Sediment

Introduction

Sediments are simulated as suspended sediments (SS) and nitrogen in algae (AE). The sum of the two **substances** is an additional output (total suspended sediments, TS). Suspended sediments are not simulated in the soil of HYPE. Suspended sediments are first introduced into the runoff of the soil by soil erosion.

The main **states** are concentration of SS and AE in all water stores of HYPE, i.e. soil, river, lakes, but also snow, aquifers (in the store and on the move there or away), irrigation water, floodplain water, and water transfer (that is delayed one time step) could hold suspended sediments and algae. In the current model though, concentration of SS and AE is only positive in river and lakes, and flows originating from them. In addition two pools of settled sediment are simulated; a pool of delayed sediment in runoff, and a pool of (temporarily) settled sediment in river. Note: No store of “settled sediment” of the soil is simulated, i.e. HYPE has an unlimited source of soil for erosion.

Figure 1: Schematic figure of sediment model.

Sources of sediment load

Soil erosion

The main source of sediment in HYPE is from soil erosion. Soil erosion is modelled in several steps. **First** particles are mobilized from the soil by rain or surface runoff. The result is here called “mobilized sediments”. The mobilized sediments are assumed suspended in an “eroding flow”, which is surface runoff plus macropore flow. **Secondly**, if there is surface runoff, the mobilized sediments is transported away from the field with the surface runoff and macropore flow (“eroded sediment”). A filtering can be applied to reduce the amount of eroded sediment. If there is no surface runoff, there will be no transport of eroded sediments. For SS, the eroded sediments are taken from an infinite pool. For PP, the eroded particulate phosphorus is taken from the soil pools. **Thirdly**, the eroded sediments in macropore flow and surface runoff (and tile runoff though that is generally zero) are delayed in a temporary pool. The release of suspended sediments from this pool is determined by the total runoff from the class, and is following the total runoff off the land.

Step 1: Mobilization of particles from soil

HYPE has two alternative models for mobilization; soil erosion model 1 and soil erosion model 2.

Soil erosion model 1 (MMF-based model): The first model is based on Morgan-Morgan-Finney erosion model (Morgan et al., 1984) and calculates particles mobilized by rainfall energy and surface runoff. The kinetic energy in rainfall is calculated as a function of rainfall (*rain*, mm/ts) 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 raindrop's energy can be absorbed by vegetation. Crop cover is defined as the portion of land that is sheltered from raindrops; for a description of how this is calculated, see Chapter Crop cover and ground cover. The factor

$common_{cropcover}$ is the sheltering effect that the main and secondary crops give together. It varies over the year due to crop growth and management. The mobilization by rain (*MobilisedRain*, g/m2/ts) is also influenced by soil erodibility (soil dependent parameter *soilerod* (g/J)).

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

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

When surface runoff occurs, soil particles are eroded and carried away as the soil surface is exposed to shear forces. The mobilization (*MobilisedSR*, g/m2/day) is calculated from the surface runoff (*sflow*, mm/day), subbasin average 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 reducing factor (*groundcover*) is described in Chapter Crop cover and ground cover. The factor $common_{groundcover}$ is the combined effect of the main and secondary crops.

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

All mobilized particles are not staying mobilized, because sometimes the transport capacity of the particle-bearing water (*eflow*) will not suffice for the task. If this is the case, a *transportfactor* reduces the particle amount mobilized:

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

Finally mobilized sediment (*mobilSed*, kg/km2/day) is calculated as the sum of rain and surface runoff caused mobilization as:

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

Soil erosion model 2 (HBV-SED based model): The second model is based on HBV-SED model (Lidén, 1999; Lidén et al., 2001) and calculates particles mobilized by rain (*rain*). It also depends on soil and land characteristics in the form of model parameters and data on subbasin characteristics.

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

The parameters *erodslope*, *erodexp* and *erodindex* are general and thus same for the whole model domain. The parameters *erodluse* and *erodsoil* are land-use and soil type dependent. Subbasin input are: *slope*, the subbasins' average slope, and an erosion index, *EI*. The many parameters give the possibility to simulate erosion as dependent on slope, soil type, land use or subbasin.

Step 2: Transport of eroded sediments off the field

If at one time step there is no surface runoff, there will be no transport of suspended sediment. Still, calculation continues with step 3, and earlier delayed eroded sediment may reach the local stream. If there is surface runoff, a fraction of the mobilised sediments is assumed to go with surface runoff (*sflow*). If there is surface runoff and tile runoff and macropore flow, a fraction of the mobilized sediments is assumed to travel with the macropore flow (*mflow*). The respective fractions depend on the respective size of the two flows, but are reduced by filtering of the particles. The filtering depends on landuse, the proximity of agricultural land to water, presence of buffer strips etc. The filtering effect on suspended sediments in surface runoff (*srfilt*) is parameterized with land use parameters and subbasin input, while the filtering effect on suspended sediments of macropore flow is parameterized with a soil type parameter (*macrofilt*).

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

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

$$eflow = sflow + mflow$$

The total amount of eroded sediment (*erodedSed*, kg/km2/day) is the sum of contributions from surface flow and macropore flow. For SS, the eroded sediments are taken from an infinite pool. For PP, the eroded particulate phosphorus is calculated from the eroded sediment (see Soil erosion) and then taken from the solid soil pools (*humusP* and *partP*). This difference exists because HYPE does not simulate any pool of “soil sediments”.

Step 3: Suspended sediment reaching the local stream

The concentration of suspended sediments of the runoff leaving the soil is calculated based on total runoff (*runoff*, mm/ts) and a pool of sediment particles (*relpool*). The pool collects the suspended sediments in the respective runoff pathways, i.e. primarily the eroded sediment from surface runoff and macropore flow calculated in the previous step. The pool constitutes a temporary delay. The release of sediment (*release* (kg/km2)) from the pool temporary is calculated with two general parameters (*pprelmax* and *pprelexp*):

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

The suspended sediments released are following the total runoff off the land. The release divided by the total runoff gives a suspended sediment concentration, which is used for all runoff pathways. This concentration is set to all runoff from the class, i.e. the sediments are transported by all flow paths off the land.

Rural household outlets and point sources

Suspended sediments may be added to the model as diffuse rural households outlets (private sewers) or point sources. Similar to other substances in HYPE, they are added as flow with concentration of the total suspended sediments and with a fraction determining the suspended part, while nitrogen in algae make up the rest (GeoData.txt PointSourceData.txt). To add only suspended sediments set the fraction to 1. The diffuse source is divided into two parts, where the division is determined by a general parameter (*locsoil*). One part is added directly to the local river. The other part is added to the water of the bottom soil layers of each class in the subbasin. The distribution between classes is done proportional to the area of each class. Point sources are added in the main river. Point sources are described in the Chapter on Water management (point sources) and rural household diffuse source in the Chapter on Nitrogen and phosphorus in land routines (rural sources).

Links to file reference

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*	
Rural household outlets and point sources		*subid, ps_vol, ps_type, ps_tsconc, ps_ssfrac, fromdate, todate*	PointSourceData.txt
		loc_ts, loc_vol, loc_ss	GeoData.txt
		locsoil	par.txt

Link to relevant processes in the code

Modules (file)	Procedures	Sections
npc_soil_processes (npc_soil_proc.f90)	particle_processes_for_runoff	Soil erosion
	calculate_hbvsed_erosion	
	calculate_erosion	
datamodule (data.f90)	load_pointsourcedata	Rural household outlets and point sources
	read_pointsourcedata	
	get_current_pointsources	
npc_surfacewater_processes (npc_sw_proc.f90)	add_point_sources_to_main_river	
	add_diffuse_source_to_local_river	
npc_soil_processes (npc_soil_proc.f90)	local_diffuse_source	

Soils

Suspended sediments are not simulated in the soil calculations of HYPE. Suspended sediments are first introduced into the runoff of the soil.

Sediment in rivers and lakes

Primary production and mineralization

Primary production in lakes and rivers is affecting sediment simulation by being a source of algae organic nitrogen (AE). Mineralisation, as a sink of AE, is the reverse process. Nitrogen in algae is assumed to grow and decline with the same function as production and mineralisation of organic nitrogen (ON). The production and mineralisation processes are modelled together and only one is active at the time. If nitrogen is simulated by HYPE it uses the actual estimated production/mineralization for AE, otherwise the potential production/mineralisation (*minprodNpot*) is used for AE. The actual production is limited by the availability of inorganic nutrients. If sediments are simulated without simultaneously simulating nitrogen, the mineralisation of algae is limited to available amount, but the production is unlimited.

The potential production/mineralisation is depending on temperature (T_w, *T10*, *T20*), long-term total phosphorus concentration (*TP*), surface area of water body (*area*) and a parameter (*wprodn*).

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

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

$$tmpfcn = tmpfcn1 \times tmpfcn2$$

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

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

Temperatures T10 and T20 are calculated as the average water temperature (T_w) of 10 and 20 days. They determine if production or mineralization dominates at the current time. The water temperature is calculated through weighting the air temperature (T) and yesterday's water temperature (see basic assumptions of rivers and lakes).

The phosphorus function (*TPfcn*) is dependent on a general half saturation parameter *hsatTP*, and a limitation parameter *limsedPP*. If phosphorus is simulated by HYPE the long-term average concentration (*TP*) is calculated from that, otherwise a lakeregion parameter is used (*tpmean*).

Sedimentation

Sedimentation in lakes is a sink for SS and AE and works the same way as for nutrients. Sedimentation (*sed*, kg/day) is calculated as a function of concentration in lake water (*conc*) and lake area (*area*). The settling velocity parameter (*sedss, sedae*) is general. The concentration used in the equation may be limited (*lim*) by general parameter (*limsedSS*) for SS, but not for AE (*lim*=0).

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

Links to file reference

<table>
<tr><td rowspan="6">Rivers and lakes</td><td>area, lakeregion</td><td></td><td>GeoData.txt</td></tr>
<tr><td></td><td>wprodn</td><td rowspan="2">par.txt or LakeData.txt</td></tr>
<tr><td>par_{sed}</td><td>sedss, sedae</td></tr>
<tr><td></td><td>hsatTP, limsedPP, limsedSS</td><td rowspan="3">par.txt</td></tr>
<tr><td>lim</td><td>limsedSS</td></tr>
<tr><td></td><td>tpmean</td></tr>
</table>

Link to relevant processes in the code

<table>
<tr><th>Modules (file)</th><th>Procedures</th><th>Sections</th></tr>
<tr><td rowspan="7">npc_surfacewater_processes (npc_sw_proc.f90)</td><td>np_processes_in_river</td><td rowspan="2">Primary production and mineralization and Sedimentation</td></tr>
<tr><td>np_processes_in_lake</td></tr>
<tr><td>production_mineralisation</td><td rowspan="3">Primary production and mineralization</td></tr>
<tr><td>calculate_lake_tpmean</td></tr>
<tr><td>calculate_river_tpmean</td></tr>
<tr><td>lake_sedimentation</td><td rowspan="2">Sedimentation</td></tr>
<tr><td>sedimentation_resuspension</td></tr>
</table>

References

Lidén, R., 1999. A new approach for estimating suspended sediment yield, HESS, 3(2):285-294.

Lidén, R., J. Harlin, M. Karlsson, and M. Rahmberg, 2001. Hydrological modelling of fine sediments in the Odzi River, Zimbabwe, Water SA, 27(3): 301-314.

R. P. C. Morgan, D. D. V. Morgan, and H. J. Finney, 1984. A predictive model for the assessment of soil erosion risk, Journal of Agricultural Engineering Research, vol. 30, pp. 245–253.