The FyrisNP model Version 3.2

– A tool for catchment-scale modelling of source apportioned gross and net transport of nitrogen and phosphorus in rivers

Technical description

by

Elin Widén-Nilsson, Klas Hansson, Mats Wallin, Faruk Djodjic, Georg Lindgren

Institutionen för vatten och miljö, SLU
Box 7050, 750 07 Uppsala

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In Swedish:
Institutionen för vatten och miljö, SLU (f.d. institutionen för miljöanalys)
SLU vattenNAV
Box 7050
750 07 Uppsala
www.slu.se/vatten-miljo, www.slu.se/vattennav

In English:
Dept. of Aquatic Science and Assessment, SLU (former Dept. of Environmental Assessment)
SLU water HUB
P.O. Box 7050
SE-750 07 Uppsala
www.slu.se/vatten-miljo, www.slu.se/vattennav

Contents

1 Model history

The dynamic FyrisNP model was originally developed by Hans Kvarnäs at the Dept. of Aquatic Sceince and Assessment at SLU[1] for calculating source apportioned nitrogen and phosphorus transport in the River Fyris catchment in central Sweden (Kvarnäs 1996). The original name was the Fyris Model. After this first application the model has been further developed in applications for the Lake Vättern catchment (Kvarnäs 1997), the Lake Storsjön catchment (Johansson & Kvarnäs 1998), catchments of coastal areas in Lake Vänern (Wallin et al. 2000) and the River Göta catchment (Sonesten et al. 2004). During 2005-2006 the platform for the FyrisNP model was changed from LabView (http://www.ni.com/labview) to Visual Studio and .Net Framework (http://msdn.microsoft.com/netframework). This technical description describes the new version of the model released in spring 2012.

2 Input data from other models

In Swedish applications with FyrisNP a major part of the input data is derived from the Swedish Pollution Load Compilation (PLC) reporting to HELCOM. The fifth PLC (PLC5) is the latest report (Brandt et al. 2008). Depending of the modelling scale PLC-data are usually complemented with local and regional data with higher spatial and temporal resolution. Some of the PLC-data are derived using different models. These models as well as some complementary models are summarised below

For several years SLU researchers have been developing robust calculation models that can be used to estimate leaching of both nitrogen and phosphorus from Swedish arable land and to see how leaching is affected by various measures. The NLeCCS (Nutrient Leaching Coefficient Calculation System) modelling system comprises the SOILNDB and ICECREAMDB models. The dynamic SOILNDB model (Johnsson 2002) is used for calculating type-specific concentration of nitrogen in leaching from agricultural land. For calculating the type-specific concentration of phosphorus in run off from agricultural land the dynamic ICECREAMDB model (Larsson et al. 2007) is used. The NLeCCS modelling system generate the type-specific concentrations for a given nutrient (N or P) as an annual average concentration normalized for climatic conditions during a longer time period and typical for a combination of crop and soil types (for phosphorus also for P-content in the soil and slope). More details about the calculations of type specific concentrations in runoff from arable land is described in Johnsson (2008).

For calculating the type-specific concentration of nitrogen and phosphorus in run off from forested areas a regression model is used (Löfgren & Westling 2002). Several options are available for calculating runoff and water discharge. Examples are the HYPE model (Lindström 2010), the HBV model (Bergström 1995), the Q model (Kvarnäs 2000) or FyrisQ, the windows version of WASMOD (Xu 2002). Atmospheric deposition of nitrogen on water is calculated by the MATCH model (www.smhi.se).

3 Model description

The dynamic FyrisNP model calculates source apportioned gross and net transport of nitrogen and phosphorus in rivers and lakes. The main scope of the model is to assess the effects of different nutrient reduction measures on the catchment scale. The time step for the model is in the majority of applications one month and the spatial resolution is on the sub-catchment level. Retention, i.e.

[1] former Department of Environmental Assessment

losses of nutrients in rivers and lakes through sedimentation, up-take by plants and denitrification, is calculated as a function of water temperature, nutrients concentrations, water flow, lake surface area and stream surface area. The model is calibrated against time series of measured nitrogen or phosphorus concentrations by adjusting two parameters.

Data used for calibrating and running the model can be divided into time dependent data, e.g. time-series on observed nitrogen and phosphorus concentration, water temperature, runoff and point source discharges, and time independent data, e.g. land-use information, lake area and stream length and width (see Fig. 1).

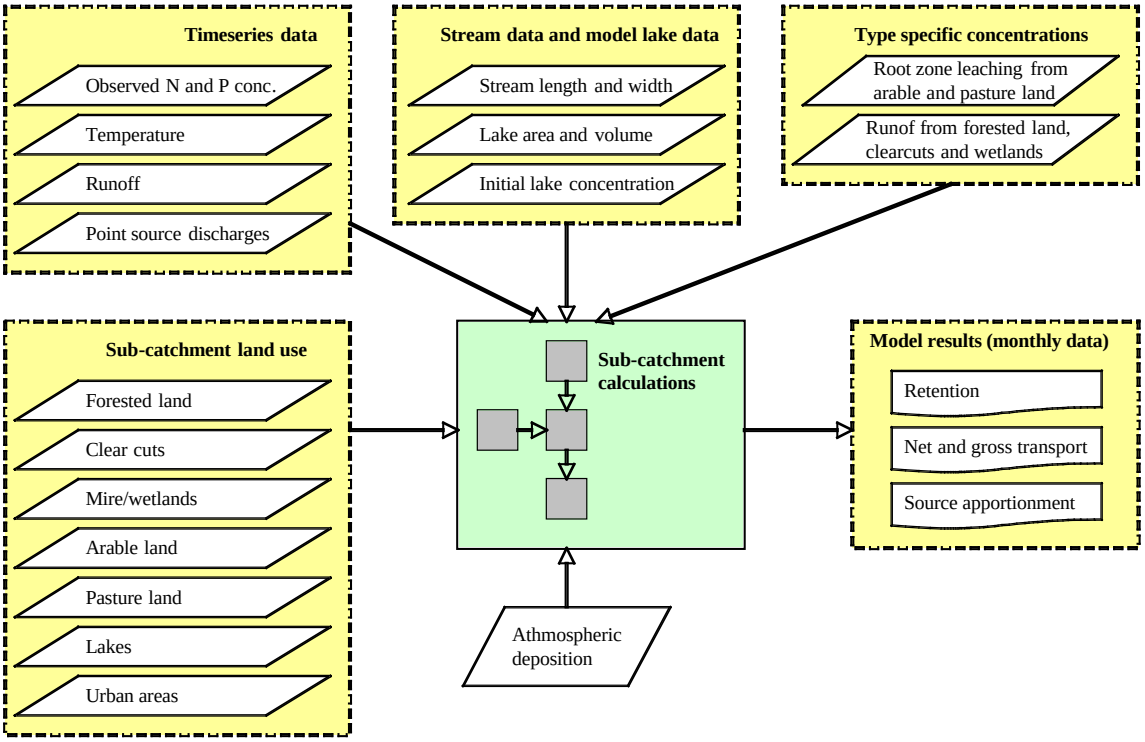

Figure 1. The general structure of inputs and outputs to the FyrisNP model.

4 Input data

The FyrisNP model requires plenty of input data (Fig. 1). The characteristics of the data varies and includes e.g. data specific for a certain type of land use (like concentration of nitrogen in the root zone in an arable land), or data that is identical for the whole catchment area (such as the temperature time-series).

4.1 Time series data

The FyrisNP model operates with a temporal resolution of one month. Consequently, the input data that has a different temporal resolution must either be averaged or interpolated in an appropriate way. The observed in-stream concentrations that are used for calibration do, however, not need to be given for every month.

Observed N and P concentrations
In-stream N and P concentrations are generally monitored at a few locations in the catchment area. This data is used for calibration and validation.

Temperature

Ideally, this should be the water temperature, but in practice the air temperature is often used as an approximation since it is more easily available. Given the relatively small size of most catchments, it is assumed that the temperature is the same throughout the catchment area. The temperature influences the nutrient retention calculations in the model.

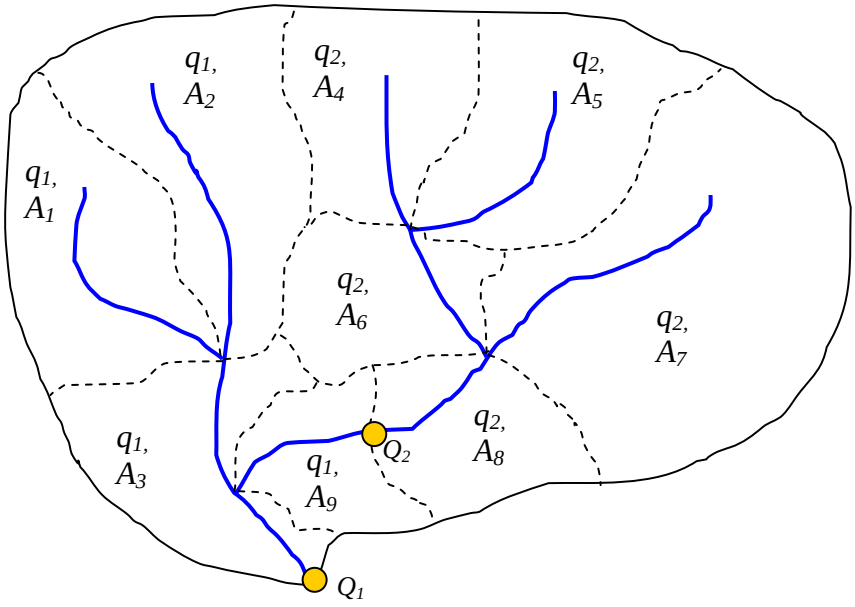

Figure 2. The areas (A), discharge measurement stations (Q), and area specific runoffs (q) within an example catchment.

Specific Runoff

The water flow determines the mobilization and transport of nutrients through the catchment. In the FyrisNP model, the area specific runoff, $q(t)$ [LT^{-1}], is used to quantify these processes. In general, the water flow data is provided externally as discharge, $Q(t)$ [L^3T^{-1}], and must thus be converted to area specific runoff before usage in the FyrisNP model. The external model typically calculates discharge for a spatial scale larger than the sub-catchment scale at which the FyrisNP model operates. Similarly, when measured values of discharge are used rather than modelled values, these measurements are not generally available for every sub-catchment. This problem is solved by assuming that the area specific runoff is equal in every sub-catchment of the catchment, for which the discharge was computed or measured.

In order to facilitate the understanding of how the area specific runoff is computed from measured discharge, an example catchment area consisting of nine sub-catchments will be used (Fig 2). The catchment area contains two stations for discharge measurements, designated Q_1 and Q_2, whose locations are marked with filled circles. Starting with the upstream discharge measurements station, the sub-catchments whose runoff contributes to the measured discharge Q_2 are numbers 4, 5, 6, 7, and 8. Thus, the area specific runoff, q_2, is given by

$$q_2 = \frac{Q_2}{A_4 + A_5 + A_6 + A_7 + A_8},$$

where q_2 is applicable for sub-catchments 4, 5, 6, 7, and 8, and A_i is the area of sub-catchment i. Next, the discharge measured in station 1 (Q_1) includes the discharge passing station 2 in addition to the runoff from areas 1, 2, 3 and 9. Hence, the discharge measured in station 2 must be subtracted from the discharge measured in station 1 in order to correctly calculate the area specific runoff from areas 1, 2, 3, and 9, as given by

$$q_1 = \frac{Q_1 - Q_2}{A_1 + A_2 + A_3 + A_9}.$$

Storage
Lakes having a turnover time larger than about three months significantly affect the downstream transport of water and nutrients. The considerable turnover time in such lakes tends to dampen variations in both water and nutrient transport. In addition, the volume of the lakes (i.e. the storage) is not constant with time. If data is available about the volume changes of the lakes, this information can be included in the model. These changes in volume are referred to as changes in storage, ΔS, and are used in the model to dampen the water mass flow rate.

Major point sources
Point sources may have a considerable impact on the nutrient transport through a catchment. In the model, major point sources often include discharge from waste water treatment plants (WWTPs), both municipal and industrial facilities. For major point sources, the input data must be given with monthly resolution, in contrast to minor point sources which are considered constant in the model (see 4.5). The data obtained from WWTPs is often in the form of kg month^{-1} or similar, and can thus be incorporated directly into the model.

4.2 Sub-catchment land use data

Each land-use type, i, is associated with a type specific input concentration, c_i. To obtain the nutrient input mass flow rate $S_i(t)$ from land-use type i, c_i is multiplied with the discharge generated within the area A_i of this land use type.

Sources with constant input concentration
The concentrations in the root zone of agricultural and pastural lands are modelled as being constant in time. However, since the concentrations are multiplied with the discharge, i.e.

$$S_i(t) = A_i \cdot q(t) \cdot c_i,$$

the contribution from these land types will have a temporal variation.

Sources with a seasonal variation in the input concentration
For some land use types, the type specific solute concentration c_i varies with season (or month). For instance, the type specific concentration is always the same in January every year, but may differ from the concentration in June. The load exerted by these land types for a given sub-catchment is calculated using

$$S_i(t) = A_i \cdot q(t) \cdot c_i(m \quad).$$

The land types modelled in this way are mountains, forests, clearcuts, mires, built environments, cities and a type called open land which among other things contains bare rock faces. The type concentrations of built environments and cities are is often set to 0 and their storm water leakage handled as one of the minor point sources. In addition, the nitrogen concentration in the leachates from the clearcuts is assumed to increase by a constant factor 0.95 mg/l when the nitrogen deposition exceeds 800 kg yr^{-1} km^{-2} (Löfgren & Westling 2002). This caluculation of the clearcuts correspond to the case "Standard" in the Settings tab in the input data file, or no Settings tab at all.

Case "PLC5" calculations in the Settings tab
The above mentioned type specific concentrations do not totally agree with the calculation procedure in PLC5 (Brandt, 2008). Thus there is an option to use PLC5 type calculations in FyrisNP. The calculations according to PLC5 differs for nitrogen, phosphorous as well as for southern and northern Sweden (Table 1). The division between northern and southern Sweden is in FyrisNP implemented such that the altitude of the sub-catchments is set to 0 in southern (Table 1).

Table 1. The type specific calculations in the PLC5 alternative.

Region	Division	Affected substance	Affected type spec conc	Changed content in type spec conc tab
Southern Sweden	Altitude = 0	Nitrogen	Clearcuts	Org-N
Northern Sweden	Altitude > 0	Nitrogen and phosphorus	Mountains, forests, clearcuts, mires, urban, open land	Monthly factors, varying around 1

In southern Sweden, the type specific concentration of nitrogen for clearcuts is calculated according to Löfgren & Westling (2002) as:

$$c_{clearcut} = \begin{cases} c_{orgN} + (0.2619 N_{dep}/100 - 1.1497), & N_{dep} > 800 \\ c_{orgN} + 0.95, & N_{dep} \le 800 \end{cases}$$

where $c_{clearcut}$ [mg/l] is the type specific concentration for clearcuts, c_{orgN} [mg/l] is the type specific concentration for organic nitrogen from forests and N_{dep} is the nitrogen deposition[kg yr^{-1} km^{-2}]. **In this case, the c_{orgN} values are written in the clearcuts column in the input data worksheet "Type spec conc".** These values can be found in Löfgren & Westling (2002).

In northern Sweden, the type specific concentration of nitrogen for mountains, forests, clearcuts, mires, urban, open land is calculated according to Löfgren & Brandt (2005) as:

$$c_i = \frac{1265 - 363 * \log_{10}(altitude)}{1000} * MF$$

where *altitude* is the average sub-catchment altitude [m] and MF is a monthly factor [-], around 1, giving the monthly variation. **In this case the MF values are written in the input data worksheet "Type spec conc".** These values can be found in Löfgren & Brandt (2005). Similary, in northern Sweden, the type specific concentration of phosphorus for mountains, forests, clearcuts, mires, urban, open land is calculated according to Löfgren & Brandt (2005) as:

$$c_i = \frac{37.2 - 10 - 7 * \log_{10}(altitude)}{1000} * MF$$

4.3 Stream data

This is the length and width of streams within every sub-catchment. The stream area is used in the retention calculations, and for determining the atmospheric nitrogen deposition on surface water. Typically, this data is generated from a GIS tool.

4.4 Atmospheric deposition

The total deposition of nitrogen on water surfaces, S_d [MT^{-1}], in every sub-catchment is modelled using a constant area specific deposition, F_d [$MT^{-1}L^{-2}$], multiplied with the sum of stream and lake surface areas [L^2] in the sub-catchment as defined by

$$S_d = \left(A_{lakes} + A_{stream}\right) \cdot F_d .$$

4.5 Minor point sources

Minor point sources [MT^{-1}] include e.g. effluents from rural houses, milk rooms, and manure pits. The minor point sources are considered constant in time. Even though they are referred to as minor in the model, these sources may be very significant in some sub-catchments. The minor point sources are given as monthly loads.

4.6 Weekly data

FyrisNP can use either monthly or weekly time resolution. Using weekly data, all time series input is given with weekly resolution except the type specific concentrations which are still 12 monthly values. The weeks are coupled to the best corresponding month (Table 2).

Table 2. Coupling between week numbers and month numbers in FyrisNP.

Week name	Month	Week name	Month	Week name	Month	Week name	Month
1	1	14	4	27	7	40	10
2	1	15	4	28	7	41	10
3	1	16	4	29	7	42	10
4	1	17	4	30	7	43	10
5	2	18	5	31	8	44	11
6	2	19	5	32	8	45	11
7	2	20	5	33	8	46	11
8	2	21	5	34	8	47	11
9	2	22	5	35	8	48	11
10	3	23	6	36	9	49	12
11	3	24	6	37	9	50	12
12	3	25	6	38	9	51	12
13	3	26	6	39	9	52	12

5 Retention model

The nutrients found in a stream as it crosses the boundary of a certain sub-catchments stem from the sub-catchment itself and, if such exist, upstream sub-catchments. Parts of the nutrients are, however, retained due to processes such as sedimentation, uptake by plants, and de-nitrification.

The relative removal is given by the retention coefficient, R [-], defined as

$$R = T_a \cdot Q_a$$

where T_a [-] is the temperature adjustment factor and Q_a [-] the flow rate adjustment factor. T_a is given by

$$T_a = \begin{cases} c_0, & T < 0 \\ c_0 + \dfrac{T(1-c_0)}{20}, & 0 \le T \le 20 \\ 1, & T > 20 \end{cases}$$

where T [K] is the water temperature, and c_0 [-] is an empirical calibration parameter. The parameter c_0 determines how strongly the retention is reduced by temperatures between 0 °C and 20 °C (Fig. 3). Before version 3.2 was T_a set to 0 instead of c_0 for negative temperatures. The flow rate adjustment factor is given by

$$Q_a = \frac{kvs}{q_s + kvs}$$

where kvs [LT^{-1}] is an empirical calibration parameter, and the hydraulic load, q_s [LT^{-1}], is given by

$$q_s = \frac{Q}{A_{lake} + A_{LM} + A_{stream}}$$

where A_{lake} is the total surface area of all lakes in the given sub-catchment, A_{LM} is the area of the lake treated in the separate lake module (if one such exists in the sub-catchment), and A_{stream} is the surface area of all streams in the sub-catchment. Q_a is a strongly non-linear function of kvs and q_s (Fig 3).

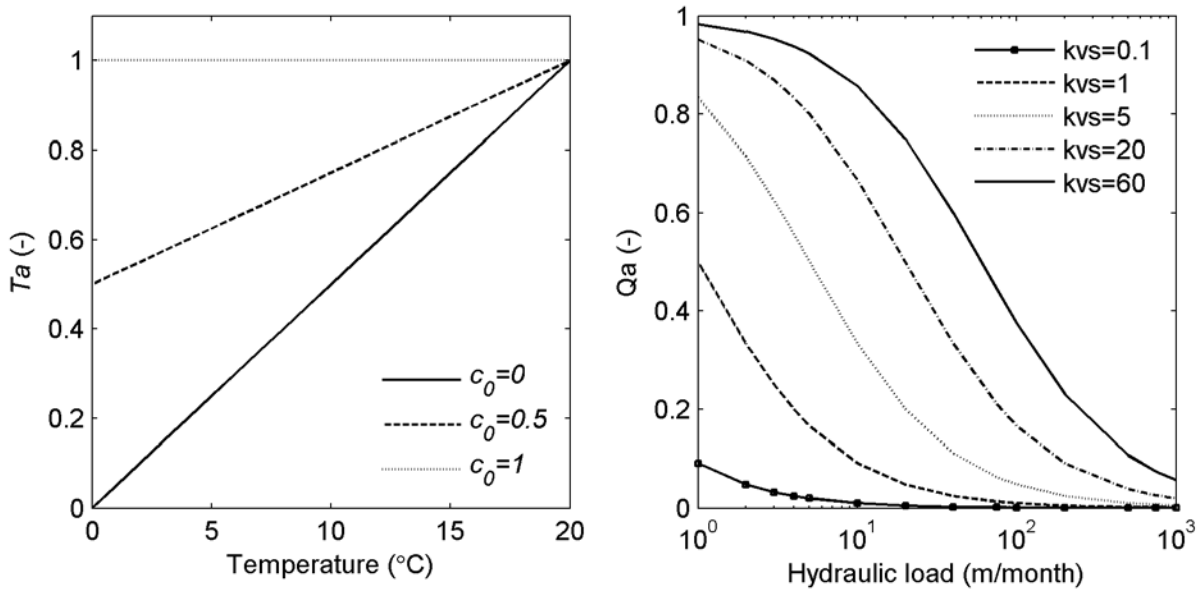

Figure 3. Left: the influence of c_0 on the temperature dependence of T_a.
Right: the influence of kvs and q_s on Q_a.

The retention coefficient varies with time, and does in practice take on unique values for each sub-catchment as the areas involved in the hydraulic load equation differs between sub-catchments.

6 Modelling river system discharge

The area specific runoff is used in the model to calculate the contribution of nutrients from every sub-catchment. However, when dealing with the transport of nutrients within the entire catchment, from one sub-catchment to another, the discharge (the mass flow rate of water) from every sub-catchment is needed. The discharge generated within a given sub-catchment *k*, for which $q_k(t)$ has been provided, is conveniently computed using

$$Q(t) = q_k(t) \cdot A_k .$$

However, many sub-catchments receive an external input of water from upstream, neighbouring sub-catchments in addition to the internally generated runoff. Hence, adding the external, incoming mass flow rate of water, as well as storage when such exists, yields the total discharge from sub-catchment *k*

$$Q_k(t) = \sum_{j=1}^{m} \left[Q_j(t) \right]_{\substack{i \\ n}} + q_k(t) \cdot A_k - \Delta S_k(t)$$

where $Q_j(t)$ is the inflow of water from upstream, neighbour sub-catchment *j*, and $\Delta S_k(t)$ [L^3T^{-1}] is the storage in large lake *k* (referred to as "model lakes" in this report). This equation thus needs to be solved for every sub-catchment, and every time step.

7 Modelling of nutrient transport

The mass transport, $Q_k(t) \cdot c_k(t)$ [MT^{-1}], of nutrients from sub-catchment *k* is given by

$$Q_k(t)\cdot c_k(t) = [1 - R_k(t)]\cdot\left\{\sum_{j=1}^{m}\left[Q_j(t)\cdot c_j(t)\right]_i + l_n \quad \rho(t)_k\right\}$$

where c_k [ML^3] is the nutrient concentration in the outgoing water, *j* indices refer to upstream, neighbouring sub-catchments, and $load_k$ [MT^{-1}] is the sum of all nutrient sources within the given sub-catchment.

8 Modelling of "Model Lakes"

In contrast to the modelling of sub-catchment areas without specific model lakes, the model lakes are affected by previous time steps, i.e. they have a "memory" and tend to dampen the response with regards to nutrient concentrations downstream. If storage change is included, the water mass flow rate variability will also be attenuated. The change of nutrient mass in a given model lake located by the outlet of catchment *k* is described by the following ordinary differential equation, derived by assuming mass conservation,

$$\frac{d[c(t)\cdot V(t)]}{d} = [1 - R_L(t)]\cdot[Q_k(t)\cdot c_k(t) + a \quad \text{ct d} \quad m \quad] - eQ_o \quad (t)\cdot c(t)$$

where c [ML^{-3}] is the lake concentration, V [L^3] is the volume of the lake, and t is time [T]. The retention coefficient R_L for a model lake is given by

$$R_L = \frac{T_a \cdot k\ v\ s}{\frac{Q_k}{A_{L\ M}} + k\ v\ s},$$

and thus differs slightly from the other retention coefficient as a result of different hydraulic load in the "model lake" compared to the rivers and smaller lakes. If no storage data is given for the model lake, the outflow mass flow rate Q_{out} [L^{3}T^{-1}] equals the inflow mass flow rate Q_k. Notice that the model lake receives the nutrient mass flow defined in paragraph 7 as input. Hence, sub-catchments must be organized such that their outlets coincide with the model lake outlet if a model lake is to be simulated. I.e., the model lakes do in a sense operate between sub-catchments.

9 Constructed wetlands

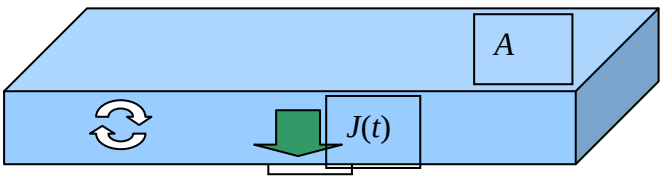

Figure 4. A constructed wetland modelled as being a well mixed body of water having constant volume and surface area.

In the FyrisNP model, constructed wetlands are seen as pure sinks of nutrients and processes such as resuspension are neglected. It is assumed that the volume and surface area of the constructed wetland is constant at all times. The turnover time however, varies with the volumetric inflow of

water to the wetland. The volume of water is considered well mixed, and the loss of nutrients due to sedimentation, uptake by plants and other processes, is modelled as being directly proportional to the nutrient concentration. The loss can be described by

$$J(t) = kTc(t),$$

where J [$MT^{-1}L^{-2}$] is the area specific removal rate, k [$LT^{-1}K^{-1}$] is the removal rate coefficient, T [K] is the water temperature, and c [ML^{-3}] is the concentration at time t (see e.g. Arheimer och Wittgren, 2002). The temperature is considered constant during the model time step. In contrast to the modelling approach of Arheimer and Wittgren (2002), the FyrisNP model uses a monthly time step rather than a daily time step, which motivated a different approach. Every month, the volume of water in the constructed wetland is fully exchanged, and there are thus no in- or outflows in a normal meaning. The turnover time of the constructed wetland is often shorter than one month, but by solving the mass balance equation for the constructed wetland a retention coefficient can be found which accounts for the removal over a few days, despite the longer model time step. Given that the volume is constant, and that there are no in- or outflows, the mass balance for the nutrients of the constructed wetland is

$$\frac{d(c(t)V)}{dt} = -J(t)A = -kTAc(t),$$

where V is the volume of the constructed wetland, and A is the surface area (Figure 4). The solution to the above equation is

$$\frac{c(t)}{c_0} = e^{-\frac{kTA}{V}},$$

where c_0 $(= c(t=0))$ is the concentration at the inlet. The concentration of the water leaving the constructed wetland can be found by setting $t = \tau$, where τ is the turnover time for the constructed wetland. In addition, using the definition of turnover time ($\tau = V/Q$) we can rewrite the equation as

$$\frac{c(\tau)}{c_0} = e^{-\frac{kTA}{Q}},$$

where Q is the water flow rate to the constructed wetland. Hence, this equation governs the relative decrease of a given nutrients' concentration in the constructed wetland. Thus, despite the typical short turnover time in constructed wetlands, we can find the relative removal for the batch of water entering the wetland during a specific month using the corresponding monthly values of Q to calculate the turnover time.

Consequently, the absolute retention, $R(t)$, for any given month, and constructed wetland in the catchment, is:

$$R(t) = \left(1 - e^{-\frac{kT(t)A}{Q(t)}}\right) c_0(t) Q(t).$$

Notice that the time-dependence was introduced at this stage to certify that it is understood that the retention varies from month to month. Apparently, we can introduce a new retention coefficient

$$R_{CW}(t) = \left(1 - e^{-\frac{kT(t)A}{Q(t)}}\right),$$

appropriate for man-made wetlands. Remember, it is assumed that the wetland has constant volume and surface area. What differs between months is the time spent in the constructed wetland, and the concentration of the incoming water. The ratio between the water flow rate and the surface area of basin-like structures is often referred to as surface load and is together with temperature the two controlling factors behind the efficiency of nutrient removal (Figure 5). When considering absolute numbers, the nutrient concentration is obviously of fundamental importance.

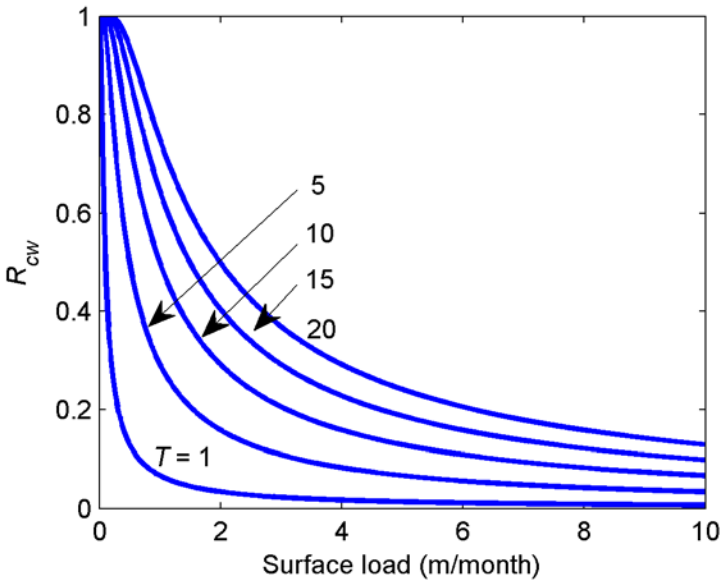

Figure 5. The retention coefficient, R_{cw}, as a function of surface load for various water temperatures. For all temperatures and surface loads, k = 0.069 m month^{-1} °C^{-1}.

10 Using measured nutrient transport as input (External load)

Occasionally, it is of interest to use measured in-stream values of discharge, $Q(t)$, and nutrient concentration, $c(t)$. It is for this reason possible to feed the measured time-series directly into a downstream sub-catchment. Consult the User's manual for more information.

11 Statistics

In order to evaluate the fit of simulated to measured values, three statistical measures are used in the FyrisNP model: the model efficiency, *E*, the correlation coefficient, *r*, and the variance *Var*. The definition of model efficiency (Nash and Sutcliffe, 1970) and *r* is

$$E = 1 - \frac{\sum_{i=1}^{n}\left(\theta_{obs,i} - \theta_{sim,i}\right)^2}{\sum_{i=1}^{n}\left(\theta_{obs,i} - \bar{\theta}_{obs}\right)^2}$$

$$r = \frac{\sum_{i=1}^{n}\left(\theta_{obs,i}\theta_{sim,i}\right) - \sum_{i=1}^{n}\left(\theta_{sim,i}\right)\sum_{i=1}^{n}\left(\theta_{obs,i}\right)/n}{\sqrt{\left(\sum_{i=1}^{n}\left(\theta_{obs,i}{}^{2}\right) - \sum_{i=1}^{n}\left(\theta_{obs,i}\right)\sum_{i=1}^{n}\left(\theta_{obs,i}\right)/n\right)\left(\sum_{i=1}^{n}\left(\theta_{sim,i}{}^{2}\right) - \sum_{i=1}^{n}\left(\theta_{sim,i}\right)\sum_{i=1}^{n}\left(\theta_{sim,i}\right)/n\right)}}$$

where n is the number of observations, and $\bar{\theta}_{obs}$ is the mean value of all observations. The θ symbolizes whatever time-series are compared. In the FyrisNP model, θ_{obs} and θ_{sim} are the observed and modelled concentrations respectively. $E = 1$ implies that the measured and modelled series are identical, and $E = 0$ indicates that the simulation is no better than a straight line representing the average value of the observations.

The FyrisNP model supports three modes of statistical measures calculation:

1. **Individual**: *E* and *r* are calculated based on all selected pairs of observed and simulated concentrations; i.e. all value-pairs are lumped before calculation of *E* and *r*. This is the default setting.

2. **Lumped**: *E* and *r* are calculated separately for each selected sub-catchment and then the arithmetic average is taken.

3. **Ensemble**: *E*, *r* and *Var* are calculated separately for each selected sub-catchment and then the arithmetic average is taken. Finally, the resulting measure is derived by taking the arithmetic average of the three previously computed averages. Notice that this value is incorrectly referred to as Efficiency in the GUI.

12 Calibration and parameter sensitivity/uncertainty

The model provides the user with three different methods for calibration and/or evaluation of sensitivity to individual parameter values. It is possible to choose which sub-catchments to include or exclude in the calibration procedure. The time period can also be specified.

1. The manual calibration allows the user to manually change both parameter values (c_0 and *kvs*), after which the model performs one simulation over the selected time period, using the selected measurement stations to calculate the model efficiency and the correlation coefficient. The user can inspect the simulation by looking at time-series graphs, or graphs of simulated versus observed concentrations for the selected sub-catchments.

2. In the Monte Carlo simulation, the user specifies a uniform distribution of values for both parameters, and the number of individual simulations to carry out. As was the case for the manual calibration, the simulation covers the selected time period, and the selected in-stream concentrations are used to calculate model efficiency and correlation coefficient. The outcome may be analyzed graphically in the model by means of scatter plots.

3. The automatic calibration option uses the Simplex algorithm (Sorooshian, S., Gupta, V.K., 1995) to find the optimal parameter values within user specified parameter intervals. The optimal parameter values are considered to be the ones that provide the highest *E* value for the chosen calibration set up. The result is presented by means of parameter values, plus *E*

and *r* values calculated in accordance with the selected statistical mode as presented in paragraph 10.

13 Computer model

The computer code generated to solve the problem described in the preceding paragraphs was written in Visual Basic 2005, utilizing the .NET-framework.

14 References

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