Nitrogen and phosphorus in land routines

HYPE simulate nitrogen and phosphorus in soil both as immobile soil pools and as fractions dissolved in soil water. The pools are changed by outside sources and internal soil processes. The following fractions are simulated:

- **fastN** - immobile pool of organic nitrogen in the soil with rapid turnover (*kg/km2 = mg/m2*)
- **fastP** - immobile pool of organic phosphorus in the soil with rapid turnover (*kg/km2 = mg/m2*)
- **humusN** - immobile pool of organic nitrogen in the soil with slow turnover (*kg/km2 = mg/m2*)
- **humusP** - immobile pool of organic phosphorus in the soil with slow turnover (*kg/km2 = mg/m2*)
- **IN** - concentration of inorganic nitrogen in soil water (*mg/L*)
- **ON** - the concentration of (dissolved) organic nitrogen in soil water (*mg/L*)
- **partP** - immobile pool of inorganic phosphorus adsorded to soil particles (*kg/km2 = mg/m2*)
- **PP** - concentration of particulate phosphorus (of organic origin) in soil water (*mg/L*)
- **SP** - concentration of soluble (reactive) phosphorus in the soil water (*mg/L*)

The figure below give an overview of the nitrogen and phosphorus in soil in HYPE. The internal processes are shown with broad arrows and described in the section Nutrient soil processes below. Sources and sinks are shown with arrows and text, and are further described in sections Nutrient sources and Vegetation and soil surface processes

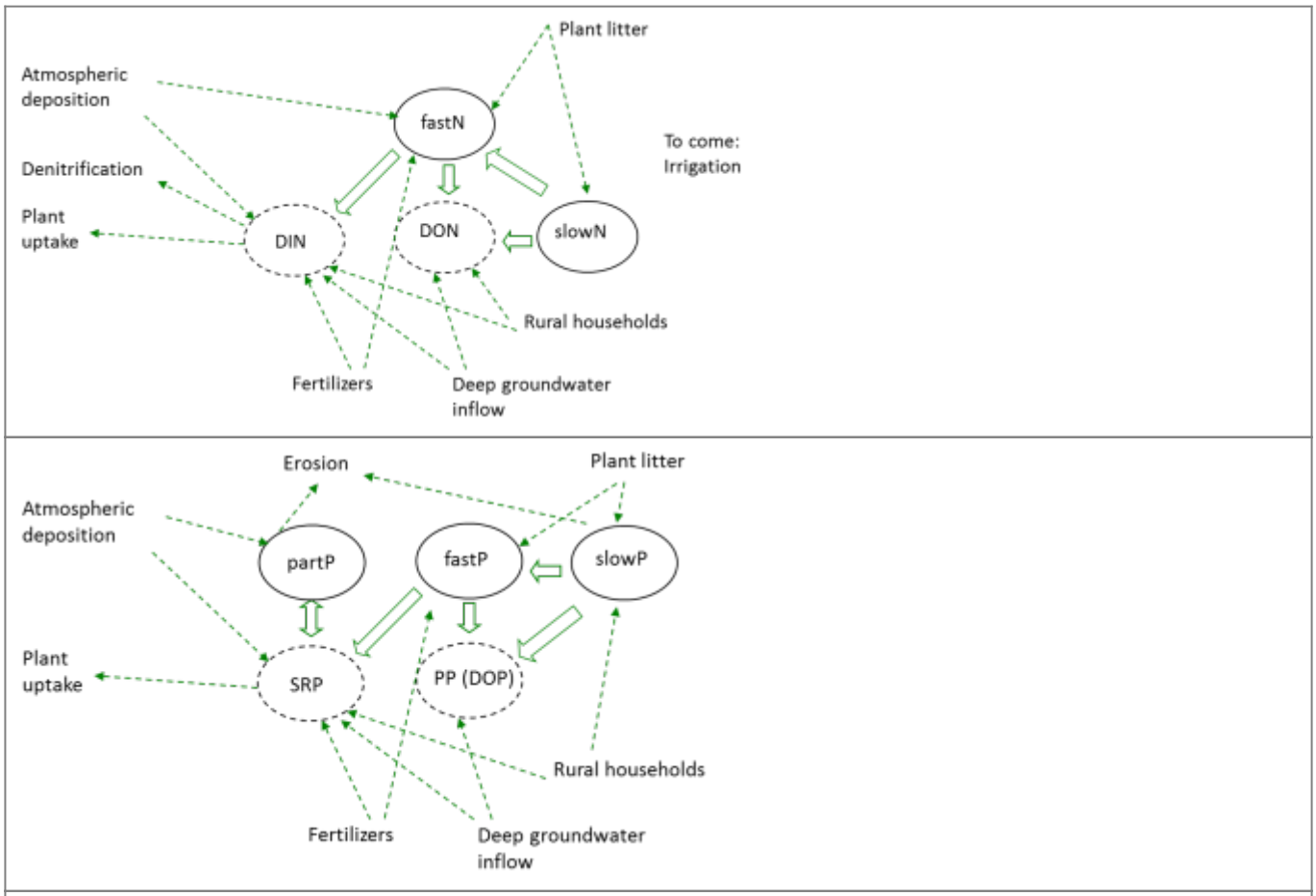


Figure 1: Sources and sinks of nitrogen and phosphorus in the soil. The humusN and humusP pools are called slowN and slowP in this figure.

Nutrient Sources

Fertilizer

Fertilization can be specified to be applied up to two times per year for each of the two fertilization forms, (commercial) fertilizer (*fert*) and manure (*man*). For each fertilization event the application date is specified, the amount of N and P (*fert(inut,ife), man(inut,ife)*, where *inut*=N,P and *ife*=1,2 the fertilization event) to be added, and a management indicator (*fdown(ife), mdown(ife)*). The last information indicates how much of the fertiliser is to be added to the second soil layer (the rest is added to the first soil layer). These parameters are given in CropData.txt and are crop and region dependent. For manure 50% of the nutrients are assumed to be in organic form (*inorgpart* = 0.5).

Fertilizer and the inorganic part of the manure are added to the IN and SP pools of the soil water. The total amount is spread out over a specified period (given by the general parameter *fertdays*) after the date of fertilization. An equal amount is applied each day for the specified period. The organic part of the manure is added to the fastN and fastP pools.

Each class can have two crops (*icrop*=1,2), the main crop and the secondary crop. The secondary crop do not have to cover (*a*) the whole class, e.g. if only 50% of the spring wheat (main crop) area have catch crop (second crop) (*a*(1)=1, *a*(2)=0.5). The total amount of added nutrients ($common_{add}$) is calculated as the sum of fertiliser additions from the main and secondary crops.

Inorganic nutrients to be added to IN and SP pools:

$$common_{add}\left(inut,layer=1\right)=\sum_{icrop=1}^{2}\sum_{ife=1}^{2}a\left(icrop\right)\times\left(\frac{fert\left(inut,ife,icrop\right)\times\left(1\text{-}fdown\left(ife,icrop\right)\right)}{fertdays}+\frac{man\left(inut,if,icrop\right)\times\left(1\text{-}mdown\left(ife,icrop\right)\right)\times inorgpart}{fertdays}\right)$$

$$common_{add}\left(inut,layer=2\right)=\sum_{icrop=1}^{2}\sum_{ife=1}^{2}a\left(icrop\right)\times\left(\frac{fert\left(inut,ife,icrop\right)\times fdown\left(ife,icrop\right)}{fertdays}+\frac{man\left(inut,ife,icrop\right)\times mdown\left(ife,icrop\right)\times inorgpart}{fertdays}\right)$$

Organic nutrients to be added to fastN and fastP pools:

$$common_{add}\left(inut,layer=1\right)=\sum_{icrop=1}^{2}\sum_{ife=1}^{2}a\left(icrop\right)\times\frac{man\left(inut,ife,icrop\right)\times\left(1\text{-}mdown\left(ife,icrop\right)\right)\times\left(1\text{-}inorgpart\right)}{fertdays}$$

$$common_{add}\left(inut,layer=2\right)=\sum_{icrop=1}^{2}\sum_{ife=1}^{2}a\left(icrop\right)\times\frac{man\left(inut,ife,icrop\right)\times mdown\left(ife,icrop\right)\times\left(1-inorgpart\right)}{fertdays}$$

Note that the terms for application of fertilizer and manure only are added during the active time, which is from the application date and for *fertdays* number of days thereafter.

Plant residues

Plant residues are added at a specified date each year. They are added to the immobile soil pools (fastN, fastP, humusN, and humusP) to get a delay of the leakage and an accumulation of humus in the soil. The amount of crop residues (*resamount(inut)*, *inut*=N,P) and the date they are added on depends on crop and region and is given in the CropData.txt file. Part of the plant residues are added to the fast pool (*resfast*), and part to the humus pool. The plant residues are added to the upper two soil layers with a distribution (*resdown*) also specified in CropData. For each class the plant residues are weighted ($common_{res}$) for main and secondary crop together every day with the help of share for each crop (*a(icrop)*, where icrop=1,2).

$$common_{res}\left(fast\text{-}inut,layer=1\right)=\sum_{icrop=1}^{2}a\left(icrop\right)\times resfast\left(icrop\right)\times resamount\left(inut,icrop\right)\times\left(1-resdown\left(icrop\right)\right)$$

$$common_{res}\left(fast\text{-}inut,layer=2\right)=\sum_{icrop=1}^{2}a\left(icrop\right)\times resfast\left(icrop\right)\times resamount\left(inut,icrop\right)\times resdown\left(icrop\right)$$

$$common_{res}\left(humus\text{-}inut,layer=1\right)=\sum_{icrop=1}^{2}a\left(icrop\right)\times\left(1-resfast\left(icrop\right)\right)\times resamount\left(inut,icrop\right)\times\left(1-resdown\left(icrop\right)\right)$$

$$common_{res}\left(humus\text{-}inut,layer=2\right)=\sum_{icrop=1}^{2}a\left(icrop\right)\times\left(1-resfast\left(icrop\right)\right)\times resamount\left(inut,icrop\right)\times resdown\left(icrop\right)$$

All crop residues are transferred into the soil at a given date as determined by the user in CropData.txt. Note that the terms for application of residues only are added that day.

Rural household diffuse source

Information on rural household diffuse source (private sewers) is located in the file GeoData.txt. The source has a flow and concentrations of total nitrogen and phosphorus and fraction of IN and SP. The diffuse source is divided into two parts, where the distribution is determined by a general parameter (*locsoil*). One part is added directly to the local river. The other part is added to soil water in the bottom soil layers in the catchment area of all land classes with a distribution proportional to the classes' area.

Links to file reference

Section	Symbol	Parameter/Data	File
Fertilizer	*fert*	*fn1, fp1, fn2, fp2*	CropData.txt
	man	*mn1, mp1, mn2, mp2*	
	fdown	*mdown1, fdown2*	
	mdown	*mdown1, mdown2*	
		reg, cropid, fday1, fday2, mday1, mday2	
		fertdays	par.txt
		cropid, cropid2	GeoClass.txt
		src_nn, slc_nn	GeoData.txt
Plant residues	*resamount*	*resn, resp*	CropData.txt
		resday, resfast, resdown	
Rural household diffuse source		*loc_tp, loc_tn, loc_vol, loc_sp, loc_in*	GeoData.txt
		locsoil	par.txt

Links to relevant procedures in the code

Modules (file)	Procedures	Sections
npc_soil_processes (npc_soil_proc.f90)	crop_sources	fertilizer
		plant residues
	local_diffuse_source	rural household diffuse source
npc_surfacewater_processes (npc_sw_proc.f90)	add_diffuse_source_to_local_river	rural household diffuse source

Vegetation and soil surface processes

The CropData.txt file contains information on the various crops that are simulated. Each soil type-land use class (SLC-class) can have a main crop and a secondary crop. To reduce the number of SLC-classes in a simulation the individual crops with similar properties are brought together in a grouped crop (e.g. row crops). In CropData.txt there is information such as the amount of fertilizer, manure and crop residues introduced into the soil for different crops in different regions. The file also provides coefficients for nutrient uptake capabilities.

Potential vegetation uptake of nitrogen

The potential uptake is used to calculate the absorption of IN and SP from the soil water (see section Vegetation nutrient uptake). The actual uptake will be limited by the nutrients available. Potential uptake of nitrogen by plants is based on a three-parameter equation (logistic growth) from SOILN (Eckersten et al., 1994). Nitrogen uptake (*uptake*) is calculated for the main and secondary crop and added to the common potential absorption function (*common_uptake*, *mg/m2/d*) using the percentage of the area of the main crop (*part* = 1.0) and secondary crop (*part*<1). The potential uptake is divided between the upper soillayer and second soillayer by a crop dependent input variable for the fraction of the upper soil layer. If the crop is growing in a class of only one soil layer, only the upper soil layer fraction of the potential uptake will be used in the calculations. The growing period with simulated nutrient uptake is determined by the sowing date (*bd2*) and continues until harvest (*bd3*). Potential

uptake depends on three parameters (*up1, up2* and *up3*) and the number of days after sowing date. The uptake for a specific crop is calculated with the parameter values for that crop as

$$help = \left(up1 - up2 \right) \times e^{-up3 \times \left(dayno - bd2 \right)}$$

$$uptake = \frac{up1 \times up2 \times up3 \times help}{\left(\left(up2 + help \right) \times \left(up2 + help \right) \right)}$$

for the growing period. Outside the growing period the uptake is assumed to be zero.

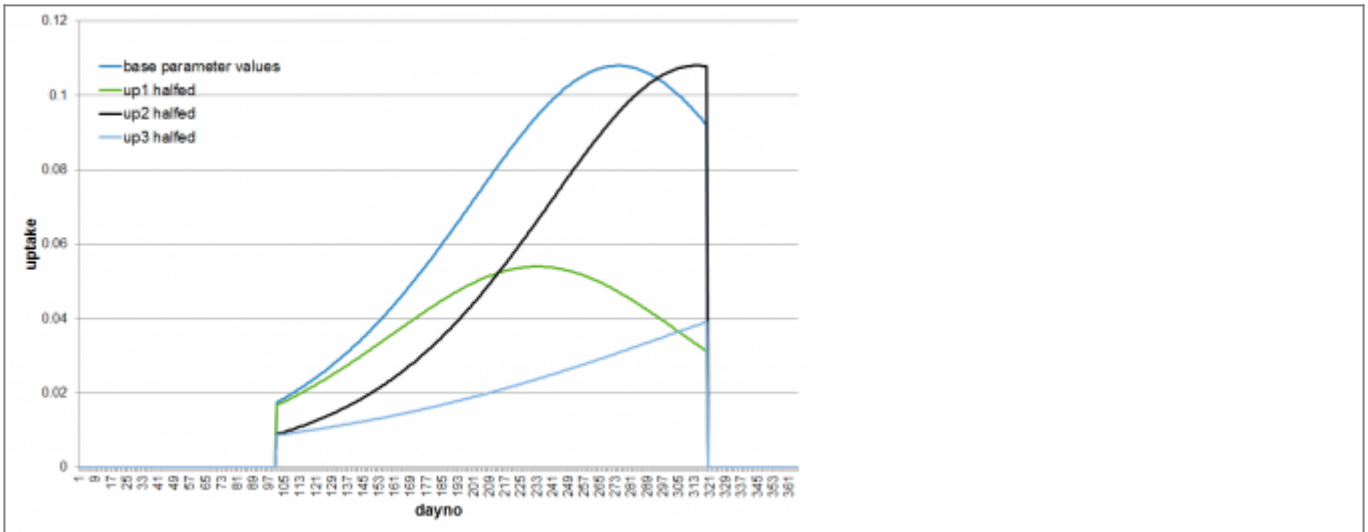


Figure 2 Uptake function over a year with growing period bd2=100 to bd3=230. Effect of changing parameters up1-up3.

Autumn-sown crops may take up IN and SP for a while after sowing in autumn. The same potential uptake of nitrogen as the main growing season are used, but uptake is limited by a temperature function. This uptake will run from the autumn sowing date (*bd5*) to the mid winter (31 December or 30 June depending on the autumn sawing date).

$$help = \left(up1 - up2 \right) \times e^{-up3 \times \left(dayno - \left(bd5 + 25 \right) \right)}$$

$$uptake = \frac{\frac{tmpfcn \times up1 \times up2 \times up3 \times help}{\left(up2 + help \right)}}{\left(up2 + help \right)}$$

where the temperature function (*tmpfcn*) is calculated as

$$tmpfcn = delim \begin{cases} MIN\left[1, \frac{\left(T - 5 \right)}{20}\right] & T > 5 \\ 0 & T < 5 \end{cases}$$

The growing period will then continue next season from *bd2* as described above.

The sowing date (*bd2*) may be given as a constant, or calculated dynamically depending on temperature. If it is dynamically determined it is set to the first day of the year which has a degreeday sum (*GDD*) above a threshold (*gddsow*). The degreeday sum (*GDD*) is calculated as

$$GDD\left(d+1\right)=GDD\left(d\right)+MAX\left(0,T\text{-}basetemp\right)$$

where *d* is day of year, *T* is air temperature (degree Celcius), *basetemp* is a temperature threshold. The GDD is accumulated for each day after *firstday* with day length larger than *daylength*. The GDD is zeroed at *firstday*.

Soil erosion

The erosion of soil particles is calculated by HYPE for transport of particulate phosphorus (PP) or for the simulation of sediment material (SS). For transport of PP an erosion model depending on mobilization of particles by rain and by surface runoff is often used. This formulation is the default model for sediment transport, but another erosion model based on catchment erosion index can also be used.

In the first model PP can leave the land by two means, by surface runoff transport and by macropore flow through drainage pipes. The calculation of PP transport is done in three steps: first the erosion (mobilization) of soil particles from the land surface is calculated, secondly how much of the mobilized particles that are leaving the field is calculated, finally the amount of soil particles is converted to phosphorus.

Mobilization (*MobilisedRain* and *MobilisedSR*) occurs due to energy from falling raindrops ($Rainfall_{energy}$) and/or from surface runoff. The kinetic energy in rainfall is calculated as a function of rainfall and day of the year (*dayno*). If the precipitation falls as snow, or if it falls on snow-covered ground or if it is smaller than 5 mm/day no mobilization occurs in the model. Some of the rain drop's energy can be absorbed by vegetation. Cropcover is defined as the portion of land that is sheltered from raindrops; for a description of how this is calculated, see next chapter. The factor $common_{cropcover}$ is the total fraction of cover that the main and secondary crop give together. It varies over the year due to crop growth and management. The mobilization is also influenced by soil erodibility (soil dependent parameter *soilerod* (g/J)).

$$Rainfall_{energy}=prec\times\left(8.95+8.44\times LOG10\left(prec\times2\times\left(0.257+0.09\times\sin\left(2\pi\times\left(dayno\text{-}70\right)/365\right)\right)\right)\right)$$

$$MobilisedRain=Rainfall_{energy}\times\left(1.\text{-}common_{cropcover}\right)\times soilerod$$

When surface runoff occurs, soil particles are eroded and carried away as the soil surface is exposed to shear forces. The mobilization is calculated from the surface runoff (*sflow*), land slope, a parameter for soil cohesion (*soilcoh* (*kPa*) soil type dependent), and a general parameter (*sreroexp*). This type of

erosion can be mitigated by protective vegetation or vegetation residues that are in contact with the ground. The calculation of this factor (*groundcover*) is described in next chapter. The variable $common_{groundcover}$ is the total fraction of cover that the main and secondary crop give.

$$MobilisedSR = \frac{\left(sflow \times 365\right)^{sreroexp} \times \left(1 - common_{groundcover}\right) \times \frac{1}{0.5 \times soilcoh} \times \sin\left(\frac{slope}{100}\right)}{365}$$

All mobilized particles is not removed from the field, because sometimes the transport capacity of the particle-bearing water (*eflow*) will not suffice for the task. A *transportfactor* will reduce the particle amount:

$$transportfactor = MIN\left(1.0, \left(eflow/4\right)^{1.3}\right)$$

Eroded sediment (kg/km2) is calculated as:

$$erodedSed = 1000 \times \left(MobilisedRain + MobilisedSR\right) \times transportfactor$$

The alternative erosion model calculates eroded sediment (*erodedSed* (kg/km2)) based on precipitation (*prec*) and a number of model parameters and subbasin input data.

$$erodedSed = 1000. \times \left(\frac{slope}{5}\right)^{erodslope} \times erodluse \times erodsoil \times \frac{EI}{erodindex} \times prec^{erodexp}$$

The parameters *erodslope*, *erodexp* and *erodindex* are general. The parameters *erodluse* and *erodsoil* are land-use and soil type dependent. Subbasin input is needed on *slope*, the subbasins average slope, and an erosion index, *EI*.

A selective process is affecting the soil erosion of phosphorus. Smaller and lighter particles are eroded easier than larger ones. The tiny particles contain more P per unit weight than the average particle of the soil. Therefore an enrichment factor (*enrichment*) is used. The enrichment factor is calculated from three parameters (*ppenrmax, ppenrstab, ppenrflow*), one of which is soil type dependent (*ppenrmax*), and the particle bearing flow. Typical values of the parameters, here called max, stab and flowstab, are given in the example in Figure 3.

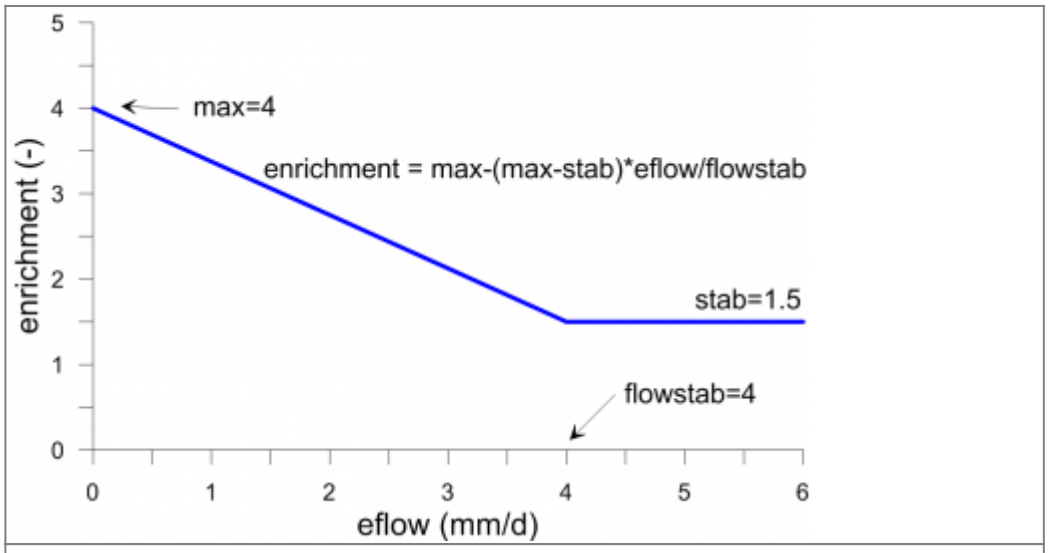


Figure 3 The enrichment factor for particulate phosphorus during soil erosion.

Eventually the eroded PP (kg/km2) is calculated as:

$$erodedP = 0.000001 \times erodedSed \times \frac{PartP + HumusP}{thickness \times bulkdensity} \times enrichment$$

The calculated eroded sediment (*erodedSed*) and eroded phosphorus (*erodedP*) are now available to add to the suspended sediment (SS) or particulate phosphorus (PP) of surface runoff.

A portion of SS and PP in surface runoff (*sflow*) is filtered out (for example by buffer zones). Filtering (*srfilt*) is determined by land use dependent parameters (*bufferfilt, innerfilt, otherfilt*), percentage of agricultural land close to a watercourse (*alfa*), and proportion of agricultural land near the rivers which have a protective buffer zone (*bufferpart*).

$$srfilt = otherfilt + alfa \times \left(1. + bufferpart \times \left(bufferfilt - 1. \right) \right) + innerfilt \times \left(1. - alfa \right)$$

Similarly, part of the SS and PP which is transported by macropore flow (*mflow*) is filtered away between the soil surface and drainage pipes. The parameter that determines this effect (*macrofilt*) is soil dependent. The SS or PP transported (*transp*) by surface runoff and macropore flow is collected in a temporary storage pool (*relpool* (kg/km2)) together with SS and PP in tile runoff (*tilep*).

$$transp = \frac{\left(srfilt \times sflow + macrofilt \times mflow \right) \times erodedSed}{eflow}$$ or

$$transp = \frac{\left(srfilt \times sflow + macrofilt \times mflow \right) \times erodedP}{eflow}$$

$$eflow = sflow + mflow$$

$$relpool = relpool + transp + tilep$$

From the temporary pool sediment and phosphorus is released (*release* (kg/km2)) and then transported to the local river depending on the size of the total runoff (*runoff* (mm)). The parameters *pprelmax* and *pprelexp* are general.

$$release = MIN\left(relpool, relpool \times \left(runoff / pprelmax \right)^{pprelexp} \right)$$

Crop cover and ground cover

Erosion can be mitigated by protective vegetation or vegetation residues that are in contact with the ground. Crop cover and ground cover reduce erosion by rain and surface runoff for particulate phosphorus (PP) and the default sediment transport model (SS). Each crop covers a fraction of the ground, thus for simultanous crops (1st and 2nd crop) their respective crop/ground cover is combined to a common crop/ground cover.

Harvested crops have seasonally varying ground and crop cover, while permanent vegetation (e.g. forest) has constant values for these parameters. The input data needed for calculations (*ccmax1, ccmax2, gcmax1, gcmax2*) are given in CropData.txt. Parameters *ccmax1* and *gcmax1* describe the maximum crop and ground cover during spring-summer growing season, parameters *ccmax2* and *gcmax2* are corresponding maxima for winter crop's growth. These maximum ratios are reached at *maxday1* and *maxday2*, which are defined as halfway between planting and harvest, and halfway between autumn planting and midwinter (1 January or 30 June depending on autumn planting date), respectively. From sowing the coverage fractions increase linearly up to their maximum values. After these dates maximum coverage is maintained to the next ploughing, harvest, or until the growing season starts again in the spring (for winter crops) (Figure 4). During the period between harvesting and ploughing, crop cover is equal to ground cover (*gcmax1*). At ploughing, ground and crop cover are reduced to zero. Parameters *bd1* and *bd4* describe the dates of spring and autumn ploughing. In the case of spring sowing, when no winter crop is crowing, either one of the ploughing parameters can be set for ploughing date.

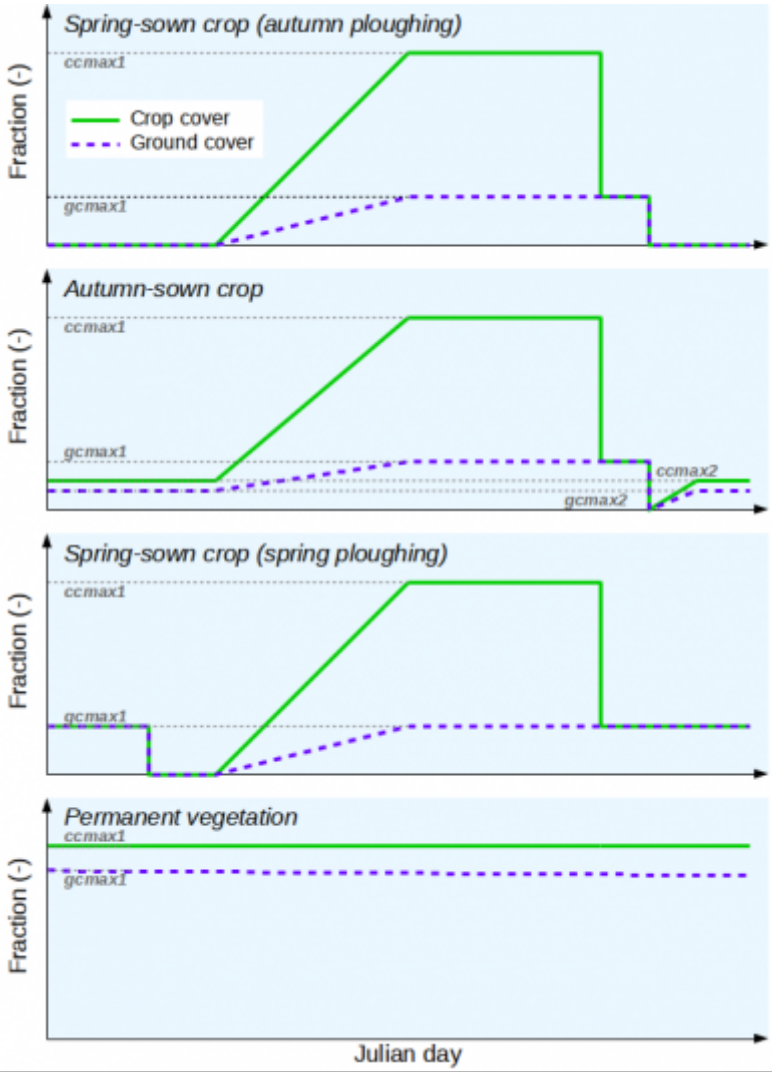


Figure 4: Crop cover and ground cover development for four different crop configurations.

Transformation of nitrogen from atmospheric deposition

The parameter *ponatm* indicates that some of the nitrogen deposition will be organic instead of only inorganic. For wet deposition and deposition on snow, this is adjusted when there is infiltration of rain and melted snow into the soil. A portion (*ponatm*) of IN in the infiltration are added to fastN in the top layer instead of following the water to the soil water.

Links to file reference

Section	Symbol	Parameter/Data	File
Potential vegetation uptake of nitrogen	*part*	*scr_nn*	GeoData.txt
		upupper, pnupr, bd2, bd3, bd5, up1, up2, up3 gddsow, basetemp, firstday, daylength	CropData.txt
	T	calculated from	Tobs.txt

Section	Symbol	Parameter/Data	File
Soil erosion		*soilerod, soilcoh, seroexp, erodslope, erodluse, erodsoil, erodindex, erodexp, bufferfilt, innerfilt, otherfilt, macrofilt, pprelmax, pprelexp*	par.txt
	slope	*slope_mean*	GeoData.txt
	EI	*eroindex*	
	alfa	*close_w*	
	bufferpart	*buffer*	
Crop cover and ground cover		*ccmax1, ccmax2, gcmax1, gcmax2, bd1, bd4*	CropData.txt
	maxday1, maxday2	calculated from *bd2, bd3, bd5*	
Transformation of nitrogen from atmospheric deposition		*ponatm*	par.txt

Links to relevant procedures in the code

Modules (file)	Procedures	Sections
npc_soil_processes (npc_soil_proc.f90)	calculate_plant	potential vegetation uptake of nutrients
	particle_processes_for_runoff	erosion calculations
	calculate_pp_transport	
	calculate_hbvsed_erosion	
	calculate_erosion	erosion calculations
		crop cover and ground cover
	atmdep_in_loss	transformation of nitrogen from atmospheric deposition

Nutrient soil processes

Soil pools – initial values

The initial pools of immobile soil nutrients are dependent on land use and is determined by the user and very important because they are changing slowly. The initial pools of the soil layers are calculated from a parameters. The parameters (*humusn0, humusp0, partp0, fastn0, fastp0*) are representative for the uppermost soil layer; the unit for these parameters is *mg/m*^{3}. The initial humusN, humusP and partP-pools decreases with depth, with half depth determined by land use dependent parameters (*hnhalf, hphalf* and *pphalf*).

The equation for a depth dependent soil nutrient is:

$$nut\left(d\right)=nut0\times e^{-par\times d}$$

where *d* is depth below zero-level, *nut0* is nutrient at zero-level (i.e. model parameter for uppermost soil layer) and *par* is calculated from respective nutrient half depth model parameter (*NNhalf*) as:

$$par=\frac{\log 2}{NNhalf}$$

As the model parameters that represent zero-level nutrient (*nut0*) is defined for the uppermost soil layer, the zero-level is the middle of uppermost soillayer. The following depths (*d*) represent the soillayers (1-3):

$$d\left(1\right)=0$$

$$d\left(2\right)=\frac{soilthick\left(1\right)}{2}+\frac{soilthick\left(2\right)}{2}$$

$$d\left(3\right)=\frac{soilthick\left(1\right)}{2}+soilthick\left(2\right)+\frac{soilthick\left(3\right)}{2}$$

The nutrient is transformed into model soil nutrient pools (unit *kg/km*^{2}) by taking into account the thickness of the soil layers.

$$pool\left(k\right)=nut\left(d\left(k\right)\right)\times soilthick\left(k\right),\quad k=1..3$$

Pools with rapid turnover (*fastN, fastP*) have initial values independent of depth.

$$pool\left(k\right)=nuto\times soilthick\left(k\right),\quad k=1..3$$

The nutrients dissolved in soil water is initialized independent of depth. The initial IN and SP concentrations are zero. The initial ON and PP concentration are determined by land use dependent parameters (*onconc0* and *ppconc0*, *mg/L*) – valid for all three soil layers.

Common functions

Many soil processes depend on temperature and soil moisture. The following equations are used in these cases. The temperature function (figure 5) depends on the estimated soil layer temperature (*soiltemp*). The soil temperature requires some parameters to be simulated, see Section Soil temperature and snow depth.

```
tmpfcn = 2**((soiltemp - 20.0) / 10.0)
IF(temp < 5.0) tmpfcn = tmpfcn * (soiltemp / 5.0)
IF(temp < 0.0) tmpfcn = 0.0
```

The humidity function (figure 6) depends on soil moisture (*soil*) in the soil layer and the parameters of wilting limit (*wp*), field capacity (*fc*) and effective porosity (*ep*) transformed to unit *mm*. All these humidities are specified as percentages. The function includes coefficients *thetaupp* = 0.12, *thetalow* = 0.08, *thetapow* = 1.0 and *satact* = 0.6. Note that another function is used in the calculation of denitrification. For soil layers *k* = 1..3 the equation is:

```
IF(soil >= wp + fc + ep) THEN
  smfcn = satact
ELSE
```

```
  smfcn = min(1.,(1-satact)*((wp+fc+ep-soil) /(thetaupp*soilthick))
**thetapow + satact,((soil-wp)/(thetalow*soilthick) **thetapow)
ENDIF
IF(soil < wp) THEN
  smfcn=0.0
ENDIF
```

The humidity function (figure 6) is always less than or equal to one while the temperature function may be greater than one when the temperature exceeds 20 degrees.

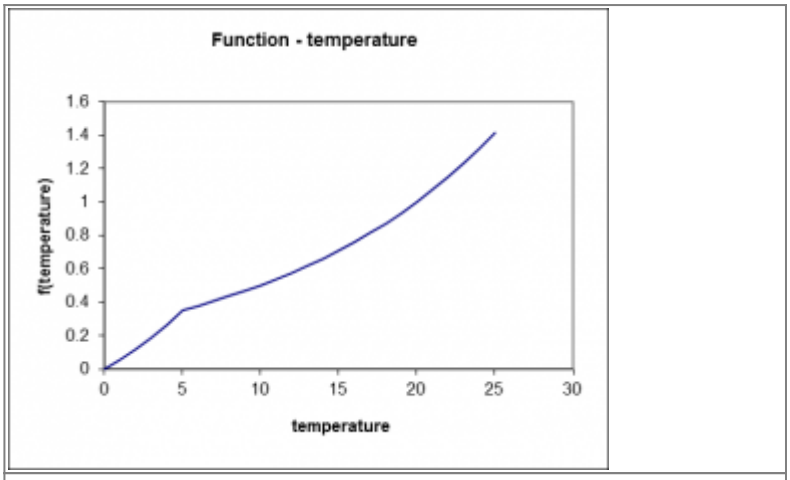


Figure 5: Common temperature function for soil processes

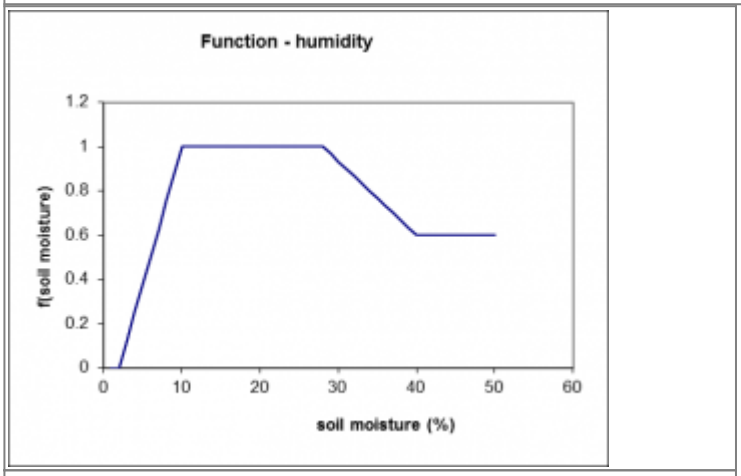


Figure 6: Common humidity function for soil processes

Vegetation nutrient uptake

Vegetation nutrient uptake is a sink of the IN and SP concentrations in the two upper soil layers. The uptake (*uptake / uptakeP*, *mg/m2/d*) depends on the potential uptake of nitrogen ($common_{uptake}$), calculated for the combination of main crop and any secondary crop of the specified class. Vegetation nutrient uptake also depends on *uptsoil1* which gives the distribution of uptake between the two layers for a crop, the pool of IN (*INpool*) and SP (*SPpool*) and for phosphorus by P / N ratio (*pnratio*). The pool of dissolved nutrients are calculated as the concentration multiplied by the water in the soil layer (in *mm*). The main and secondary crop of a class is specified in GeoClass.txt.

$$uptakeN\left(1\right)=MIN\left(uptsoil_1\times common_{uptake},a\times INpool\left(1\right)\right)$$

$$uptakeN\left(2\right)=MIN\left(\left(1\text{-}uptsoil_1\right)\times common_{uptake},a\times INpool\left(2\right)\right)$$

$$uptakeP\left(1\right)=MIN\left(pnratio\times uptsoil_1\times common_{uptake},a\times SPpool\left(1\right)\right)$$

$$uptakeP\left(2\right)=MIN\left(pnratio\times\left(1\text{-}uptsoil_1\right)\times common_{uptake},a\times SPpool\left(2\right)\right)$$

$$a=\frac{\left(soil\text{-}wp\right)}{soil}$$

The plants can take up a maximum factor *a* of the pool. This factor is calculated as a percentage of soil water over the wilting point. The equations for the potential uptake of nitrogen ($common_{uptake}$) are described under that section above. The constants *uptsoil1* (percentage of plant nutrients absorbed top layer) and *pnratio* (ratio of N and P uptake) are given for each crop.

Denitrification

Denitrification is a sink for IN in all three soil layers. Denitrification (*denitr*, *mg/m2/d*) depends on the denitrification rate and the pool of IN (*INpool*) in each soil layer (*k* = 1.3). The denitrification rate depends on a rate coefficient (*drate*), soil temperature, IN concentration and soil moisture.

$$denitr\left(k\right)=drate\times INpool\left(k\right)\times tmpfcn\left(k\right)\times smfcn\left(k\right)\times concfcn\left(k\right)$$

The coefficient *drate* is determined by land use dependent model parameters *denitrlu* and *denitrlu3*. The temperature dependence (*tmpfcn*) is described above. The soil moisture function (figure 7) is exponential and thus different from the general soil moisture function.

$$smfcn=\begin{cases}0 & soil<pw\times lim\\ \left(\frac{\frac{soil}{pw}\text{-}dlim}{\left(1\text{-}dlim\right)}\right)^{\exp} & else\end{cases}$$

where $pw=wp+fc+ep$

The function depends on soil moisture (*soil*) and pore volume (*pw*). Is also depends on two constants; the limit where moisture is high enough to allow denitrification to occur (*dlim*= 0.7) and the exponent (*exp*= 2.5). These cannot currently be changed. The dependence of the denitrification rate on the IN concentration is described by a function with a half-saturation concentration (general parameter *hsatINs* was in earlier HYPE versions a constant equal to 1 mg/L) (Figure 8).

$$concfcn=\frac{conc}{conc+hsatINs}$$

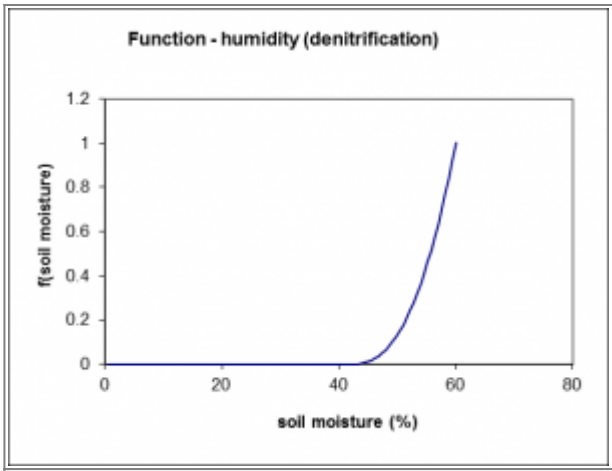


Figure 7: Soil moisture function in the denitrification process.

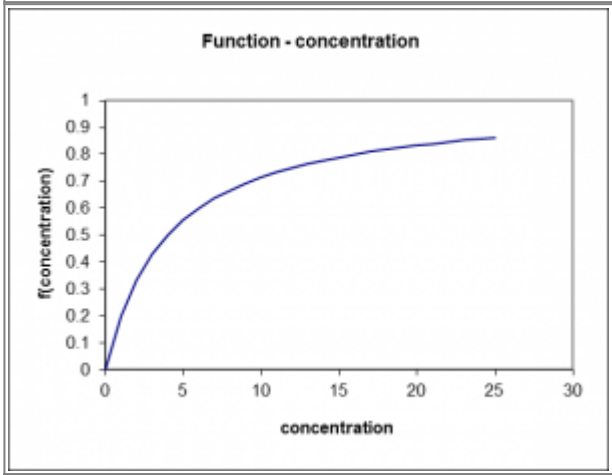


Figure 8: Concentration function in the denitrification process.

Immobile soil nutrient pool transformations

Turnover of fastN

Turnover of fastN is a sink for fastN and a source of IN in all three soil layers (k = 1..3). Turnover (*transfN*, *mg/m2/d*) depends on a general parameter (*minerfn*), temperature function (*tmpfcn*), humidity function (*smfcn*) and the pool of fastN (*fastN*).

$$transfN\left(k\right)=minerfn\times tmpfcn\left(k\right)\times smfcn\left(k\right)\times fastN\left(k\right)$$

Turnover of fastP

Turnover of fastP is a sink for fastP and a source of SP in all three soil layers (k = 1..3). Turnover (*transfP*, *mg/m2/d*) depends on a general parameter (*minerfp*), temperature function (*tmpfcn*), humidity function (*smfcn*) and the pool of fastP (*fastP*).

$$transfP\left(k\right)=minerfp\times tmpfcn\left(k\right)\times smfcn\left(k\right)\times fastP\left(k\right)$$

Turnover of humusN

Turnover of humusN is a sink for humusN and a source of fastN in all three soil layers (*k* = 1..3). It is supposed to be a very slow process. Turnover (*degradhN, mg/m2/d*) depends on a general parameter (*degradhn*), temperature function (*tmpfcn*), humidity function (*smfcn*) and the pool of humusN (*humusN*).

$$degradhN\left(k\right)=degradhn\times tmpfcn\left(k\right)\times smfcn\left(k\right)\times humusN\left(k\right)$$

Turnover of humusP

Turnover of humusP is a sink for humusP and a source of fastP all three soil layers (*k* = 1..3). It is supposed to be a very slow process. Turnover (*degradhP*, *mg/m2/d*) depends on a general parameter (*degradhp*), temperature function (*tmpfcn*), humidity function (*smfcn*) and the pool of humusP (*humusP*).

$$degradhP\left(k\right)=degradhp\times tmpfcn\left(k\right)\times smfcn\left(k\right)\times humusP\left(k\right)$$

Dissolution of soil organic pools

All organic soil pools of nutrient (humusN, fastN, humusP and fastP) contribute to dissolved organic nutrients in soil water (i.e. ON and PP). This process is a sink of the soil pools and a source of ON and PP in all three soil layers (*k* = 1..3). Dissolution (*mg/m2/d*) depends on a model parameter (one for each soil pool, *dispar*), temperature function (*tmpfcn*), humidity function (*smfcn*) and the size of the soil pool (*soilpool*).

$$dissolution\left(k\right)=dispar\times tmpfcn\left(k\right)\times smfcn\left(k\right)\times soilpool\left(k\right)$$

The dissolution model parameters (*dispar*) is land use dependent and named *dissolfp*, *dissolfn*, *dissolhp*, and *dissolhn* for dissolution of nutrient pools fastN, fastP, humusN and humusP respectively.

Percolation

ON and PP concentration are reduced as the water percolates down through the soil layers. The decrease in concentration depends on land use dependent model parameters (*par*).

$$conc=conc\times\left(1.-par\right)$$

Balance SP – PartP

SP is in a dynamic equilibrium with P adsorbed to soil particles (partP). The equilibrium is described by the Freundlich equation. From the total amount of P (SP + partP) in the soil an equilibrium concentration of SP is calculated in the soil solution using the iterative Newton-Raphson method.

```
coeff = Kfr * bulkdensity * soilthick
DO WHILE
  fxn = xn * vol + coeff * (xn ** Nfr) - totalP
  fprimxn = vol + Nfr * coeff * ( xn **(Nfr-1))
  xn_1 = xn - fxn / fprimxn
  xn = xn_1
ENDDO
```

The coefficients *Kfr*, and *Nfr* are soil dependent, bulkdensity is the dry density of soil (= 1300 kg/m3) and soilthick is the soil layer thickness. *fxn* is function value for the concentration *xn*, *fprimx* is the function value of the derivative of *fxn*, and xn_1 is the concentration of the next iteration. The resulting SP equilibrium concentration ($xn = xn_1$) is used to calculate the PP eqiuilibrium concentration ($PPequi_{conc}$). A new SP concentration (SP_{conc}) is calculated from the previous concentration ($SP_{conc\ old}$) and the equilibrium concentration, taking into account the balance is not reached during the time step.

$$PPequi_{conc} = Kfr \times \left(xn_1^{Nfr} \right)$$

$$Adsdes = \left(PPequi_{conc} - concsolid \right) \times \left(1 - e^{-Kadsdes} \right)$$

$$SP_{conc} = SP_{conc\ old} - \frac{\left(Adsdes \times bulkdensity \times soilthick \right)}{vol}$$

Adsdes is the amount of adsorbed/desorbed P, *Kadsdes* is a soil dependent rate constant, *equi_concsolid* is the solid phase equilibrium concentration, and *concsolid* is the initial concentration the solid phase.

Crop rotation effect on soil pools

The soil pools of nutrients are shared by crops on rotation on a field. This is modelled by averaging the soil pools once per year for the classes which are in the same crop rotation group.

Links to file reference

Section	Symbol	Parameter/Data	File
Soil pools - initial values	*nut0*	*humusn0, humusp0, partp0, fastn0, fastp0*	par.txt
	NNhalf	*hnhalf,hphalf, pphalf*	
		onconc0, ppconc0	
	soilthick	calculated from *soillayerdepth*	GeoClass.txt
Common functions	*wp, fc, ep*	calculated from *wcwp, wcwp1-3, wcfc, wcfc1-3, wcep, wcep1-3*	par.txt

Section	Symbol	Parameter/Data	File
Vegetation nutrient uptake		*cropid, cropid2*	GeoClass.txt
	uptsoil1	*upupper*	CropData.txt
	pnratio	*pnupr*	
Denitrification		*denitrlu, denitrlu3, hsatINs*	par.txt
Immobile soil nutrient pool transformations		*minerfn, minerfp, degradhn, degradhp*	par.txt
Dissolution of soil organic pools	*dispar*	*dissolfp, dissolfn, dissolhp, dissolhn*	par.txt
Percolation	*par*	*onpercred, pppercred*	par.txt
Balance SP - PartP	*Kfr*	*freuc*	par.txt
	Nfr	*freuexp*	
	Kadsdes	*freurate*	
Crop rotation effect on soil pools		*crop rotation*	GeoClass.txt

Links to relevant procedures in the code

Modules (file)	Procedures	Sections
npc_soil_processes (npc_soil_proc.f90)	soil_np_processes	
	initiate_soil_npc_state	soil pools - intial values
	plant_uptake	vegetation nutrient uptake
	soil_denitrification	denitrification
	soil_pool_transformations	immobile soil pool transformation
		dissolution
	onpp_percolation_reduction	percolation
	balance_spsoil	balance SP-partP
	freundlich	
	croprotation_soilpoolaverage	crop rotation
general_functions (general_func.f90)	tempfactor	common functions
	moisturefactor	
	halfsatconcfactor	denitrification
	exponential_moisturefactor	

Transport with soil water

IN, ON, SP and PP comes with water when it flows through the soil, but remain when water evaporates. Different flow paths contribute to the runoff of water and concentration of IN, ON, SP and PP from the corresponding soil layer. The flow paths possible today are: surface runoff (soil layer 1), runoff (soil layer 1, 2 and 3) and runoff through drainage pipe (soil layer 1, 2 or 3).

Diagnostic output variables of soil nutrients

Some additional output variables are calculated from the soil variables. Gross and net soil load is calculated for the “root zone”, e.g. soil layer one and two together, and for soil layer three separate. A third option for soil load is calculated not strictly based on the soil layers but as an approximation for “groundwater” based on third soil layer but manipulated with tile drainage.

Gross soil loads

Gross load to soil layer one and two (root zone). Components included: atmospheric deposition (wet and dry), fertilizers, crop residues, rural load if number of soil layers is less than three. HYPE variable IDs: sl01=IN, sl03=ON, sl05=sl01+sl03=TN, sl07=SP, sl09=PP, sl11=sl07+sl09=TP

Gross load to soil layer three (lower soil). Components included: percolation from soil layer two to three, rural load if number of soil layers is three. HYPE variable IDs: sl13=IN, sl15=ON, sl17=sl13+sl15=TN, sl19=SP, sl21=PP, sl23=sl19+sl21=TP

Gross load to “groundwater” (modified soil layer three). Components included: percolation from soil layer two to three, rural load if number of soil layers is three, tile drain runoff if tile is in soil layer one or two. HYPE variable IDs: sl25=IN, sl27=ON, sl29=sl25+sl27=TN, sl31=SP, sl33=PP, sl35=sl31+sl33=TP

Net soil loads

Net load from soil layer one and two (root zone). Components included: percolation from soil layer two to three, runoff from soil layer one and two, tile drain runoff if tile is in soil layer one or two, surface runoff. HYPE variable IDs: sl02=IN, sl04=ON, sl06=sl02+sl04=TN, sl08=SP, sl10=PP, sl12=sl08+sl10=TP

Net load from soil layer three (lower soil). Components included: runoff from soil layer three, tile drain runoff if tile is in soil layer three. HYPE variable IDs: sl14=IN, sl16=ON, sl18=sl14+sl16=TN, sl20=SP, sl22=PP, sl24=sl20+sl22=TP

Net load from “groundwater” (modified soil layer three). Components included: runoff from soil layer three, tile drain runoff if tile is in any soil layer. HYPE variable IDs: sl26=IN, sl28=ON, sl30=sl26+sl28=TN, sl32=SP, sl34=PP, sl36=sl32+sl34=TP

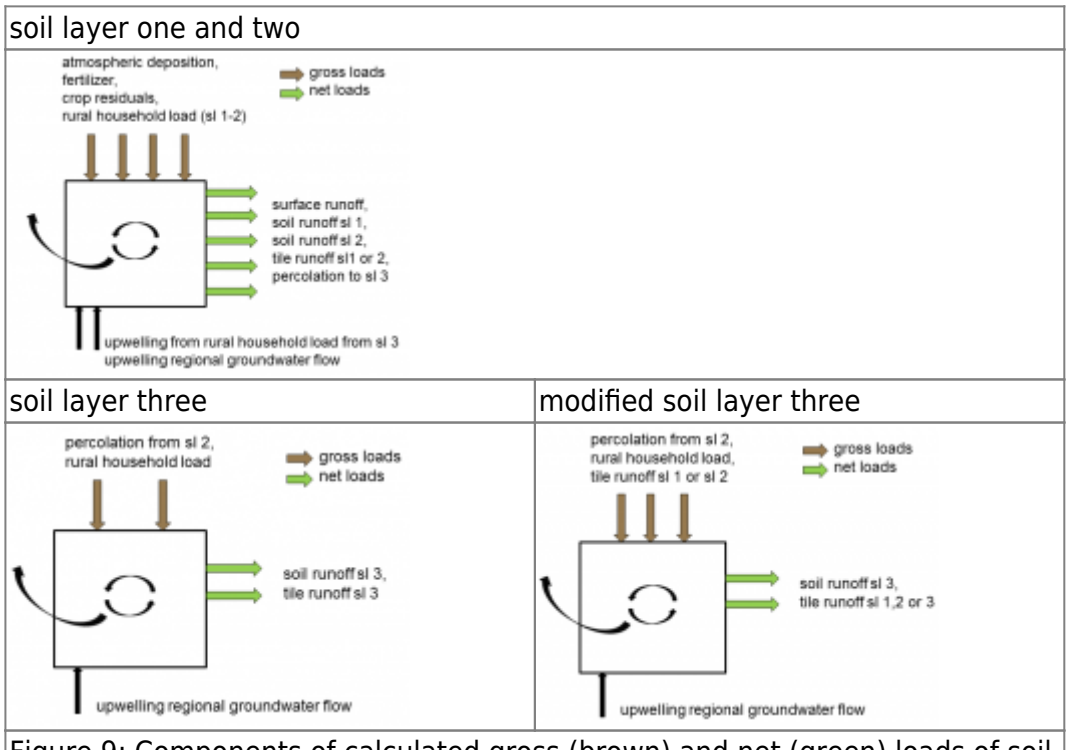


Figure 9: Components of calculated gross (brown) and net (green) loads of soil.

Links to relevant procedures in the code

Modules (file)	Procedures
modelmodule (model_hype.f90)	model
	define_output_variables

Nutrient soil leakage from outer source

There is a model option to skip calculating nutrients with HYPE and instead use nutrient soil leakage from an outer source. In this case the calculations above is skipped, while soil water and runoff processes is calculated as usual. HYPE output variables related to soil nutrients are set to missing values.

The first implemented soil leakage model was

1. montly seasonal variation of concentrations for each subbasin

The soil leakage is introduced into the model as inorganic and organic nitrogen, and soluble reactive phosphorus and particulate phosphorus concentrations of the total runoff. Different possibilities exist on how to introduce these regarding time variations (montly seasonal variation, daily), spatial variations (subbasin, regions) and land use dependence (class groups). So far the only implemented alternative is the monthly seasonal variation.

The nutrient concentration of total runoff (HYPE variable ID `crun`) is set, and then used for all further calculations in the streams and lakes.

The default is to use HYPE calculated runoff concentrations with the processes described above (`modeloption soilleakage 0`).

Links to file reference

Parameter/Data	File
ALL	LeakageData.txt

Links to relevant procedures in the code

Modules (file)	Procedures
modelmodule (model_hype.f90)	model
datamodule (data.f90)	load_soilleakage_concentrations
modvar (modvar.f90)	get_current_soil_leakage

References

Eckersten, H., P.-E. Jansson, and H. Johnsson 1994. SOILN model – user's manual 2nd edition, Division of Agricultural Hydrotechnics Communications 94:4, Department of Soil Sciences, Swedish University of AgriculturalSciences, 58pp, Uppsala.