MCSIM documentation

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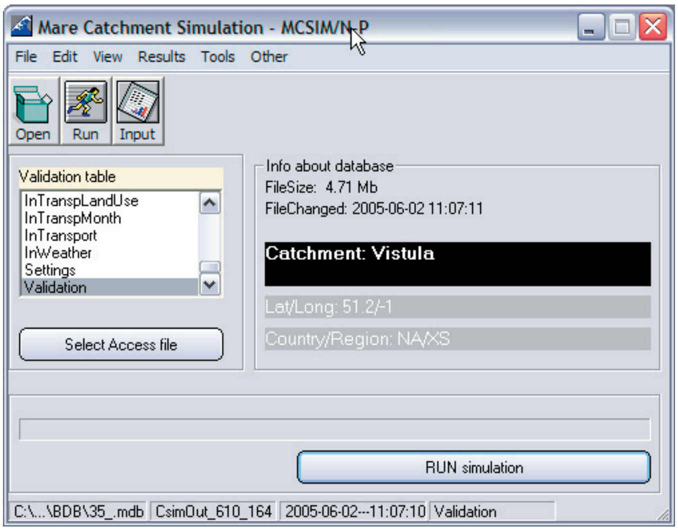

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Content

PART I – General comments

Introduction

The CSIM model is based on the BasinSim model (Dai et al. 2000) which is based on the GWLF (Generalized Watershed Loading Functions) model (Haith and Shoemaker 1987). Its loading functions are specific for the actual watershed and used with the hydrologic cycle to predict nutrient loads from surface runoff, groundwater, point sources and septic systems. The loads of nitrogen and phosphorus in stream flow are calculated as the product of water discharge times the nutrient concentrations with addition of point sources and septic systems. In the CSIM-model, stream flow consists of total watershed runoff from all source areas plus groundwater discharge from the saturated zone (see for example the BasinSim model, (Dai et al. 2000).

This GWFL model (and all varieties of this model) is a lumped hydrologic model (Haith and Shoemaker 1987, Haith et al. 1992) that uses daily historic precipitation data to simulate monthly discharge, sediment load, and nutrient transport. It divides the watershed into land-use and soil-type categories and considers the loads from each category separately. Both groundwater and runoff are considered, including the transport of both dissolved and particulate nutrients. Sediment is generated by a variation of the Universal Soil Loss Equation, and then transported from the watershed using a nonlinear relationship with stream flow. However, within-stream processes are not considered and therefore no biogeochemical dynamics of nutrients are included. Instead they are assumed transported passively in the stream flow. Neither is atmospheric deposition considered explicitly. Still the model captures the seasonal and annual stream flow and sediment dynamics and is sensitive to changes in land use and management

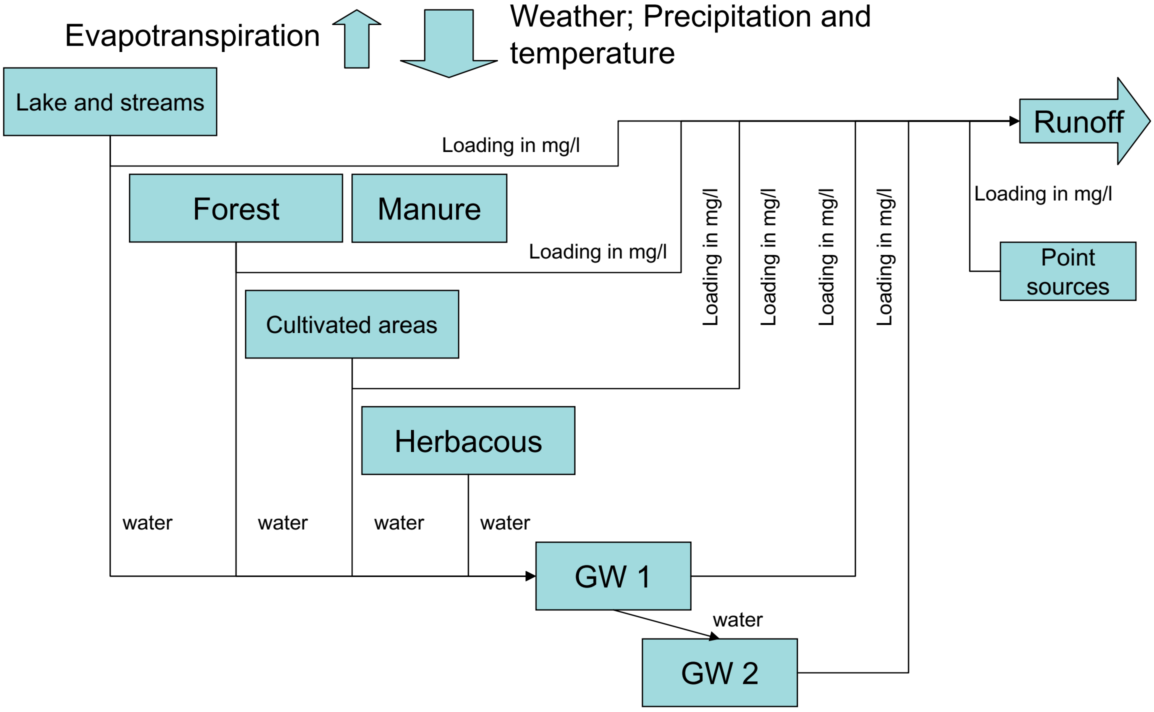


Fig. 1. Schematic block diagram of model structure. Precipitation and evapotranspiration are applied to the various land covers. Water from each land cover type is routed both directly to stream flow and down to the soil water compartment. From the soil water compartment water is routed to stream flow and to the groundwater compartment, and from there on to the stream.

(see manual of Haith et al. 1996, BasinSim manual).

Data requirements

In the present application the whole Baltic Sea drainage area is divided into 105 different drainage basins. The division follows the JRC (Join Research Centre) data compilation for watersheds in Europe, which also is the base for the division of basins for the water framework directive (WFD). Each catchment must be supplied with data on e.g. land use, hydrology, soil type, erosion and sediment, nutrient concentrations in runoff, as well as daily temperature and precipitation data (see Fig. 1).

The data required and used in the modelling of the Baltic Sea drainage basin in CSIM can be divided into the following groups;

- General information of total catchment area (in ha)
- Rainfall and temperature, daily observations in order to drive the hydrology
- Land use data; now divided into the following land classes, Decidious, Coniferous, Mixed forest, Herbaceous, Wetlands, Cultivated areas, Bare areas, Water, Snow and ice and Artificial areas. For each land use the following parameters are set; area (in ha), CN (Curve Number, see section about hydrology), KLSCP which is a combined value of land cover/ soil type combination and type concentrations for N and P
- Groundwater; two boxes with storage volumes and parameters defining their tapping time as well as type concentrations for these boxes
- Point sources. Manure and septic systems are also considered as point sources
- Validation and calibration data from BED (BED database). Data from the BED database was extracted and reorganized so that each drainage basin has its own database table with N and P fluxes as well as water discharge on a monthly basis in the period 1980 to 2000.

Some aspects of the model used data to must be discussed in more detail;

Meteorology

The necessary forcing data are extracted from synoptic stations in the whole Baltic drainage area. Synoptic precipitation and temperature observations for the period 1979 to present time are available in an interpolated 1x1 degree grid database at SMHI. This database includes 700-800 stations. A much more detailed precipitation network exists in the Baltic region, but some of these observations are not available for longer time periods. (For scenario analysis synthetic weather can be formed from the existing database.) From these 6-hour data daily observations were generated for each of the 105 drainage basins.

Hydrology

Temperature and rainfall is the driving force for the hydrological model. The model is also capable of dealing with snow and snow melt. The snow melt routine is one of the modifications done compared to the original model. In CSIM the temperature threshold where snow is melting can be set to any temperature as well as the amount of snow melting each day.

The BasinSim model has two types of boxes, one soil box for each land use and one groundwater box common to the whole catchment. In CSIM one more groundwater box has been added in order to better simulate hydrology and a source for nutrients in the northerly drainage basins. The upper soil box, linked to the land use, is from now on called runoff. The runoff (Figure A-3, Appendix A, (Dai et al. 2000) is computed from daily weather data by the U.S. Soil Conservation Service's Curve Number Equation:

$$Q_{kt} = \frac{(R_t + M_t - 0.2 * DS_{kt})^2}{R_t + M_t + 0.8 * DS_{kt}}$$

Here rainfall=Rt (cm) and snowmelt=Mt (cm of water) on day t are estimated from daily precipitation and temperature data.

The detention parameter DS_{kt} (cm) determines how large fraction of the precipitation and snowmelt that is routed through the surface runoff and it is determined from a curve number CN_{kt}

$$DS_{kt} = \frac{2540}{CN_{kt}} - 25.4$$

Curve numbers are selected as functions of antecedent moisture. The numbers for conditions 1 (dry), 2 (average) and 3 (wet) are denoted CN_{1K}, CN_{2k} and CN_{3k} respectively. The actual curve number for day t, CN_{kt}, is selected as a linear function of A_t, the 5-day antecedent precipitation (cm):

$$A_t = \sum_{n=t-5}^{t-1} (R_n + M_n)$$

Recommended values for the break points for dormant and growing seasons are AM_1 = 1.3 & 3.6 cm, and AM_2 = 2.8 & 5.3 cm respectively. For snowmelt conditions, it is assumed that the wettest antecedent moisture conditions prevail and hence regardless of At, $CN_{kt} = CN_{3k}$ when snowmelt $M_t > 0$.

According to Table B2 and B3 (Dai et al. 2000) the CN_{2k}-values are in the range 30-95 depending on rural land use, soil hydrologic group and hydrologic condition. Assuming a dormant season, 30 mm rain during the previous 5 days (A_t) and CN_{2k}-values in the range 70-95, yields runoff figures in the range 12-61% of the precipitation. Hence, for many soil types the model estimates a substantial proportion surface of runoff.

The groundwater discharge is estimated from the daily water balances for the unsaturated and shallow saturated zones (Appendix A, Dai et al. 2000)

$$U_{t+1} = U_t + R_t + M_t - Q_t - E_t - PC_t$$
$$S_{t+1} = S_t + PC_t - G_t - D_t$$

In these equations, U_t and S_t are the unsaturated and shallow saturated zone soil moistures at the beginning of day t and Q_t, E_t, PC_t, G_t and D_t are watershed runoff, evapotranspiration, percolation into the shallow saturated zone, groundwater discharge to the stream and seepage flow to the deep saturated zone, respectively (cm). The seepage into the deep aquifer is not assumed to influence the stream water discharge and thereby not the nutrient loads. In the MARE version of the BasinSIM-/GWLF-model, CSIM, the shallow saturated zone is split into two boxes (as mentioned above), both generating stream water discharge.

Water balance constraints

The stream runoff is conceptually described as the sum of surface runoff (Q_t) and groundwater discharge (G_t) and the proportion of surface runoff can be considerable. This is not in agreement with the general picture of how surface water is generated in boreal areas. Many studies show that during episodic events in forested hill slopes in Scandinavia, which dominate the annual stream water discharge, the main groundwater flow path is as a lateral flux in the upper soil horizon due to the high hydraulic conductivity compared to deeper layers (Rodhe 1987, Nyberg 1995). A large proportion of the stream water during such flow events is generated by "old" water previously held in the unsaturated zone (Seibert et al. 2003), giving the opportunity for biogeochemical processes to modify the groundwater chemistry compared with the composition of precipitation. However, the mechanism for such changes seems not to be completely understood considering that only a small part of the discharge water consist of 'new' water (Kirchner 2003).

The proportion of surface runoff in agricultural areas varies markedly between sites and years depending on soil, topography, climate, crops etc (Vagstad et al. 2001). Studies in the Nordic and Baltic countries exhibits base flow indexes (BFI, an estimate of the slow groundwater discharge) in the range 5-95% with the highest values in sandy soils in Denmark and the lowest in clayey soils in Finland. Most BFI-values are in the range 15-40%, mainly representing clayey-loamy soils (Vagstad et al. 2001). Low BFI-values indicate shallow groundwater flow paths and/or overland and subsurface flows via macro pores, cracks etc (Vagstad et al. 2001).

In most mire areas, regardless of

being marshes (discharge areas) or bogs (recharge areas), the water movements are generally rapid through the surface peat. This is due to the decreasing hydraulic conductivity with increasing humification. Studies in Finland, probably relevant for the other countries in the Baltic region as well, shows that the hydraulic conductivity decreases from 10^{-4} to 10^{-8} m/s along the vertical humification gradient (Päivänen 1973). It has also been found a high proportion of preferential flow within highly humified peat. Hence, the proportion of extremely shallow, lateral groundwater fluxes and macro pore flows is large from peat areas. During snowmelt when heavy rain episodes occur, surface runoff might be substantial.

In the CSIM model, specific type concentrations for each land use class can only be applied on surface runoff (Q_t) and not on groundwater discharge (G_t). This creates difficulties in defining relevant type concentrations since the proportion of surface runoff, macro pore flow and groundwater discharge from different compartments of the soil profile have very different nutrient concentrations especially in cultivated areas. The problem is further accentuated by the mathematical definition of surface runoff (Q_t), causing precipitation and snowmelt to turn into runoff as soon as the AM-breakpoints are reached (see above). Hence, runoff in the model is conceptually simulating surface runoff and perhaps macro pore flow, but not shallow groundwater discharge with substantially longer transit times than a day. In agricultural areas, the former two flow routes are important for the P losses, while the latter flow path is of uttermost importance for the N losses.

Hence, the CSIM model might to some extent be relevant for estimating the nutrient runoff caused by erosion, but not for simulating the losses caused by leakage on a process level. The latter flux, which often is the most dominating flow path for nitrogen in agricultural areas, is poorly handled in the model. The groundwater discharge is simulated at two levels ($G_t=G_{Box1}+G_{Box2}$) where the upper flow path (G_{Box1}) is relatively quickly responding to precipitation. The lower flow path (G_{Box2}) has a slow climate response, not substantially affecting the seasonal stream water discharge pattern. At both levels, the type concentrations are independent of land use class, implying similar groundwater concentrations of N and P from e.g. arable land and forestland. The scientific as well as administrative value of such a model assumption could be argued. The only way to overcome this obstacle is to smear out an average type concentration for all land use classes over the entire catchment.

Due to the large influence of water discharge on the nutrient fluxes in streams, this should be calibrated and validated before simulating the nutrient runoff.

Population and point sources

The model also requires input data in form of descriptive statistics for each sub area, i.e. population and point sources. For the moment the official HELCOM data (PLC4) is used for the point source calculations within each drainage basin. Since the data on point sources are divided per country the assumption was made that the population density is a good proxy for the distribution of point sources. Therefore, the population in each basin was estimated and the load of N and P within each drainage basin was distributed proportionally from the given total load of N and P in each country.

Type concentrations of N and P

As described above, the hydrological assumptions in the CSIM model affects the possible choices of N and P type concentrations. Generally, studies of nutrient leakage to surface waters are performed in streams draining small catchments dominated by the land use of interest. Hence, the information gained is the sum of N and P losses due to surface runoff, preferential flow (micro pore flow) and groundwater discharge. Information about the proportion of nutrients reaching the stream by the different hydrological pathways is rarely available. Studies performed in small, experimental fields or in tile drained systems give some insight into the problem (Rekolainen et al. 1997).

Another way to assess the N and P concentrations in different compartments of the soil profile is to use mathematical simulation models. The method has mainly been used on agricultural land, since the nutrient losses are much higher from this land use compared with boreal and alpine systems. The latter exhibits more closed nutrient cycles compared with arable fields. Generally, the models are simulating the root zone losses of N and the surface runoff of P and they have been used to simulate the nutrient losses from vast areas in e.g. the Nordic countries (Johnsson et al. 2002). Considering the root zone losses, retention processes in discharge areas or in iron rich sandy soils might reduce the N concentrations due to denitrification. The P losses are basically assumed to be in particulate form, while dissolved P is poorly estimated.

Hence, none of the available techniques are optimal for defining type concentrations in the CSIM-model.

In the MARE-project, the spatial resolution for the CSIM simulations is on catchment scale. These areas vary within a factor >1000 (min: 265 km^2, mean 16500 km^2, max 286000 km^2), neglecting all the spatial variations within each basin and land use class. Regarding cultivated land, differences in climate, soil and agricultural practices create extremely variable prerequisites for nutrient losses from different parts of the large catchments. Studies in 35 Nordic and Baltic catchments (4-2000 ha) dominated by agriculture (60-80%) found nitrogen and phosphorus losses in the range 5-75 kg N ha^{-1} y^{-1} and 0.1-4.7 kg P ha^{-1} y^{-1}, respectively. Excluding 7 catchments in Norway, the five-year mean annual flow-weighed total nitrogen (TN) and total phosphorus (TP) concentrations varied in the range 1.4-11.9 mg TN/l and 0.04-0.68 mg P/l (Vagstad et al. 2001).

Looking at the long-term variation (1990-2000, n$_{year}$=4-15) in 33 small Swedish streams (177-5787 ha) with agriculture as dominating land use shows a similar pattern with N and P losses in the range 3-36 kg N ha^{-1} y^{-1} and 0.06-0.58 kg P ha^{-1} y^{-1}, respectively. The mean annual flow-weighed N and P concentrations varied in the range 1.1-12.2 mg N/l and 0.03-0.31 mg P/l (Carlsson et al. 2004). In Finland, the N and P losses were found to be in the range 8-20 kg N ha^{-1} y^{-1} 0.9-1.8 kg P ha^{-1} y^{-1}, respectively (Rekolainen et al. 1993).

Results from 70 streams (26-138000 ha) in Poland with agriculture as dominating land use showed very large variation in the N and P losses as well. The N and P fluxes varied in the range 2-180 kg N ha^{-1} y^{-1} and 0.000-2.2 kg P ha^{-1} y^{-1}, respectively (Tonderski 1997). There was a positive correlation between nutrient loss and water discharge as well as a strong relation between nutrient flux and soil type. The nutrient losses were higher from heavy soils compared with light soils. The average nutrient concentration in heavy soils was 4 mg N/l and 0.45 mg P/lwhile in moderately permeable soils the average nutrient concentration was 2.5 mg N/l and 0.03-0.06 mg P/l (Tonderski op. cit.).

Looking at the concentration variations during 3 years (N=1997-1999, P=1998-2000) in approximately 30 small Swedish streams (n$_N$=26, n$_P$=36, 19-9480 ha) with forests as dominating land use show much less variation for N and much lower area losses for both elements. The nitrogen and phosphorus fluxes were in the range 1.4-4.2 kg N ha^{-1} y^{-1} and 0.000-0.095 kg P ha^{-1} y^{-1}, respectively. The mean annual flow-weighted N and P concentrations varied in the range 0.28-0.84 mg N/l and 0.001-0.030 mg P/l (Löfgren and Westling 2002). The fluxes of organically bound N and P are approximately double as high from peatland compared to forestland, while the inorganic fractions seem to be at similar levels (Löfgren and Olsson 1990).

In urban areas, surface runoff can be considerable due to extensive areas of more or less impermeable surfaces. Studies of different urban sources show that the average phosphorus concentrations can vary within a factor of 25 depending on type of source-area. Phosphorus concentrations above 1 mg P l^{-1} were common (Bannerman et al. 1993).

Hence, the extremely large variations in the N and P concentrations due to different climates, soil types, land use classes, management practices etc. makes it dubious to apply a single type concentration for N and P respectively, on each land use class in large catchments. In the MARE project, this hesitance is enhanced due to the aggregation of land use classes with very different nutrient losses (see below). Retention and internal loading in the watercourses are not handled by the model. This prevents us from using the model for making simulations of administratively relevant management scenarios.

Type concentrations in "Groundwater" - constraints

In groundwater, the nitrogen concentrations exhibit large spatial variations as well. In non-polluted regions, the nitrate concentration rarely exceeds 1 mg NO_3-N l^{-1}, while it can be well above 10 mg NO_3-N l^{-1} in agricultural and urban areas. There is also a pronounced vertical gradient between surficial and deep groundwater.

In Sweden, the median nitrate concentration in dug (n=1709) and drilled (n=10062) wells were 3 mg NO_3-N l^{-1} and 1 mg NO_3-N l^{-1}, respectively. In 13% of the superficial wells the concentrations exceeded 5 mg NO_3-N l^{-1}, while the same figure was 3% in the deep wells (Aastrup et al. 1995). In Denmark, the median groundwater nitrate concentrations were <3 mg NO_3-N l^{-1} in 20 different types of aquifers (average soil depth 25-58m). In 14% of the Danish drinking water wells, the nitrate concentrations exceeded 5.6 mg NO_3-N l^{-1} (Jorgensen 2004). In Poland, approximately 60% of the drinking water wells at farms in the Ostrolenka voivodship (n=646) had nitrate concentrations >5 mg NO_3-N l^{-1} and 14% of them had >40 mg NO_3-N l^{-l}, indicating severe nitrogen pollution (Sapek and Sapek 1993). A survey in 1978 of 72 500 wells in Hungary showed that only 15-30% of the wells had nitrate concentrations <9 mg NO_3-N l^{-1} and around villages it frequently exceeded 100 mg NO_3-N l^{-1} (Olah and Olah 1996). However, wells in rural areas are often placed in the farmyard, subjected to local pollution connected to animal husbandry and manure handling. Hence, the very high nitrate concentrations are probably not representative for larger areas. In urban areas, the influence of local nitrogen sources is evident, with ammonium and nitrate concentrations in the groundwater in the ranges 0-285 mg NH_4-N l^{-1} and 0-107 mg NO_3-N l^{-1}, respectively (Wakida and Lerner 2005).

Data on the phosphorus concentrations in groundwater is much scarcer, but in 10-15% of the analyses from Danish aquifers the total phosphorus concentration exceeded 0.5 mg P l^{-1}. Due to local pollution, this value was exceeded in 37% of the dug wells. In most groundwater drinking water plants (72%), the P concentrations were in the range 0.01-0.15 mg P l^{-1} (Jorgensen 2004). Studies of the groundwater in four forest dominated Swedish catchments show that the P concentrations generally are below 0.05 mg P l^{-1} (Löfgren 2004).

The large variation in especially the N concentrations within cultivated areas and between cultivated areas and other land use classes makes it dubious to apply a single type concentration for N and P on the entire catchment.

Aggregation of land use classes - constraints

The scientific knowledge on how the N and P losses vary from different forest types is relatively poor. It is well known that the C/N ratios in soils, atmospheric N deposition and forest management (Löfgren and Westling 2002) affect the nutrient leakage, but these relations can not easily be converted into the deciduous, mixed or coniferous types as used within the MARE project. The boreal areas could preferably be split into different classes depending on the C/N ratios in soil, atmospheric N deposition, fertilization level, clear-felled areas as well as other management practises such as draining, scarification etc. Probably, substantial areas within the herbaceous class could be within any of the suggested new tree cover classes, since they are covered by vegetation throughout the year.

The aggregation of areas covered by lichens, mosses and wetlands into one class is unlucky since lichens evolve on predominantly dry areas, while mosses and wetlands indicate moist and wet conditions, respectively. Hence, it could be expected larger nutrient losses from the marsh and bog types compared with the lichens type. Draining and excavation of peat lands could greatly affect the nutrient losses.

The aggregation of cultivated and managed areas into a single class makes it very difficult to estimate reliable N and P type concentrations and prohibits the possibilities to estimate the effects of different agricultural management practises. This class should be separated into many different classes depending on climate, soil type, crop production and animal density as well as regional differences in management. This is for the moment, however, not possible since the GIS-data are lacking.

Discussion of type concentrations

The suggested N and P type concentrations are not reflecting a true picture of the runoff and groundwater concentrations in the Baltic Sea catchments. Instead, they should be considered as possible levels yielding relevant nutrient flux estimates in the rivers if simulated with the MARE version of the CSIM-model. The assumptions behind the chosen levels are briefly described below.

Runoff

Measured or simulated N&P concentrations in runoff and/or in drainage water in different regions (se above) have been taken into consideration.

The same type concentrations have been used for all the three forest classes and the herbaceous class. Gradients in N-deposition and precipitation are used for applying different N type concentrations in different regions. Only small gradients are assumed to occur in the P type concentrations, mainly due to different precipitation.

The N and P type concentrations are assumed to be double as high from the lichens and wetland class compared to the forest classes. This might be completely wrong for the coastal regions and catchments in the most southern parts of the Baltic (Latvia and southwest to Denmark), due to a relatively small proportion of peat lands. However, we cannot separate marshes from peat lands. Still, my believe is that very fertile marshes export almost as large amounts of organically bound N as peat lands. In the southern region, an alternative approach could be to assume a somewhat lower N-concentration e.g. a factor of 1.5 instead of 2.

For the cultivation class, general gradients in climate, type of production, soils and management practises have been taken into consideration before applying the N&P type concentrations. However, the suggested values are very uncertain due to the large variation within each catchment. Hence, tangible corrections might have to be performed during the calibration process.

For the water class, general gradients in N-deposition have been taken into consideration before applying the N type concentrations. A constant P type concentration of 0.01 mg P/l is assumed in the entire Baltic catchment. The P concentrations in precipitation vary considerably, but the main sources are generally of local origin (dust, pollen, spores etc.).

For the bare area class, the N&P type concentrations are assumed to be the same as in precipitation.

For the snow and ice class, the N&P type concentrations are assumed to be half of that in precipitation.

For the artificial class, constant N&P type concentrations (3 mg/l and 0.1 mg P/l) are assumed in the entire Baltic catchment.

Groundwater

Measured or simulated N&P concentrations in groundwater and/or in percolating water at root zone level in different regions (se above) have been taken into notice.

Before applying the N&P type concentrations, the land use cover in each catchment was considered.

The N&P type concentrations in groundwater box2 are lower than in groundwater box 1, since it is assumed to be a deep groundwater with a long turnover time and thereby efficient N&P retention processes.

Scenarios

The CSIM-model can be used for making four principally different types of scenarios.

- Changing land use from one class into another is possible if the change is not too large. Otherwise, the groundwater N&P type concentrations have to be changed.
- The scenario itself can include the levels of nutrient reduction or increase. The simplest way to produce such a scenario is to test what happens if e.g. the nutrient losses from a certain land use are reduced with 5%, 10% etc. If the changes are assumed to be large, the groundwater type concentrations have to be changed in this scenario as well.
- Thirdly reduction or increase in point sources is another possible simulation change.
- Climate changes, like increased/decreased rainfall and/or temperature

Two examples of the second type of scenario could be:

- The manure and fertilizer handling (storage, application rates, timing etc.) and utilization efficiency (crop harvests) within agriculture can be improved in such a way that the N concentrations are reduced with 10% in runoff and 5% in groundwater. The corresponding figures for phosphorus are 15% in runoff and 3% in groundwater.

- The share of agricultural land covered by catch crops can be increased to such an extent that the N concentrations are reduced with 5% in runoff and 15% in groundwater. The corresponding figures for phosphorus are 0% in runoff and 0% in groundwater.

If there is a need of knowing what to be done in detail for achieving a certain nutrient reduction, the CSIM-model cannot answer that. Hence, process-based models should be used for creating such information. The complexity of large catchments makes it impossible to make expert judgements as well.

Part II - Technical information

Introduction

The CSIM model is written in Visual Basic 6.0 Pro (SP5) using modules from ComponentOne (www.componentone.com), FMS (www.fmsinc.com) and SamLogic (www.samlogic.com). In the centre of the model is an Access database which stores all information (also from multiple runs). The input data is organized in several different tables (for more information on tables and Access in general see the Access documentation). In the tables there are listings of variables which are given the appropriate values. The CSIM program opens the input tables and reads data identified by the variable names. For a full documentation of input tables and their variables see appendix A. Output tables are also structured (see appendix B) and if a validation table is given, data from the validation table is merged with the simulation data to facilitate the evaluation. The CSIM model uses Julian days for this relationship. Julian days is used throughout the modelling and is the base for the daily time step.

Calibration - Validation

The calibration of the model was performed on data from 1995 to 2000. This period was chosen because it was considered to consist of the best data available. The period from 1995 to 2000 is also the period used in the runs for NEST and the NEST scenarios. For NEST a yearly average value based on the daily results is reported for this period.

The database for each drainage basin, however, contains calibration and weather data from 1980 and onwards (to 2000) to enable validation and calibration for any period within this time span. In the current simulations for NEST only yearly fluxes have been considered (see above), but the model is capable (as mentioned earlier) to generate daily data. One of the reasons for working on this time step is that the model can simulate erosion which may be very important for especially P episodically (high discharge periods for example). By doing simulations only on a yearly basis such episodes are not catched which probably will

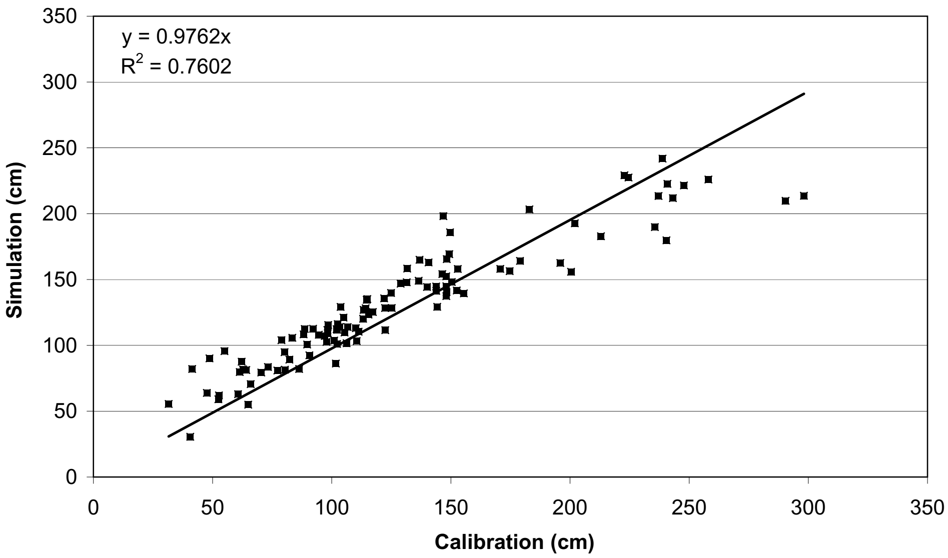


Fig. 2 Linear fit (through zero) for the water discharge in all 105 investigated drainage basins- for the validation period, 1990 to 1994.

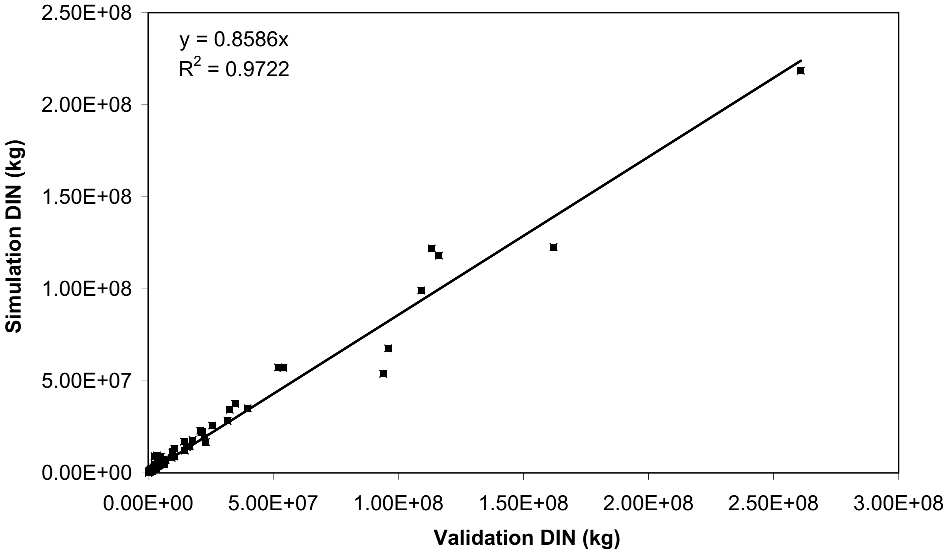


Fig. 3 Linear fit (through zero) for the DIN load in all 105 investigated drainage basins for the validation period, 1990 to 1994.

lead to an underestimation of the total loads of N and P. In the model erosion is estimated from the USLE (Universal Soil Loss Equation) algorithm which gives monthly erosion and sediment yields using monthly rainfall-runoff coefficients. These calculations require KLSCP values for each source area (e.g., land cover/soil type combination data, calculated from GIS). A sediment delivery ratio based on watershed size and transport capacity (which is based on average daily runoff) is applied to the calculated erosion. This gives the sediment yield for each source (land use class) area.

The validation period was chosen to be 1990 to 1994 and the figures 2 to 6 plots the data for these periods by comparing with simulated data. In general the data seems to be fitted very well, but for example rivers with high water discharge the simulation data is a little bit underestimated. This is manly caused by the fact that weather data was collected and calculated for rather large areas. In river basins that have different climate in different parts of the basin this may be the result, i.e. higher rainfall for example in a mountainous area is not compensated for dryer lowland

N and P loads

In the marine (Baltic Sea) model organic and inorganic N and P are handled differently. The CSIM model, on the other hand, does not calculate loads for these two forms directly but extracts information from the total and inorganic N and P loads. This is a problem since information is lacking on how inorganic and organic forms of N and P are distributed from point sources in the Baltic Sea drainage

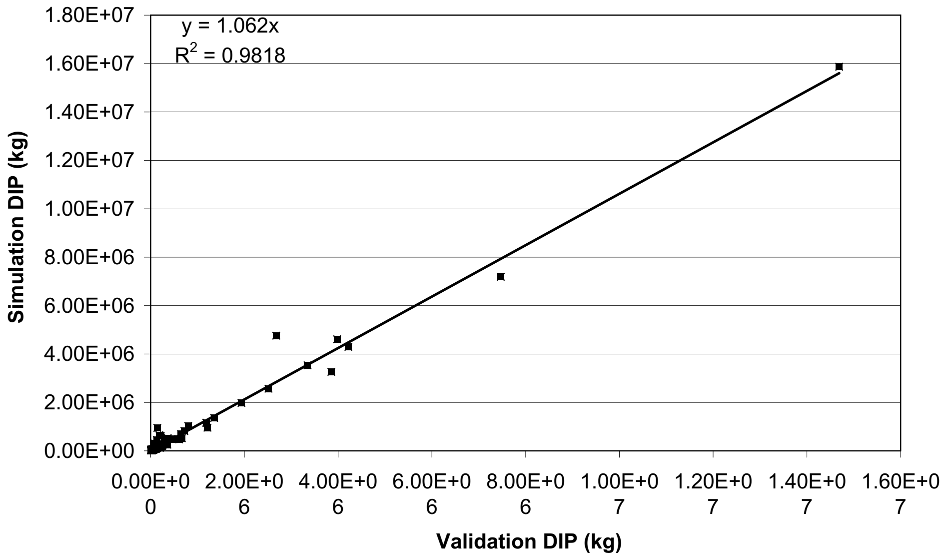
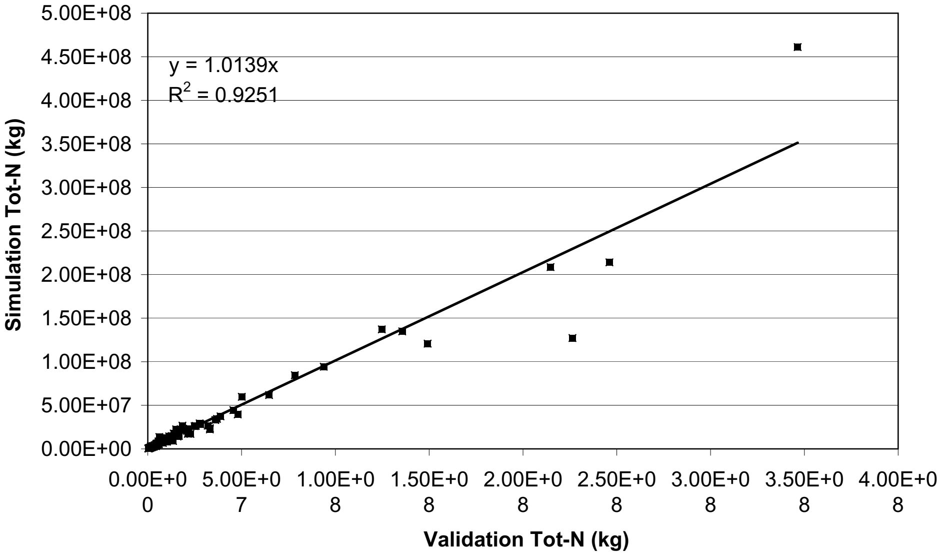


Fig. 4 Linear fit (through zero) for the DIP load in all 105 investigated drainage basins for the validation period, 1990 to 1994.

Fig. 5 Linear fit (through zero) for the Total-N load in all 105 investigated drainage basins for the validation period, 1990 to 1994.



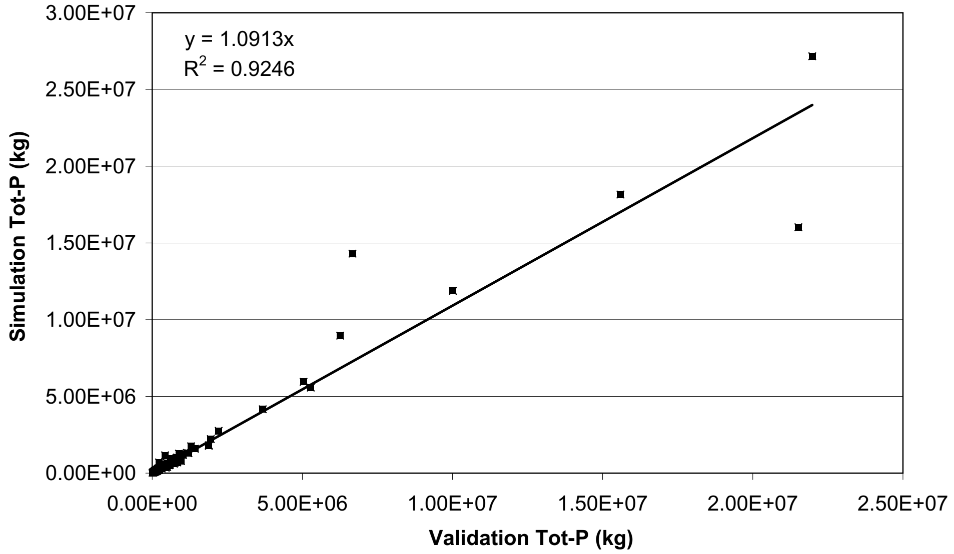


Fig. 6 Linear fit (through zero) for the Total P load in all 105 investigated drainage basins for the validation period, 1990 to 1994.

basins. The CSIM model assumes that type concentrations are of the inorganic forms of N and P and that organic forms are added through erosion and point sources, if point sources are distributed. If the distribution between inorganic and organic forms is missing, point sources must be added to either the inorganic or the organic load of N and P. In the current version of the model, point sources are assumed to be inorganic and therefore the organic forms must come from erosion and sediment yields. In order to balance the calibration data this will give too high numbers on erosion and sediment yields (alternatively much too high concentrations of N and P in the soil that erodes).

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Appenidx A, Input tables and input data

Table 1. Input tables in Access and input variables used in the modeling of CSIM.

InputTable	Variable	TypeOfVariable	Format	VariableText	Status	Unit
InNutrient	sednitr	Number		Sediment N concentration	UserInput	mg/kg
InNutrient	sedphos	Number		Sediment P concentration	UserInput	mg/kg
InNutrient	grnitrconc	Number		N concentration in groundwater box 1	UserInput	mg/l
InNutrient	grnitrconc2	Number		N concentration in groundwater box 2	UserInput	mg/l
InNutrient	grphosconc	Number		P concentration in groundwater box 1	UserInput	mg/l
InNutrient	grphosconc2	Number		P concentration in groundwater box 2	UserInput	mg/l
InNutrient	manuredareas	Integer		Number of manured areas	UserInput	Number of manured areas (sets the number of rows in NutrientManure)
InNutrient	firstmanuremonth	Integer	1-12	First month for manure	UserInput	Number of month (1-12)
InNutrient	lastmanuremonth	Integer	1-12	Last month for manure	UserInput	Numnber of month (1-12)
InNutrient	dsflag	Interger	0-3	Simulation options	UserInput	0=No septic system and multi year point source, 1=Septic system only, 2=Multi year point source, 3=Septic system and multi year point source
InNutrient	eloadN	Number		Effluent load of N	UserInput	gr/day N from septic systems
InNutrient	eloadP	Number		Effluent load of P	UserInput	gr/day P from septic systems
InNutrient	upN	Number		Uptake of N in	UserInput	gr/day efficiency in WWTPs
InNutrient	upP	Number		Uptake of P in	UserInput	gr/day efficiency in WWTPs
InNutrienta	a1	Integer		Septic system 1 (no of people)	UserInput	Number of people using four different categories of septic systems
InNutrienta	a2	Integer		Septic system 2 (no of people)	UserInput	Number of people using four different categories of septic systems
InNutrienta	a3	Integer		Septic system 3 (no of people)	UserInput	Number of people using four different categories of septic systems
InNutrienta	a4	Integer		Septic system 4 (no of people)	UserInput	Number of people using four different categories of septic systems
InNutrientManure	ManNitr	Number		Manure N concentration entering stream	UserInput	mg/l (manure that enters the stream)
InNutrientManure	ManPhos	Number		Manure N concentration entering stream	UserInput	mg/l (manure that enters the stream)
InNutrientPoint	PointNitr	Number		Point N source - monthly input (first 12 months)	UserInput	kg/month for each month of the year
InNutrientPoint	PointPhos	Number		Point P source - monthly input	UserInput	kg/month for each month of the year
InNutrientPointOption	PointNitr	Number		Point N source for consecutive months (after first 12)	UserInput	kg/month for each month of the year
InNutrientPointOption	PointPhos	Number		Point P source for consecutive months (after first 12)	UserInput	kg/month for each month of the year
InNutrientRural	LandUse	String		Defined LandUses (same as in InTranspLandUse)	UserInput	Defined LandUses (same order as in InTranspLandUse)
InNutrientRural	NitrConc	Number		N concentrion input from LandUse	UserInput	mg/l
InNutrientRural	PhosConc	Number		P concentrion input from LandUse	UserInput	mg/l
InNutrientUrban	LandUse	String		Defined LandUses (same as in InTranspLandUse)	UserInput	Defined LandUses (same order as in InTranspLandUse)
InNutrientUrban	UrbanPhos	Number		N mass flux input	UserInput	kg/ha/day

Table 1. continued... (Input tables in Access and input variables used in the modeling of CSIM.)

InputTable	Variable	TypeOfVariable	Format	VariableText	Status	Unit
InNutrientUrban	UrbanNitr	Number		P mass flux input	UserInput	kg/ha/day
InTranspAntmoist	1	Number		Moisture day 1	UserInput	cm (Moist the five days before moedeling starts), day 1
InTranspAntmoist	2	Number		Moisture day 2	UserInput	cm (Moist the five days before moedeling starts), day 2
InTranspAntmoist	3	Number		Moisture day 3	UserInput	cm (Moist the five days before moedeling starts), day 3
InTranspAntmoist	4	Number		Moisture day 4	UserInput	cm (Moist the five days before moedeling starts), day 4
InTranspAntmoist	5	Number		Moisture day 5	UserInput	cm (Moist the five days before moedeling starts), day 5
InTranspLandUse	Class	String	Rural/Urban	Rural/Urban LandUseClass	UserInput	Rural/Urban
InTranspLandUse	LandUse	String		LandUse Name	UserInput	Landuse name (order tha areas with manure first)
InTranspLandUse	Area	Number		Area for LandUse	UserInput	ha
InTranspLandUse	CN	Number		Curve Number	UserInput	
InTranspLandUse	KLSCP	Number			UserInput	
InTranspMonth	Month	Integer	1-12	Month (fixed)	SetByPrg	Apri to March, fixed
InTranspMonth	cv	Number		Evapotranspiration ceofficient	UserInput	Evapotranspiration coefficient, weighted for landuse
InTranspMonth	DayHrs	Number		Number of hours for the day	UserInput	Number of hours for the day, 2 decimals
InTranspMonth	Grow	Integer	0/1	Growing season	UserInput	True/False i.e. 0=False/1=True
InTranspMonth	Acoef	Number		Erosivity coefficient	UserInput	Erosivity coefficient
InTransport	nrur	Integer		Number of rural areas (see LandUse)	UserInput	Number of rural areas
InTransport	nurb	Integer		Number of urban areas (see LandUse)	UserInput	Number of urban areas
InTransport	recesscoef	Number		Recession coefficient box 1	UserInput	Decay from stormflow, groundwater box 1 - no unit
InTransport	recesscoef2	Number		Recession coefficient box 2	UserInput	Decay from stormflow, groundwater box 2 - no unit
InTransport	grcoef	Number		Ground water transfer from box1 to 2	UserInput	no unit
InTransport	seepcoef	Number		Seepage coefficient - water lost from the system	UserInput	Bottom tap in system lost to deep groundwater (from groundwater box 2)
InTransport	unsatstor	Number		Reservoir of water in the unsaturated zone	UserInput	cm (Initial water storage in the unsaturated zone)
InTransport	satstor	Number		Reservoir of water in the saturated zone - box 1	UserInput	cm (Initial water storage in the saturated zone, box 1)
InTransport	satstor2	Number		Reservoir of water in the saturated zone - box 2	UserInput	cm (Initial water storage in the saturated zone, box 2)
InTransport	snow	Number		Reservoir of snow as water	UserInput	cm (Initial snowpack)
InTransport	avunsatzone	Number		Average reservoir of water in the unsaturated zone	UserInput	cm (Average storage of water in the saturated zone)
InTransport	sedelratio	Number		Sediment delivery ratio	UserInput	Factor
InTransport	firstyear	Integer	yyyy	First year for simulation	UserInput	Start year (YYYY)

Table 1. continued... (Input tables in Access and input variables used in the modeling of CSIM.)

InputTable	Variable	TypeOfVariable	Format	VariableText	Status	Unit
InTransport	lastyear	Integer	yyyy	Last year for simulation	UserInput	Real year (YYYY)
InTransport	noyears	Integer		Number of years for the simulation	Calculated	Number of years for the simulation
InTransport	initmonth	Integer	1-12	Start month for the simulation (fixed to 4)	SetByPrg	Starting month given as number (4=default)
InWeather	JulianDay	Integer		JulianDay (number of days since 1 jan 4713 BC)	Calculated	Calculated from Date
InWeather	Date	String	yyyy-mm-dd	Date for the weather observation	UserInput	Date as YYYY-MM-DD in numbers
InWeather	Year	Integer	yyyy	Year	Calculated	Calculated from Date
InWeather	Month	Integer	mm	Month	Calculated	Calculated from Date
InWeather	Day	Integer	dd	Day	Calculated	Calculated from Date
InWeather	Temp	Number		Average temperature	UserInput	oC/day
InWeather	Prec	Number		Precipitation	UserInput	mm/day
CatchmentInfo	RiverName	String		River name	UserInput	
CatchmentInfo	ID	String		Unique ID for river	UserInput	
CatchmentInfo	MareCatchmentID	String		Mare catchment ID	UserInput	
CatchmentInfo	MareCatchmentName	String		Mare catchment name	UserInput	
CatchmentInfo	TributaryTo	String		Tributary to (drains into)	UserInput	
CatchmentInfo	StreamLevel	Number	1-5	Stream level (order) 1 to 5	UserInput	
CatchmentInfo	CatchmentArea	Number		Cacthment Area	UserInput	km2
CatchmentInfo	Latitude	String		Latitude at entry point to sea/river/lake	UserInput	In degrees
CatchmentInfo	Longitude	String		Longitude at antry point to sea/river/lake	UserInput	In degrees
CatchmentInfo	Country	String		Country at entry point	UserInput	
CatchmentInfo	Region	String		Name of region	UserInput	
InTransport	tempcoef	Number		Temperature coefficient for snow melt	UserInput	Factor (no Unit)
InTransport	tempthresh	Number		Temperature threshold for snow melt	UserInput	oC

Appenidx B, Output table and output data

Table 2. Output Access table and output variables from CSIM.

Category	Variable	TypeOfVariable	Format	VariableText	Status
DateTime	JulianDay	Integer		JulianDay (number of days since 1 jan 4713 BC)	Calculated
DateTime	Date	String	yyyy-mm-dd	Date for the weather observation	UserInput
DateTime	Year	Integer	yyyy	Year	Calculated
DateTime	Month	Integer	mm	Month	Calculated
DateTime	Day	Integer	dd	Day	Calculated
Weather	CPrec	Number		Precipitation	Calculated
Weather	CEvapoT	Number		Evapotranspiration	Calculated
Hydrology	CGrFlow	Number		Groundwater flow from box 1	Calculated
Hydrology	CGrFlow2	Number		Groundwater flow from box 2	Calculated
Hydrology	CRunoff	Number		Water flow from top soil layers	Calculated
Hydrology	CStrFlow	Number		Stream flow	Calculated
Hydrology	CErosion	Number		Erosion of soils (particle transport)	Calculated
Hydrology	CSediment	Number		Erosion of sediments (particle transport)	Calculated
Nutrient	CDisNitr	Number		Load of dissolved nitrogen (nitrate)	Calculated
Nutrient	CNO3Conc	Number		Concentration of dissolved nitrogen (nitrate)	Calculated
Nutrient	CTotNitr	Number		Load of total nitrogen	Calculated
Nutrient	CTNConc	Number		Concentration of total nitrogen	Calculated
Nutrient	CDisPhos	Number		Load of dissolved phosphorous	Calculated
Nutrient	CPConc	Number		Concentration of dissolved phosphorous	Calculated
Nutrient	CTotPhos	Number		Load of total phosphorous	Calculated
Nutrient	CTPConc	Number		Concentration of total phosphorous	Calculated