Nitrogen and phosphorus processes in rivers and lakes

HYPE simulates concentration of inorganic nitrogen (IN), organic nitrogen (ON), soluble reactive phosphorus (SP) and particulate phosphorus (PP) in discharge and other surface waters. As output also the total nitrogen (TN) and phosphorus (TP) concentration can be had. In addition total suspended sediments (TS) can be simulated. It consists of the sum of suspended sediments (SS) and algae (AE) simulated concentrations.

Basic assumptions

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 delayed water in a queue and in the damping box, the processes is performed only in the damping box.

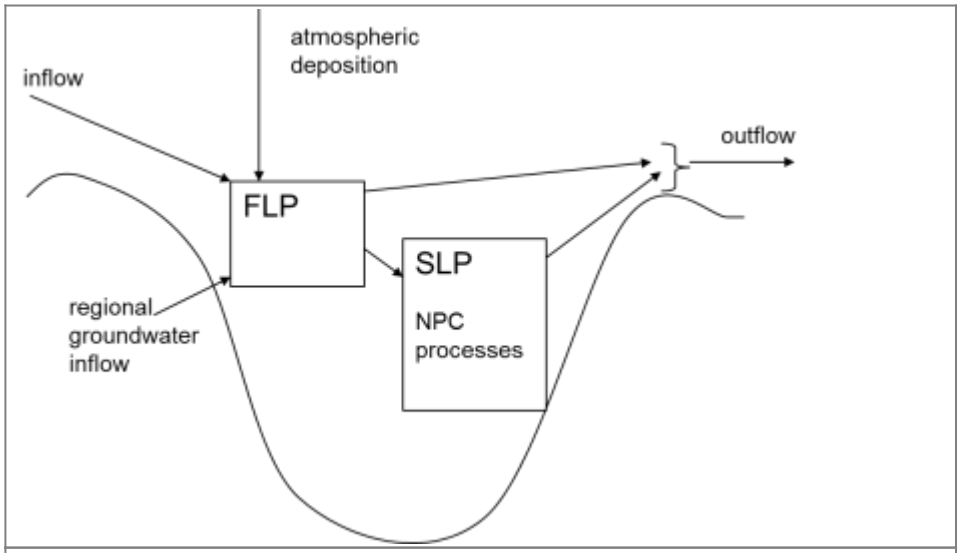


Figure 1: Nutrient flows in a lake that is affected by nutrient processes.

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).

$$velocity = 10^{vel_1} \times meanflow^{vel_2} \times \left(\frac{flow}{meanflow} \right)^{vel_3}$$

$$width = 10^{width_1} \times \left(\frac{flow}{velocity} \right)^{width_2 + width_3 \times log_{10} \left(\frac{flow}{velocity} \right)}$$

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

where *vel1-vel3* and *width1-width3* are lake region dependent parameters, *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 as input. The watercourses **bottom area** is calculated as the length times the width, where the maximum of the above-calculated width and dead volume width is used. The bottom area is used for the nutrient processes. If the river is a class and thus has a defined class area, the class area is used to estimate the bottom area instead.

The water temperature (T_w) is used in some of the process calculations. It is calculated through weighting the air temperature (T) and yesterday's water temperature. The weighting constant (similar to moving average period) T_{wdays} is set to 20 days for rivers and is by default 5 days for lakes. For lakes a depth dependent T_{wdays} can also be used. Then the weighting constant is set to the equivialent days of the lake's depths up to a maximum (*maxpar*, a parameter) plus 5 days. Note that the water temperature can fall below $0^{\circ}C$.

$$T_w = \left(1 - \frac{1}{T_{wdays}} \right) \times T_w + \frac{1}{T_{wdays}} \times T$$

$$T_{wdays} = \begin{cases} MIN\left(MAX\left(lake_{depth}, 5 \right), 5 + maxpar \right) & lake \\ 20 & river \end{cases}$$

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

Links to file reference

Symbol	Parameter/Data	File
	rivlen, loc_rivlen	GeoData.txt
vel1, vel2, vel3	*rivvel1, rivvel2, rivvel3*	par.txt
width1, width2, width3	*rivwidth1, rivwidth2, rivwidth3*	
	deadl, deadm, maxwidth	
maxpar	*laketemp*	
$lake_{depth}$	*lake_depth*	GeoData.txt or LakeData.txt or DamData.txt
	gldepo, olldepth, gldepi, illdepth	par.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 (*conc*) in water volume, water temperature (T_w) and a rate parameter. The dependence on concentration is formulated as a half saturation equation. In the concentration function, the half saturation parameter (par_{half}) is a general parameter, but it was in earlier HYPE versions a constant equal to 1.5 mg/L. Denitrification (*denitr*, *kg/day*) is limited to a maximum of 50% of the available IN pool (i.e. in SLP).

$$tmpfcn = \begin{cases} 0 & T_w < 0 \\ \frac{T_w}{5} \times 2^{\frac{T_w - 20}{10}} & 0 < T_w < 5 \\ 2^{\frac{T_w - 20}{10}} & else \end{cases}$$

$$concfcn = \frac{conc}{conc + par_{half}}$$

$$denitr = MIN\left(0.5 \times INpool, par_{den} \times area \times concfcn \times tmpfcn\right)$$

The bottom area (*area*) is equal to the lake area for lakes, and watercourse width multiplied by the length for rivers (see above). The rate parameter (par_{den}) depend on the water body. Local and main rivers have general parameters (*denitwrl, denitwrm*), while lakes in addition to use a general parameter (*denitwl*) can have lake specific values.

Links to file reference

Symbol	Parameter/Data	File
par_{half}	*hsatINw*	par.txt
par_{den}	*denitwrl, denitwrm*	
	denitwl	par.txt or LakeData.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
	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. The processes is modelled together and only one is active at the time. Primary production and mineralization are controlled by two temperature functions. The first (*tmpfcn1*) is solely dependent on the water temperature (T_w). 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.

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

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

$$tmpfcn = tmpfcn1 \times tmpfcn2$$

The primary production and mineralization processes are also governed by long-term average concentrations of modelled total phosphorus (*TP*) in the lake 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. A limiting concentration (*lim*) can be set, and then the long-term average concentration is reduced before using it in the concentration function.

$$TPfcn = \frac{TP - lim}{\left(TP - lim\right) + hsatTP}$$

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 the potential transformation, and may be limited by the availability of nutrients. Only 50% of the available IN the pool (at the primary production) or 50% of the 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). Similarly, there is a restriction against transforming maximum 50% of the SP and PP pools. The parameters *wprodn* and *wprodp* is generic or can be specified for each lake. The area is equal to lake area for lakes and bottom area for rivers (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 of the suspendend material. 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 then unlimited.

Links to file reference

Symbol	Parameter/Data	File
	hsatTP, tpmean	par.txt
lim	*limsedPP*	
	wprodn, wprodp	par.txt or LakeData.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
	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 for suspended sediments (SS) and algae (AE). Sedimentation (*sed*, *m/day*) is calculated as a function of concentration (*conc*) in the lake and lake area (*area*). The sedimentation rate (par_{sed}) is given by parameters (*sedon*, *sedpp*, *sedss*, *sedae*) which are generic, but ON and PP sedimentation can be specified for each lake. The concentration used in the equation may be limited (*lim*) by general parameters (*limsedON*, *limsedPP*, *limsedSS*), but not for AE (*lim*=0).

$$sed = par_{sed} \times \left(conc - lim \right) \times area$$

In the river no particles are removed, but they are redistributed over time. This process is used for particulate phosphorus (PP) and suspended sediments (SS). The process is a combination of sedimentation (*sed*, *m/day*) and resuspension (*resusp*, *m/day*). Particles in the sediments is collected in a pool (*sedimentpool*) which will increase as particles from the water volume (*waterpool*) settle at low water flows. The higher the water flow the lower the sedimentation and more particles returns to the water. This combined process is governed by the general parameter *sedexp*. The net effect is determined by the sign of the variable (-1 <*sedresp* <1).

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

$$sed = \begin{cases} sedresp \times waterpool & sedresp > 0 \\ 0 & sedresp < 0 \end{cases}$$

$$resusp = \begin{cases} -sedresp \times sedimentpool & sedresp < 0 \\ 0 & sedresp > 0 \end{cases}$$

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 file reference

Symbol	Parameter/Data	File
area	*slc_nn, area*	GeoData.txt
par_{sed}	*sedpp, sedon*	par.txt or LakeData.txt
	sedss, sedae	par.txt
lim	*limsedON, limsedPP, limsedSS*	
	sedexp	

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. release of phosphorus during oxygen deficiency or the mixing of the previously sedimented emissions. Internal load can be simulated for SP or PP or both fractions of phosphorus. With two parameters the release of PP or SP is obtained for a specific lake (par_{prod}, *m/d*). The load to the lake (*load, kg/day*) is calculated as a function of lake water temperature (T_w), average concentration of phosphorus in the lake (*TPfcn*) and lake area (*area*). *TPfcn* is currently not depending on simulated concentration as it is set to constant 0.1 mg/L.

$$load = \frac{par_{prod} \times TPfcn \times tmpfcn \times area}{1000}$$

$$tmpfcn = 0.86^{\left|T_w - 15\right|}$$

$$TPfcn = 0.1$$

Links to file reference

Symbol	Parameter/Data	File
par_{prod}	*prodPP, prodSP*	par.txt

Links to relevant procedures in the code

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