Nitrogen and phosphorus processes in rivers and lakes

Transformations of nutrients take place in lakes and rivers. For lakes, which are divided into fast (FLP) and slow (SLP) lake parts, the process is performed only in SLP (Fig. 1). For rivers, which hold water in a queue and in the damping box, the processes is performed only in the damping box.

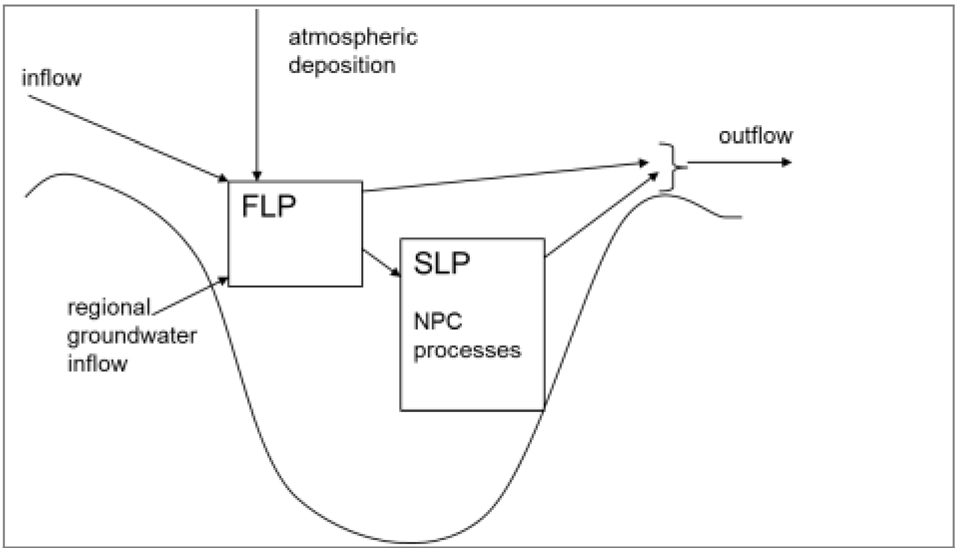

Figure 1: Nutrient flows in a lake that is affected by nutrient processes.

The processes of denitrification, primary production and mineralization have been implemented for both rivers and lakes. For particulate phosphorus (PP) there is an exchange with the river sediments. The rivers dimensions are used in the calculation of these processes. The width and depth of the watercourse are calculated from a number of empirical equations (for more information on these equations see “Modelling phosphorus transport and retention in river networks” by Jörgen Rosberg).

$$velocity = 10^{rivvel_1} \times meanflow^{rivvel_2} \times \left(\frac{flow}{meanflow}\right)^{rivvel_3}$$

$$width = 10^{rivwidth_1} \times \left(\frac{flow}{velocity}\right)^{rivwidth_2 + rivwidth_3 \times log_{10}\left(\frac{flow}{velocity}\right)}$$

$$depth = \frac{\left(\frac{flow}{velocity}\right)}{width}$$

where *rivvel1, rivvel2, rivvel3, rivwidth1, rivwidth2* and *rivwidth3* are lake region dependent parameters located in the file par.txt, *flow* is the flow of water in the watercourse (*m3/s*) and *meanflow* is a 365-day rolling average flow. The river’s width is limited by the dead volume width and a parameter *maxwidth*. The rivers length is estimated at square root of catchment area or is given in GeoData.txt for the main river. The watercourses **surface area** is calculated as the length times the width, where the maximum of the above-calculated width and dead volume width is used.

The water temperature (*watertemp*) is used in some of the process calculations. It is calculated through weighting the air temperature (*airtemp*) and yesterday's water temperature. The weighting constant (similar to moving average period) *watertemp_days* is set to 20 days for rivers and is by default 5 days for lakes. For lakes a depth dependent *watertemp_days* can also be used. Then the weighting constant is set to the equivialent days of the lake's depths up to maximum the general parameter *laketemp* plus 5 days. Note that the water temperature can fall below $0^\circ C$.

```
IF(laketemp>0) watertemp_days = MIN(MAX(lake_depth,5),5+laketemp)
weightair = 1 / watertemp_days
watertemp = (1-weightair) * watertemp + weightair * airtemp
```

Alternatively the water temperature calculated as a tracer (called T2) may be used. This model option is set in info.txt.

Links to relevant procedures in the code

Modules (file)	Procedures
npc_surfacewater_processes (npc_sw_proc.f90)	np_processes_in_river
	np_processes_in_lake
	river_characteristics
surfacewater_processes (sw_proc.f90)	calculate_water_temperature
	set_water_temperature

Denitrification

Denitrification, a sink for inorganic nitrogen in lakes and rivers, is a function of the bottom area, the IN concentration (*concfcn*) in water volume, water temperature (*tmpfcn*) and the general parameters *denitwrl* (local river), *denitwrm* (main river) and *denitwl* (lakes). In the concentration function, the half saturation parameter (*hsatINw*) is a general parameter, but it was in earlier HYPE versions a constant equal to 1.5 mg/L. Denitrification (*denitri_water*, *kg/day*) is limited to a maximum of 50% (*maxdenitriwater*) of the available IN pool (i.e. in SLP).

```
tmpfcn = 2**((watertemp - 20) / 10)
IF(watertemp < 5.) tmpfcn = tmpfcn * (watertemp / 5)
IF(watertemp < 0.) tmpfcn = 0.
concfcn = conc / (conc + hsatINw)
denitri_water = MIN(maxdenitriwater * INpool, denitw * area * concfcn *
tmpfcn)
```

The bottom area (*area*) is equal to the lake area, for lakes, and watercourse width multiplied by the length, for rivers.

Links to relevant procedures in the code

Modules (file)	Procedures
npc_surfacewater_processes (npc_sw_proc.f90)	np_processes_in_river
	np_processes_in_lake
	denitrification_water

Primary production and mineralization

Primary production in lakes and rivers is a source of organic nitrogen and particulate phosphorus and a sink for inorganic nitrogen and soluble reactive phosphorus in the model. The reverse is true for mineralization. Primary production and mineralization is controlled by two temperature functions. The first (*tmpfcn1*) is solely dependent on the water temperature. It simulates the increased activity at warmer temperatures. The second (*tmpfcn2*) governs the relationship between primary production and mineralization and determines which one dominates. Net primary production is highest in spring (northern hemisphere) and changes into net mineralization when the temperature *T10* is less than the temperature *T20* in autumn. These two temperatures are calculated as the average water temperature of 10 and 20 days.

$$tmpfcn1 = \frac{watertemp}{20.}$$

$$tmpfcn2 = \frac{\left(T10 - T20\right)}{5.}$$

$$tmpfcn = tmpfcn1 \times tmpfcn2$$

The primary production and mineralization processes are also governed by long-term average concentrations of modelled total phosphorus in the lake (*TPconc*) or watercourse through a concentration function (*TPfcn*) with the general half saturation parameter *hsatTP*. The half saturation parameter was in earlier HYPE versions a constant equal to 0.05 mg/L. If phosphorus is not modelled a long-term average total phosphorus concentration as a lake region dependent parameter (*tpmean*) is used. If set, the long-term average concentration is reduced by the general parameter *limsedPP* before using it in the concentration function.

$$TPfcn = \frac{\left(TPconc - limsedPP\right)}{\left(TPconc - limsedPP + hsatTP\right)}$$

For lakes, the process is acting only in lake part SLP, while the processes are active throughout the watercourse volume. The estimated production/mineralization (*minprodNpot*, kg / day) is potential and may be limited by the availability of nutrients by only 50% of the available IN the pool (at the primary production) and ON-pool (for mineralization) can be transformed. The potential phosphorus conversion (*minprodPpot*) is calculated in the same way, but with its own parameter (*wprodp*) and a factor for phosphorus/nitrogen ratio (*NPratio* = 1/7.2). Additionally, there is a restriction against SP and PP pools instead. The parameters *wprodn* and *wprodp* is generic or can be specified for each lake. The area is equal to lake area for lakes and river width multiplied by the length of the watercourse.

$$minprodNpot = wprodn \times TPfcn \times tmpfcn \times area$$

$$minprodPpot = wprodp \times TPfcn \times tmpfcn \times area \times NPratio$$

For simulations of total suspended sediments, algae is simulated as a component. Nitrogen in algae is assumed to grow and decline with the same function as production and mineralisation of organic nitrogen. If nitrogen is simulated it uses the actual estimated production/mineralisation, but otherwise the potential production/mineralisation (*minprodNpot*) is used. The mineralisation of algae is limited to available amount, but the production is unlimited.

Links to relevant procedures in the code

Modules (file)	Procedures
npc_surfacewater_processes (npc_sw_proc.f90)	np_processes_in_river
	np_processes_in_lake
	production_mineralisation
	calculate_lake_tpmean
	calculate_river_tpmean

Sedimentation/Resuspension

Sedimentation in lakes is a sink for particulate phosphorus (PP) and organic nitrogen (ON), as well as suspended sediments (SS) and algae (AE). Sedimentation (*sedON, sedPP, sedSS*, *sedAE*, *m/day*) is calculated as a function of water concentration and lake area (*area*). The parameters *sedon*, *sedpp*, *sedss*, and *sedae* are generic, but ON and PP sedimentation can be specified for each lake. The water concentration may be limited by the general parameters *limsedON*, *limsedPP*, and *limsedSS*.

$$sedON = sedon \times \left(waterconcON - limsedON \right) \times area$$

$$sedPP = sedpp \times \left(waterconcPP - limsedPP \right) \times area$$

$$sedSS = sedss \times \left(waterconcSS - limsedSS \right) \times area$$

$$sedAE = sedae \times waterconcAE \times area$$

No particles (PP and SS) disappears in river but only redistributed over time through sedimentation (*sedPP, sedSS*, *m/day*) and resuspension (*resuspPP, resuspSS*, *m/day*). Particles in the sediments is simulated as a pool (*PPsedimentpool, SSsedimentpool*) which may be given particles from the water volume (*PPpool, SSpool*) at low water flows. The higher the water flow the less sedimentation while more particles returns to the water (*resuspPP, resuspSS*). This combined process is governed by the general parameter *sedexp*. The net effect is determined by the sign of the flow (-1 <*sedresp* <1).

$$sedresp = \max\left(-1., \min\left(1., \frac{qbank - flow}{qbank}^{sedexp} - \frac{flow}{qbank}^{sedexp} \right) \right)$$

$$sedPP = \begin{cases} sedresp \times PPpool & sedresp > 0 \\ 0 & sedresp < 0 \end{cases}$$

$$resuspPP = \begin{cases} -sedresp \times PPsedimentpool & sedresp < 0 \\ 0 & sedresp > 0 \end{cases}$$

$$sedSS = \begin{cases} sedresp \times SSpool & sedresp > 0 \\ 0 & sedresp < 0 \end{cases}$$

$$resuspSS = \begin{cases} -sedresp \times SSsedimentpool & sedresp < 0 \\ 0 & sedresp > 0 \end{cases}$$

where *flow* is the current river flow (*m3/s*) and *qbank* is the flow when river is filled to the brim. This flow is calculated as the second largest simulated flow in the last year. It is adjusted with a correction factor of 0.7 before use in the *sedresp* equation.

Links to relevant procedures in the code

Modules (file)	Procedures
npc_surfacewater_processes (npc_sw_proc.f90)	np_processes_in_river
	np_processes_in_lake
	lake_sedimentation
	sedimentation_resuspension

Internal load

Lakes can leak phosphorus from the bottom e.g. the release of phosphorus during oxygen deficiency or the mixing of the previously sedimented emissions. With two parameters the release of PP or SP is obtained for a specific lake. The parameters, *prodPP* and *prodSP* (*m/d*), is specified in LakeData.txt. The load (*loadPP, loadSP, kg/day*) is calculated as a function of lake water temperature (*T20*), average concentration of phosphorus in the lake (*TPconc*) and lake area (*area*). *TPconc* is currently hardcoded to 0.1 mg/l as an estimated avarage value.

$$loadPP = \frac{prodPP \times TPconc \times tmpfcn \times area}{1000.}$$

$$loadSP = \frac{prodSP \times TPconc \times tmpfcn \times area}{1000.}$$

$$tmpfcn = 0.86^{|T20 - 15|}$$

$$TPconc = 0.1$$

Links to relevant procedures in the code

Modules (file)	Procedures
npc_surfacewater_processes (np_sw_proc.f90)	np_processes_in_lake
	internal_lake_load