6.3. Annex 3: Method 3 - Nutrient transport and transformation (retention), the Swedish approach

The HBV-NP simulates nitrogen (N) and phosphorus (P) transport and transformation at the catchment scale (from 1 km^2 to more than 1 000 000 km^2). The objectives are usually to estimate water flow, concentration and retention. The model may also be used for estimation of nutrient transport, source apportionment, separation of human impact from anthropogenic, and to evaluate climate and management scenarios. It is based on the hydrological HBV model, which gradually has been equipped with a N submodel (Bergström et al. 1987, Brandt 1990, Arheimer and Wittgren 1994, Arheimer and Brandt, 1998). The P routine has recently been developed within the Swedish Water Management Research Programme (Andersson et al., 2002).

HBV-NP is a dynamic mass-balance model, which is run at a daily time-step, including all sources in the catchment coupled to the water balance:

$$\frac{d(cV)}{dt} = \sum \{c_{in}V_{in}\} + S - \Phi - cV_{out}$$

where:

volume of *c*	= concentration of nutrient fraction
V	= water groundwater, river or active part of lake
in	= inflow (for groundwater: soil leakage from various land uses through micropores and macropores separately for P; for river: generated runoff, surface flow; for lakes/wetlands: upstream rivers and local discharge, precipitation on the surface)
out	= outflow to river, lake or downstream subbasin, evaporation
S	= atmospheric deposition on water surfaces, emissions from point sources or rural households
Φ	= retention (removal or release), equations in Table 1.

The fractions modelled are dissolved inorganic nitrogen (IN), dissolved organic nitrogen (ON), particulate phosphorus (PP), and soluble reactive phosphorus (SRP).

The river basin is divided into several coupled subbasins, for which the calculations are made. This subbasin division gives the spatial distribution of the model results. The HBV-N has been applied in large-scale studies, including southern Sweden (145 000 km^2 divided into 3700 catchments; Arheimer and Brandt, 1998), the country of Sweden (450 000 km^2 divided into 1000 subbasins; www.nrc-trk/slu.se, used for PLC4), and the Baltic Sea drainage basin (~1 720 000 km^2 divided into 30 subbasins; Pettersson et al., 2000). The model has also been used for more detailed studies in smaller catchment, e.g. for the Genevadsån River (200 km^2 divided into 70 subbasins; Arheimer and Wittgren, 2002; Arheimer et al, 2003). The model has been applied in several European countries; Matsalu River in Estonia (Lidén et al., 1999), Neckar and Warnov Rivers in Germany (Fogelberg, 2003), and six European catchments in the EuroHarp project (www.euroharp.org).

The parameter sensitivity has been evaluated earlier (Arheimer and Wittgren, 1994, Arheimer, 1998), in addition to the impact of hydrological model structure and calibration strategy (Arheimer and Bergström, 1999; Pettersson et al., 2001). Submodels has been independently checked for N in soil (Bergström et al., 1987; Brandt, 1990) and in forests (Andreasson, 2002), for P in small agricultural catchments (Andersson et al., 2002) and for N in wetlands (Arheimer and Wittgren, 2002).

The model includes a number of free parameters, which are calibrated against some observed time-series of river discharge and riverine nutrient concentrations. For large-scale catchment applications, the calibration procedure is made step-wise for groundwater, rivers and lakes, with simultaneous consideration to several monitoring sites in a region. Simultaneous calibration of water balance and nutrient concentrations may be performed (Pettersson et al., 2001). The magnitude of data requirement depend on wether it is linked to agricultural models (Table 2).

The hydrological part (i.e. the HBV-96 version of the HBV model) consists of routines for accumulation and melt of snow, accounting of soil moisture, groundwater and runoff response in the response box, and finally lakes and routing.

In the nutrient submodel, soil leaching concentrations are assigned to the water percolating from the unsaturated zone to the response box of the hydrological HBV model (Fig. 1). Different concentrations are applied to water originating from different combinations of land use and soils. The arable land may be further divided into a variety of crops and management practices (e.g. fertiliser used), for which the nutrient leaching is achieved by using field-scale models, e.g., SOILN (Johnsson et al., 1987); or ICECREAM (Tattari et al., 2001) extended with macropore flow. For P, soil leaching is divided in micropore and macropore flow, each with its typical concentration and macropores with possible seasonal variation. The micropore concentration is applied to the water percolating from the unsaturated zone but macropore P concentration is added to the water leaving the HBV response box. A part of the water leaving the HBV response box is assumed to come from macropore flow. How much depends on the rain and moisture of the soil and on soil type. For P, also soil surface erosion and water transport is considered, using a GIS-based model component, i.e. DelPi (Hellström 2003), which is based on USLE and curve number (CN). The particulate phosphorus from soil erosion is added as a source to the river, while the SRP of surface flow is added to the water leaving the response box.

In addition to the diffuse soil-leaching, nutrient load is also added from point sources, such as rural households, industries, and wastewater treatment plants. Atmospheric deposition is added to lake surfaces, while deposition on land is implicitly included in the soil-leaching. The model simulates residence, transformation and transport of N and P in groundwater, rivers, wetlands and lakes. The equations (Table 1) used to account for the nutrient turnover processes are mainly based on empirical relations between physical parameters and concentration dynamics. In groundwater, production and degradation of organic N is calculated in addition to retention of inorganic N. The model considers that stream bank erosion, as well as sedimentation and resuspension processes in the rivers may have an impact on the PP river load. SRP in rivers is exchanged with sediment. IN may have retention in rivers and ON production or retention depending on season. Wetlands can be located within a subbasin, thus receiving a part of the subbasins local runoff before it reaches the local river. A wetland may also be located in the main river receiving all water from the subbasin and upstreams basins. In the wetland, IN is retained, while total phosphorus can have a net retention or production depending on which of the modelled processes, sedimentation and uptake, dominates. Only lakes at the outlet of a subbasin or in the main river course have transformation of nutrients. IN and PP have retention (i.e. denitrification and sedimentation), while ON and SRP may have positive or negative retention. ON have a net production in the spring and a net degradation in autumn, and may also have sedimentation. PP is produced in the spring and reduced in the warm half of the year. All lake processes except sedimentation depends on temperature.

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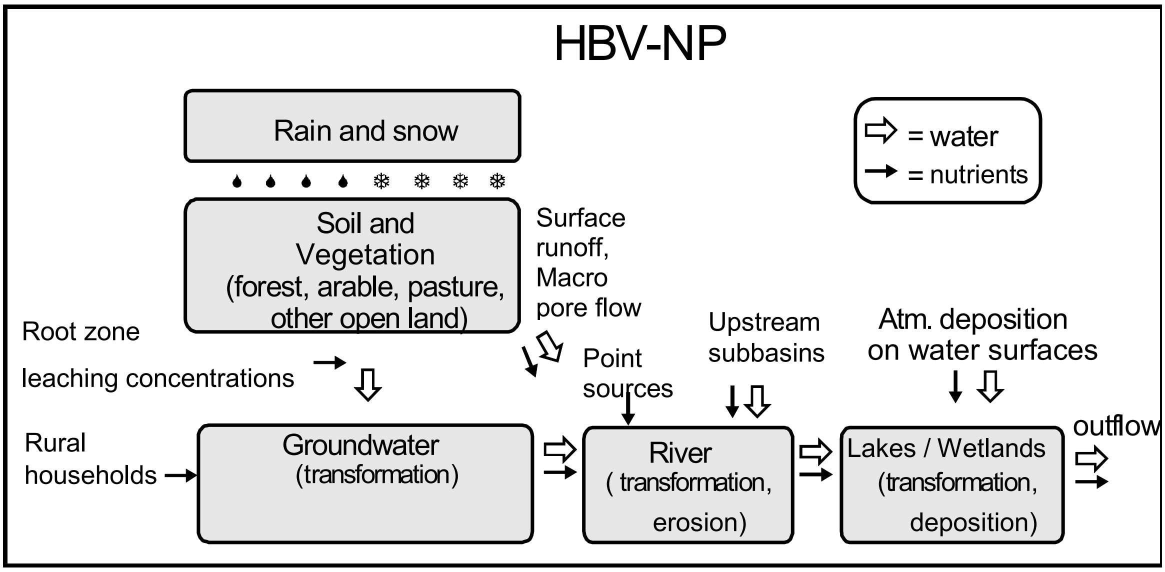

Figure 6.1: Schematic structure of one subbasin in the HBV-NP model concept.

Table 6.5: Description of the retention (Φ) in Eq. 1.

Groundwater equations	Explanations of symbols
$\Phi_{IN\_G} = k_8 * c * \overline{T_2} * V_G$	(+)1 = retention (+1) if increasing temperature
$-\Phi_{ON\_G} = k_9 * c_{origIN} * \left(\overline{T_{10}} - \overline{T_{20}}\right) * A_G$	(+/-)1 = retention (+1) if increasing temperature, production (-1) if decreasing temperature
River equations	A_G = soil surface area
$\Phi_{IN\_R} = k_6 * \overline{T_{10}} * \sum c_{in} V_{in}$	A_L = lake surface area A_W = wetland surface area
$-\Phi_{ON\_R} = k_7 * c_{origIN} * 0.86^{\lvert \overline{T_{30}} - 15 \rvert} * \sum V_{in}$	c, c_t = concentration in the water body
$\Phi_{PP\_R} = -\Phi_{SRP\_R} = k_{10} * 0.85^{\lvert \overline{T_{20}} - 15 \rvert} * \frac{X}{v} * c_{SRP}$	c_{orig} = c_{in} at initial time-step ($\frac{\sum c_{in} v_{in}}{\sum v_{in}}$) G = groundwater
$\Phi_{SRP\_R} = k_{11} * \frac{v}{h} * \left(c^t - c^{t-1}\right)$	h = river channel depth IN = inorganic nitrogen
$\Phi_{PP\_R} = \left(\frac{\bar{q}_b - q}{\bar{q}_b}\right)^{k_{12}} * V_R * c$	k_n = calibration parameter L = lake ON = organic nitrogen
$-\Phi_{PP\_R} = \left(\frac{q}{\bar{q}_b}\right)^{k_{12}} * S_{ack}$	PP = particulate phosphorus q = discharge
Wetland equations	

$\Phi_{IN\_W} = k_{14} * c_{in} * \overline{T_5} * A_W$	$\overline{q}_b$ = discharge at bankful channel
$\Phi_{TP\_W} = k_{15} * c * A_W$	R = river
	SRP = soluble reactive phosphorus
$-\Phi_{TP\_W} = k_{16} * c_{in} * 1.2^{(\overline{T_{30}}-20)} * A_W$	S_{ack} = accumulated PP in river sediment
Lake equations	t = time step
$\Phi_{IN\_L} = k_1 * c * 0.86^{\lvert\overline{T_{30}}-15\rvert} * A_L$	TP = total phosphorus = PP + SRP
$\Phi_{ON\_L} = k_2 * c_{orig} * 0.86^{\lvert\overline{T_{30}}-15\rvert} * V_L * (+/-)1$	$\overline{T_n}$ = *n*-day-mean air temperature
	v = water flow velocity
$\Phi_{ON\_L} = k_3$	V_{in} = volume of inflow
$-\Phi_{SRP\_L} = k_4 * c_{orig} * 0.86^{\lvert\overline{T_{20}}-15\rvert} * A_L$	V_G = volume of ground water
	V_L = volume of lake
$\Phi_{PP\_L} = k_5 * c * A_L$	V_R = volume of river water
$\Phi_{SRP\_L} = k_{13} * c_{orig} * 0.86^{\lvert\overline{T_{20}}-5\rvert} * V_L * (+)1$	W = wetland
	X = river channel length

Table 6.6: Data requirement of HBV-NP

Data requirement	Subbasin division and coupling, altitude, slope, soil and land cover distribution, river length, lake depths, time-series of precipitation and temperature (time-series of observed water discharge and concentrations at some site), soil leaching concentration for each landcover type, lake depths, atmospheric wet and dry deposition, emissions from rural households and point-sources (i.e., wastewater treatment plants, industries), ploughing dates
Additional data requirement when coupled to SOILNDB, ICECREAM, and DelPi	Relative humidity, wind, cloudiness, soil type (texture) and average soil P and organic matter, crop distribution, crop sequence (or non-existent combinations), crop management and yield, fertilization and manuring, N fixation rates in ley, deposition rates, river network, slope, livestock density.