250; d4 = day 280), effective plant heights for d1-d4, effective rooting depth of vegetation, and the relative amount of impervious areas by land use class.

Table 1. Values for albedo and stomata resistance (rsc0) by land cover class.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Stomata resistance (rsc0) | | | | | | | | | | | |
| LID | Description | Albedo | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Min. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Max. |  | 1 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| Units |  | -- | s/m | s/m | s/m | s/m | s/m | s/m | s/m | s/m | s/m | s/m | s/m | s/m |
| 1 | Urban SG>80% | 0.1 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 2 | Urban SG<80% | 0.1 | 90 | 90 | 80 | 70 | 50 | 55 | 55 | 55 | 60 | 70 | 90 | 90 |
| 3 | Grassland | 0.25 | 80 | 80 | 70 | 60 | 40 | 45 | 45 | 45 | 50 | 60 | 80 | 80 |
| 4 | Coniferous forest | 0.12 | 70 | 70 | 60 | 55 | 45 | 45 | 45 | 45 | 50 | 65 | 70 | 70 |
| 5 | Deciduous forest | 0.17 | 80 | 80 | 70 | 65 | 55 | 55 | 55 | 55 | 60 | 75 | 80 | 80 |
| 6 | Mixed forest | 0.15 | 75 | 75 | 65 | 60 | 50 | 50 | 50 | 50 | 55 | 70 | 75 | 75 |
| 7 | Agriculture | 0.25 | 80 | 80 | 75 | 65 | 45 | 50 | 50 | 50 | 50 | 65 | 80 | 80 |
| 8 | Shrubs | 0.2 | 80 | 80 | 70 | 60 | 50 | 50 | 50 | 55 | 55 | 70 | 80 | 80 |
| 9 | Wetlands | 0.2 | 80 | 80 | 70 | 60 | 50 | 50 | 50 | 55 | 55 | 70 | 80 | 80 |
| 10 | Bare ground | 0.1 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| 11 | Water bodies | 0.05 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |

Table 2. Leaf area index for specific days in the year (d1 = day 110; d2 = day 150; d3 = day 250; d4 = day 280),

effective plant heights for d1-d4, effective rooting depth of vegetation, and the relative amount of impervious

areas by land use class.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Leaf area index (LAI) | | | | effective plant height | | | |  |  |
| LID | Description | d1 | d2 | d3 | d4 | d1 | d2 | d3 | d4 | Root Depth | Sealed Grade |
| Min. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Max. |  | 100 | 100 | 100 | 100 | 50 | 50 | 50 | 50 | 50 | 1 |
| Units |  | n/a | n/a | n/a | n/a | m | m | m | m | dm | n/a |
| 1 | Urban SG>80% | 1 | 1 | 1 | 1 | 10 | 10 | 10 | 10 | 2 | 1 |
| 2 | Urban SG<80% | 1 | 1 | 1 | 1 | 3 | 5 | 5 | 3 | 3 | 0.8 |
| 3 | Grassland | 2 | 5 | 5 | 2 | 0.3 | 0.5 | 0.5 | 0.3 | 6 | 0 |
| 4 | Coniferous forest | 9 | 13 | 13 | 9 | 10 | 10 | 10 | 10 | 5 | 0 |
| 5 | Deciduous forest | 1 | 8 | 8 | 1 | 3 | 10 | 10 | 3 | 20 | 0 |
| 6 | Mixed forest | 2 | 10 | 10 | 2 | 3 | 10 | 10 | 3 | 20 | 0 |
| 7 | Agriculture | 1 | 5 | 3 | 1 | 0.05 | 0.5 | 0.3 | 0.05 | 1.5 | 0 |
| 8 | Shrubs | 3 | 5 | 5 | 3 | 1.5 | 2.5 | 2.5 | 1.5 | 15 | 0 |
| 9 | Wetlands | 2 | 5 | 5 | 2 | 3 | 5 | 5 | 3 | 10 | 0 |
| 10 | Bare ground | 1 | 1 | 1 | 1 | 0.05 | 0.05 | 0.05 | 0.05 | 1 | 0 |
| 11 | Water bodies | 1 | 1 | 1 | 1 | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 0 |