

# Processes above ground

## Temperature and precipitation

HYPE has many possibilities to adjust the precipitation and temperature given in the Pobs.txt and Tobs.txt files. Adjustment is done because the supplied data can be of different reference height or (known to be) wrong in some areas, or because data vary over the subbasin but the input is given as one value, and or to compensate for non modelled processes.

### Temperature adjustments

Subbasin air temperatures (*tempi*) in the input file are normally assumed to be for the subbasin's average elevation (*elev*).

(1) If data with other reference height is used it is possible to adjust for that. The subbasin temperature can be adjusted depending on subbasin elevation with general parameter *tcelevadd* (° / 100m). This adjustment assumes observations are located at sea level.

(2) Alternatively it can be adjusted based on the difference between subbasin elevation and temperature observation elevation by general parameter *tcobselev* (° / 100m). The temperature observation elevation (*obselev*) then need to be supplied to the model.

(3) It can be adjusted based on month with the monthly dependent parameter *monthlapse* (° / 100m)). These three subbasin elevation adjustments should not be used together. Subbasin temperature can be adjusted equally over all subbasins within a region with the parameter region dependent parameter *tempcorr*.

$$tempgc = tempi + tempcorr - \frac{tcelevadd \times elev}{100} - \frac{tcobselev \times (elev - obselev)}{100} - \frac{monthlapse \times elev}{100}$$

The temperature can also be adjusted for each class depending on their deviation from the subbasin average elevation (*deltah*). The class-dependent temperature (*temp*) is calculated using the parameter *tcalt*. The temperature lapse rate often has a value of 0.6 (° / 100m).

$$temp = tempgc - \frac{tcalt \times deltah}{100}$$

### Precipitation adjustments

Subbasin input precipitation (*preci*) can be adjusted equally over all subbasins with the general parameter *pcaddg* or for some subbasins with the parameter region dependent parameter *preccorr*. Additionally it is possible to adjust precipitation for undercatch with different parameters (*pcurain*, *pcusnow*) depending on if the precipitation falls as snow or rain.

Subbasin precipitation (*precgc*) is for subbasin average elevation (*basinelev*), but can be adjusted for elevation variations within the subbasin. The precipitation of a class (*prec*) is adjusted for classes

where the class average elevation is greater than a threshold (general model parameter  $pcelevth$ ). The adjustment is determined by a general parameter ( $pcelevadd$ ) that is the correction per 100m. The class elevation adjustment can alternatively be determined from the basin standard deviation of elevation ( $stdbasinelev$ ) and a parameter  $pcelevstd$ . The class height adjustment is limited by a general parameter  $pcelevmax$ . The precipitation of a class can additionally be adjusted with land-use dependent parameter  $pcluse$ , e.g. for interception evaporation.

$$precgc = preci \times (1 + pcaddg) \times (1 + preccorr) \times \left( 1 + \left( pcurnain \times (1 - snowfraction) + pcusnow \times snowfraction \right) \right)$$

$$pcorr_{height} = \begin{cases} 0 & basinelev + deltah < pcelevth \\ MIN \left( \frac{basinelev + deltah - pcelevth}{100 \times pcelevadd} + \frac{stdbasinelev}{100 \times pcelevstd}, pcelevmax \right) & else \end{cases}$$

$$prec = precgc \times (1 + pcorr_{height}) \times (1 - pcluse)$$

Where  $deltah$  is a class's elevation deviation from the subbasin average elevation and  $snowfraction$  is the average fraction of precipitation that falls as snow calculated from subbasin temperature ( $tempgc$ ) and class-dependent temperature threshold or from input.

## Rainfall and snowfall calculation

The rain/snow fraction of precipitation is calculated based on temperature or given as an input time series. When the air temperature ( $temp$ ) is around the threshold temperature for mixed precipitation (land-use dependent parameter  $ttmp$  plus general parameter  $ttpd$ ) both rain and snow. The interval for mixed precipitation is given by the parameter  $ttpi$ . For temperature below threshold minus  $ttpi$ , the precipitation is assumed to be in solid form only and is added to the snowpack ( $snow$ ). If the air temperature is greater than the threshold temperature plus  $ttpi$ , the precipitation is assumed to be solely in liquid form. For intermediate temperatures, the precipitation is assumed to be a mixture of liquid and solid forms i.e. as both rain and snow. The proportion ( $arain$ ) of precipitation ( $prec$ ), which falls as rain depends linearly on the temperature.

$$a_{rain} = \begin{cases} 0 & temp < ttmp + ttpd - ttpi \\ 1 & temp > ttmp + ttpd + ttpi \\ \frac{temp - (ttmp + ttpd - ttpi)}{(2 \times ttpi)} & else \end{cases}$$

Alternatively snowfall fraction ( $sfrac$ ) may be read from input file.

$$a_{rain} = 1 - sfrac$$

The amount of rainfall and snowfall is calculated from the corrected precipitation.

$$rainfall = prec \times a_{rain} \quad snowfall = prec \times (1 - a_{rain})$$

## Links to relevant procedures in the code

Modules (file)	Procedures
<a href="#">modelmodule (model_hype.f90)</a>	model
<a href="#">soil_processes (soil_proc.f90)</a>	calculate_snow infiltration
<a href="#">atmospheric_processes (atm_proc.f90)</a>	calculate_class_atmospheric_forcing calculate_rain_snow_from_precipitation calculate_subbasin_temperature calculate_subbasin_precipitation set_atmospheric_parameters_corrections

## Evaporation

Potential evaporation ( $epot$  in mm) is calculated based on the temperature if it is not read in from file (Xobs.txt). Alternative PET models exist, and is described [below](#). When the air temperature ( $temp$ ) is greater than the threshold temperature  $ttmp$  evaporation is assumed to occur. Snow melting, snow density and evaporation use the same threshold temperature. The basic potential evapotranspiration ( $epot_{base}$ ) depends on the land use dependent rate parameter  $cevp$ .

$$cseason = 1 + cevpam \times \sin \left( \frac{2 \times \pi \times (dayno - cevpph)}{365} \right)$$

$$epot_{base} = (cevp \times cseason) \times (temp - ttmp)$$

A seasonal factor  $cseason$  adjusts the potential evaporation rate ( $cevp$ ) e.g. making it higher in the spring when the air is often dry, and lower in autumn when the air is often more humid than in spring. The factor is sinusoidal with two parameters  $cevpam$  and  $cevpph$ . It is not used if  $cevpam$  is zero. A  $cevpph$  around 45 days give a maximum correction in mid May ( $dayno=45+91=136$ ). The minimum correction will then be a half year later in September ( $dayno=136+182$ ). For an earlier maximum, reduce  $cevpph$ .

The basic potential evapotranspiration may be adjusted with a regional correction factor ( $cevpcorr$ ) equally over the year depending on parameter region.

$$epot = epot_{base} \times (1 + cevpcorr)$$

Evaporation from soil is assumed to occur from the two upper layers. The potential evaporation is assumed to decrease exponentially with depth (depending on the parameter  $epotdist$ ). The potential evaporation is divided between the two layers ( $epotfrac$ ) with the distribution depending on the potential evaporation in the midpoint of each soil layer (figure 1). This is then used by approximating to a rectangle. Since soil layers differ between classes, the evaporation distribution do to.

$$epot1 = EXP \left( -epotdist \times soilayerdepth(1) / 2 \right)$$

$$epot2 = EXP \left( -epotdist \times \left( soilayerdepth(1) + \frac{soilayerdepth(2) - soilayerdepth(1)}{2} \right) \right)$$

$$area1 = soilayerdepth(1) \times epot1$$

$$area2 = \left( soilayerdepth(2) - soilayerdepth(1) \right) \times epot2$$

$$epotfrac1 = \frac{area1}{area1 + area2}$$

$$epotfrac2 = \frac{area2}{area1 + area2}$$

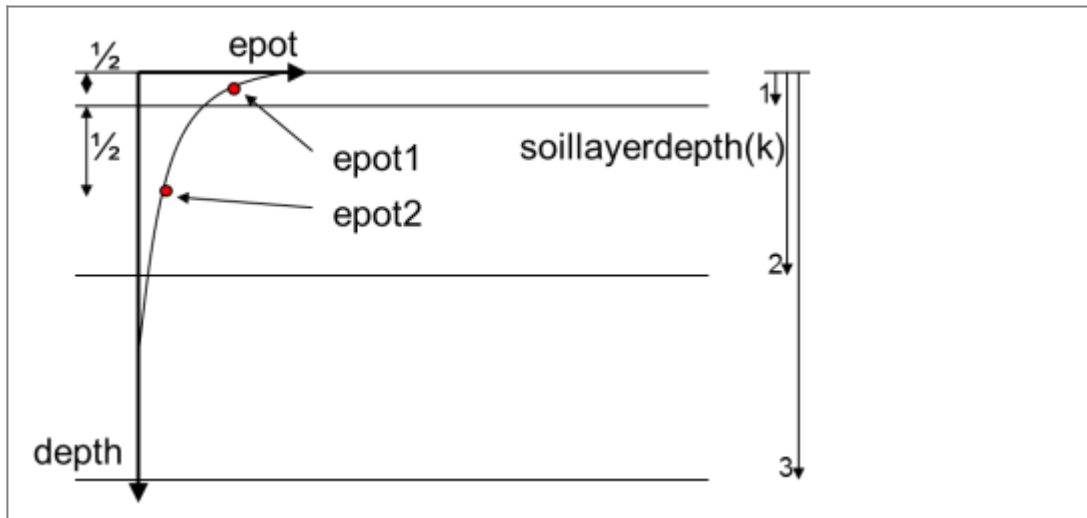


Figure 1 The distribution of potential evaporation between the top two soil layers.

The actual evaporation from a soil layer (*evap*) is limited by the availability of water in the soil (*soil*) above the wilting point (*wp*, mm). Evaporation is at potential rate only if the water exceeds field capacity (*fc*, mm) or a (large) proportion (general parameter *lp*) of field capacity. In between these limits evaporation increase linearly.

$$evapp = \begin{cases} 0 & soil - wp < 0 \\ epot \times epotfrac & soil - wp > lp \times fc \\ epot \times epotfrac \times \frac{soil - wp}{lp \times fc} & else \end{cases}$$

$$evap = MAX \left( evapp, soil - wp \right)$$

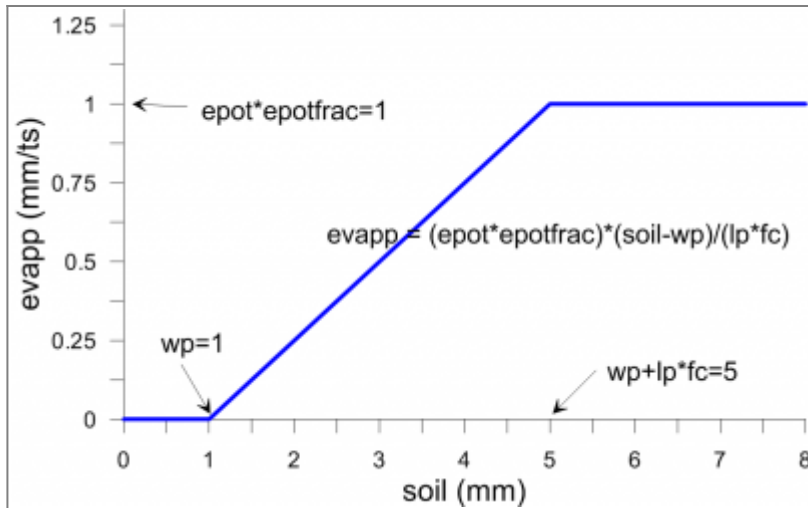


Figure 2 Evaporation as a function of soil water.

The actual evaporation may also depend on soil temperature (*soiltemp*). It is then reduced for temperatures above land use parameter *ttrig* and depend on two other land use parameters (*tredA*, *tredB*) as well (Figure 3).

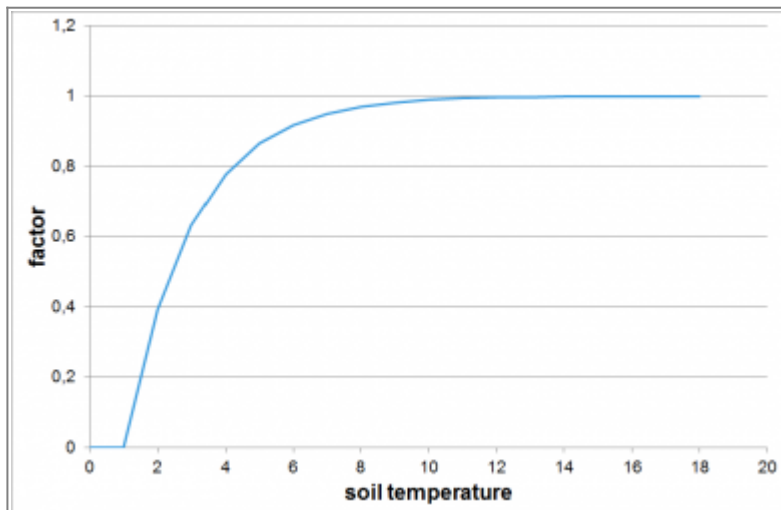


Figure 3 Soil temperature factor for reduction of soil evapotranspiration. Parameter values: *ttrip*=1, *tredA*=0.5, *tredB*=1.

The actual evaporation is set to zero for temperatures below the threshold temperature and for negative potential evaporation estimates (condensation). The soil evapotranspiration reduction is calculated as:

$$factor = 1 - e^{-tredA \times (soiltemp - ttrig)^{tredB}}$$

$$evapp = evapp \times factor$$

A river with an area (is a class), flooded floodplains and lakes are assumed to evaporate at the potential rate, when the air temperature is above the threshold temperature (*ttmp*). Evaporation is limited by the water body's volume.

## Alternative potential evaporation models

HYPE give the option to exchange the default potential evaporation model for another model. Only the basic potential evaporation ( $epot_{base}$ ) differs between models. Models 0-2 only use air temperature forcing. Models 3-5 want shortwave radiation and minimum and maximum daily air temperature, although if lacking approximations are made (see section [Input to alternative potential evaporation models](#) below). In addition, model 5 wants relative humidity and wind speed if available.

### Model 0 (default)

As described above; evapotranspiration depends on the rate parameter  $cevp$  and air temperature ( $temp$ ) above a threshold  $ttmp$ . If  $epot$  is given in Xobs.txt those values are used.

$$epot_{base} = (cevp \times cseason) \times (temp - ttmp)$$

### Model 1

Model 1 is the same as model 0, but it will not be using  $epot$  from input data, even if it is present.

### Model 2 - Modified Jensen-Haise/McGuinness

The modified Jensen-Haise/McGuinness model follow Oudin et al. (2005). The potential evaporation depends on extraterrestrial radiation ( $radext$ ), latent heat of vaporization ( $\lambda$ ) and temperature ( $temp$ ). Two general parameters ( $jhtadd$  and  $jhtscale$ ) are used and one land use dependent (crop coefficient  $kc2$  or  $kc$ ).

$$epot_{base} = \frac{kc}{jhtscale} \times MAX \left( 0, \frac{radext}{\lambda} \times (temp + jhtadd) \right)$$

### Model 3 - Modified Hargreaves-Samani

The Hargreaves-Samani evaporation is modified to limit the “turbidity-factor”. The potential evaporation depends on extraterrestrial radiation ( $radext$ ), latent heat of vaporization ( $\lambda$ ), temperature ( $temp$ ) and turbidity ( $turbidity$ ). One general parameter ( $krs$ ) is used and one land use dependent (crop coefficient  $kc3$  or  $kc$ ).

$$epot_{base} = MAX \left( 0, kc \times 0.0023 \times \frac{radext}{\lambda} \times \frac{turbidity}{krs} \times (temp + 17.8) \right)$$

## Model 4 - Priestly-Taylor

The Priestly-taylor potential evaporation depends on net downward radiation ( $netrad$ ), slope of saturated vapour pressure curve ( $dsatvap$ ), latent heat of vaporization ( $\lambda$ ) and a psychrometric constant ( $\gamma$ ). One general parameter ( $alfapt$ ) are used and one land use dependent (crop coefficient  $kc4$  or  $kc$ ).

$$epot_{base} = MAX \left( 0, kc \times alfapt \times \frac{dsatvap \times netrad}{\lambda \times (dsatvap + \gamma)} \right)$$

## Model 5 - FAO Penman-Monteith

The FOA Penman-Monteith potential evaporation depends on net downward radiation ( $netrad$ ), slope of saturated vapour pressure curve ( $dsatvap$ ), saturated and actual vapour pressure ( $satvap$  and  $actvap$ ), temperature ( $temp$ ), wind speed ( $wind$ ) and a psychrometric constant ( $\gamma$ ). One land use dependent parameter (crop coefficient  $kc5$  or  $kc$ ) is used.

$$epot_{base} = MAX \left( 0, \frac{kc \times 0.408 \times dsatvap \times netrad + \gamma \times \frac{900}{temp + 273} \times wind \times (satvap - actvap)}{dsatvap + \gamma \times (1 + 0.34 \times wind)} \right)$$

## Input to alternative potential evaporation models

Summary of alternative input to PET models:

Model	Parameters	Static data	Forcing data
0	cevp, ttmp		Xobs:repo, Tobs
1	cevp, ttmp		Tobs
2: modified Jensen-Haise/McGuinness	jhtadd, jhtscale, kc	latitude	Tobs
3: modified Hargreaves-Samani	kc, krs	elevation, latitude	SWobs, Tobs
3: modified Hargreaves-Samani	kc, krs	elevation, latitude	TMINobs, TMAXobs, Tobs
4: Priestly-Taylor	alb, alfapt, kc	elevation, latitude	RHobs, SWobs, TMINobs, TMAXobs, Tobs
4: Priestly-Taylor	alb, alfapt, kc, krs	elevation, latitude	SWobs, TMINobs, TMAXobs, Tobs
4: Priestly-Taylor	alb, alfapt, kc, krs	elevation, latitude	TMINobs, TMAXobs, Tobs

Model	Parameters	Static data	Forcing data
5: FAO Penman-Monteith	alb, kc, roughness, zphd, zwind, zwish	elevation, latitude	RHobs, SWobs, TMINobs, TMAXobs, Tobs, Uobs
5: FAO Penman-Monteith	alb, kc, mwind	elevation, latitude	RHobs, SWobs, TMINobs, TMAXobs, Tobs
5: FAO Penman-Monteith	alb, kc, krs, roughness, zphd, zwind, zwish	elevation, latitude	SWobs, TMINobs, TMAXobs, Tobs, Uobs
5: FAO Penman-Monteith	alb, kc, krs, mwind	elevation, latitude	SWobs, TMINobs, TMAXobs, Tobs
5: FAO Penman-Monteith	alb, kc, krs, roughness, zphd, zwind, zwish	elevation, latitude	TMINobs, TMAXobs, Tobs, Uobs
5: FAO Penman-Monteith	alb, kc, krs, mwind	elevation, latitude	TMINobs, TMAXobs, Tobs

Actual vapour pressure

Actual vapour pressure (*actvap*) is calculated following FAO recommended procedure and function/data priority. Depending on availability of minimum, mean and maximum relative humidity (*rh*) and minimum, mean and maximum air temperature (*temp*) equations with different combinations of saturated vapour pressure (calculated from temperature) times relative humidity is used. For example:

$$actvap = \frac{satvap\left(temp_{max}\right) \times rh_{min} + satvap\left(temp_{min}\right) \times rh_{max}}{2}$$

$$actvap = satvap\left(temp_{min}\right) \times rh_{max}$$

$$actvap = satvap\left(temp\right) \times rh_{mean}$$

$$actvap = satvap\left(temp_{min}\right) \times 1$$

In case not enough data is available, minimum temperature is calculated from turbidity and a general parameter (*krs*) and the last equation of those above is used.

$$temp_{min} = temp_{mean} - 0.5 \times \left(\frac{turbidity}{krs}\right)^2$$

Eventually actual vapour pressure is limited by the calculated saturated vapour pressure.

## Air pressure

Air pressure ( $pa$ ) is calculated as a function of elevation for the class ( $elev$ ).

$$pa = 101.3 \times \left( \frac{293 - 0.0065 \times elev}{293} \right)^{5.26}$$

## Shortwave radiation

Shortwave radiation ( $swrad$ ) is supplied as input forcing time series or otherwise calculated from extraterrestrial radiation.

$$swrad = radext \times turbidity$$

## Extraterrestrial radiation

Extraterrestrial solar radiation ( $radext$ ) is estimated from day of year and latitude. The equations used comes from FAO. The day of the year are used to estimate distance to the sun and declination. The sunset hour angle are calculated from latitude, but with special care for high latitudes (polar night and midnight sun). These variables together with latitude and the solar constant eventually give the current extraterrestrial radiation for each subbasin.

## Latent heat of vaporization

Latent heat of vaporization ( $\lambda$ ) is a function of temperature ( $temp$ ).

$$\lambda = 2.501 - 0.002361 \times temp$$

## Net downward radiation

The net downward radiation ( $netrad$ ) is used explicitly for PET model 4 and 5 (Priestly-Taylor and FAO Penman-Monteith). The net radiation is calculated following FAO recommended procedure. It is calculated as net shortwave radiation minus net longwave radiation. Net shortwave radiation ( $net_{short}$ ) is calculated from the shortwave radiation ( $swrad$ ) and the land use dependent albedo parameter ( $alb$ ). Net longwave radiation ( $net_{long}$ ) is calculated using temperature ( $tmin$ ,  $tmax$ , or  $tmean$ ), actual vapour pressure ( $actvap$ ) and relative shortwave radiation ( $relsh$ ) if those are available, otherwise it is set to zero. The relative shortwave radiation is shortwave radiation in relation to clear sky shortwave radiation.

$$net_{short} = swrad \times (1 - alb)$$

$$net_{long} = 4.903 \times 10^9 \times \frac{\left( temp_{max} + 273.15 \right)^4 + \left( temp_{min} + 273.15 \right)^4}{2} \times \left( 0.34 - 0.14 \times actvap^{0.5} \right) \times \left( 1.35 \times relsh - 0.35 \right)$$

$$relsh = \frac{turbidity}{clearturb}$$

## Psychrometric constant

The psychrometric constant ( $\gamma$ ) is a function of air pressure ( $pa$ ) and latent heat of vaporization ( $\lambda$ ) following FAO.

$$\gamma = \frac{0.001013 \times pa}{0.622 \times \lambda}$$

## Saturated vapour pressure

Saturated vapour pressure ( $satvap$ , kPa) is calculated from temperature ( $temp$ ) following FAO. If daily minimum and maximum air temperature is available  $satvap$  is set to the average of the saturated vapour pressure calculated for each of those two temperatures, otherwise it is calculated from daily average air temperature.

$$satvap = 0.6108 \times EXP \left( \frac{17.27 \times temp}{temp + 237.3} \right)$$

## Slope of saturated vapour pressure curve

The slope of saturated vapour pressure temperature function ( $dsatvap$ ) is used explicitly for PET model 4 and 5 (Priestly-Taylor and FAO Penman-Monteith). The slope is calculated from air temperature ( $temp$ ).

$$dsatvap = 4098 \times 0.6108 \times EXP \left( \frac{17.27 \times temp}{temp + 237.3} \right) \times \frac{1}{\left( temp + 237.3 \right)^2}$$

## Turbidity

The turbidity factor is used explicitly for the PET model 3 - modified Hargreaves-Samani. If shortwave radiation ( $swrad$ ) has been given as forcing data time serie, the turbidity factor is calculated as

$$turbidity = \frac{swrad}{radext}$$

but limited by a minimum turbidity value (0.25) and an estimated clearsky turbidity. The clearsky

turbidity (*clearturb*) is estimated by the Ångström formula (FAO):

$$clearturb = 0.75 + elev \times 0.00002$$

where *elev* is subbasin elevation in meter above sea level. If no shortwave radiation time series are given, but time series of daily minimum and maximum temperature are, the turbidity is calculated as in the “ordinary” Hargreaves-Samani turbidity function:

$$turbidity = krs \times SQRT(T_{max} - T_{min})$$

but still limited by the minimum turbidity value and the calculated clearsky turbidity.

## Wind speed

Wind speed is used in PET model 5 - FAO Penman-Monteith. Wind speed (*wind*) may be given as a constant general parameter (*mwind*) or as a forcing data time series. The time series wind is given for each subbasin (*windi*). It is possible to adjust the time series wind speed to different height than observations. If the general parameters *zwind*, *zwish*, *roughness*, and *zpdh* is set, wind speed is adjusted with the transformation factor *windtrans*.

$$wind = windi \times windtrans$$

$$windtrans = \frac{\ln(zwind - zpdh) - \ln(roughness)}{\ln(zwish - zpdh) - \ln(roughness)}$$

## Links to relevant procedures in the code

Modules (file)	Procedures
<a href="#">soil_processes (soil_proc.f90)</a>	initiate_soil_water
	calculate_potential_evaporation
	calculate_actual_soil_evapotranspiration
<a href="#">surfacewater_processes (sw_proc.f90)</a>	calculate_river_evaporation
	calculate_actual_lake_evaporation

## References

Richard G. Allen, Luis S. Pereira, Dirk Raes & Martin Smith, 1998. Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements. FAO Irrigation and drainage paper 56. Rome, Italy: Food and Agriculture Organization of the United Nations. ISBN 92-5-104219-5

Oudin, L., F. Hervieu, C. Michel, C. Perrin, V. Andreassian, F. Anctil and C. Loumagne 2005. Which potential evapotranspiration input for a lumped rainfall-runoff model?: Part 2—Towards a simple and efficient potential evapotranspiration model for rainfall-runoff modelling, *Journal of Hydrology* 303(1-4):290-306.

# Atmospheric deposition of nitrogen and phosphorus

## Wet deposition

Atmospheric deposition in the form of wet deposition of IN and SP is added as a concentration of rainfall. You can specify a time series of the concentration in precipitation in Xobs.txt (implemented for IN, SP, and T1). Otherwise nitrogen wet deposition (as a concentration) is specified in GeoData.txt for each subbasin, while the wet deposition of phosphorus is specified by a general model parameters (*wetdepsp*).

If parameter (*aloadconst*) is set, the wet deposition load is considered constant and not dependent on precipitation corrections. Thus the concentration of precipitation is changed to keep the load constant, when precipitation correction is applied.

## Atmospheric deposition to the soil

Nitrogen dry deposition is specified in GeoData.txt for each subbasin and different vegetation groups, while dry deposition of phosphorus is specified by a model parameter *drydepPP* (land use dependent).

Dry deposition of nitrogen and phosphorus is added to the snow or, if there is no snow, directly to the ground. Phosphorus deposition is added to PartP-pool in the upper soil layer and nitrogen deposits to the IN dissolved in soil water if the parameter *ponatm* is not set. A new concentration of IN in the soil water is then calculated. The parameter *ponatm* indicates that some of the nitrogen deposition will be added to organic nitrogen pool (*fastN*) instead of to the IN pool.

For both nitrogen and phosphorus wet deposition is added through the concentration of precipitation. Precipitation may fall as snow and be added to the snow pack or if it is rain added to the potential infiltration. Depending on the fate of the infiltration, the wet atmospheric deposition will mix with the receiving water (e.g. surface runoff, soil layer water, macropore flow).

## Atmospheric deposition to rivers and lakes

Nitrogen dry deposition on water surfaces is specified in GeoData.txt for each subbasin, while dry deposition of phosphorus is specified by a model parameter *drydepPP* (land use dependent).

For both nitrogen and phosphorus wet deposition is added through the concentration of precipitation (as described above), while for dry deposition an amount of the nutrient is added to the river (if it has a class-area) or lake water. If the lake is divided atmospheric deposition are added to the fast lake part (FLP).

Alternatively wet deposition of phosphorus on water surfaces can be specified by a general model parameter (*wetdepspl*) as a load. Monthly load of IN atmospheric deposition on water surfaces can be specified in GeoData.txt for each subbasin.

## Links to relevant procedures in the code

Modules (file)	Procedures
<a href="#">npc_soil_processes (npc_soil_proc.f90)</a>	set_class_precipitation_concentration_and_load
	add_dry_deposition_to_landclass
	atmdep_in_loss
<a href="#">atmospheric_processes (atm_proc.f90)</a>	set_precipitation_concentration
<a href="#">npc_surfacewater_processes (npc_sw_proc.f90)</a>	add_dry_deposition_to_river
	add_dry_deposition_to_lake