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# NL-CAT application to six European catchments


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ABSTRACT

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In EUROHARP, an EC Framework V project, a detailed intercomparison of contemporary catchment-scale modelling approaches was undertaken to help characterise the relative importance of point and diffuse pollution in surface freshwater systems under different European conditions. This report focusses on the application of the NL-CAT model, a combination of the SWAP (unsaturated zone/groundwater-flow), ANIMO (nutrient processes and flow), and SWQN (surface water quantity) and the NuswaLite surface water quality model (SWQL), on 6 European catchments. A description of the model setup and discretisation of all catchments is presented. Soil balances are presented in terms of nutrient input, nutrient off-take by crops, nutrient turnover processes like accumulation in soils (mineral and organic), denitrification and nutrient discharges to deeper groundwater and surface waters. Finally retention in the surface water is calculated for each catchment on catchment scale.Furthermore the results of a scenario analysis on two catchments, Enza and Zelivka, are presented.

Keywords: nitrogen, phosphorus, nutrient pollution models, manure, fertiliser, catchment, diffuse pollution, Vecht, Enza, Ouse, Vansjo-Hobol, Zelivka, Odense.

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# Preface

At the very end of the Euroharp project, after all results were submitted, the idea emerged to bring the combined efforts of Alterra together in one single report; a report that presents an overview of modelling the fate of nitrogen and phosphorous fertiliser and manure applications and the nutrient loads on surface waters in six European catchments as well as a detailed description of each catchment. The following report is the result.

The intention of this report is two sided. First of all it gives an insight into the hydrology and nutrient losses in six European catchments, each with its own typical characteristics, data availability and accuracy. None of the catchments is the same. They range from flat to hilly, from 465 $km^2$ to 3702 $km^2$ in size. Some have intensive agriculture, others are still largely forested. Two catchments have enormous reservoirs, another contains more than 40 weirs regulating the surface water system. This report describes what implications these factors have on nutrient loads. What influences the concentrations in the surface water? What are the main sources? And what causes the main retention within the whole system? Secondly it is meant to preserve the lessons learned during the past five years. Modelling the diffuse nutrient (N, P) losses to surface freshwater systems and coastal waters is not an easy task. After five years of modelling the integrated water management team of Alterra has gained significant experience in modelling this interesting and truly integrated subject. Decisions had to be made on the complexity of the processes and the detail of data input. What emerged after five years is a general methodology to model the nutrient loads to the surface water. The description of the method and its practical implications will improve future modelling efforts in new catchments.

The NL-CAT package was created and tested during the project. This package is a combination of the models SWAP (unsaturated zone/groundwater-flow), ANIMO (groundwater-nutrient flow), and SWQN (surface water quantity) and the NuswaLite (SWQL, surface water quality model). The Dutch models SWAP and ANIMO are the main models of the STONE model package that is used to quantify the distribution of nutrient losses from rural areas in The Netherlands. Within this EC-project, processes in surface waters were also taken into account in order to compare modelled nutrient discharges with the measured nutrient discharges at the outlet of the (sub) catchment. Therefore the surface water models SWQN and NuswaLite were added. The whole model instrument is called NL-CAT (Nutrient Losses at CATchment scale).

A model does not work without a modeller. The Euroharp project has been a group effort in which a large part of the team Integrated Water Resource Management (IWRM) was involved. This modelling team consisted of the following persons; Pim Dik, Margriet Groenendijk, Piet Groenendijk, Michel Jeuken, Joop Kroes, Jan Roelsma, Oscar Schoumans, Christian Siderius, Robert Smit and Dennis Walvoort. Useful assistance and advice was given by the following members of the waterboards in the Dutch part of the Vecht area; J. Uunk of the Waterboard Regge en Dinkel, H. Koskamp-Kielich and W. Oosterloo of Waterboard Velt en Vecht and W. Wiegman of Waterboard Groot Salland. Grateful use was made of the provided data on the Vecht catchment. Furthermore P. Boers of the Institute for Inland Water Management and Waste Water Treatment (RIZA) added valuable input into the project concerning retention in surface waters.

This report is intended for those who want to gain understanding in the modelling of nutrient flows on a regional scale, the related data interpretation problems, the discretisation procedures, the sensitivity of parameters and the reliability and uncertainty of results. It is not the intention to knock out the interested reader with 274 pages of graphs, tables and technical descriptions. The extensive summary gives a quick overview of the whole report. The conclusions and discussions focus mainly on the general lessons learned. Each catchment chapter can be read on its own.

More information on the Euroharp project can be found on (www.euroharp.org). Results of the Euroharp have also been published in a special issue of the Journal of Environmental Monitoring in the following articles:

- Basin characteristics and nutrient losses: the EUROHARP catchment network perspective (Bouraoui et al., 2009)
- Description of nine nutrient loss models: capabilities and suitability based on their characteristics (Schoumans et al., 2009a)
- Evaluation of diffuse pollution model applications in EUROHARP catchments with limited data (Silgram et al., 2009a)
- Evaluation of the difference of eight model applications to assess diffuse annual nutrient losses from agricultural land (Schoumans et al., 2009b)
- Subannual models for catchment management: evaluating model performance on three European catchments (Silgram et al., 2009b)
- Ensemble modelling of nutrient loads and nutrient load partitioning in 17 European catchments (Kronvang *et al.*, 2009)
- Nitrogen and phosphorus retention in surface waters: an inter-comparison of predictions by catchment models of different complexity (Josef Hejzlar *et al.*, 2009)
- Comparative study of model prediction of diffuse nutrient losses in response to changes in agricultural practices (Vagstad *et al.*, 2009)

For questions about the Euroharp, the NL-CAT package or single models the reader is referred to main authors Mr. Schoumans (oscar.schoumans@wur.nl) and Mr. P. Groenendijk (piet.groenendijk@wur.nl).

Wageningen, March 2009

# Extended summary

*Introduction*

The enrichment of fresh water systems with nutrients is acknowledged as a major problem in many European countries. One of the major aims of the EU-project EUROHARP was to determine the performance and potential capability of different type of nutrient quantification tools to assess nutrient losses to surface waters by means of a 'practical' test by comparing the results of the quantification tools on the measured data of three core catchments.

Based on an a priori intercomparison of the quantification tools used in the Euroharp project only a few models are able to evaluate the impact of both nitrogen and phosphorus applications in agriculture on nutrient loads at catchment scale. The NL-CAT model is one of them and the results of this model are presented in this report for six catchments on which the model has been applied (Vansjø-Hobøl (Norway), Yorkshire Ouse (England), Enza (Italy), Odense (Denmark), Zelivka (Czech Republic) and the transboundary catchment of the Vecht (The Netherlands-Germany). The catchments differ in size, elevation, population density, land use, livestock density and soil types. Table 0.1 shows several characteristics related to fertilizer and manure application in each catchment. The German-Dutch catchment of the Vecht clearly has the highest nitrogen and fosforous application rate. Nitrogen application in the Zelivka decreased after the political and socio-econmic changes in the beginning of the 1990'ies and is the lowest of all catchments.

*Table 0.1 fertilizer and manure application amount in six European catchments for the period 1996-2000*

| | Ouse | Zelivka | Vecht | Vansjø-Hobøl | Enza | Odense |
|---|---|---|---|---|---|---|
| **Catchment characteristics** | | | | | | |
| area (ha) | 323711 | 116077 | 370225 | 62711 | 92139 | 46536 |
| agricultural area (ha) | 226542 | 62216 | 291294 | 10813 | 66530 | 34359 |
| | | | | | | |
| **Nitrogen (kg/ha)** | | | | | | |
| Application | | | | | | |
| -manure | 83 | 68 | 198 | 32 | 161 | 92 |
| -fertilizer | 134 | 52 | 133 | 128 | 75 | 97 |
| -deposition | 62 | 12 | 38 | 9 | 49 | 23 |
| Ammonia volatilisation | 2 | 3 | * | 4 | 3 | 4 |
| | | | | | | |
| **Phosphorus (kg/ha)** | | | | | | |
| Application | | | | | | |
| -manure | 4.8 | 3.7 | 12.0 | 1.4 | 11.5 | 5.0 |
| -fertilizer | 29.7 | 21.1 | 44.7 | 23.7 | 30.5 | 32.3 |
| -deposition | 1.0 | 0.7 | 0.0 | 0.2 | 0.9 | 0.2 |

* Already deducted from manure input

The NL-CAT package, which is used by Alterra in the Euroharp project, is able to model the nutrient flow starting from the application rates of manure and fertiliser on land until the discharge at the outlet of the surface water system of the whole catchment. This model package is a combination of the models SWAP (soil water flow), ANIMO (soil water-nutrient flow), SWQN (surface water quantity) and NuswaLite (surface water quality).

*Data*

With NL-CAT both the soil system and surface water system are modelled in detail. As a result, data requirements are huge. In work package 2 of the Euroharp project data was collected in a standardized way for all catchments. Still, data availability and detail differed between the catchments. Table 0.2 shows an overview of the available data and suggestions if data should be improved to obtain better model results with NL-CAT.

*Table 0.2 Data availability for the different catchments and suggestions for improvement*

| | Ouse | Zelivka | Vecht | Vansjø-Hobøl | Enza | Odense |
|---|---|---|---|---|---|---|
| Climate data | ok | More precipitation data from different stations would be useful | ok | ok | Only precipitation and temperature data were available. Spatial coverage is very low for a mountainous area. Temperature data contained many missing values for the validation period. | ok |
| Soil data | ok | Any information on the specific regional characteristics of the deeper soil layers, not only FAO classification, could improve soil discretisation | ok | Only for arable land available | Soil information near the catchment boundary is missing. Soil profile description only available for the top layer. No information was available on soil thickness, soil water retention, soil hydraulic conductivity, pH, C/N ratio, Al and Fe contents | The assembled soil profiles are quite coarse Soil chemistry data were lacking |
| Geographical data | ok | ok | Different projections | ok | ok | ok |
| Hydrological data | No information on groundwater levels and fluctuations | Only one point measurement of groundwater levels. More information on levels related to soil classes would be useful | limited information on groundwater levels and fluctuations | No information on groundwater levels and fluctuations No information on dam(outlet) discharge control | No information on groundwater levels and fluctuations | No information on groundwater levels and fluctuations |
| Nutrient monitoring data | ok | ok | ok | ok | Concentrations are point samples. These are not very representative for an area with peak flow events. No data on flow or time proportional concentrations available. | ok |
| Point source data | No direct discharge figures for non-WWTP sources | ok | Historical discharges for German WWTP lacking, information on people not connected to wwtp (direct discharge) in Germany lacking | ok | Very rough global estimates | ok |
| Topographic data | ok | ok | Ok | ok | ok | ok |
| Land use data | No information on location and type of arable land use | ok | Location of land use types in Germany lacking | ok | Only available for a limited number of years. Data are coarse grained. | Change of land use over the years was lacking. |
| Agricultural data | Fertilizer application data are similar for all crops | Amount and application date of manure and fertilizer per agricultural crop could be improved. Now all crops have the same average application amount | Amount, type and application date of manure and fertilizer per agricultural crop for Germany is lacking | Extensive but lot of repetition | Data on nutrient management and tillage only available for a limited number of years. Data seem not very accurate, but merely very rough averages for large areas. | No distinguish in arable land use data. Too rough data on fertiliser application |
| Administrative data | ok | ok | ok | ok | | ok |

The accuracy and availability of climate data was sufficient for most catchments. However, if precipitation data is lacking or of questionable quality as in the Enza catchment, modelling the groundwater flow and water discharges becomes almost impossible and further modelling of the nutrient loads is useless. This was the main problem for all model applications in the Enza catchment within the Euroharp project. Especially the deterministic models, like NL-CAT, are capable of highlighting these inconsistencies. In sloping areas, with more local variation in rainfall often correlated to elevation, it is important to append the correct area to the right meteorological stations as the Zelivka case showed. Simply applying the Thiessen polygon method was not sufficient. In the Zelivka catchment still four meteorological stations were present whereas in the Enza catchment there was only one.
Topography and administrative data were available in sufficient detail although in the Vecht catchment it took some time to merge German and Dutch data. This is often a problem in transboundary catchments.
Overall, no or hardly any information was available on groundwater levels and fluctuations (except for the Netherlands). All European models could therefore only be calibrated indirectly by comparing measured and calculated discharges mostly from surface water monitoring stations further downstream. The runoff from different locations and various types of land use is then already aggregated in the surface water system. Information on soil chemical parameters was largely missing. Those parameters are very important which respect to modelling phosphorus losses.
Most important, information on land use and its corresponding manure and fertilizer application amounts, type and date of application was generally missing as well for most catchments. Manure and fertilizer amounts are, together with precipitation, basic inputs for NL-CAT. Inaccuracy or lack of fertilization data makes modelling of the contribution of diffuse sources by agriculture a difficult task.
Information on the surface water extensions was sufficient for catchment scale modelling with NL-CAT. A minor problem was the lack of information on the amount of people not connected to waste water treatment plants (WWTP) or historical trends in WWTP discharges.

*Discretisation and parameterization*

Table 0.3 shows the groundwater drainage discretisation as used in the SWAP model. The more hilly catchments Enza, Ouse, Vansjø-Hobøl and, to a lesser extend, Zelivka have the shallowest profile depth. The surface water classification overlaps somewhat between the catchments. The depth of the first drain class of interflow and trenches in the Vecht catchment (- 0.8 m) is for example almost similar to the depth second surface water class of the field drains and drain tubes in the Odense (-0.6 m) and part of the Vansjø-Hobøl catchment (-0.8 m to 1.4 m).

*Table 0.3 Discretisation of the groundwater model (SWAP)*

| | Ouse | Zelivka | Vecht | Vansjø-Hobøl | Enza | Odense |
|---|---|---|---|---|---|---|
| profile depth (m) | 5 | 7 | 13 | 3 | 2 - 5 | 11 |
| | | | | | | |
| Surface water classification | | | | | | |
| interflow and trenches (depth - m) | -0.5 | -0.5 to - 0.2 | -0.8 to -0.2 | -0.2 | | -0.2 |
| field drains and drain tubes (depth - m) | | -1.5 to -1 m | -1 to -0.7 | -0.8 to -0.5 | | -1.3 or -0.6 |
| streams and canals (depth - m) | -3.5 or -1.5m | -6 m | -1.8 to -1.4 | | -4.5 or -1.6 m | -10 or -5.5 |

The surface water discretisation is shown in table 0.4. Two different approaches have been used. A maximum length for the watercourse sections is used in the Zelivka and Odense catchment resulting is quite a large number of sections. In the other catchments the length of the sections is based on the presence of structures or intersecting watercourses. The SWQN model gave good results for both approaches. The Zelivka and Vansjø-Hobøl catchment both have three dammed reservoirs. Typical of the Vecht catchment is the large amount of weirs controlling the water flow. In the Enza catchment no surface water quantity or quality model was used as the residence time is less than a few days so mineralization and sedimentation processes are expected to be negligible.

*Table 0.4 Surface water discretisation*

| | Ouse | Zelivka | Vecht | Vansjø-Hobøl | Enza | Odense |
|---|---|---|---|---|---|---|
| subcatchments | 27 | 30 | 35 | 9 | 7 | 18 |
| sections | 103 | 643 | 194 | 45 | - | 224 |
| ma ximum length (m) | 15695 | 500 | 48766 | 20152 | - | 500 |
| | | | | | | |
| weirs | - | - | 36 | - | - | - |
| reservoirs | - | 3 | - | 3 | - | - |
| | | | | | | |
| Chezy resistance coefficient | 20-30 | 30 | 30-40 | 20-40 | - | 30 |

The parameters for the surface water quality model, Nuswalite, differ per catchment as well. Table 0.5 gives the ranges for different parameters. All catchments are calibrated independently by the different modellers. As can be seen some parameters like the denitrification rate vary greatly. However table 0.5 has to be interpreted with care. Some parameters might be less influential in certain catchments and therefore not calibrated elaborately. A proper calibration of mineralization and denitrification of nitrogen and the sediment sink speed of phosphorus is much more important in catchments with a large residence time and deeper water depths, e.g. in catchments with gentle slopes like the Vecht and Odense or in catchments with artificial barriers like dams and weirs as in the Vansjø-Hobøl, Vecht and Zelivka catchment. When large lakes are present like in Vansjø-Hobøl and Zelivka the calibrated parameters represent both streams and lakes. Therefore parameters might differ from the values in other catchments.

*Table 0.5 Parameterization of the surface water quality model (NuswaLite)*

| | Ouse | Zelivka | Vecht | Vansjø-Hobøl | Enza | Odense |
|---|---|---|---|---|---|---|
| Mineralization | 0.4 | 0.3 | 0.25 | 0.25 | - | 0.5 |
| Denitrification rate | 0.0015 | 0.003 | 0.07 | 0.002 | - | 0.2 |
| Sediment sink speed | 0.02 | 0.15 | 0.1 | 0.03 | - | 0.04 |
| Respiration rate | 0.1 | 0.2 | 0.2 | 0.15 | - | 0.25 |

*Results*

The run-off from the agricultural area, here defined as all water leaving agricultural land via the soil surface or drains, and average groundwater level is shown in table 0.6 (model results of SWAP).

*Table 0.6 Runoff (surface flow and drainage) and average groundwater level from the SWAP model*

| | Ouse | Zelivka | Vecht | Vansjø-Hobøl | Enza | Odense |
|---|---|---|---|---|---|---|
| runoff (mm/ha) agricultural area | 341 | 181 | 328 | 616 | 349 | 244 |
| average groundwaterlevel (m - ss) | 1.41 | 2.47 | 0.94 | 0.63 | 1.25 | 2.52 |
| period | 1990-1994 | 1996-2000 | 1996-2000 | 1996-2000 | 1996-2000 | 1996-2000 |

Table 0.7 shows the fertilizer input, uptake and discharge for each catchment. The relatively small differences in total nitrogen load to the surface water (in between 22.5 kg/ha for Ouse and 31 kg/ha for Odense) despite the large differences in manure and fertilizer application are remarkable. The main reason is that higher application amounts result in higher crop uptake and harvest. Furthermore denitrification plays a key role and increases when application rates and net input rates increase. The presented denitrification figures are split up in denitrification of the soil

layers within 1 meter below the soil surface, thus including the root zone, and denitrification of the whole soil profile below 1 meter.
The mineralization and mobilization of nitrogen in the deeper soil layers and the loss to deeper layers are the main uncertainties. There is no catchment specific empirical information about this and, as a result, these processes are highly influenced by assumptions made by the modeller. It is therefore better to look at total losses.

The erosion is presented as total erosion from the whole catchment including urban and nature areas but is expected to originate mainly from the agricultural areas. Where erosion of nitrogen is only a minor component in nitrogen loads, erosion of phosphorus contributes about 20 to 30 % to total phosphorus loads in the Zelivka, Enza, Vansjø-Hobøl and Odense catchments.

*Table 0.7 Nutrient input, uptake and discharge from the ANIMO model*

| | Ouse | Zelivka | Vecht | Vansjo-Hobol | Enza | Odense |
|---|---|---|---|---|---|---|
| **Nitrogen (kg/ha)** | | | | | | |
| Total input | 277 | 130 | 369 | 165 | 282 | 208 |
| Harvest | 164 | 100 | 220 | 100 | 171 | 152 |
| Nett input | 113 | 29 | 150 | 66 | 112 | 55 |
| N supply from soil | 7 | 22 | -1 | 30 | 44 | 5 |
| Denitrification first meter | 79 | 1 | 56 | 55 | 67 | 2 |
| Denitrification below first meter | 18 | 20 | 66 | 14 | 58 | 17 |
| | | | | | | |
| Load on surface water * | | | | | | |
| -Surface runoff | 1 | <1 | <1 | 3 | 2 | <1 |
| -Subsurface + deep groundwater | 21 | 28 | 29 | 25 | 29 | 31 |
| interflow and trenches | 11 | 1 | 15 | 1 | | <1 |
| field drains and drain tubes | | 21 | 11 | 24 | | 24 |
| streams and canals | 10 | 6 | 3 | | 29 | 7 |
| | | | | | | |
| **Phosphorus (kg/ha)** | | | | | | |
| Total input | 35.5 | 25.5 | 56.6 | 25.3 | 42.9 | 37.4 |
| Harvest | 23.1 | 15.6 | 35.9 | 17.3 | 24.0 | 29.6 |
| Nett input | 12.4 | 9.9 | 20.7 | 8.0 | 18.9 | 7.9 |
| Accumulation | | | | | | |
| -organic | 13.1 | 10.3 | 18.3 | 11.1 | 23.7 | 7.2 |
| -mineral | -1.1 | -0.7 | 2.2 | -3.0 | -5.1 | -0.1 |
| | | | | | | |
| Load on surface water | | | | | | |
| -Erosion (total catchment) | 0.01 | 0.09 | <0.01 | 0.36 | 0.07 | 0.14 |
| -Surface | 0.06 | 0.07 | 0.03 | 0.20 | 0.10 | 0.02 |
| -Subsurface + deep groundwater | 0.38 | 0.15 | 1.18 | 0.73 | 0.21 | 0.50 |
| interflow and trenches | 0.22 | 0.01 | 0.96 | 0.03 | | 0.00 |
| field drains and drain tubes | | 0.10 | 0.16 | 0.70 | | 0.39 |
| streams and canals | 0.16 | 0.04 | 0.06 | | 0.21 | 0.11 |

* For Zelivka, Vansjo-Hobol and Enza a minor amount of N erosion was simulated and added to the surface water model

In table 0.8 the retention in the *groundwater* for the agricultural area is calculated. The retention figures are based on the Nett input minus the total output via surface run-off, subsurface and deep groundwater drainage as shown in table 0.7. Overall retention is very high. As can be seen in table 0.7 most nitrogen retention is caused by denitrification. For phosphorus, accumulation in the organic component of the soil is the main cause for retention. Interesting is the low retention of 3% for nitrogen in the Zelivka catchment. Table 0.7 shows that despite a relatively large loss by denitrification output almost equals Nett input due to supply from the soil.

*Table 0.8 Retention in the soil system for the agricultural lands*

| | | Ouse | Zelivka | Vecht | Vansjø-Hobøl | Enza | Odense |
|---|---|---|---|---|---|---|---|
| period | | 1990-1994 | 1996-2000 | 1996-2000 | 1996-2000 | 1996-2000 | 1996-2000 |
| $N_{in}$ | (ton/yr) | 25599 | 1804 | 43694 | 712 | 7451 | 1890 |
| $N_{out}$ | (ton/yr) | 5090 | 1742 | 8448 | 306 | 2076 | 1062 |
| Retention | N (ton/yr) | 20509 | 62 | 35247 | 405 | 5376 | 828 |
| Retention | N | 80% | 3% | 81% | 57% | 72% | 44% |
| $P_{in}$ | (ton/yr) | 2809 | 614 | 6039 | 86 | 1257 | 270 |
| $P_{out}$ | (ton/yr) | 99 | 13 | 352 | 10 | 20 | 18 |
| Retention | P (ton/yr) | 2710 | 601 | 5687 | 76 | 1237 | 252 |
| Retention | P | 96% | 98% | 94% | 88% | 98% | 93% |

In Table 0.9 the average retention in the *surface water* calculated with the NuswaLite model is presented. There is a large variation in incoming loads. This depends on the size of the catchment, population, erosion susceptibility and intensity of agriculture. The Vecht catchment is the largest catchment, densely populated and with a very intensive agriculture, which is reflected in the high incoming loads. The effect of large lakes on the retention can be seen in the Zelivka and Vansjø-Hobøl, with an average nitrogen retention of 36% and 49% and phosphorus retention of 91% and 79% respectively. In the Vecht catchment there are no large reservoirs, but in a large part of the catchment there is only a gentle slope. This, together with the many weirs and dams, results in a longer residence time and therefore more retention.
An exception is the Ouse catchment. No reservoirs or dams are present in this catchment in the North East of England. The catchment is one of the most sloping catchments, so residence time is very short. This is reflected in the low retention for both nitrogen and phosphorus. For the Enza catchment retention in the surface water was not modelled at all. It was assumed that surface water reaches the outlet within a matter of hours or at highest days so that surface water processes and, thus, retention are negligible.

*Table 0.9 Average retention in the surface water calculated for five European catchments (NuswaLite)*

| | | Ouse | Zelivka | Vecht | Vansjø-Hobøl | Enza | Odense |
|---|---|---|---|---|---|---|---|
| period | | 1989-2000 | 1995-2000 | 1990-2000 | 1990-2000 | | 1990-2000 |
| $N_{in}$ | (ton/yr) | 6921 | 2513 | 13589 | 796 | | 1506 |
| $N_{out}$ | (ton/yr) | 6789 | 1658 | 8836 | 417 | | 1109 |
| Retention | N (ton/yr) | 132 | 855 | 4753 | 379 | | 397 |
| Retention | N | 2% | 36% | 36% | 49% | | 29% |
| $P_{in}$ | (ton/yr) | 259 | 44 | 730 | 45 | | 42 |
| $P_{out}$ | (ton/yr) | 239 | 4 | 422 | 9 | | 26 |
| Retention | P (ton/yr) | 19 | 41 | 308 | 35 | | 15 |
| Retention | P | 8% | 91% | 44% | 79% | | 40% |

Table 0.10 shows the model efficiency for the 6 catchment for NL-CAT and two other process based models. Model efficiency is high except for the SWAT application in Norway (Vansjo-Hobol) and the NL-CAT application in the Vecht regarding discharges. In the Vecht catchment measured discharges at the outlet seem to be too low compared to measured discharges upstream taking into account catchment area and precipitation. In the case of clear errors in measured data a high NSE should of course be considered questionable. In the Enza catchment modelling was not possible due to highly inconsistent input data.

*Table 0.10 Model efficiency (Nash-Suttcliffe: NSE) for NL-CAT and two other process based models used in the Euroharp project (see also Schoumans et al., 2009a and Schoumans et al., 2009b)*

| | | flow_m3s | TP_kgha | TN/DIN_kgha |
|---|---|---|---|---|
| Ouse | NL-CAT | 0.8 | - | 0.7 |
| | TRK | 1.0 | - | - |
| | SWAT | 1.0 | - | 0.7 |
| Enza | NL-CAT | - | - | - |
| | TRK | - | - | 0.5 |
| | SWAT | 0.8 | - | 0.8 |
| Vansjø-Hobøl | NL-CAT | 0.9 | 0.67 | 1.0 |
| | TRK | 1.0 | - | 0.9 |
| | SWAT | 0.6 | 0.03 | 0.1 |
| Zelivka | NL-CAT | 0.8 | 0.5 | 0.8 |
| | TRK | - | - | - |
| | SWAT | - | - | - |
| Odense | NL-CAT | 0.9 | 0.7 | 0.8 |
| | TRK | - | - | - |
| | SWAT | - | - | - |
| Vecht | NL-CAT | 0.15 | 0.7 | 0.4 |
| | TRK | 0.9 | - | 0.7 |
| | SWAT | - | - | - |

*Conclusions*

Nutrient transport is closely related to hydrological pathways. A detailed hydrologically based nutrient transport model gives a valuable insight in the different processes leading to the surface water load on both field and catchment scale.

It is shown that with one of the quantification tools involved in the EUROHARP project, NL-CAT, the fate of nutrients in soils can be determined together with the nutrient losses from agricultural land. The nutrient losses can vary remarkably within European catchments as a result of nutrient application rates, landscape, soil type and climatic and hydrological conditions.

Denitrification in groundwater controls the total loss for nitrogen. Assessment of the denitrification is still very uncertain as detailed empirical information from most catchments is lacking. For phosphorus the soil chemical sorption capacity, meteorological conditions and the drainage conditions controls the P losses from agricultural land.

The nutrient discharges downstream depend highly on the hydraulic conditions. An increase in residence time of the water results in an increase of retention in surface water as a result of more denitrification or sedimentation.

Based on the experiences from this European study it is concluded that the reliability and plausibility of the model results can be improved by means of:

- Independent validation of specific individual processes like denitrification and phosphorus sorption/desorption kinetics (detailed laboratory and field studies)

- Increase the experience of the modeller (system analysis in relation to internal model assumptions)

- Expert judgment of the modeller with respect to missing data. The general experience is that the model result depends for 25% of the model, 50% of the experience of the modeller to model at catchment scale and 25% of good luck.

- If the harmonization of procedures and tools is a main objective of an intercomparison of quantification tools, the design of the study should take account for this human (subjective) influence on the results. Exchanging the tools and exchanging scientists among different groups could also contribute to the harmonization aim.

# 1 Introduction

The enrichment of fresh water systems with nutrients is acknowledged as a major problem in many European countries. In order to monitor the contribution of nutrient pollution of river basins from different sources a series of nine "HARP" guidelines were developed (Borgvang and Selvik, 2000). However, with respect to the contribution of agriculture to the diffuse nutrient losses no single method could be agreed upon because of the complexity of processes involved. On request of OSPAR (Oslo-Paris Commission for the protection of the northeast Atlantic), a project was initiated, and in 2002 funded by the EC Framework V, for the intercomparison of these different approaches. There is an urgent need to understand the fate of nutrients applied to agricultural land because the Water Framework Directive (2000/60/EG) requires the identification of problem areas and the assessment of agricultural contributions to surface water quality. Furthermore, mitigation options should be implied within river basins in order to improve the surface water quality. From this point of view an evaluation of different types of tools that are able to assess the fate of nutrients applied agricultural land is important in order to support water managers with policy making at river basin scale.

One of the major aims of the EU-project EUROHARP is to determine the performance and potential capability of different type of nutrient quantification tools to assess nutrient losses to surface waters at first by means of an *a* priori scientific evaluation and secondly by means of a 'practical' test by comparing the results of the quantification tools on the measured data of three core catchments.


The 17 catchments involved in the EUROHARP project represent different sizes of river basins (from 254 km² to 10.600 km²) and due to their widespread location they also vary in climate, geology, soil types and land use conditions (Figure 1-1). The annual export of nutrients from these rivers basins shows extreme variations, e.g. for nitrogen from 2.8 to 25.7 kg $ha^{-1}$ N (Kronvang et al., 2003). Despite of a low annual nutrient export from the outlet of some catchments the annual nutrient losses from agricultural areas within the catchment is assumed to be very high because of the high retention capacity of surface waters for nutrients within the catchments (lakes, reservoirs) (Kronvang et al., 2003). This is mainly caused by denitrification processes in surface water and sedimentation of phosphorus rich particles.

*Figure 1-1 Map of Europe showing the location of the 17 EUROHARP catchments*

The results of the NL-CAT model will be presented for the six catchments on which the model has been applied (Vansjø-Hobøl (Norway), Ouse (England), Enza Italy, Odense (Denmark), Zelivka (Czech Republic) and the transboundary catchment of the Vecht (The Netherlands-Germany).

# 2 Short model description of NL-Cat

**P. Groenendijk, R. Smit & D. Walvoort**

In the Netherlands the STONE model chain (Wolf, et al., 2003) is used for the assessment of the intended fertilisation measures on nitrate concentrations in groundwater and nutrient load on surface water systems (Overbeek *et al.*, 2001; Milieu- en Natuurplanbureau, 2002; Milieu- en Natuurplanbureau, 2004; Schoumans, *et al.*, 2004). In this model chain the SWAP model (Van Dam, 2000; Kroes and Van Dam, 2004) is used to generate hydrological input to the ANIMO model (Groenendijk and Kroes, 1999) ANIMO simulates the nutrient cycle in soil and the nutrient leaching to groundwater and surface waters. The CLEAN model is used to generate the nation-wide manure and fertiliser input for the ANIMO model over a long-term period (Wolf *et al.*, 2003).

For the assessment of the relation between the agricultural land use and the surface water quality at the catchment scale, more or less the same model chain is used. The manure and fertiliser model input to ANIMO is generated in more detail, using local expert judgement and additional information concerning the (international) market structure, fertiliser restrictions and directives. In addition extra models are used for simulation of the nutrient retention in surface waters. The surface water flow the WATDIS model (WATer DIStribution model; Rijtema *et al.*, 1991) has been adapted and this Surface Water Quantity Model is called SWQN (Smit *et al.* 2003). Simulation of surface water quality processes and retention estimates within a (large) catchment are performed by the SWQL model (Siderius *et al.*, 2008). The SWQL model has been derived by simplifying the NUSWA model model (Van der Kolk et al., 1995). The soil modules are field plots models. For simulation soil water flow and nutrient leaching at the regional scale, a catchment is sub-divided into a number of calculation units. The GIS-based discretisation procedure is an essential part of the so-called NL-CAT (Nutrient Losses on CATchment scale;Figure 2-1).

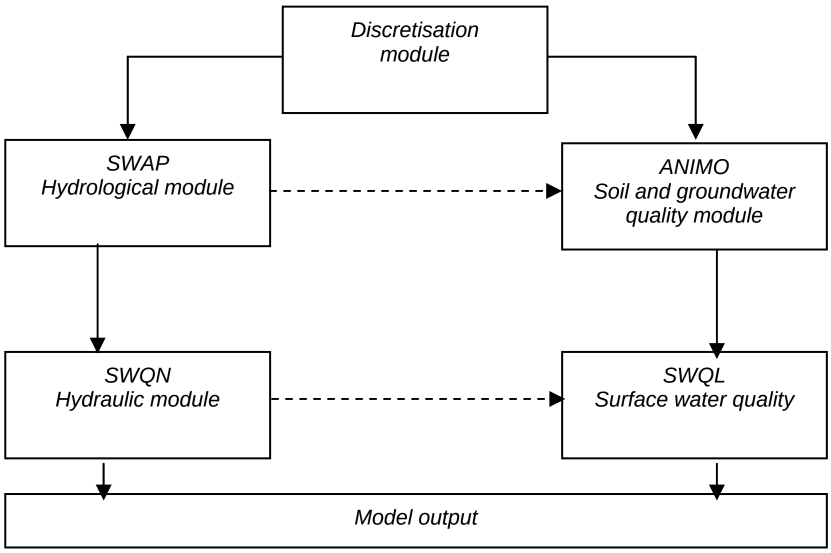



*Figure 2-1 Model components of the quantification tool NL-CAT*

## 2.1 Soil water flow (SWAP)

Water discharge to groundwater and surface water is schematised by a pseudo-two-dimensional flow in a vertical soil column with unit surface. The ground level provides the upper boundary of the model and the lower boundary is at the hydrological basis of the system defined. The lateral boundary consists of one or more different drainage systems. The position of lower and lateral boundaries depends on the scale and type of model application.

Hydrological data, such as water fluxes and the moisture content of the distinct soil layers, are supplied by the field plot model SWAP (Van Dam 2000; Kroes and Van Dam, 2004). The discretisation of the soil profile and the main terms of the water balance for a particular drainage situation are depicted in Figure 2-2.

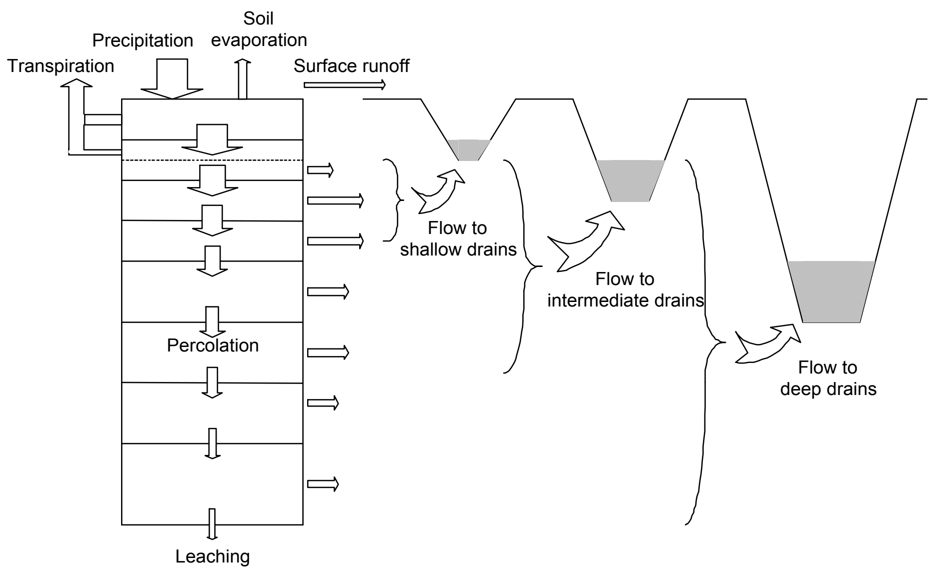



*Figure 2-2 Scheme of water flows in a soil profile and the main terms of the water balance.*

In regions with high groundwater levels and water discharge towards surface water, residence times are strongly influenced by the size and depth of the drainage system. In non-point water quantity models, the extent of water flows to each of the drainage systems must be calculated by using drainage formulae applicable to the local flow.

In the non-point water quality models, regional spatially distributed patterns of soil type, land use and hydrology are schematised by a number of homogeneous sub-regions. The size of a sub-region depends on the heterogeneity of these factors and on the ultimate goal of the model application. The boundary between local and regional flow can be defined as the depth below which no discharge to local surface water occurs. Above this depth, the greater part of the precipitation surplus flows to water courses and other drainage systems. This depth depends on the deepest streamline discharging water to the drainage systems.

Once the regional and local flow have been segregated by the position of the boundary surface, the streamline pattern within the top system is schematised into vertical fluxes between soil layers and into lateral fluxes in the saturated zone. Information on water discharges and drainage distances is used to simulate residence times of water and solute in the saturated zone.

## 2.2 Soil nutrient cycle and leaching (ANIMO)

ANIMO model aims to quantify the relation between fertilisation level, soil management and the leaching of nutrients to groundwater and surface water systems for a wide range of soil types and different hydrological conditions. The upper and horizontal boundary systems of the model are the surface of agricultural land (where the nutrient inputs take place) and the edge of the field/plot (horizontal nutrient out flow). The lower boundary system is, most of the time very low (e.g. 7-15 m below surface level). It should be noted that only retention in the soil is described.

The ANIMO model focuses on the following processes:
- additions (fertiliser, manure, crop residues, atmospheric deposition),
- mineralization of nutrient compounds in relation to formation and decomposition of different types of organic matter as organic fertilisers, root residues, yield losses and native soil organic matter;
- volatilisation ($CO_2$, $NH_3$, $N_2$, $N_2O$),
- nitrification of $NH_4$ and denitrification of $NO_3$;
- sorption onto and diffusion within soil particles, described by a combination of instantaneous and time dependent sorption and chemical precipitation of phosphates (Schoumans and Groenendijk, 2000);
- uptake by the vegetation;
- transport of dissolved organic and inorganic nutrients with water flow to deeper soil layers and to adjacent surface water systems; and
- overland flow of dissolved organic phosphorous, inorganic phosphate and particulate phosphate with water flow to adjacent fields (runoff and erosion)

In the most recent version of ANIMO (version 4.0; Groenendijk *et al.*, 2005) also two other important processes are described:
- (preferential) macro-pore flow
- snow melting

ANIMO comprises description of the organic matter cycle (Figure 2-3) , the nitrogen cycle (Figure 2-4) and the phosphors cycle (Figure 2-5) since these cycles are interrelated in most of the modern farming systems and in soil bio-chemistry.

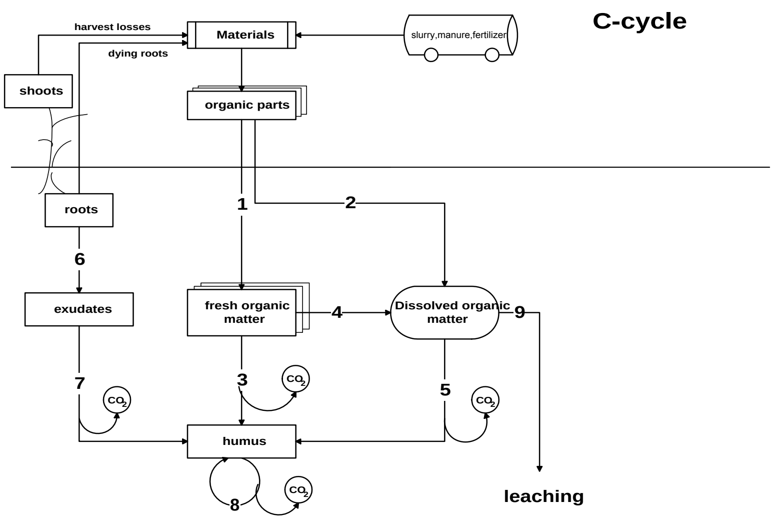



*Figure 2-3 Relational diagram of the organic matter cycle described in the ANIMO-model*

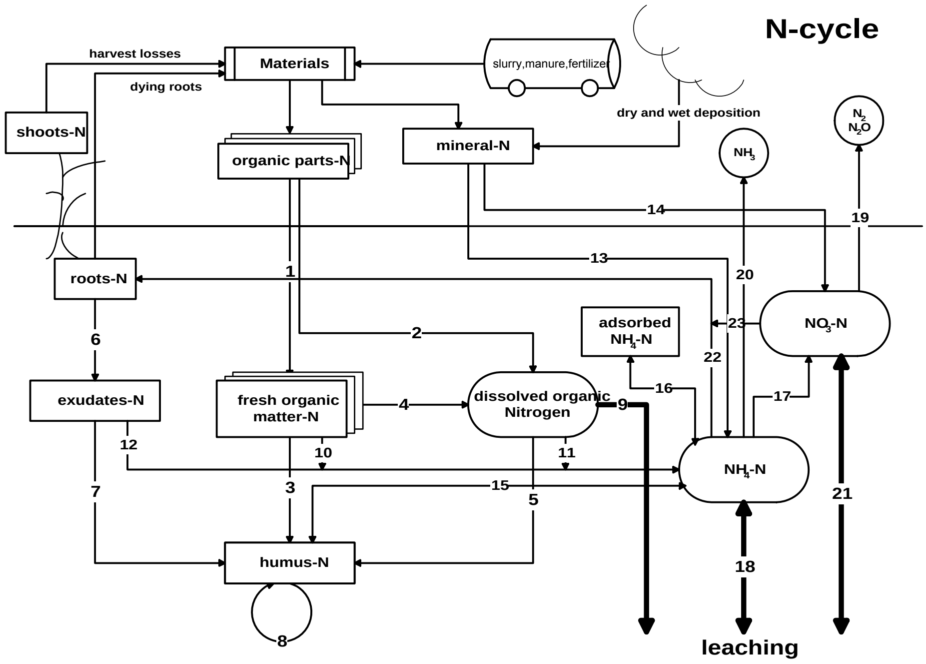



*Figure 2-4 Relational diagram of the nitrogen cycle described in the ANIMO-model*

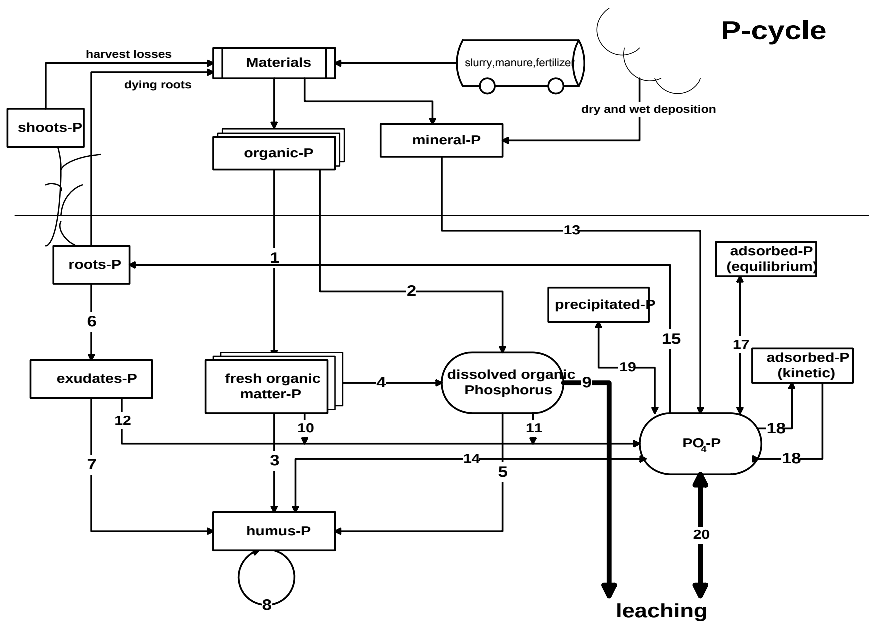



*Figure 2-5 Relational diagram of the phosphorus cycle described in the ANIMO-model*

*Nutrient losses from land to surface waters*
Transport routes from agricultural land are related to surface runoff, leaching to groundwater and leaching to surface water systems (Figure 2.6).

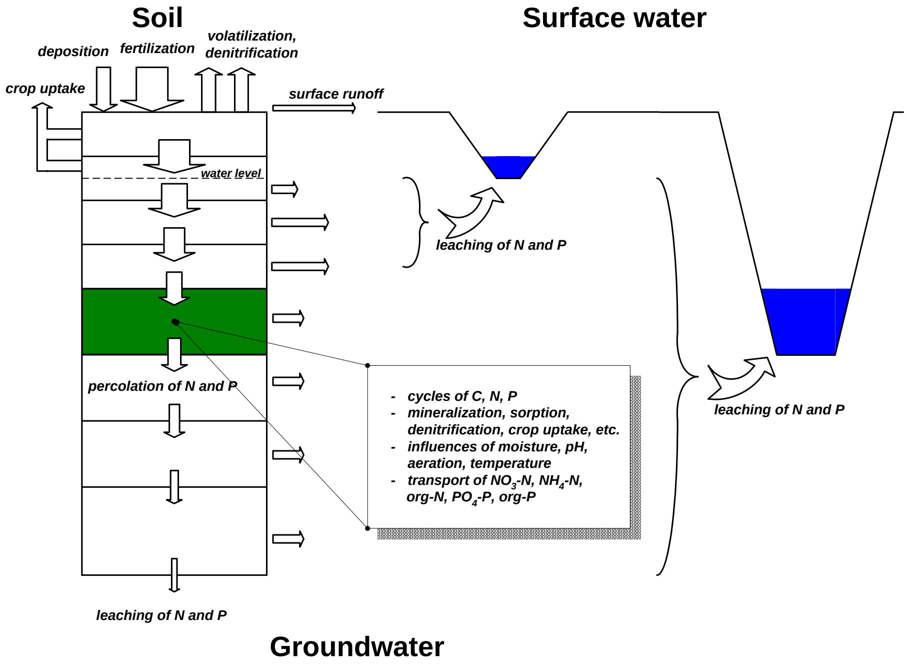



*Fig. 2.6 Transport routes and nitrogen and phosphorus related processes included in the ANIMO model*

The model has been reviewed and compared to other process oriented dynamic models by Wu and McGechan (1998), Vinten (1999), Lewis and McGechan (2002), McGechan and Lewis (2002).

## 2.3 Surface water quantity model (SWQN)

Computing water levels and flows in very large schemes of open watercourses requires a robust and relatively fast algorithm. To meet such requirements the SWQN model has been developed in which watercourses are schematised into a network of nodes linked by segments. The earliest versions were used to compute the water distribution in large irrigation schemes, such as the complete Nile Delta (Rijtema et al., 1991; Smit and Abdel Gawad, 1992). Performance was so good in terms of computation time and accuracy (on that particular scale), that it was decided to derive a version which could also be used for Dutch catchments, where unlike the Nile Delta de-watering is the dominant process. In order to fit in the new modelling framework developments at Alterra, it was decided to rebuild the original program into a dynamic link library (Groenendijk et al., 1999).

The SurfaceWater DLL provides a method to compute flows and water levels in a network of nodes labelled as 'volumes' and segments labelled as 'connectors'. Water levels are calculated in the nodes and, together with the estimated velocity head, form the driving force behind the one-dimensional flow in the connectors between the volumes.

The model is pseudo-dynamical in time, based on the assumption that steady-state conditions prevail during a time step. A connector can be specified as an open watercourse or an artefact like a weir, underflow, pump, etc. It is assumed that the flow between 2 nodes is linear dependent on the difference in water level, the wetted profile and a given resistance. Each artefact, on the other hand, has its own specific stage-discharge relation and is linearised using a number of intervals.

The model is designed in a way that simplifies the addition of new functionality. Both the data transfer (through a structure block), and the internal structure of the model are prepared for this. New functionality will chiefly consist of different types of structures. The latest version allows for large network configurations up to thousands of nodes, depending on the internal memory of the computer used. The internal computational time step is usually set from 1 to several hours, but strongly depends on the water storage capacity associated with the volumes and the dynamic behaviour of the modelled system. The specifications of structures can be changed in time by providing structure control time series. Water flow between the nodes is calculated as a linear function of the water level difference during the distinguished time steps and the calculated resistance of the connections. Simulation results are redirected to CSV-files to enable easy post processing. Optionally SWQN can send the results to input files for the next step in the model chain: NUSWALITE.

## 2.4 Surface water quality model (NUSWALITE)

The surface Water Quality Model NUSWALITE (Siderius *et al.*, 2008) indirectly calculates the nutrient retention in a surface water system by process oriented model descriptions. The model consists of a simplification of the NUSWA model (NUtrient modelling in Surface Waters; Van der Kolk, 1996). The model describes the dissolved organic and mineral fractions of nitrogen and phosphorus concentrations in a network of nodes. Also two fractions of living biomass are considered: a floating fraction, which can be transported with water flow, and an immovable fraction having roots in the sediment. Biomass is considered to have a fixed nutrient ratio, so no separate pools of nitrogen and phosphorus in biomass are defined. Besides inflow, outflow (not for immobile biomass) and loading (not for biomass), the following processes are taken into account (Figure ):

- Growth of biomass with linked uptake of nutrients and limited by solar radiation and nutrient availability
- Death of biomass which adds to the organic nutrient pools
- Degradation of organic nutrients to their mineral forms
- Denitrification of inorganic nitrogen
- Linear sorption of mineral nutrients to the sediment
- Sedimentation of inorganic phosphorus

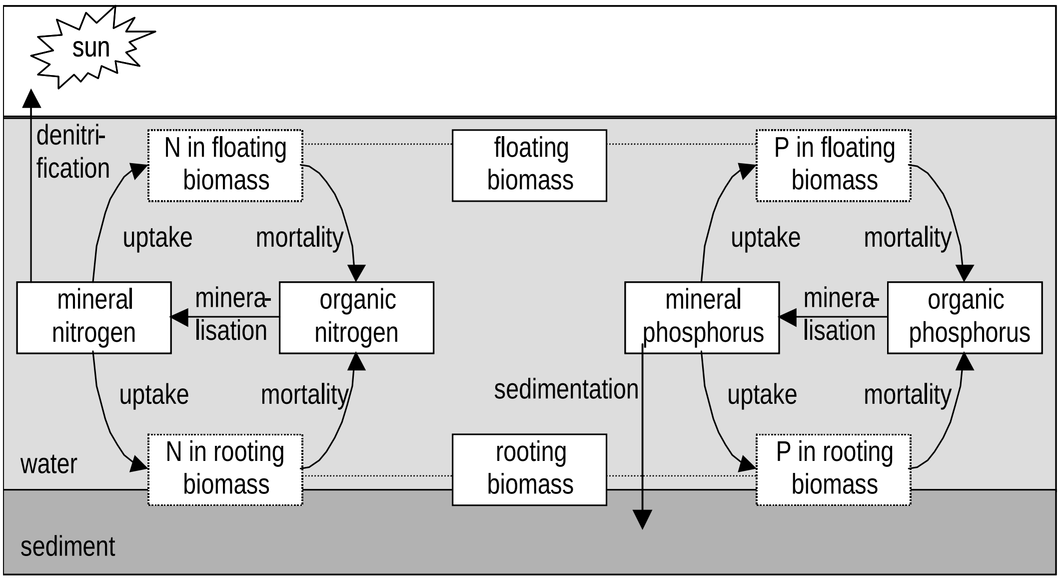



*Figure 2.7 Nutrient cycles described in the NUSWALITE model*

The set of equations describing these processes is solved using a numerical finite difference solution technique. The time variable is solved analytically which enables the use of large time steps (usually limited to one day due to variability of boundary conditions). Input consists of a network layout and a water balance (as could be provided by SWQN or any other hydraulic model), nutrient loading from various sources (e.g. leaching as calculated by ANIMO or point sources), environmental conditions (e.g. temperature and global radiation), initial conditions and parameter settings.

## 2.5 Erosion module (P-USLE)

To quantify the amounts of P (and optionally N) added to the surface water system via surface erosion, the NL-Cat model has been extended with a simple erosion module, *i.e.*, P-USLE. This module is based on the modified and revised Universal Soil Loss Equations (respectively MUSLE and RUSLE) and implemented in a GIS-environment. P-USLE quantifies the amounts of P entering the surface water system by surface erosion in two steps. First, the amount of sediment generation $E$ for each grid cell is computed as the product of:

- the rainfall and run-off factor $R$;
- the soil erodibility factor $K$;
- the soil cover factor $C$;
- the slope length and steepness factors $LS$;
- the erosion control practice factor $P$;
- and the coarse fragment factor $r$.

Compared to MUSLE and RUSLE, factors $R$ and $C$ have been adapted in order to better match data availability. Appendix 1 gives a full explanation of the used equations.

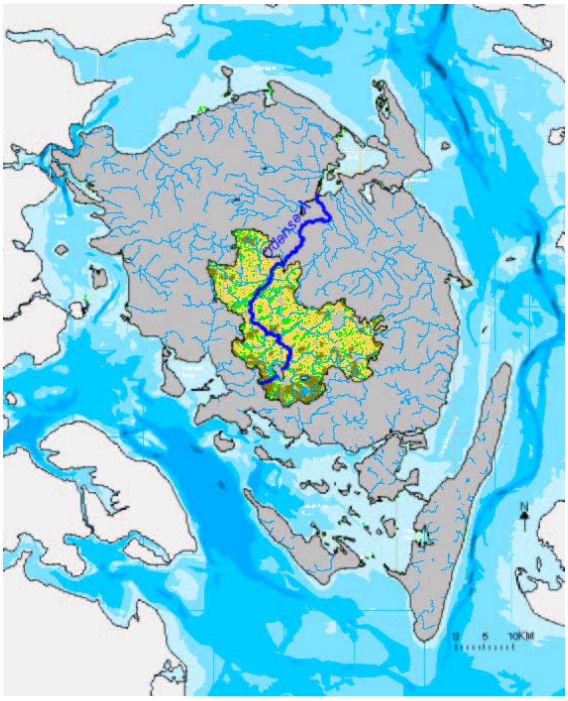
During the second step, the amount of particulate P entering the surface water system is computed by combining $E$ and the amount of phosphorus in the top soil. The latter is computed by ANIMO.

# 3 The Odense catchment

P.E. Dik & P. Groenendijk

## 3.1 Introduction

The Odense Å catchment is situated at the island of Fyn central in Denmark. The upper part of the catchment ( 486 km$^2$) is included in the EUROHARP project.




Odense Å is draining lowland areas where agriculture (around 80%) is the dominating land use. Forest and pristine areas (14%) open waters (2%) and urban areas (3%) account for the rest of the catchment.

Dominating crops grown are cereals (approx. 2/3). Pig and cattle farming includes 40.000 Livestock Units (mainly pigs).

Sewage outlets from small cities (20.000 inh.) is treated well in sewage treatment plants. However, nutrient concentrations in main stream course are high due to the intensive agricultural land use (N and P) and sewage outlets from approx. 10.000 inh. in rural areas (P).

*Table 3.1 General information of the Odense catchment*[1]

| | |
|---|---|
| Catchment Area | 486 km$^2$ |
| Elevation Range | Low-land |
| Rainfall /y (1990-2000) | 896 mm |
| Run-Off/y (1990-2000) | 298 mm (4,6 m$^3$/s) |
| Soils | Loamy |
| Arable Land | Approx. 80% |
| Inhabitants | Approx. 20.000 inh. |
| Live-stock units | Approx. 40.000 LU |
| Nitrogen and Phosphorus in main stream course | 6.0 mg N/l<br>0.25 mg P/l |

[1] This information is retrieved from the Euroharp website: http://euroharp.org/map/img/den.htm

## 3.2 Discretisation

### 3.2.1 General

The objective of the discretisation is to support the simulation by defining calculation units. There is a general rule that the discretisation should not be too detailed (to avoid too long run times) and not too simple (to avoid too coarse results). The discretisation should be based on the availability of data and processknowledge. The discretisation can be divided in three.
Firstly the area has to be subdivided into representative units for the area, including meteo, land use, soil and (geo) hydrology. The units will be modelled as one dimensional soil columns. In chapter 3.3 the parameterisation of these units is described. These units are connected to the surface water system.
The second part of the discretisation is the definition of the calculation units for the surface water system.
The third part is the discretisation of the soil columns; the definition of the soil layers.

### 3.2.2 Areal units

#### 3.2.2.1 Definition of meteorology regions

*General*
There are two sources of data available for the meteodata:

- meteostation data: rainfall, solar radiation, sunshine hours
- grid data: for Denmark grid data is available:
    - for the 10x10 km-grids: precipitation
    - for the 20x20 km-grids: air temperature, daily potential evapotranspiration.

In the description accompanying the data it is advised not to make the one meteo station representative for the whole catchment. It is suggested to relay on the grid-data, because this data accounts for the spatial variability in the region.

*Precipitation*
As shown in Table 3.2 the meteo-station has a much lower precipitation amount than the mean of the grid data: the differences amount up to 200 mm/yr!
The table shows that the mean difference in precipitation per grid equals about 8%.

*Table 3.2 Precipitation and characteristics for the grids of the Odense catchment (and for meteostation 28280)*

| year | grid data mean | grid data std | grid data max | grid data min | grid data max-min | *meteo-station* |
|---|---|---|---|---|---|---|
| 1990 | 984 | 41 | 1034 | 916 | 117 | *746* |
| 1991 | 811 | 40 | 859 | 732 | 128 | *605* |
| 1992 | 819 | 27 | 857 | 782 | 75 | *635* |
| 1993 | 955 | 52 | 1026 | 876 | 150 | *740* |
| 1994 | 1114 | 49 | 1171 | 1029 | 142 | *825* |
| 1995 | 756 | 31 | 800 | 717 | 83 | *529* |
| 1996 | 605 | 23 | 637 | 578 | 59 | *441* |
| 1997 | 717 | 21 | 766 | 687 | 79 | *533* |
| 1998 | 1066 | 45 | 1133 | 1001 | 132 | *781* |
| 1999 | 1047 | 37 | 1104 | 980 | 124 | *863* |
| 2000 | 883 | 32 | 919 | 827 | 92 | *729* |
| 2001 | 882 | 45 | 947 | 816 | 131 | *640* |
| mean | 886 | 22 | 927 | 856 | 71 | *672* |

The grids with about the same mean precipitation are clustered. The reason for the clustering is to avoid too long calculation times. In Table 3.4 and Figure 3.1 the clustering is given. In Table 3.2 the mean yearly precipitation per grid is given.

*Table 3.3 Average yearly precipitation*

| Meteogrid | Average yearly precipitation (mm) |
|---|---|
| 10379 | 859 |
| 10380 | 906 |
| 10381 | 927 |
| 10382 | 865 |
| 10404 | 884 |

*Table 3.4 Assigned meteostations to the grids*

| Meteogrid | Assigned meteogrid |
|---|---|
| 10351 | 10382 |
| 10352 | 10404 |
| 10353 | 10379 |
| 10379 | 10379 |
| 10380 | 10380 |
| 10381 | 10381 |
| 10382 | 10382 |
| 10402 | 10404 |
| 10403 | 10380 |
| 10404 | 10404 |
| 10419 | 10404 |
| 10420 | 10380 |

*Evapotranspiration*

The differences between the grids for the evaporation data are very small (Table 3.5), it ranges between 595 and 606 mm/y. Therefore the data of one grid is used as input for the model. Grid 20111 approximates the mean very close and is used as the grid for the whole catchment.

*Table 3.5 Evaporation characteristics for the grids of the Odense catchment*

| | Grid number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | 20095 | 20096 | 20111 | 20112 | 20121 | 20122 | mean | min | max |
| 1990 | 604 | 595 | 615 | 603 | 616 | 611 | 607 | 595 | 616 |
| 1991 | 577 | 578 | 577 | 577 | 580 | 581 | 578 | 577 | 581 |
| 1992 | 635 | 634 | 640 | 635 | 645 | 645 | 639 | 634 | 645 |
| 1993 | 553 | 549 | 554 | 553 | 564 | 565 | 556 | 549 | 565 |
| 1994 | 612 | 612 | 615 | 615 | 620 | 622 | 616 | 612 | 622 |
| 1995 | 631 | 636 | 633 | 636 | 638 | 643 | 636 | 631 | 643 |
| 1996 | 573 | 572 | 577 | 578 | 582 | 582 | 577 | 572 | 582 |
| 1997 | 639 | 641 | 644 | 643 | 647 | 650 | 644 | 639 | 650 |
| 1998 | 543 | 544 | 545 | 548 | 553 | 554 | 548 | 543 | 554 |
| 1999 | 614 | 614 | 617 | 619 | 623 | 628 | 619 | 614 | 628 |
| 2000 | 578 | 576 | 582 | 582 | 588 | 591 | 583 | 576 | 591 |
| 2001 | 584 | 590 | 587 | 591 | 593 | 598 | 591 | 584 | 598 |
| mean | 595 | 595 | 599 | 598 | 604 | 606 | | | |

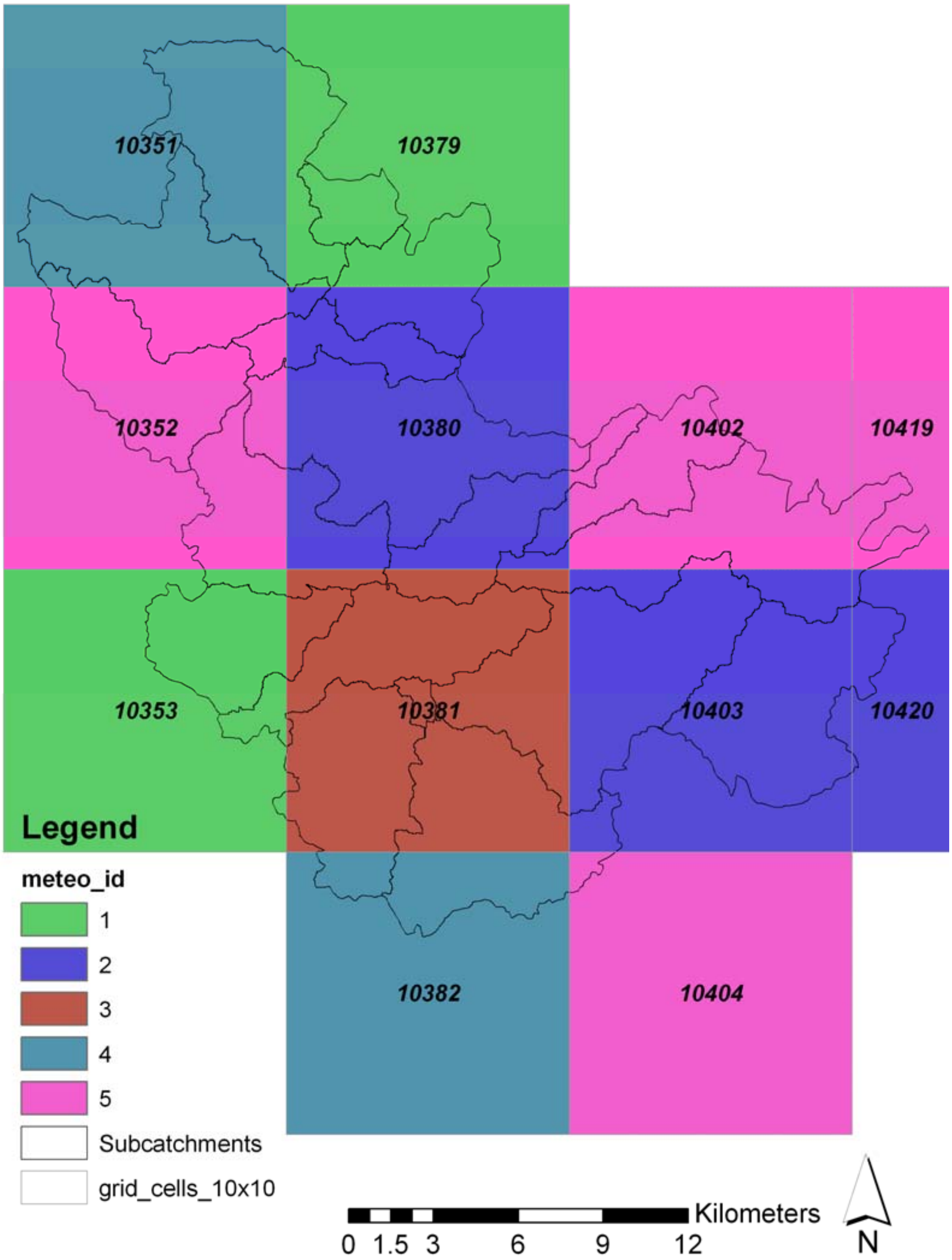



*Figure 3-1 Schematised meteo-districts for precipitation*

#### 3.2.2.2 Definition of land use classes

The land is mainly used as arable land (70%). About 8% is used as urban areas and roads. The forests cover about 13% of the catchment and are found in the southern part (Table 3.6).

*Table 3.6 Land use in the catchment*

| Land use | % | Classified |
|---|---|---|
| Arable land inclusive fallow | 70.3 | 1 Arable |
| Urban areas, roads | 8.9 | 2 Urban |
| Deciduous forest | 8.2 | 3 Forest |
| Coniferous forest | 4.9 | 3 Forest |
| Peat bog | 2.4 | 5 Water |
| Inland marsh | 1.9 | 5 Water |
| Lake and streams > 8-12 m | 1.6 | 5 Water |
| Unclassified | 0.7 | 4 Natural |
| Natural grassland | 0.7 | 4 Natural |
| Pastures | 0.4 | 1 Arable |
| Heath land | 0.1 | 4 Natural |

In the discretisation several classes are joined:

- the class ‘arable’ consists also ‘permanent grass’, which contributes only a few percentages to this class. Therefore also the ‘pastures’ are joined to this class;
- the class ‘urban’ only consists of the urban land use types;
- the class ‘natural’ consists of the land use types ‘unclassified’, ‘natural grassland’ and ‘heath land’;
- the class ‘forest consists of ‘decidious’ and ‘coniferous forest’;
- the class ‘water’ also includes the strongly evaporation wet land use types (‘peat bogs’, ‘inland marsh’).

So in total 5 land use types are distinguished and presented in Figure 3-2. In Table 3.7 the assigned areal percentages are given.

*Table 3.7 Assigned land use for the model*

| land use | Areal percentage |
|---|---|
| arable | 70.9% |
| urban | 8.7% |
| forest | 13.0% |
| nature | 3.3% |
| water | 4.0% |

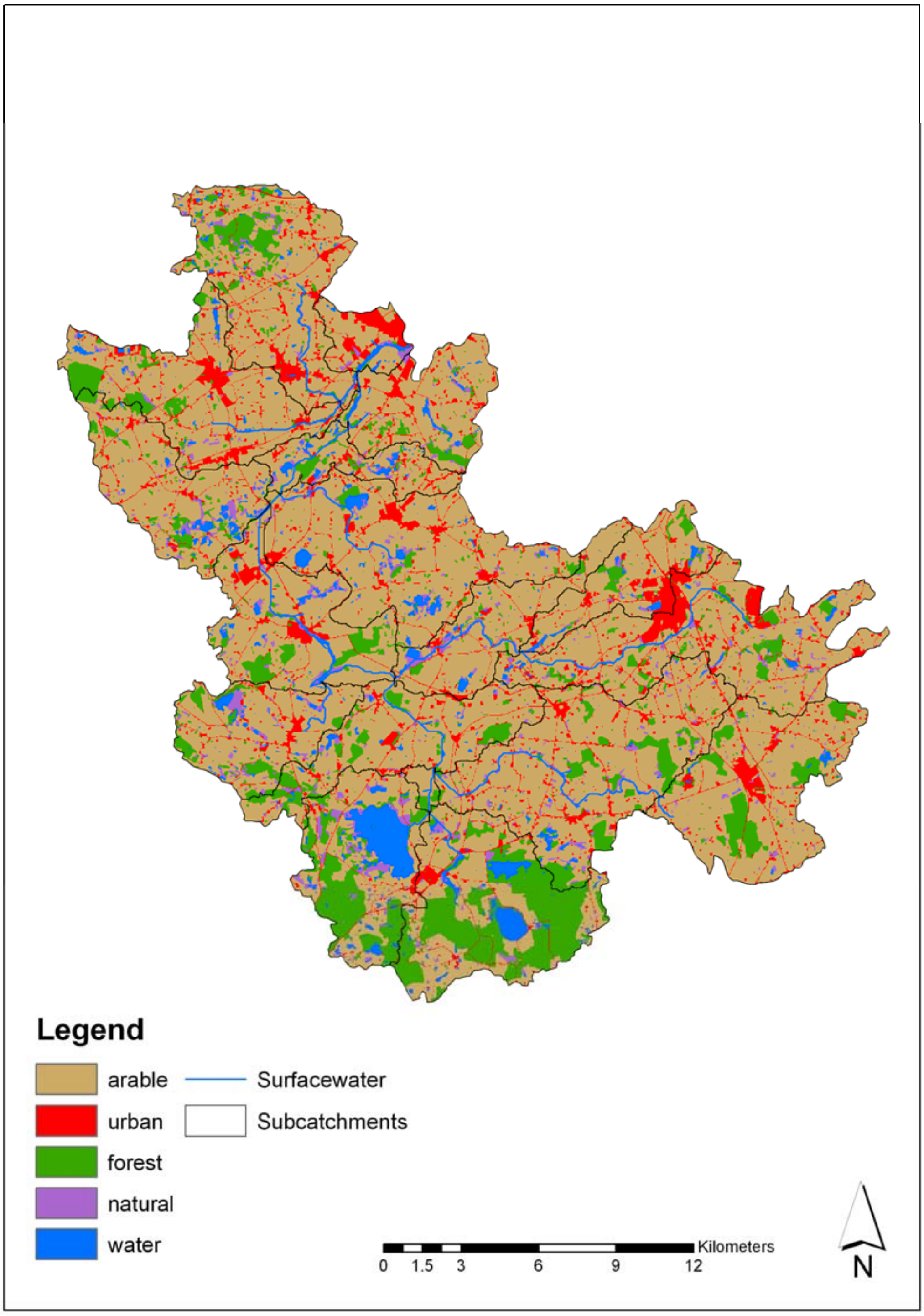



*Figure 3-2 Distinguished land use classes*

#### 3.2.2.3 Definition of soil type classes

The soil information is available for three layers with depths 0 – 30, 30 – 80 and deeper than 80 cm minus soil surface.

To determine the soil physical characteristics the HYPRES classification is used. According to this classification the soil layers should be schematised as coarse, medium, medium fine, fine, very fine or organic. The texture data of Odense soils shows that the layers are of the type coarse, medium or organic. On the base of the three layers a profile is assembled. It has the following three identifiers, for example 132 indicating the top layer to be Coarse, the mid layer to be Organic (peat) and the bottom layer to be Medium.

Profiles with small areas are joined together to one class, to reduce the number of profiles. Very important for this study is the presence of peat in the soil profile. The profiles with peat in the column cover 7,5% of the total area. Therefore profiles with peat are only joined with other profiles with peat.

In total three main profiles are considered (Figure 3-3).

*Table 3.8 Classifying the soil profiles*

| Profile identifier | Area (%) | New profile identifier |
|---|---|---|
| 111 | 27.01 | 111 |
| 121 | 0.01 | 111 |
| 112 | 64.35 | 112 |
| 122 | 0.01 | 112 |
| 212 | 0.93 | 112 |
| 222 | 0.17 | 112 |
| 131 | 0.26 | 313 |
| 132 | 0.91 | 313 |
| 232 | 0.13 | 313 |
| 313 | 3.89 | 313 |
| 333 | 2.32 | 313 |

*Table 3.9 Reclassified soil profiles*

| Description | Profile identifier | Area (%) | Profile number |
|---|---|---|---|
| Coarse profile (sandy) | 111 | 27.0 | 1 |
| Coarse top layer Medium deeper (sandy clay / clay) | 112 | 65.5 | 2 |
| Organic profile (peat in profile) | 313 | 7.5 | 3 |

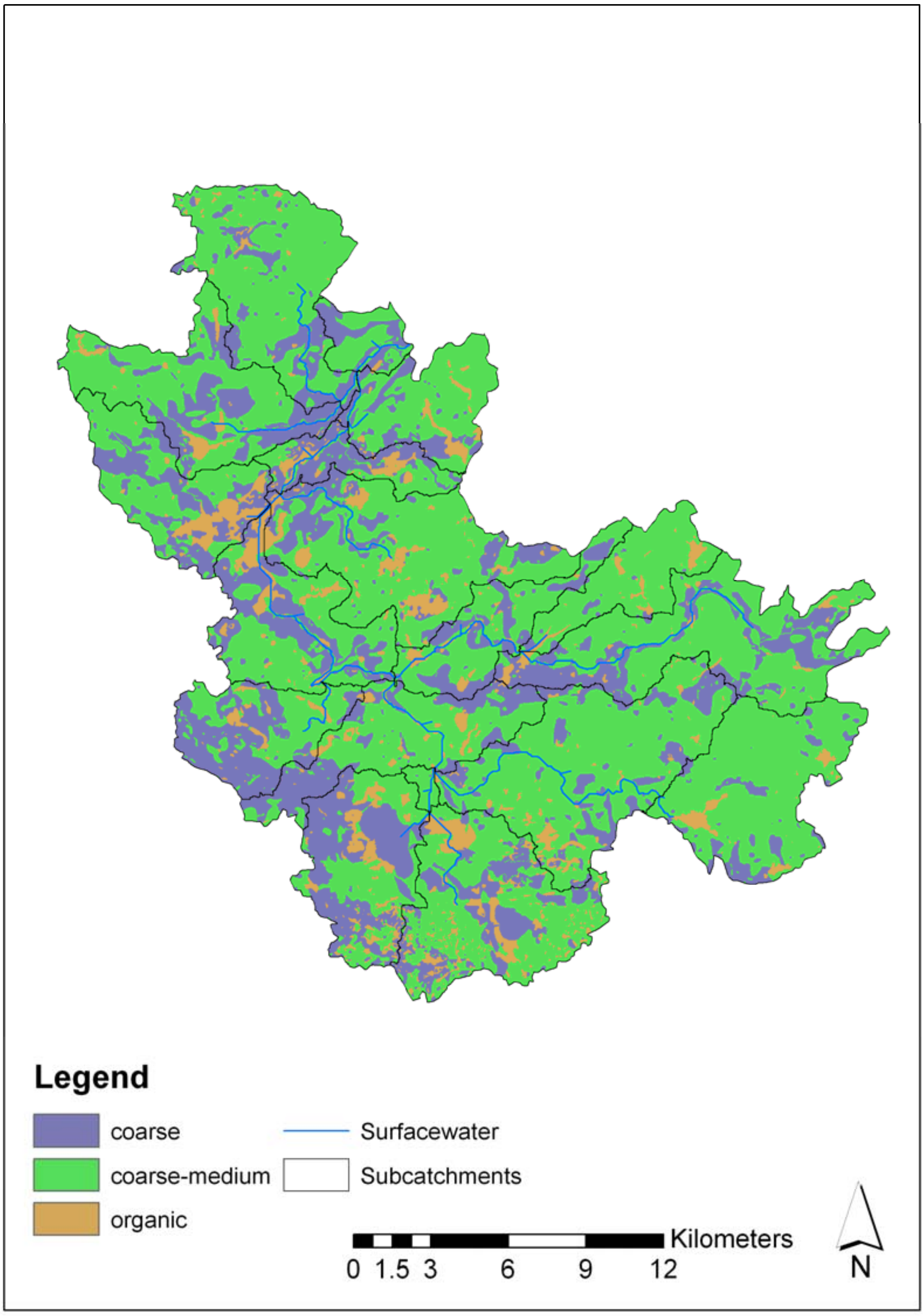



*Figure 3-3 Distinguished soil classes*

#### 3.2.2.4 Definition of groundwater classes

*Groundwater levels*
An important characteristic is the groundwater class and especially the class with high groundwater levels. High groundwater levels influences both the discharges at high precipitation rates and the denitrification.

There is map with isohypses available but this map is based on data of filters on various depth and measurements from 1850 till now! Therefore this map only gives a rough indication of the freatic groundwater levels.

*Drainage*
Based on soil maps and modelled groundwater levels a map of potentially drained areas has been derived for the agricultural land. The drained area is probably overestimated. In 1979 the tile-drained agricultural area was estimated to be 55% (Aslyng, H.C., 1980). In the following 10 years probably another 5-15% of the total agricultural area has been tile-drained.

*Groundwater classes*
There is no good map with groundwater levels available. The available map with isohypses is used to detect the areas with shallow and deep groundwater levels.
The following classes are used:

- 1: non drained areas with high groundwater levels
  The assumption is that the mean groundwater level is at 1 meter minus soil surface
- 2: non drained areas with deep groundwater levels
  The assumption is that the mean groundwater level is at 4 – 8 meter minus soil surface
- 3: drained areas
  These are area's with traditionally relatively high groundwater levels which are now controlled by the drainage. The map with drained areas is used.
  It is assumed that the mean groundwater level equals 1 meter minus soil surface

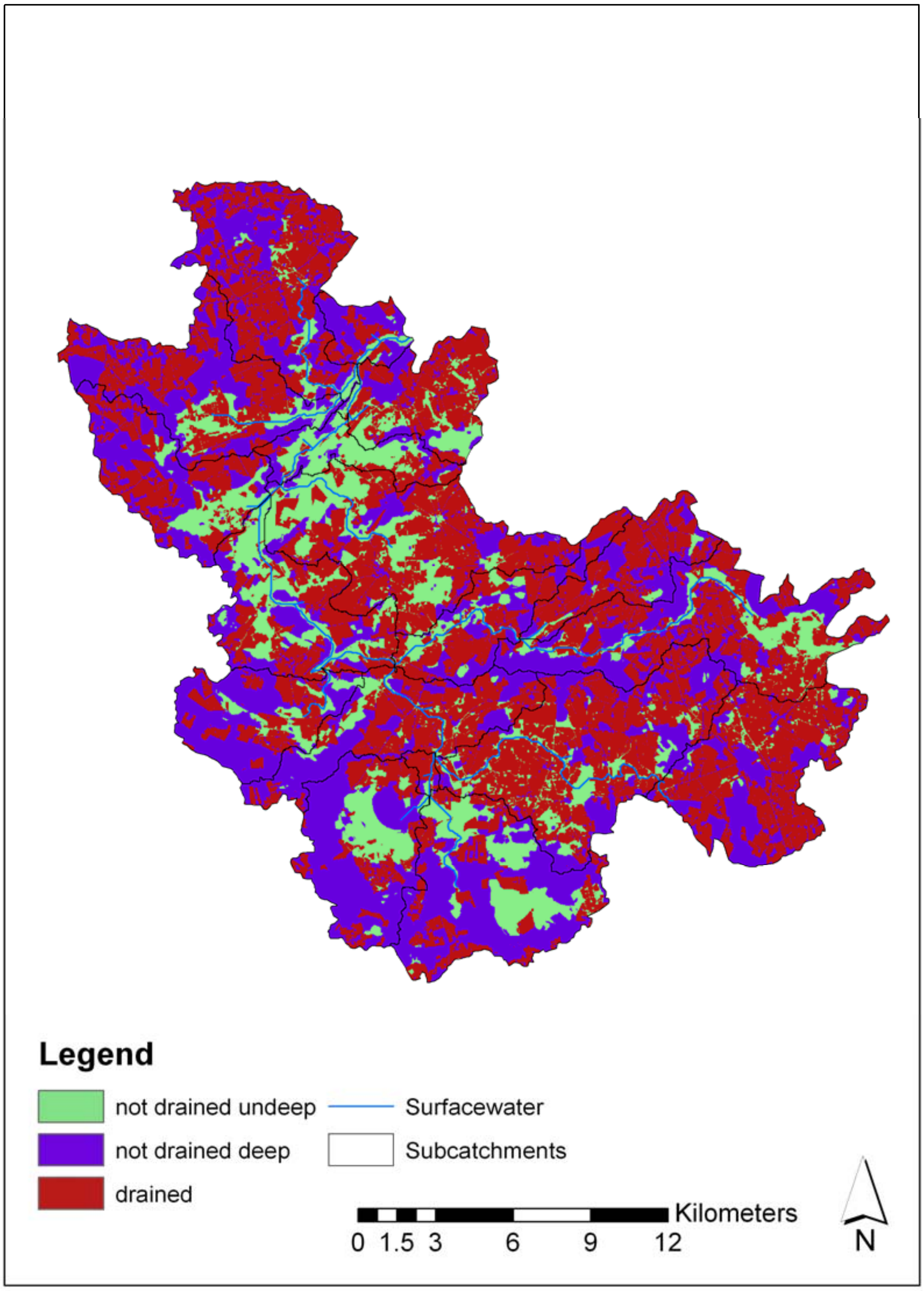



*Figure 3-4 Distinguished groundwater classes*

#### 3.2.2.5 Areal units

The calculation units depend on:
- rainfall grid (5 types)
- land use type (3 types plus urban and water)
- soil type (3 types)
- groundwater classes (3 types)

Each unique combination is represented by a four digit number ABCD:
- A: meteo (see Table 3.10)
- B: land use (see Table 3.11)
- C: soil type (see Table 3.12)
- D: groundwater class (see Table 3.13)

*Table 3.10 Classified meteo grids*

| Number A | Meteogrid |
|---|---|
| 1 | 10379 |
| 2 | 10380 |
| 3 | 10381 |
| 4 | 10382 |
| 5 | 10404 |

*Table 3.11 Classified land uses in the catchment*

| Number B | Land use |
|---|---|
| 1 (8,9)* | Arable |
| 3 | Forest |
| 4 | Natural |
| *2*** | *Urban* |
| *5*** | *Water* |

* *The arable land use types are modelled as a rotation of three crops*
*** Urban and Water are not separately modelled with SWAP*

*Table 3.12 Classified soil types in the catchment*

| Number C | Classified |
|---|---|
| 1 | 111 |
| 2 | 112 |
| 3 | 313 |

*Table 3.13 Classified groundwater classes*

| Number D | Classified |
|---|---|
| 1 | not drained shallow groundwater level |
| 2 | not drained deep groundwater level |
| 3 | drained |

So in theory a maximum of 5x3x5x3 = 225 different combinations (units) can be generated. It turns out that all these units exist in the model area. The units with smaller areas are left out. To detect those units a cumulative frequency distribution of the area is made (Figure 3-5).

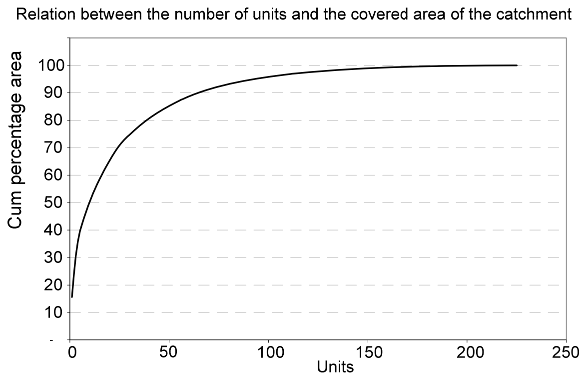



*Figure 3-5 Cumulative frequency distribution of the area (%) of calculation units (plots)*

The units covering 95% of the area of the catchment are not changed. The land use types 'Urban' and 'Water' are combined to one class. The remaining 5% is combined with the 95%-units. After this operation the total number of units equals 67 (including the urban and water-units).

When combining the units several rules are followed:

- the land use type 'Urban' is combined to one class '5213';
- the land use type 'Water' is combined to one class '5511';
- the other land use types are not changed;
- the profiles with organic layers are always combined with profiles with organic layers. Profiles without organic layers are combined with profiles without organic layers;
- the groundwater class is usually not changed. In the case of the class 'drained' in combination with 'forest' or 'natural' the class can be changed to 'not drained, shallow groundwater level'.

### 3.2.3 Surface water units

The catchment Odense is discretised into subcatchments and watercourses using 3 maps:

- a DEM (Digital Elevation Model)
  The DEM is based on a map with isolines. This map is converted to a grid with a cell distance of 25 m.
- the boundary of the catchment
  This is the catchment area as provided by the EuroHarp-site
- the locations of the rivers
  The base map is available on the EuroHarp-site. The main watercourses as well as the smaller watercourse are used to derive another watercourse map using the AVSWAT.

The package AVSWAT is used to derive the subcatchments and the streams (Figure 3-6). The resemblance between the AVSWAT-watercourses and the base map is very good. AVSWAT not only derives the watercourses but also the subcatchments.

The watercourses are divided into trajectories (calculation units) with a maximum length of 500 m. These trajectories do not resemble all the watercourses in the catchment. The smaller watercourses are modelled as added storage. Per subcatchment the length of the added storage is derived.

The discretisation resulted in 224 sections and 18 subcatchments. No structures are modelled.

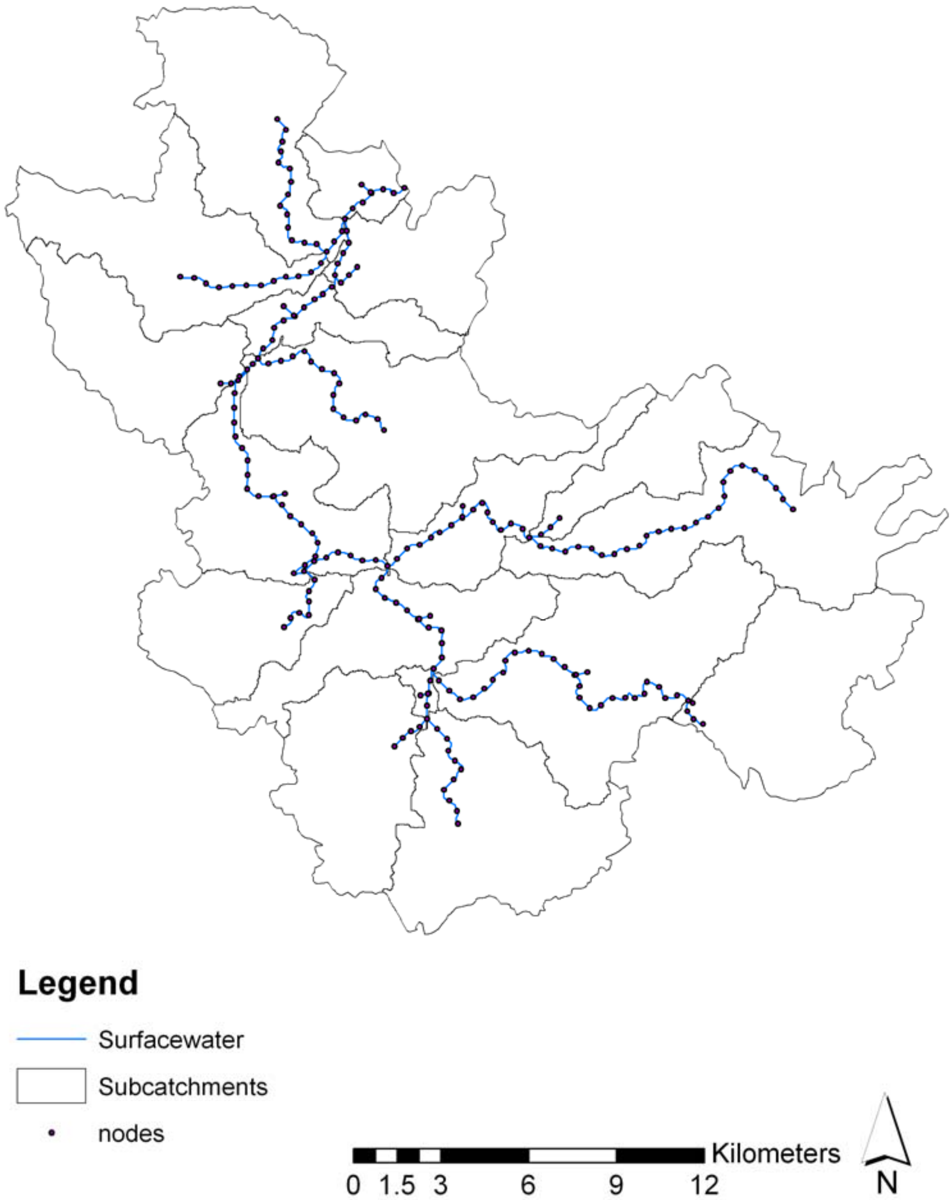



*Figure 3-6 Discretisation of subcatchments and surface water system*

## 3.3 Parameterisation

### 3.3.1 Meteorology

Meteorological data is of significant importance for any detailed discharge study. As written in paragraph 3.2.2.1 the grid data will be used.

*Precipitation*
In Figure 3-7 the mean monthly precipitation is given in mm $d^{-1}$. It shows that the precipitation amounts are high in September, December and January and are low in April, May and July.

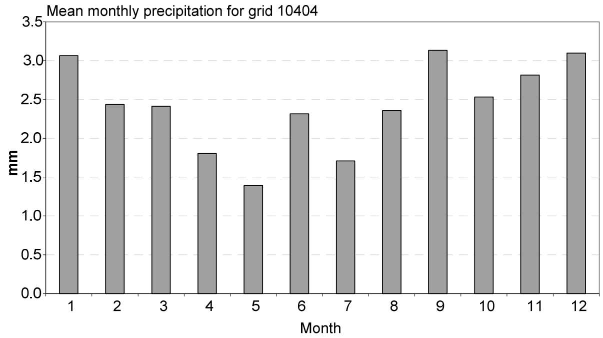



*Figure 3-7 Mean monthly precipitation (mm $d^{-1}$) for station 10404*

In Figure 3-8 the yearly amounts of precipitation are given. It shows a relatively dry period from 1995 till 1997.

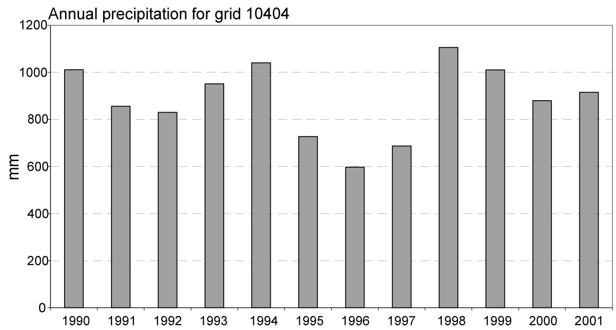



*Figure 3-8 Annual precipitation for station 10404*

*Evapotranspiration*
The Makkink equation (1957) was applied to determine evapotranspiration of a reference (grassland) crop. Figure 3-9 shows the mean monthly precipitation and Figure 3-10 the annual amounts.

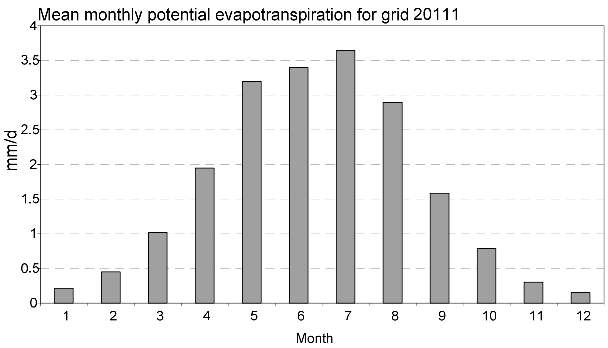



*Figure 3-9 Mean monthly evaporation*

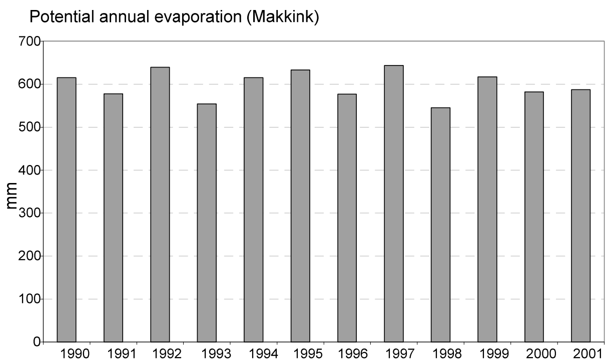



*Figure 3-10 Yearly potential evaporation*

*Temperature*
A typical temperature range is given in Figure 3-11. It shows that the mean monthly temperature ranges between 1 and 17 degrees Celsius. The daily temperature is given in Figure 3-12.
Snow melt is of importance when calculating the runoff. The precipitation is assumed to be snow, when the temperature is below zero degrees Celsius. Snow melt will occur when the temperature rises above zero.

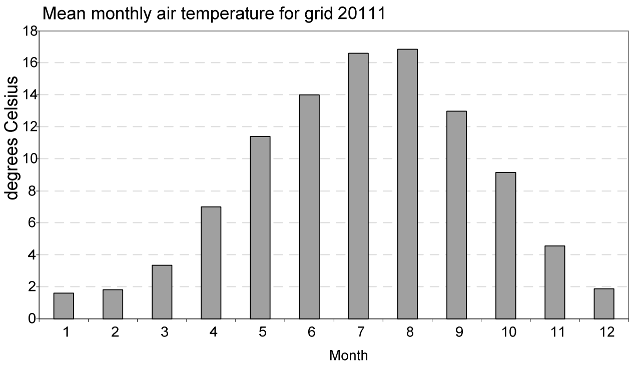



*Figure 3-11 Mean monthly temperature*

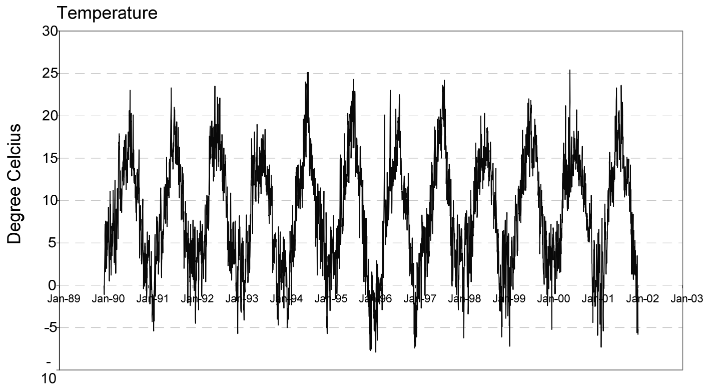



*Figure 3-12 Daily temperatures*

### 3.3.2 Soil

The data on the soil represents three layers. Soil physical parameters were assigned to soil types and soil hydraulic properties (Table 3.14) were taken from the HyPrES database (Wösten et al, 1999).

*Table 3.14 Soil hydraulic properties from HyPrES (Wösten et al, 1999)*

| Hypres-classification | Topsoil/subsoil | SPU | thetar | thetas | Ks | alpha | λ | n |
|---|---|---|---|---|---|---|---|---|
| coarse | topsoil | B01 | 0.03 | 0.40 | 60.00 | 0.04 | 1.25 | 1.38 |
| medium | topsoil | B02 | 0.01 | 0.44 | 12.06 | 0.03 | -2.34 | 1.18 |
| organic | topsoil | B03 | 0.01 | 0.77 | 8.00 | 0.01 | 0.40 | 1.20 |
| coarse | subsoil | O01 | 0.03 | 0.37 | 70.00 | 0.04 | 1.25 | 1.52 |
| medium | subsoil | O02 | 0.01 | 0.39 | 12.68 | 0.02 | -0.74 | 1.17 |
| organic | subsoil | O03 | 0.01 | 0.77 | 8.00 | 0.01 | 0.40 | 1.20 |

Soil chemical data were derived from Dutch databases relating soil chemical parameters to soil properties (Table 3.15).

*Table 3.15 Soil physical and chemical properties*

| soilID | top | bottom | soilPhysicsID | $\rho_d$ | AlFe | SOM | sand | silt | clay | pHKCl | C/N ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 30 | B01 | 1.60 | 60.00 | 2.50 | 78 | 12 | 10.00 | 5.50 | 12 |
| 1 | 30 | 80 | B01 | 1.60 | 60.00 | 1.30 | 78 | 12 | 10.00 | 5.50 | 12 |
| 1 | 80 | 1000 | O01 | 1.60 | 40.00 | 0.10 | 78 | 12 | 10.00 | 5.60 | 30 |
| 2 | 0 | 30 | B01 | 1.60 | 60.00 | 2.50 | 78 | 12 | 10.00 | 5.50 | 12 |
| 2 | 30 | 80 | B01 | 1.60 | 60.00 | 1.30 | 78 | 12 | 10.00 | 5.50 | 12 |
| 2 | 80 | 1000 | O02 | 1.60 | 60.00 | 0.10 | 42 | 35 | 23.00 | 6.00 | 30 |
| 3 | 0 | 30 | B03 | 1.10 | 200.00 | 20.00 | 9 | 27 | 64.00 | 3.60 | 13.6 |
| 3 | 30 | 80 | B03 | 1.10 | 200.00 | 20.00 | 9 | 27 | 64.00 | 3.60 | 13.6 |
| 3 | 80 | 1000 | O03 | 1.10 | 100.00 | 20.00 | 9 | 27 | 64.00 | 3.60 | 20 |

### 3.3.3 Land use

In total 5 land use types are distinguished:

- arable;
- urban;
- natural (but not forest);
- forest;
- water.

Water is simulated in the surface water model and not with the SWAP-columns.

Parameters for Urban were approached by grassland with some addition of nutrients.

*Table 3.16 Crop distribution on arable land in 2000 (Fyns Amt, 2003)*

| Crop | Area (%) |
|---|---|
| Winter cereals | 45 |
| Spring cereals | 23 |
| Grass/green fodder | 10 |
| Seed crops | 8 |
| Root crops | 5 |
| Permanent grass | 4 |
| Market gardens | 3 |
| Pulses | 2 |

The change in crop use in the last decades is given in Figure 3.13 (Fyns Amt, 2003).

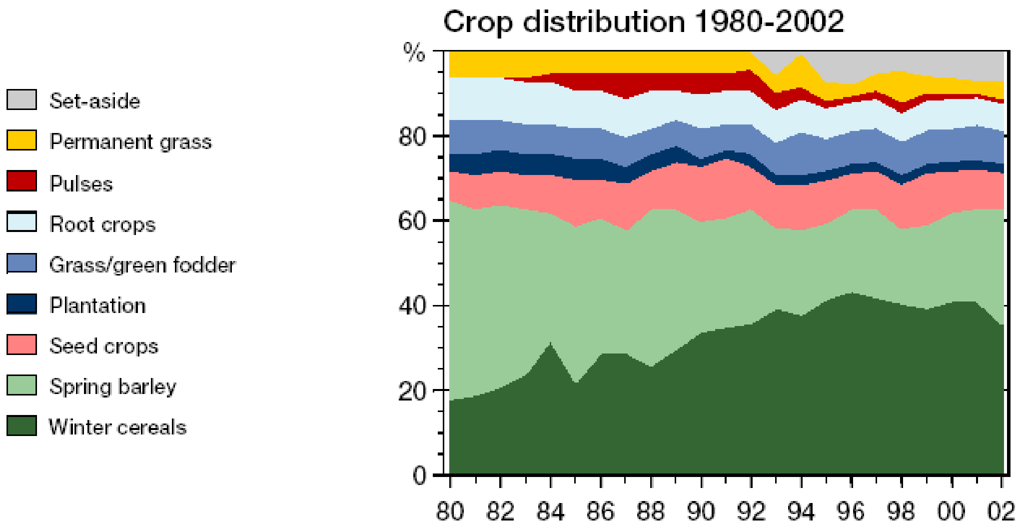



*Figure 3-13 Crop distribution*

The arable land is simulated as a crop rotation of winter cereal, spring cereal and 'other crops'. Therefore three SWAP columns are used for arable land, see Table 3.17. As a consequence it is assumed that these three crops are evenly distributed.

*Table 3.17 Simulating arable land*

| Year | Rotation 1 | Rotation 2 | Rotation 3 |
|---|---|---|---|
| 1 | Winter cereal | Spring cereal | Other crops |
| 2 | Spring cereal | Other crops | Winter cereal |
| 3 | Other crops | Winter cereal | Spring cereal |

So it is assumed that the winter cereals, spring cereals and other crops all cover 33% of the arable area. The emergence and harvest data of the three crops are given in Table 3.18. Of course the winter cereal is sown in the autumn of the previous year, but is modelled as if present from the beginning of January.

*Table 3.18 Crop season*

| crop | emergence | harvest | $2^{nd}$ crop | emergence | end date |
|---|---|---|---|---|---|
| spring cereal | 03-15 | 08-07 | $2^{nd}$ crop | 08-07 | 10-30 |
| winter cereal | 01-02 | 08-21 | $2^{nd}$ crop | 08-21 | 10-01 |
| arable rest | 04-25 | 09-01 | - | - | - |

Important for the water uptake and the sensitivity for dryness and wetness is the rooting depth. The rooting depth in Table 3.19 is the depth till which the plant extracts most of the water.

*Table 3.19 Rooting depth*

| Crop | Rooting depth (m) |
|---|---|
| spring cereal | 1.20 |
| winter cereal | 1.20 |
| arable rest | 1.20 |
| forest | 3.00 |

### 3.3.4 Groundwater

#### 3.3.4.1 Abstractions

A list with the groundwater abstractions is available. The total amount of abstraction equals about 8 till 10 million $m^3$ per year (this equals about 5% of the net rainfall in the catchment). The abstractions are incorporated in the bottom boundary conditions.

*Table 3.20 Groundwater abstractions*

| year | abstraction (Mm3) |
|---|---|
| 1990 | 10.8 |
| 1991 | 10.3 |
| 1992 | 12.1 |
| 1993 | 10.7 |
| 1994 | 10.3 |
| 1995 | 11.7 |
| 1996 | 11.8 |
| 1997 | 10.6 |
| 1998 | 9.6 |
| 1999 | 8.9 |
| 2000 | 10.1 |

#### 3.3.4.2 Bottom boundary condition

Several groundwater classes are distinguished. It is supposed that there disappears water from the modelled area via the bottom. This is partly due to the abstraction of groundwater in the modelled area (about 10 Mm3/yr). There is also redistribution within the modelled area: it is assumed that the "not drained shallow" groundwater class receives water from the other areas.
The downward flux from non-drained soils with deep groundwater levels depends on the groundwater level. So when the groundwater level is deep the flux is low and vice versa.

#### 3.3.4.3 Lateral boundary condition

The discharge from the groundwater in the soil system to the surface water system is schematised in 4 routes:

i) surface runoff with a very short residence time (within 1 day);
ii) gulleys, a shallow drainage system with a short residence time (a few days);
iii) pipe drains, a drainage system with a medium residence time;
iv) bigger watercourses, a drainage system with a long residence time.

The drainage level depends on land use, soil type and groundwater class. Several assumptions are made:

- Only 'arable' land is drained;
- 'Arable' land in the 'not drained shallow' groundwater class is nevertheless supposed to be drained;
- 'Natural' and 'forest' are supposed to have gulley's;
- the infiltration resistance is supposed to be infinite.

*Table 3.21 Drainage systems for the different land use and groundwater classes*

| Groundwater class | Land use | Gulleys depth (m-sl) | resistance (d) | Tile drains depth (m-sl) | resistance (d) | Watercourses depth (m-sl) | resistance (d) |
|---|---|---|---|---|---|---|---|
| not drained shallow | arable | -0.20 | 20 | -1.20 | 100 | -5.00 | 100.000 |
| not drained shallow | nature/ forest | -0.20 | 20 | -0.50 | 20* | -5.00 | 100.000 |
| not drained deep | all | -0.20 | 20 | - | - | -9.90 | 13.500 |
| drained** | arable | -0.20 | 20 | -1.20 | 100 | -5.00 | 30.000 |

** infinite infiltration resistance*

*** no forest or nature on drained land*

### 3.3.4.4 Dimensions drain systems

The common depth of tile drains is 1,2 m. The drain distance varies between 12 - 25 m depending on soil type (% clay). The average drain distance in the Odense catchment is assumed to be 15 m.

*Table 3.22 Drain spacings for the different drainage systems*

| Drainage system | Drain spacing (m) |
|---|---|
| 1 | 500 |
| 2 | 15 |
| 3 | 40 |

### 3.3.5 Nutrients

#### 3.3.5.1 Atmospheric deposition

The atmospheric deposition of N in the county is estimated at approximately 20 kg/ha/yr.

*Table 3.23 Dry and wet atmospheric deposition*

| | | |
|---|---|---|
| NH4-N in precipitation | 0.25 | mg/l |
| NO3-N in precipitation | 0.08 | mg/l |
| PO4-P in precipitation | 0.025 | mg/l |
| NH4-N dry deposition | 10.5 | kg/ha/yr |
| NO3-N dry deposition | 9.5 | kg/ha/yr |

#### 3.3.5.2 Manure and chemical fertilizer

There is geographical information available with the chemical and animal fertiliser gifts for 2000. This data is used to derive a mean gift for the land use types (Table 3.24).

*Table 3.24 Chemical and animal fertiliser dosages for arable land in 2000*

| | Animal-N (kg/ha) | Chemical-N (kg/ha) | Total-N (kg/ha) |
|---|---|---|---|
| Arable land | 93 | 90 | 183 |

Detailed information on the application rates per crop is not available. Therefore it is assumed that all the crops do have the same application rates. The total gifts are given in Table 3.25 and the distribution over the year in Table 3.26.

*Table 3.25 Assumed nutrient gifts for the simulation in 2000*

| Crop | Total-N (kg N/ha/yr) | | Total-P (kg P/ha/yr) | |
|---|---|---|---|---|
| | Animal | Inorganic | Animal | Inorganic |
| Winter cereal (wheat) | 93 | 90 | 21 | 8 |
| Spring cereal (barley) | 93 | 90 | 21 | 8 |
| Other crops (sugar beet) | 93 | 90 | 21 | 8 |

The chemical fertiliser application decreased in the period 1990 till 2000 with about 27% (see Figure 3-14 and Figure 3-15). The manure additions remained constant during this period.

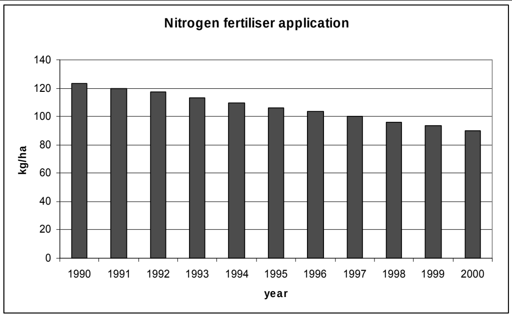



*Figure 3-14 Annual N-fertiliser applications on arable land*

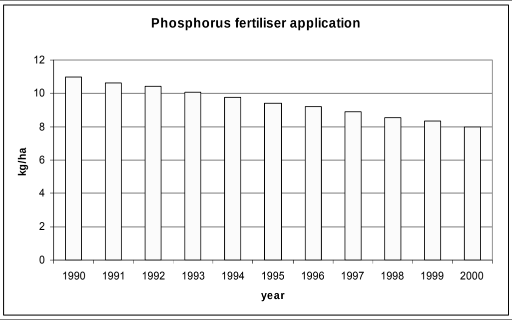



*Figure 3-15 Annual P-fertiliser applications on arable land*

*Table 3.26 Fertiliser gifts for the simulated crops*

| crop | date | N-gift | P-gift |
|---|---|---|---|
| spring cereal | 1-3 | 50% manure | 50% manure |
| spring cereal | 11-3 | 50% manure | 50% manure |
| spring cereal | 11-3 | 50% chemical | 100% chemical |
| spring cereal | 5-4 | 50% chemical | |
| winter cereal | 25-8 (previous year) | 100% manure | 100% manure |
| winter cereal | 25-8 (previous year) | | 100% chemical |
| winter cereal | 1-3 | 100% chemical | |
| other crops | 21-4 | 50% manure | 50% manure |
| other crops | 28-4 | 50% manure | 50% manure |
| other crops | 28-4 | 50% chemical | 100% chemical |
| other crops | 21-6 | 50% chemical | |

#### 3.3.5.3 Bottom boundary

As described in paragraph 3.3.4.2 it is assumed that groundwater flows from the higher regions to the lower parts. This groundwater carries nutrients to the lower parts. The concentrations in the upward seepage water in the lower parts is based on some initial calculations. The assumed concentrations in the upward seepage water are given in Table 3.27.

*Table 3.27 Seepage concentrations*

| Item | Concentration (mg/l) |
|---|---|
| NH3 | 5 |
| NO3 | 10 |
| PO4 | 0.13 |
| dissolved organic matter | 1 |
| dissolved organic nitrogen | 0 |
| dissolved organic phosphorus | 0 |

#### 3.3.5.4 Waste water treatments and unsewaged dwellings

For the treatment plants information is available on treated volumes, concentrations and loads (Figure 3-16 and Figure 3-17).

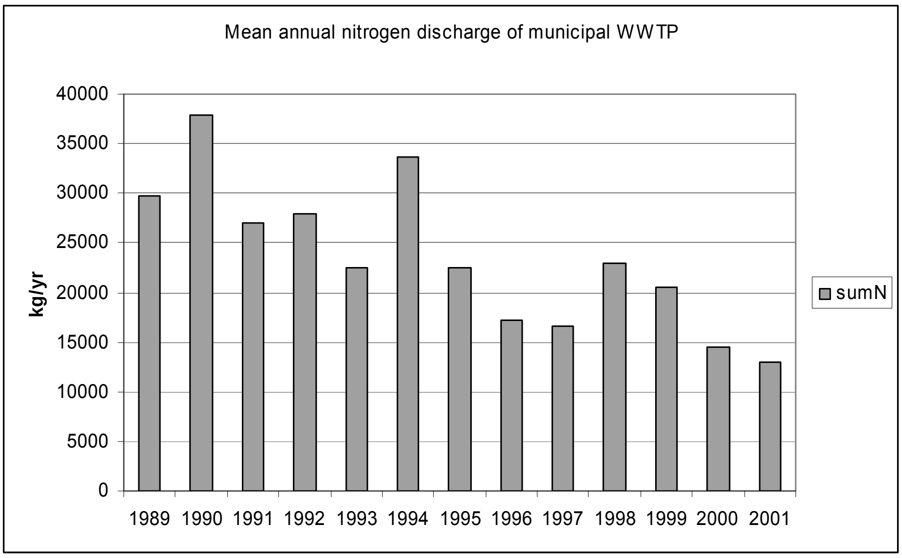



*Figure 3-16 Annual discharge of nitrogen from waste water treatment plants*

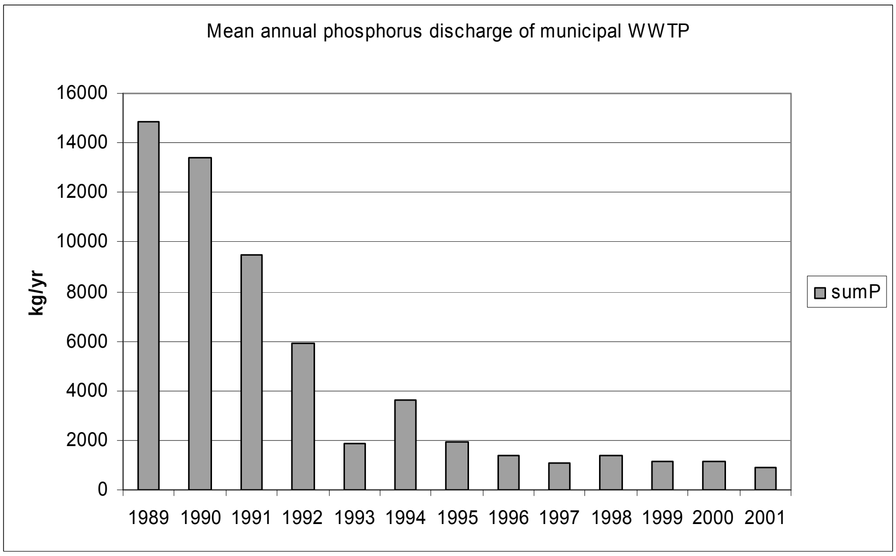



*Figure 3-17 Annual discharge of phosphorus from waste water treatment plants*

About 10% of the population lives in areas not connected to a waste water treatment plant. The sewage water from these dwellings is directly discharged to the surface water. The amount of phosphorus equals about 4.400 kg P/yr.

### 3.3.5.5 Temperature in the soil

For chemical and biological processes the temperature in the soil is of great importance. The temperature is modelled as a function of the air temperature and the temperature conductance of the soil. The latter depends on the organic, the sandy and the clay fraction. Figure 3-11 and Figure 3-12 give an indication of the temperature during a longer period.

### 3.3.6 Surface water

#### 3.3.6.1 Lakes

The characteristics of the lakes are given in Table 3.28

*Table 3.28 Characteristics of lakes*

| ID | Name | Volume | Average depth (m) | CenterCoordinates.x | CenterCoordinates.y |
|---|---|---|---|---|---|
| 8383 | Arreskov | 5880000 | 1.9 | 583249 | 6113278 |
| 9335 | | 1600000 | 2.3 | 587987 | 6112160 |
| 9864 | | 864000 | 0.8 | 588063 | 6110065 |

*Watercourses*

In the EuroHARP project the width of the main watercourses were provided by the catchment authorities. Fyns Amt has provided data of the bottom level of the Odense River. The data of this river is used to determine the dimensions of the other watercourses. The data shows that the mean bottom depth equals about 2 m minus soil surface. The width of the river depends on the location. An approximate relation was found between the bottom level and the bottom width, see Figure 3-18.

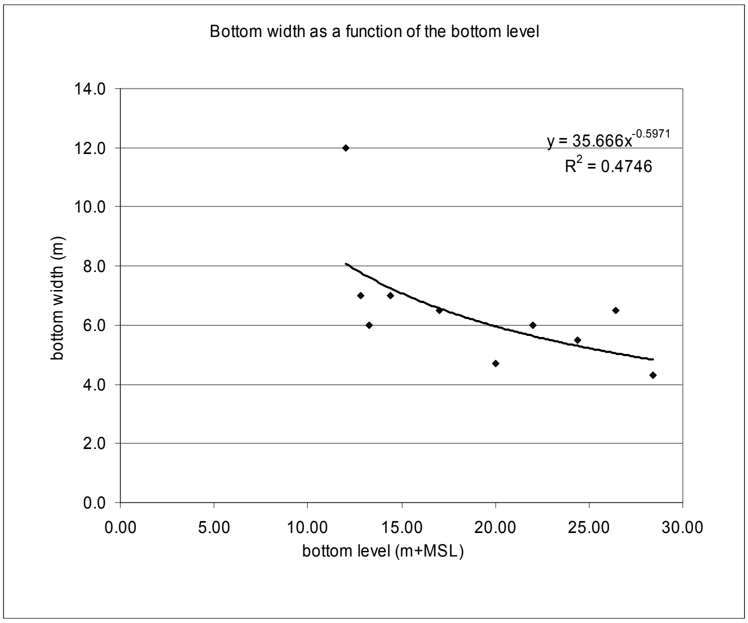



*Figure 3-18 Approximated bottom width*

#### 3.3.6.2 Added storage

In Fyns Amt, 2003 general information on the Odense River Basin is given Table 3.29. This information is used to determine the length of added storage for each of the subcatchments.

*Table 3.29 Distribution of watercourses*

| Width | < 2 m | 2 – 10 m | > 10 m |
|---|---|---|---|
| Length (m/square km) | 698 | 315 | 40 |

The assumed dimensions of these smaller watercourses are:
- the bottom width equals 1 m;
- the slope equals 1:1;
- the bottom height equals the upstream bottom height of the watercourse it is connected to;
- lakes are also modelled as added storage with a length and width equal to the square root of the area and a bottom height equal to the bottom height of the connected watercourse minus the mean depth (Table 3.28).

### 3.3.6.3 Bank erosion

Bank erosion can be due to high flow velocities, which usually occur in the winter season, but also because of cattle trampling the banks of the watercourses usually in the summer period. For this study there is no quantitative information available on the contribution of bank erosion to the nitrogen and phosphorus load of the surface water. But is commonly supposed to contribute considerably. Therefore, during the calibration process the contribution is assessed at 6.600 kg P/yr. This amount is assumed to be evenly distributed over the year and it is assumed that the bank erosion depends on the yearly discharges. It is assumed that the nitrogen amounts in the eroded soil are negligible.

## 3.4 Simulation results

### 3.4.1 Calibration

To calibrate the models the following measurements are used:

- the discharges at the measurement stations 102235 and 103580 for the period 1990 - 2000;
- the N- and P-concentrations at the stations 102235 and 103580 for the period 1990 - 2000;
- the N- and P-loads at both stations (calculated as the multiplication of discharges and concentrations) for the period 1990 - 2000.

The measurements are presented in paragraph 3.4.3.

In the calibration process the following parameters are changed:

- for the water in the soil:
  - the bottom fluxes and type of bottom boundary condition;
  - the drain depths and resistances;
- for the nutrients in the soil:
  - denitrification rate (only active under nitrate limited conditions)
  - nitrification rate;
  - decomposition rates of organic matter;
  - assimilation factor of dissolved organic matter, exudates and humus/biomass;
  - volatilisation;
  - diffusion parameter of oxygen.
  - max. P. sorption fraction;
  - AlFe-content;
  - factor for snowmelt;
- for the water in the surface water:
  - no calibration;
- for the nutrients in the surface water:
  - Respiration loss during primary production;
  - Mortality rate at 20 $^{o}$C;
  - Mineralization rate of organic material;
  - Denitrification rate of mineral N;
  - Mineral phosphorus adsorption capacity;
  - Sedimentation loss rate for mineral and organic P.

### 3.4.2 Initialisation period per model

Very important for the calculated nutrient leaching is the length of the initialisation period for the concatenated models:

- SWAP and ANIMO: a period of 48 years is used to initialise. More precisely, four times after each other the meteodata of the period 1990-2001 is used as the initialisation period.
- SWQN: taking into account the rapid reaction time of the surface water system, a relative short period of 15 days is used for the initialisation;
- NUSWALITE: no initialisation period is used.

### 3.4.3 Measurements

#### 3.4.3.1 Discharges

A first check is made to control if the discharges and meteodata are consistent. The net rainfall in the area should resemble the discharges from the catchment. There can be differences due to groundwater abstractions, difference between pot. and act. evapotranspiration, groundwater flow over the catchment border, etc.. Table 3.30 shows that the net rainfall resembles the discharges very well.

*Table 3.30 Net rainfall and discharge*

| | Precipitation (mm/j) | Pot.evaporation (mm/j) | Net rainfall (Mm3/j) | | Measured discharge (Mm3/j) | |
|---|---|---|---|---|---|---|
| | | | 102235 | 103580 | 102235 | 103580 |
| 1990 | 984 | 607 | 183 | 115 | 148 | 101 |
| 1991 | 811 | 578 | 113 | 71 | 135 | 88 |
| 1992 | 819 | 639 | 87 | 55 | 125 | 83 |
| 1993 | 955 | 556 | 194 | 122 | 150 | 101 |
| 1994 | 1114 | 616 | 242 | 152 | 221 | 149 |
| 1995 | 756 | 636 | 58 | 37 | 162 | 105 |
| 1996 | 605 | 577 | 14 | 9 | 59 | 39 |
| 1997 | 717 | 644 | 35 | 22 | 76 | 51 |
| 1998 | 1066 | 548 | 252 | 159 | 179 | 126 |
| 1999 | 1047 | 619 | 208 | 131 | 184 | 124 |
| 2000 | 883 | 583 | 146 | 92 | 156 | 101 |
| Average | 886 | 600 | 139 | 88 | 145 | 97 |

In Figure 3-19 for two surface water station the measured discharges are given. It shows that at the outlet point the discharge can be greater than 25 $m^3/s$ and that in the summer there is base flow of at least 0.5 $m^3/s$.

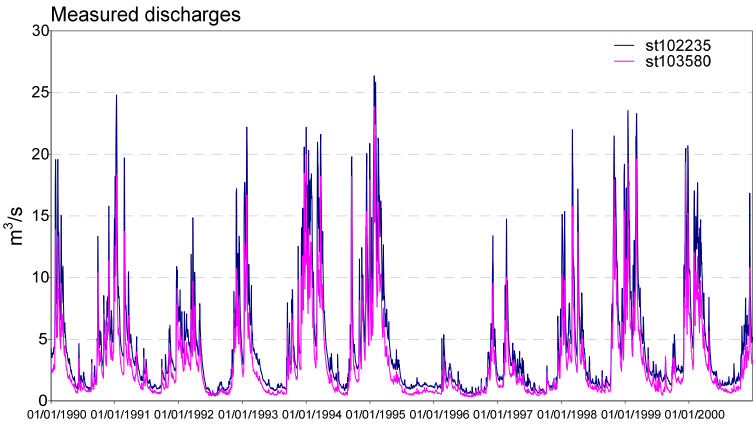



*Figure 3-19 Discharges for the measuring stations 102235 and 103580*

There are several measuring stations around the lake Arreskov. One of these stations measures the outflow. In dry summer periods the discharge from the lake becomes zero.

### 3.4.3.2 Concentrations

Figure 3-20 shows the concentrations for two measurement stations.

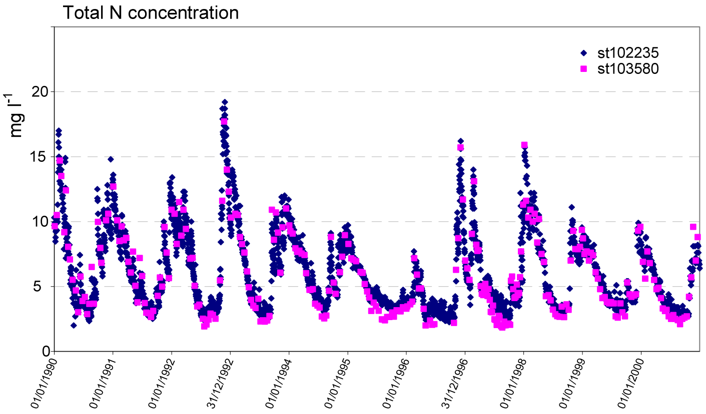



*Figure 3-20 Total nitrogen concentration in surface water at outlet point*

*Table 3.31 Average concentrations of nitrogen*

| Average | st102235 | st103580 |
|---|---|---|
| totN (mg/l) | 5.96 | 5.72 |
| NO3-N (mg/l) | 5.16 | 4.97 |
| NH4-N (mg/l) | 0..08 | 0.09 |
| organic? (mg/l) | 0..71 | 0..66 |

Table 3.31 shows that the NO3-N contributes the most to the total N–concentration.

Figure 3-21 and Table 3.32 gives information on the phosphorus concentration.

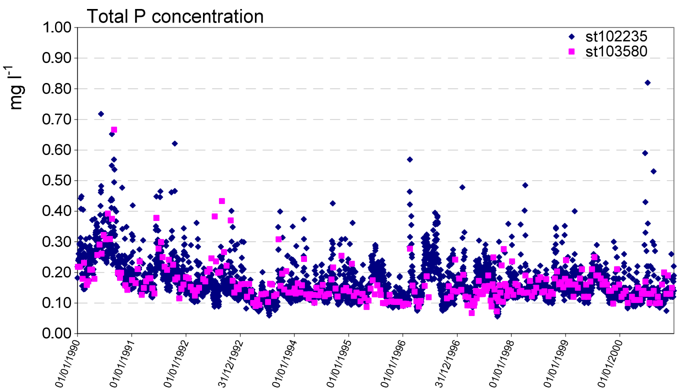



*Figure 3-21 Total phosphorus concentrations in surface water at outlet point*

*Table 3.32 Average concentrations of phosphorus*

| | st102235 | st103580 |
|---|---|---|
| TotP (mg/l) | 0. 172 | 0. 169 |
| Part. P (mg/l) | 0. 086 | 0. 077 |
| Soluble Reactive P (mg/l) | 0. 091 | 0. 092 |

#### 3.4.3.3 Loads

On base of the measured discharges and concentrations the loads are calculated. The loads of nitrogen and phosphorus are presented in Figure 3-22 and Figure 3-23.

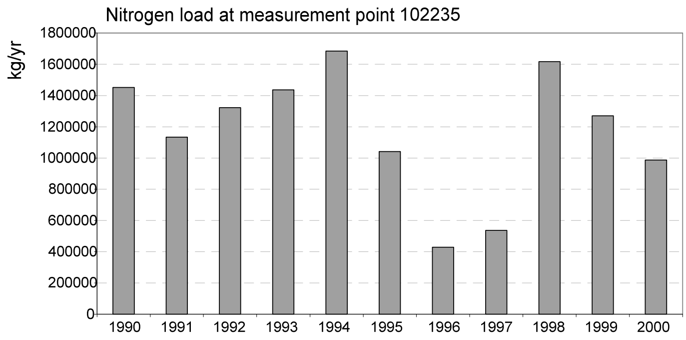



*Figure 3-22 Yearly load of nitrogen at outlet point*

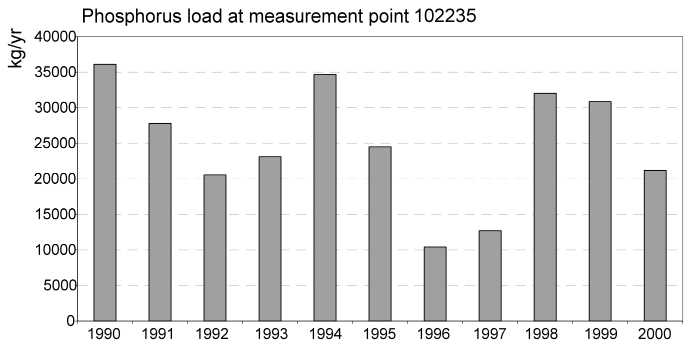



*Figure 3-23 Yearly load of phosphorus at outlet point*

### 3.4.4 Results after calibration

#### 3.4.4.1 Discharges

The simulated discharges are compared to the measured ones at the outlet (Figure 3-25) and at a measurement station halfway (Figure 3-26). For both measurement stations there is a good resemblance between the measured and simulated discharges. Especially for measurement station 103580 the peak discharges are very good simulated. For the station at the outlet the simulated peak discharges are a bit too low.

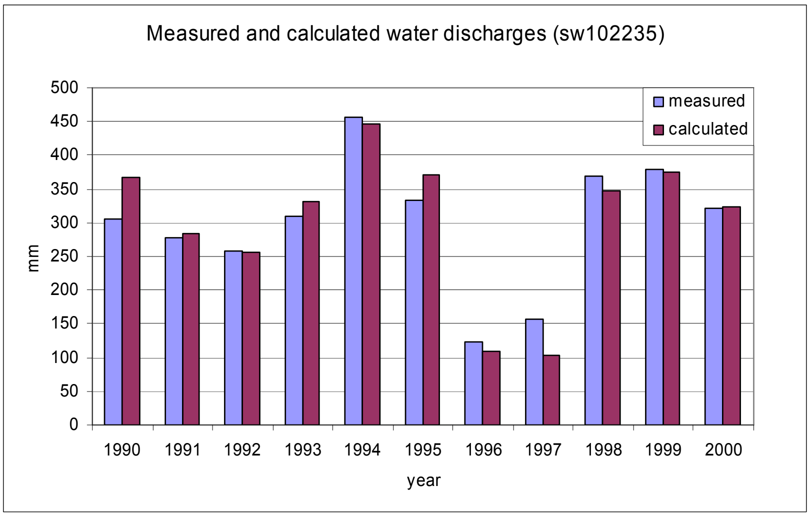



*Figure 3-24 Measured and calculated yearly discharges at the outlet*

In Figure 3-24 the yearly discharges at the outlet point are shown. For 1990 there is a maximum difference between modelled and measured discharge of 62 mm. In the dry years 1996 and 1997 the modelled discharges are too low (respectively 13 and 53 mm). Presumably the base flow should be higher. Over the period of 11 years the mean yearly deviation amounts only 2 mm.

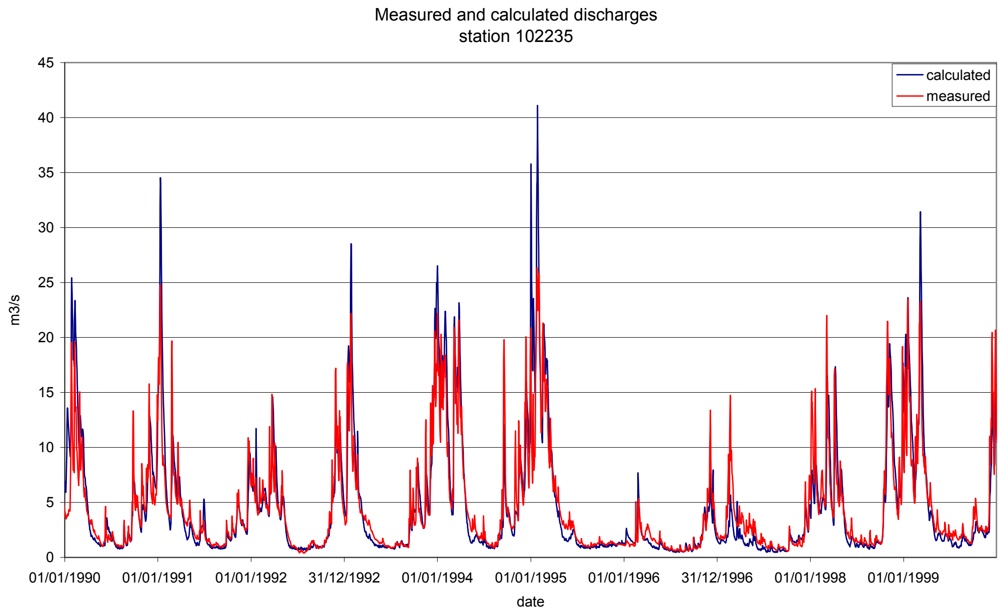



*Figure 3-25 Measured and calculated discharges at the outlet*

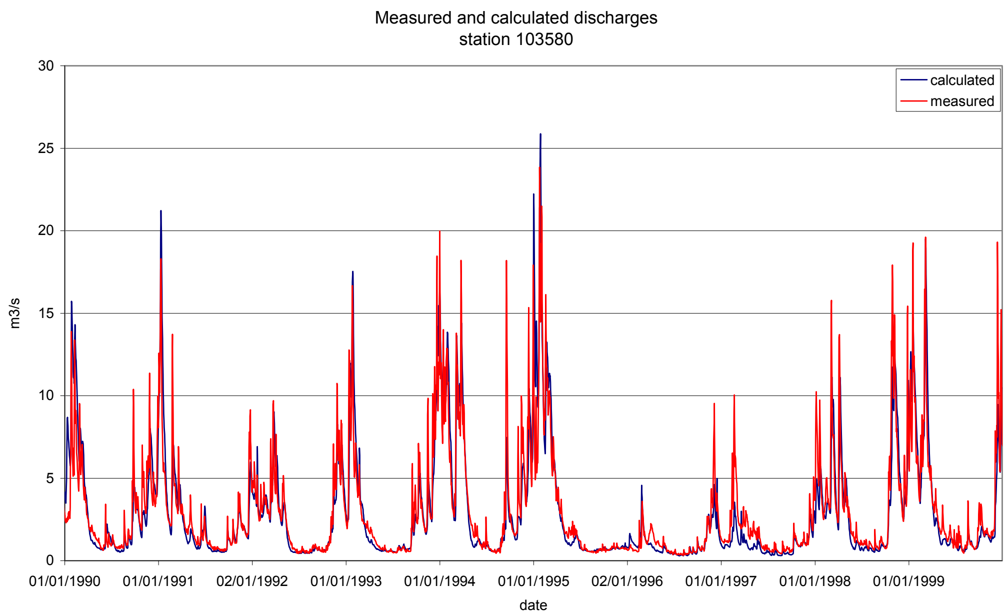



*Figure 3-26 Measured and calculated discharges halfway*

### 3.4.4.2 Nitrogen

*Concentrations*

In Figure 3-27 and Figure 3-28 the measured and simulated nitrogen concentrations are given. The simulated concentrations agree quite well with the measurements. The model does not simulate the peak concentrations during the winter periods.

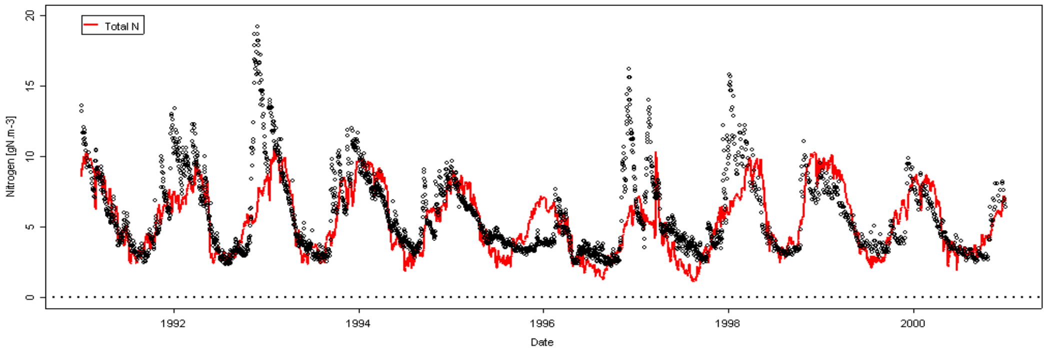



*Figure 3-27 Measured and calculated nitrogen concentrations at the outlet*

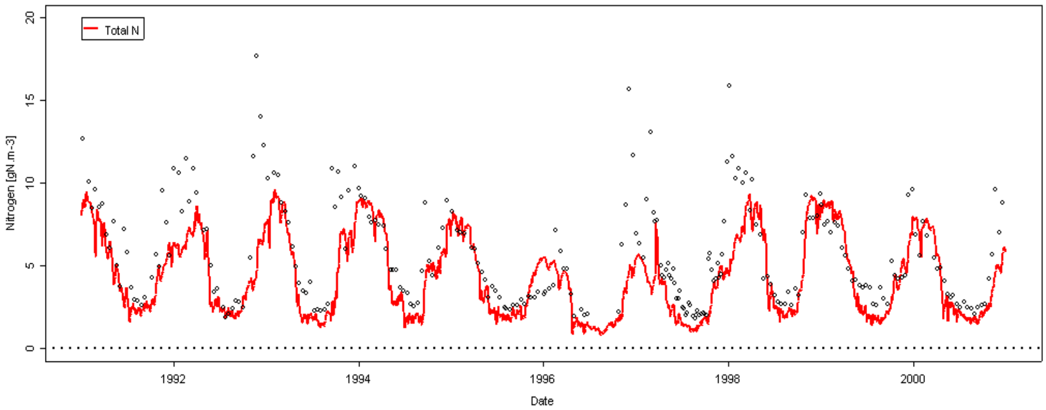



*Figure 3-28 Measured and calculated nitrogen surface water concentrations at an observation location halfway the outlet*

*Loads*
Figure 3-30 and Figure 3-31 show the measured and simulated nitrogen loads. The simulated loads agree quite well with the measurements. In 1997 the peak discharges are not simulated. Figure 3-29 presents the yearly loads based on the measurements and the simulations. In 1992, 1996 and 1997 the simulated lows are relatively low. The main line however is quite good.

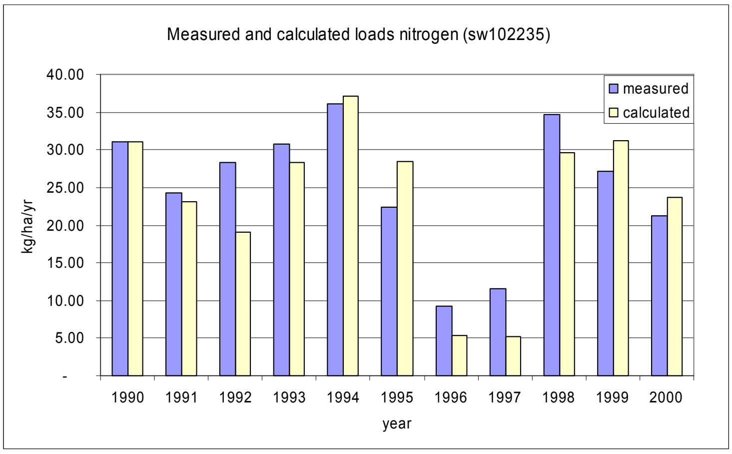



*Figure 3-29 Annual measured and calculated nitrogen loads at the outlet*

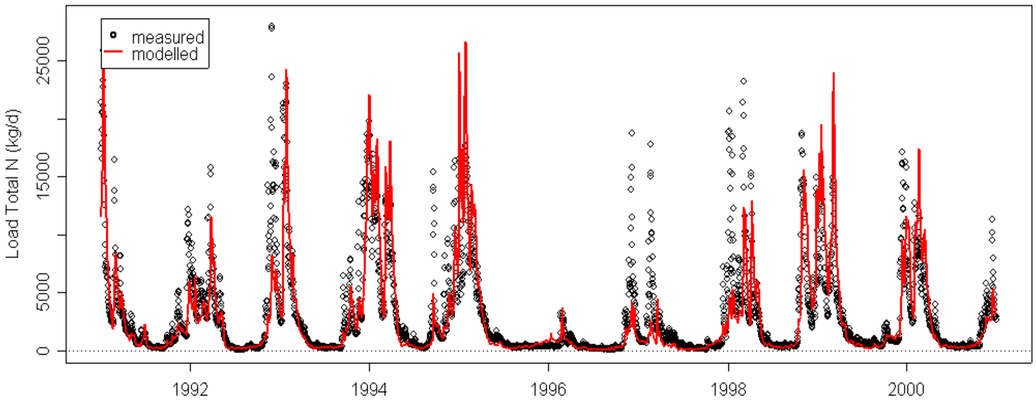



*Figure 3-30 Measured and calculated nitrogen loads at the outlet*

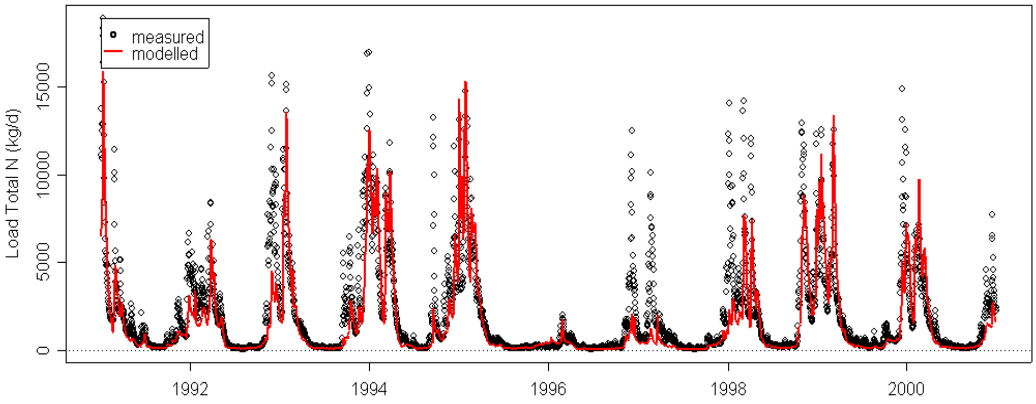



*Figure 3-31 Measured and calculated nitrogen loads halfway*

#### 3.4.4.3 Phosphorus

*Concentrations*

In Figure 3-32 and Figure 3-33 the measured and simulated concentrations are given. The simulations show a different pattern from the measurements. The measurements have more short peaks and the simulations show a smoother pattern. The simulated concentrations for the measurement station halfway overestimate the observations slightly.

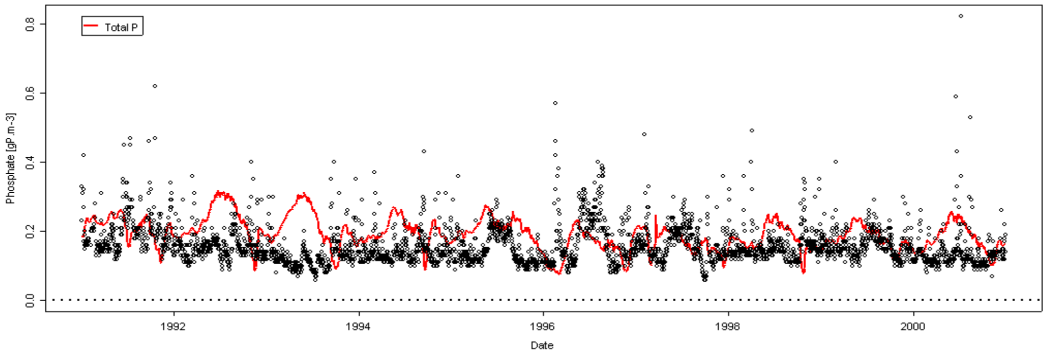



*Figure 3-32 Measured and calculated phosphorus concentrations at the outlet*

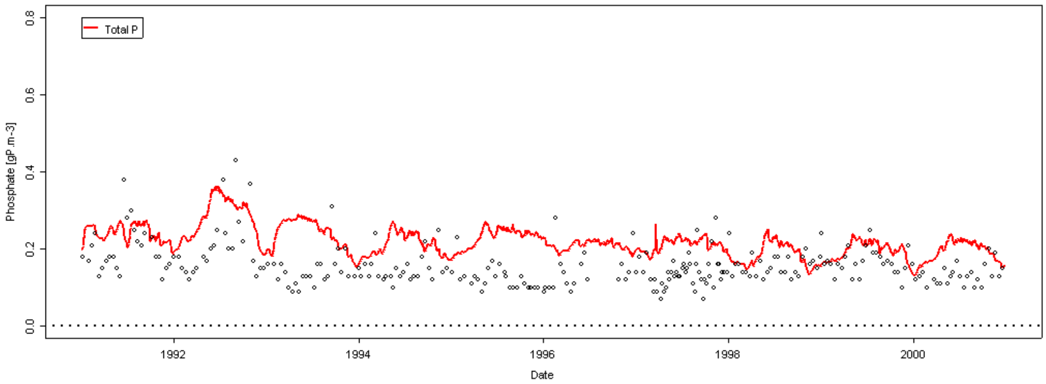



*Figure 3-33 Measured and calculated phosphorus surface water concentrations at an observation location halfway the outlet*

*Loads*

The agreement between the loads based on measurements and simulations is very good (Figure 3-35 and Figure 3-36). Not only the daily loads but also the annual yearly loads should have a good agreement. In Figure 3-34 the annual loads are presented. The main deviations are found for the dry years 1995 and 1996 with low water discharges In these years, the model underestimates the measured values.

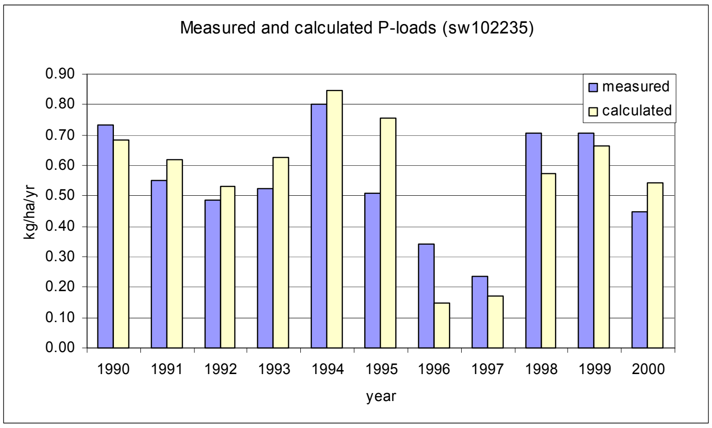



*Figure 3-34 Annual measured and calculated phosphorus loads at the outlet*

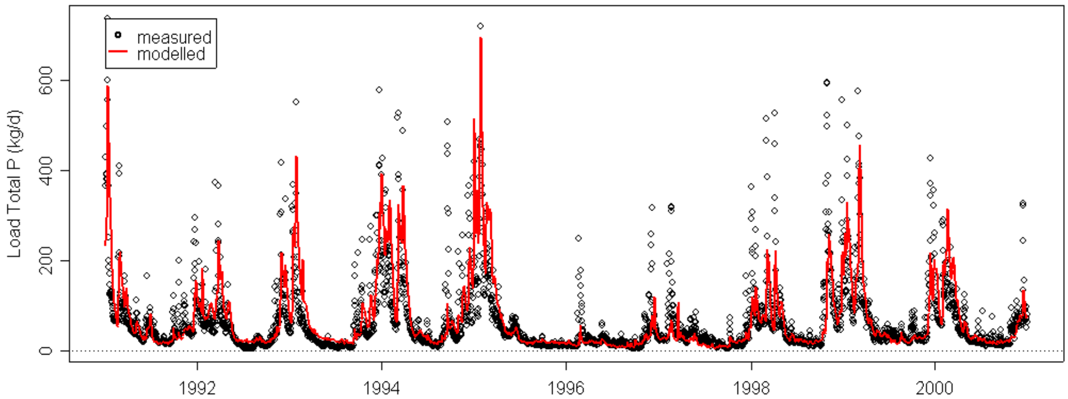



*Figure 3-35 Measured and simulated phosphorus loads at the outlet*

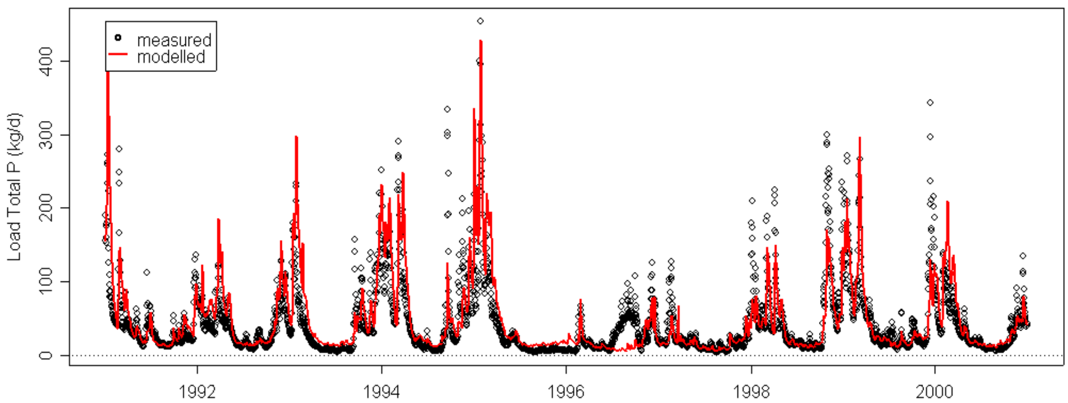



*Figure 3-36 Measured and simulated phosphorus loads halfway*

## 3.4.5 Balances

### 3.4.5.1 Total catchment, soil

In Table 3.33 the balance for the soil compartment for the catchment is given.

*Table 3.33 Balance for the soil compartment (total catchment for the period 1990-2000)*

| **total** | 46536 | ha | |
|---|---|---|---|
| | | | |
| **Waterbalance** | | | mm |
| Input | | Output | |
| Precipitation | 891.6 | Interception | 69.9 |
| | | Transpiration | 320.5 |
| | | Evaporation | 121.0 |
| Infiltration | 0.0 | Surface runoff | 1.3 |
| | | Subsurface runoff | 292.5 |
| Upward seepage | 39.1 | Downward seepage | 126.3 |
| Storage Change | 0.8 | | |
| | 931.5 | | 931.6 |
| | | | |
| **Nitrogen balance** | | | kg/ha |
| Input | | Output | |
| Deposition | 22.8 | Volatilization | 3.2 |
| Fertilizer | 78.7 | Crop yield | 119.7 |
| Manure | 72.6 | Denitrification | 17.3 |
| Infiltration | 0.0 | Surface runoff | 0.1 |
| | | Subsurface runoff | 30.8 |
| Upward seepage | 5.9 | Downward seepage | 12.7 |
| Soil depletion | 3.8 | | |
| | 183.8 | | 183.8 |
| | | | |
| **Phosphorus balance** | | | kg/ha |
| Input | | Output | |
| Deposition | 0.2 | Crop yield | 23.6 |
| Fertilizer | 26.1 | | |
| Manure | 3.9 | | |
| Infiltration | 0.0 | Surface runoff | 0.0 |
| | | Subsurface runoff | 0.6 |
| Upward seepage | 0.0 | Downward seepage | 0.3 |
| | | Soil enrichment | 5.7 |
| | 30.2 | | 30.2 |

### 3.4.5.2 Arable, soil

In Table 3.34 the balance of the soil compartment for the arable part of the catchment is given.

*Table 3.34 Balance for the soil compartment (arable part of the catchment for the period 1990-2000)*

| **arable** | | 34359 | ha |
|---|---|---|---|
| | | | |
| **Waterbalance** | | | mm |
| Input | | Output | |
| Precipitation | 891.8 | Interception | 42.4 |
| | | Transpiration | 329.1 |
| | | Evaporation | 122.9 |
| Infiltration | 0.0 | Surface runoff | 1.4 |
| | | Subsurface runoff | 296.6 |
| Upward seepage | 31.7 | Downward seepage | 131.9 |
| Storage Change | 0.6 | | |
| | 924.1 | | 924.2 |
| | | | |
| **Nitrogen balance** | | | kg/ha |
| Input | | Output | |
| Deposition | 22.8 | Volatilization | 4.2 |
| Fertilizer | 106.6 | Crop yield | 152.9 |
| Manure | 91.7 | Denitrification | 19.4 |
| Infiltration | 0.0 | Surface runoff | 0.1 |
| | | Subsurface runoff | 38.5 |
| Upward seepage | 4.8 | Downward seepage | 16.9 |
| Soil depletion | 6.2 | | |
| | 231.9 | | 231.9 |
| | | | |
| **Phosphorus balance** | | | kg/ha |
| Input | | Output | |
| Deposition | 0.2 | Crop yield | 29.8 |
| Fertilizer | 33.2 | | |
| Manure | 5.0 | | |
| Infiltration | 0.0 | Surface runoff | 0.0 |
| | | Subsurface runoff | 0.6 |
| Upward seepage | 0.0 | Downward seepage | 0.3 |
| | | Soil enrichment | 7.6 |
| | 38.3 | | 38.4 |

#### 3.4.5.3 Surface water

In table 4.6 the surface water balance for the catchment is given.

Table 3.35 Balance for the surface water (for the period 1990-2000)

| **Waterbalance** | | | 10^6 m3 |
|---|---|---|---|
| In | | Out | |
| Runoff | 145.9 | Outflow | 146.4 |
| Precipitation | 2.8 | Evaporation | 2.3 |
| Storage change | 0.0 | | |
| Total | 148.7 | | 148.7 |

| **Nitrogen balance** | | | Ton |
|---|---|---|---|
| In | | Out | |
| Subsurface +_ surface Runoff | 1480.8 | Outflow | 1108.8 |
| Point sources | 24.7 | Biomass losses | 123.4 |
| Erosion | 0.0 | Denitrification | 274.9 |
| Storage change | 1.6 | | |
| Total | 1507.1 | Total | 1507.1 |

| **Phosphorus balance** | | | Ton |
|---|---|---|---|
| In | | Out | |
| Subsurface + surface Runoff | 31.0 | Outflow | 26.1 |
| Point sources | 3.9 | Biomass losses | 6.2 |
| Erosion | 6.7 | Sedimentation | 7.3 |
| | | Storage change | 2.0 |
| Total | 41.6 | Total | 41.6 |

** Runoff includes surface and subsurface runoff*
*** Biomass losses not measured losses. It is floating and suspended biomass.*

## 3.5 Concluding remarks

The agreement between daily simulated and daily measured loads at the catchment outlet is good. The agreement between the annual measured and simulated loads is good, but the model underestimates the annual loads in the dry years with low water discharges (1996 and 1997).

The simulated N balance, averaged for all soils in the catchment, shows an excess (fertilization – crop yield) of 31.6 kg $ha^{-1}y^{-1}$ of which 17.3 kg $ha^{-1}y^{-1}$ is denitrified. The net leaching to deeper groundwater is estimated at 6.8 kg $ha^{-1}y^{-1}$. The nitrogen transport to surface waters amounts to 30.8 kg $ha^{-1}y^{-1}$.
The simulated N balance for the soils used for agricultural activities shows an excess of 45.4 kg $ha^{-1}y^{-1}$ of which 19.4 is denitrified. The net leaching to deeper groundwater is estimated at 12.1 kg $ha^{-1}y^{-1}$. The nitrogen transport to surface waters amounts to 38.5 kg $ha^{-1}y^{-1}$. The soil itself serves as a nitrogen source: the depletion of the organic bounded nitrogen amounts to 6.2 kg $ha^{-1}y^{-1}$. It is uncertain whether this source should really be attributed to the depletion of the organic N stock in the soil. Biological N fixation has not been accounted for in the modelling procedure as such, but could also easily explain this minor N source.

The total N inputs to surface waters are estimated at 1505.5 ton $y^{-1}$, of which 1108.8 ton $y^{-1}$ leaves the catchment at the outlet. The retention in surface waters is calculated at 26%.

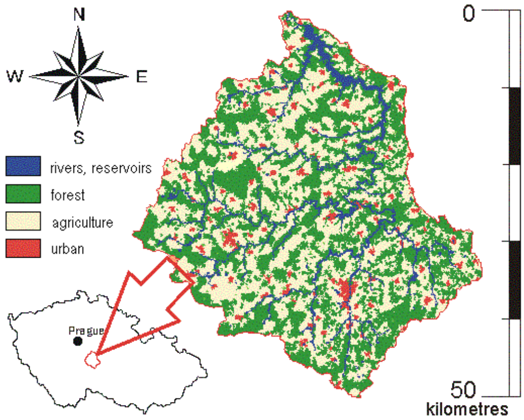
The simulated P balance, averaged for all soils in the catchment, shows an excess of (fertilization – crop yield) 6.4 kg $ha^{-1}y^{-1}$ of which 5.7 kg $ha^{-1}y^{-1}$ is stored in the soil. The phosphorus transport to surface waters amounts to 0.6 kg $ha^{-1}y^{-1}$. The simulated P balance for the soils used for agricultural activities shows an excess of 8.4 kg $ha^{-1}y^{-1}$ of which 7.6 is stored in the soil. The phosphorus transport to surface waters amounts to 0.6 kg $ha^{-1}y^{-1}$.
The total P inputs to surface waters are estimated at 41.6 ton $y^{-1}$, of which 26.1 ton $y^{-1}$ leaves the catchment at the outlet. The retention in surface waters is calculated at 37%.

# 4 The Zelivka Catchment

C. Siderius

## 4.1 Introduction

The Zelivka catchment is situated in the European ecoregion of the Central Highlands and belongs to the Elbe basin. The Zelivka River is a middle size river with maximum flow after the snowmelt in March and April and minimum flow in autumn. The mean annual discharge near the outlet is 6.8 $m^3 s^{-1}$.




The river was dammed at its lower reach in 1971 to construct the Zelivka Reservoir. Since the 1980's, this reservoir has become the most important source of drinking water for more than 1 million inhabitants of the capital of Prague. Water quality has periodically deteriorated due to high nitrate concentrations caused by nitrate leaching from farmland and due to an excessive growth of phytoplankton proliferating on high phosphorus loads from municipal sources.

The bedrock of the Zelivka basin is formed by nutrient-poor rocks - paragneiss and mica-schist. Soils are mostly Dystric Cambisol and Eutric Gleysol (pH 3.8 to 4.2) with 17, 57 and 26% clay, silt and sand fractions, respectively.

The main land use is intensive agriculture with cereal production and breeding of cattle, pigs, and poultry. The fertilisation of arable land dropped by about 35% in the early 1990's, however, no corresponding decrease of the nitrate concentration in streams has been observed. Forests are cultural, mostly coniferous with dominance of spruce.

The population in the catchment is ~53,000 people. Approximately one half of the population lives in towns and villages with more than 500 inhabitants. Waste waters from these municipalities are purified in secondary treatment plants, with an enhanced phosphorus removal technology at the two largest towns. The rest of the population, living in smaller villages and scattered dwellings disposes their sewage in septic tanks.

*Table 4.1 General Catchment information*[2]

| | |
|---|---|
| Catchment Area | 1 189 $km^2$ |
| Elevation Range | 318-765 m a. s. l. |
| Mean Annual Rainfall | 669 mm |
| Specific Run-Off | 173 mm |
| Soils | Dystric Cambisol, Eutric Gleysol |
| Arable Land | 50% |
| Grassland | 13% |
| Open Water | 1.8% |
| Cities with over 500 inhabitants | 14 |

[2] This information is retrieved from the Euroharp website: http://euroharp.org/map/img/cze.htm

## 4.2 Discretisation

### 4.2.1 Delineation of sub catchments

First step in the discretisation of the Zelivka catchment is the delineation of the subcatchments. With AVSWAT 2000 29 'natural' sub catchments were defined using:

- a DEM (Digital Elevation Model);
- the boundary of the catchment;
- the location of the rivers and streams.

One subcatchment division was added manually at the reservoir outflow point. Figure 4.2 shows the 30 catchments and the main watercourses as determined with the AVSWAT tool.

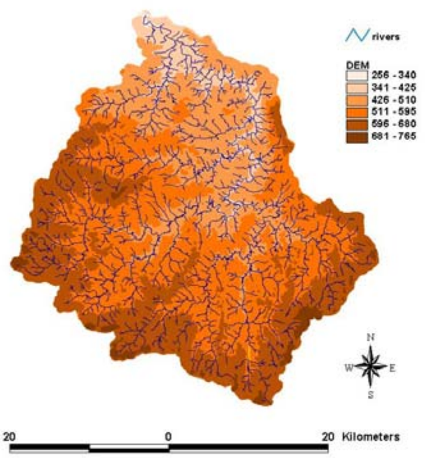



*Figure 4-1 before watershed delineation*

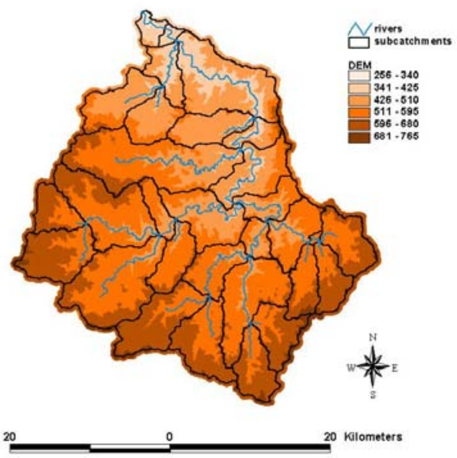



*Figure 4-2 after watershed delineation*

The 30 sub catchments have an average size of 3958 ha, with a minimum size of 177 ha and a maximum size of 11615 ha.

### 4.2.2 Derived surface water system

The surface water system was descretisized into sections with a maximum length of 500 meters. This resulted to 581 sections . Depth and width were defined for each section.
In the next step the total volume of all the small watercourses was determined for each subcatchment. This volume minus the volume of the already schematized main surface water system gives the extra storage of the small streams not incorporated in the main surface water system. Together with the volume of the small lakes this makes up the total extra storage in each subcatchment. This volume was added as an extra section to each subcatchment. Width of the extra storage sections was taken similar as the width of the recipient section of the main surface water system. Calculated discharges from the soil model SWAP were attributed to these extra sections first and have to pass through them.

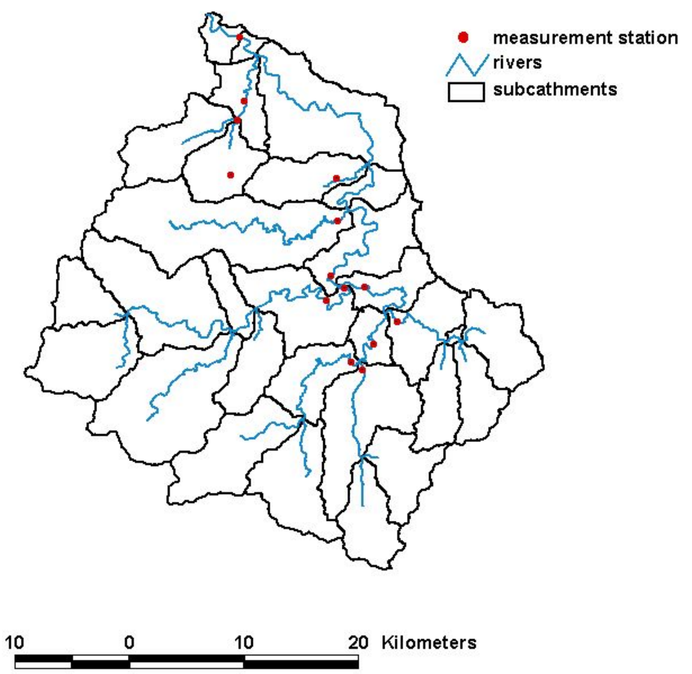



*Figure 4-3 The generalised surface water system*

Data of 14 surface water stations are available were both water quality and quantity is measured for at least the period 1996-2000 (Figure 4-3).

### 4.2.3 Generalisation of the soil map

Figure 4-4 shows the different soils, according to the FAO soil classification, which are present in the Zelivka catchment.

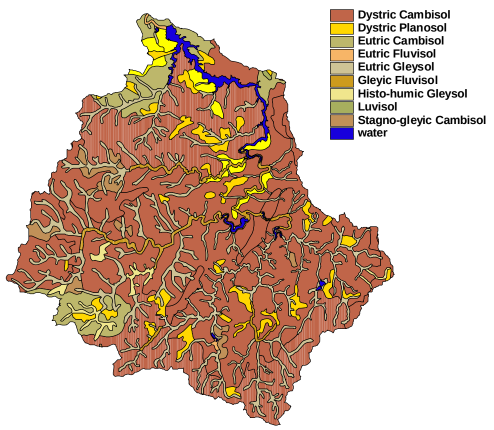



*Figure 4-4 Soil map with FAO soil classification*

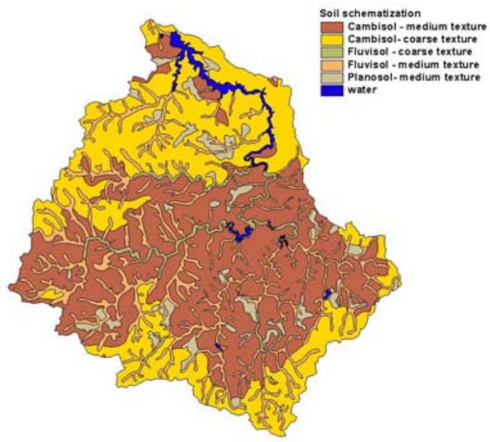



*Figure 4-5 Soil map after discretisation*

Soil hydraulic parameters used by the soil model are derived from the European Hypress database (Wosten et al, 1999). After checking the provided soil data with needed data for deriving the Hypress classes the number of soil types was reduced from 15 to 5 as the soil properties of several soil types were almost similar (Figure 4-5). After clustering two main groups can be distinguished; fluvisols and cambisols, both subdivided into coarse and medium textured variant (Table 4.1)

*Table 4.1 FAO soil types and new model classes*

| | New Model Class | FAO Soil Type | New ID |
|---|---|---|---|
| Fluvisols | Coarse texture | Gleyic fluvisol | 4 |
| | Medium texture | Eutric fluvisol | 6 |
| | | Eutric gleysol | |
| | | Histo-humic gleysol | |
| Cambisols | Coarse texture | Eutric cambisol (nr 2) | 2 |
| | | Dystric cambisol (nr 1) | |
| | | Dystric cambisol (nr 2) | |
| | Medium texture | Eutric cambisol (nr 1) | 7 |
| | | Dystric cambisol (nr 3) | |
| | | Dystric cambisol (nr 4) | |
| | Medium texture shallow groundwatertable | Dystric planosol | 3 |
| Water | water | Water | - |

The FAO Soil types Eutric gleysol (id 11) and Luvisol (id 15) were not similar to one of these classes but they are marginal in the Zelivka area so their plots were attributed to one of the other types by the Eucladian distance option in Arcview.

### 4.2.4 Generalisation of land cover and management

A land use map was available with 5 land use classes (Table 4.2 and Figure 4.6). Urban area and water are not used for the soil water modelling discretisation. This leaves 3 land use units, arable, forest and natural grassland.

*Table 4.2. Distribution of land use (km2 and as % of the total catchment area)*

| land use | km² | % |
|---|---|---|
| Arable | 614.0 | 51.7 |
| Forest | 357.3 | 30.1 |
| Grassland | 148.0 | 12.5 |
| Urban area | 48.2 | 4.1 |
| Water | 20.0 | 1.7 |

The area of open water is integrated in the surface water modelling. The urban area is assumed to be reacting as well drained grassland and is added to the area of a drained grassland plots or a grassland plot with a deep groundwatertable in each subcatchment.

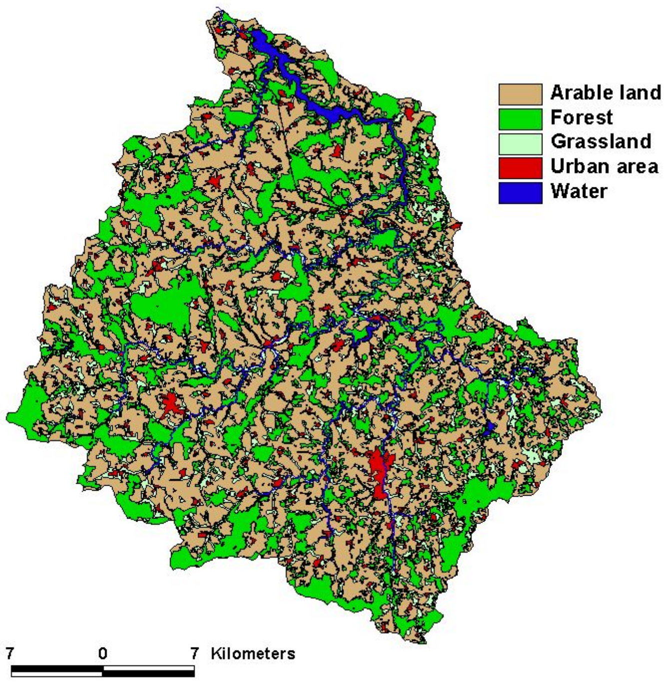



*Figure 4.6 Land cover map*

### 4.2.5 Meteorology

A proper meteorological data set is an important condition for any detailed hydrological study. This is even more important if large spatial and temporal variation occurs. Meteorological data were available from 4 stations varying in altitude and location (Table 4.3). As can be seen from table 4.3 Hulice and Hradek have a low and Cechtice and Novy Rychnov a higher average annual rainfall. This does not seem to be directly related to altitude or longitude or latitude at least not for station 4001 -4003. Only station 4004 (Novy Rychnov) is situated higher and has a higher precipitation.

*Table 4.3. Available weather stations with daily values for precipitation*

| ID | Name | Coordinates.x | Coordinates.y | Elevation | Average Annual Rainfall |
|---|---|---|---|---|---|
| 4001 | Hulice | 15.08 | 49.72 | 375 | 646 |
| 4002 | Cechtice | 15.04 | 49.62 | 496 | 714 |
| 4003 | Hradek | 15.03 | 49.50 | 511 | 639 |
| 4004 | Novy Rychnov | 15.34 | 49.40 | 704 | 720 |

The influence areas of the meteorological stations were derived with the Thiessen polygon method. A map with weather regions was then created by assigning each subcatchment to the nearest weather stations (Figure 4.7 and 4.8). In this way catchment and meteorological stations have the same borders and the amount of plots is only multiplied by the number of meteorological stations as sub catchments in the same meteorological regions share the same meterological characteristics.

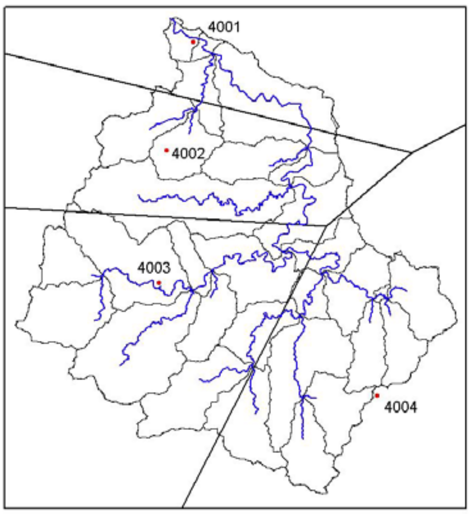



*Figure 4.7 Weather station and Thiessen polygons to determine influence region*

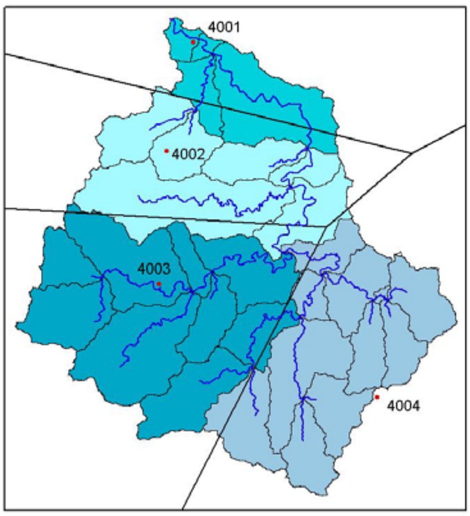



*Figure 4.8 Weather regions*

### 4.2.6 Bottom boundary conditions

Groundwater levels and fluctuations are not known exactly. According to the provided data groundwater levels range between 0-2 meter for shallow soils near the rivers and streams and up to 4-6 meters for higher situated soils. Mineral subsoil consists of fractured rock, paragneiss. Data of the only present groundwater level measurement location show water levels between 4 and 4.6 meter below soil surface. Next to this information an isoline map and a drainage map are available.

Three different kind of bottom boundary conditions were derived based on: i) the information on groundwatertabledepth for every soil type; ii) the isoline map for groundwater depth; iii) the drainage map

Near the rivers and streams water tables are close to soil surface according to the isoline map and the drainage shapefile. But this information on groundwater tables and drainage levels only partly corresponds with the soil types with shallow groundwater tables. More than 50% of this area was located in soils with (according to the soil map) deeper groundwater tables. It is decided to merge the areas with shallow groundwater tables from the isoline map with the soil types with shallow groundwater tables. Then all areas from the drainage map were classified as drained soils with shallow groundwater tables. All other areas had deeper groundwater tables.

- Class1[shallow, undrained] = soil map[river soils] or Isoline map[water table < 3m] and drainage map[no drains]
- Class2[shallow, drained] = drainage map [drains at 0.90 cm]
- Class3[deep]= rest

The resulting map for bottom boundary conditions is given in Figure 4.9. Table 4.4 shows the parameter settings for the different classes. For each class a small bottom boundary seepage of 0.1 mm day$^{-1}$ is imposed.

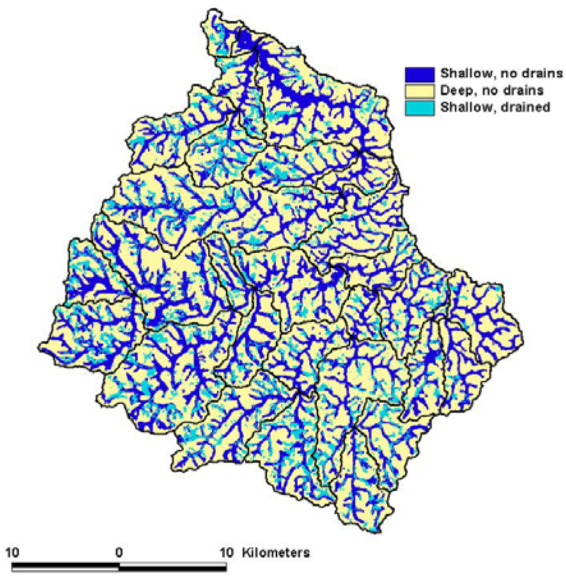



*Figure 4.9 Generalised map with bottom boundary conditions*

*Table 4.4 Discretisation and settings for bottom boundary classes*

| | Drain 1 | | | Drain2 | | | Drain 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | depth (m) | resistance (d) | spacing (m) | depth (m) | resistance (d) | spacing (m) | depth (m) | resistance (d) | spacing (m) |
| Class 1 | 6 | 30000 | 500 | 1.20 | 500 | 500 | 0.30 | 20 | 40 |
| Class 2 | 6 | 30000 | 500 | 1.20 | 500 | 500 | 0.90 | 20 | 20 |
| Class 3 | 6 | 30000 | 500 | 3.00 | 500 | 500 | 0.30 | 20 | 50 |

### 4.2.7 Calculation units

All maps were converted into grids with a cell size of 25 m. Unique combinations were created by making an overlay of the following maps with primary data:

- Meteorological areas – 4 types
- Soils – 5 types (excluding water)
- Landover – 3 types (excluding urban and water)
- Bottom boundary - 3 types

The overlay of these 4 maps resulted in:

- 150 unique plot combinations
- 8 plots urban or water (one for every meteo area) – excluded for SWAP, but used in the water quantity and quality models

To improve the calculation time the number of calculation units (for Swap/Animo) was then reduced by discarding the smallest 5 % plots in each meteorological area (Figure 4.10). In this way 71 plots were eliminated, leaving 79 unique calculation plots.

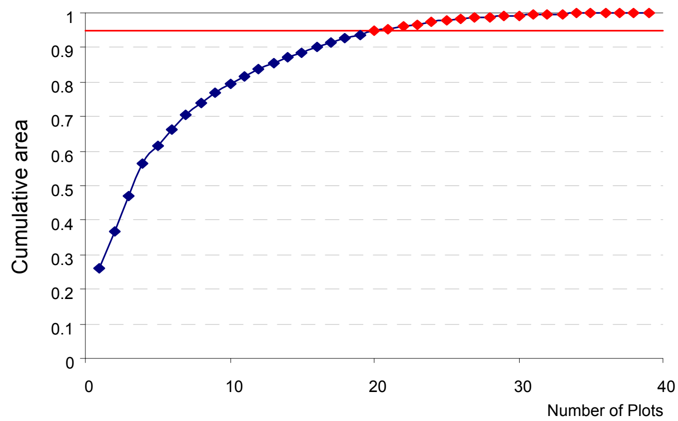



*Figure 4.10 Cumulative frequency distribution of the size (fraction) of calculation units (plots) for meteorological area 4004 (red = smallest 5 %)*

The cells of the small eliminated plots were assigned to the nearest with the Arcview script 'EUCallocation' (range set to 550m).

Table 4.5 shows the difference in the number of plots and their relative size before and after this selection for the different bottom boundary types. Because the drained land use types (bottom boundary type 3) are scattered and have a small area they are likely to be excluded. Still they might be an important contributor to for example peak flows. As table 5 shows there is after correction only a slight decrease in area percentage for this boundary type as for the others. No adjustments in the selection criteria had to be made.

*Table 4.5 Number of plots and their area percentage for the bottom boundary classes before and after selection*

| | before selection | | after selection | |
|---|---|---|---|---|
| Bottom boundary type | number of plots | area percentage | number of plots | area percentage |
| 1 | 57 | 23.1 | 33 | 22.2 |
| 2 | 36 | 59.3 | 28 | 60.6 |
| 3 | 57 | 11.5 | 18 | 10.6 |
| urban and water | 8 | 6.1 | 8 | 6.6 |
| | 158 | | 87 | |

A map with the final 79 calculation units is given in Figure 4.11. The darkest plots represent water and urban areas which were not explicitly modelled in the soil water model.

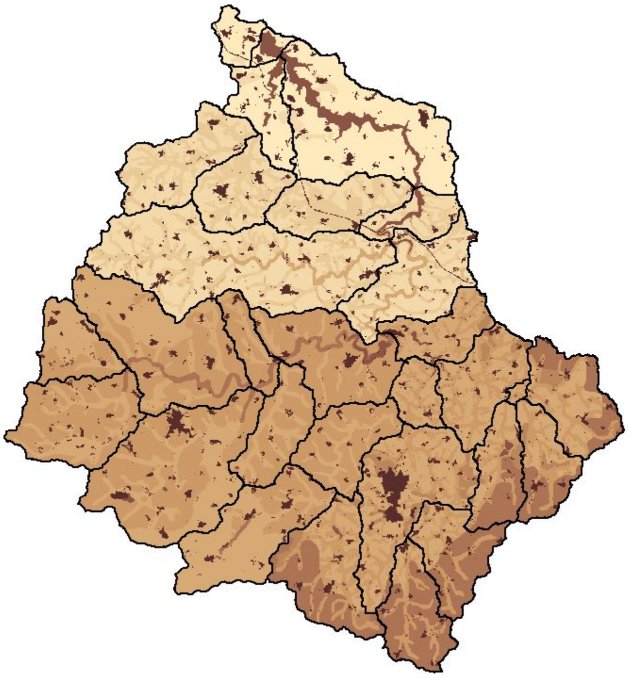


*Figure 4.11 The calculation units*

### 4.2.8 Suggestions for improvement

- Surface water: Use a varying surface water section length. Some parts like the Zelivka storage lake are now over dimensioned, which results in more calculation time.
- Meteorological areas: determine influence areas of meteorological stations not only by nearest distance but also by elevation classes.
- Land use: Merge urban areas directly with drained grassland in the discretisation phase instead of attributing them later on manually. This saves time without any loss of information.

## 4.3 Parameterisation

The study was carried out with the NL-Cat package which consists of the sub models:

- for soil hydrology: Swap version 3.0.3 (Kroes and Van Dam, 2003);
- for soil nutrients: Animo version 4.0.14 (Groenendijk *et al*, 2005, Renaud et al, 2004);
- for surface water quantity: SWQN version 1.0.7 (Smit *et a*l, 2008);
- for surface water quality: NuswaLite version 1.16 (Siderius *et al.,* 2008).

This chapter will explain how the different sub models were parameterised for the Zelivka catchment.

### 4.3.1 Meteorology

#### 4.3.1.1 Evapotranspiration

Evapotranspiration was calculated using the Makkink reference evapotranspiration equation (1957). This equation requires values for minimum and maximum daily air temperature and global radiation. Data on minimum and maximum daily air temperature were only available for station 4001, Hulice (Figure 4.12). Global radiation is not measured directly but can be calculated with the Angstrom formula:

$$R_s = (a_s + b_s\ (n/N))\ R_a$$

| | |
|---|---|
| $R_s$ | solar or shortwave radiation (MJ/ m²/d) |
| n | actual duration of sunshine (hour) |
| N | maximum possible duration of sunshine or daylight hours (hour) |
| n/N | relative sunshine duration (-) |
| $R_a$ | extraterrestrial radiation (MJ/ m²/d) |
| $a_s$ | regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n=0) |
| $a_s + b_s$ | fraction of extraterrestrial radiation reaching the earth on clear days (n+N) |

The actual duration of sunshine is not available either. As a substitute the relative sunshine duration (n/N) is estimated with '1 - cloudiness factor' which was measured at station 4001. Angstrom constants $a_s$ and $b_s$ are not adjusted. Default values of 0.25 for $a_s$ and 0.5 for $b_s$ were used. The resulting evapotranspiration of the reference crop ranges between 568 mm in the year 1987 to 664 in the year 1992 (Figure 4.15).

Evapotranspiration calculated at station 4001 is used for the whole catchment (Figure 4.13). No temperature or elevation correction is applied as their effects are contrarily. Meteorological station 4001 is situated at relative low altitude (see table 2), but the positive effect on evapotranspiration for the higher elevated parts of the catchment (about +1%) is tempered by the lower temperature. Average catchment temperature is some 0.6 $^{o}$C lower (catchment owner reference).

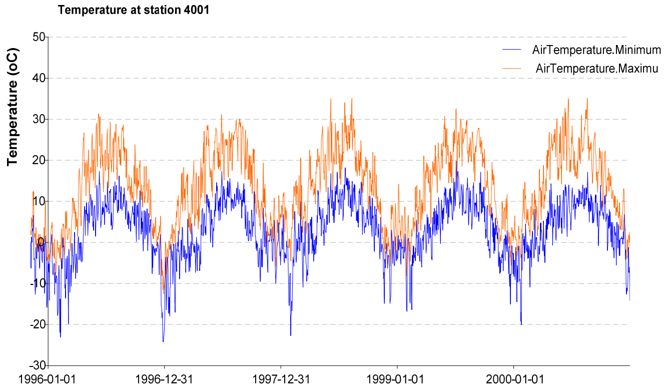



*Figure 4.12 Daily minimum and maximum air temperature (°C) at station 4001*

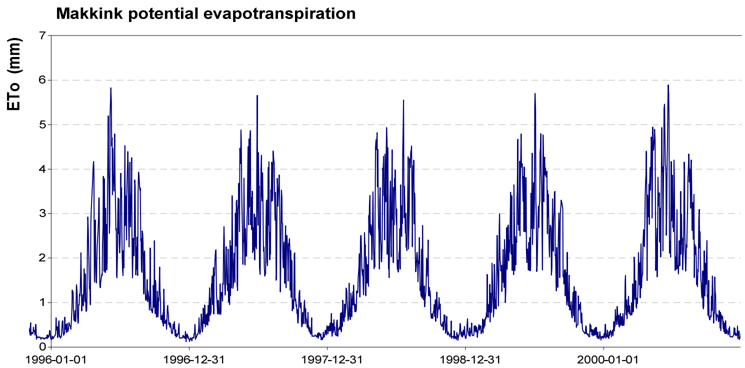



*Figure 4.13 Daily evapotranspiration with Makkink at station 4001*

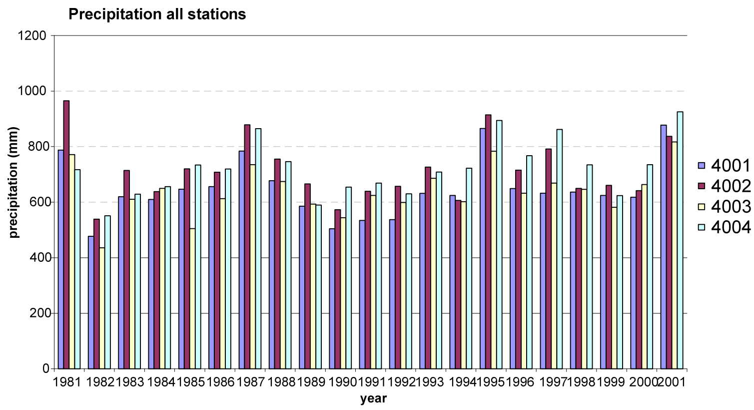



*Figure 4.14 Yearly sum of precipitation (mm yr⁻¹) for all stations*

### 4.3.2 Precipitation

Test runs showed that especially in meteorological area 4004 calculated discharges for 1997 and 1998 were some 20-25% higher than measured discharges. During these years the deviation of station 4004 from average precipitation of the other three stations was higher than in other years. As it is likely that the precipitation measured at the higher elevation of station 4004 is not representative for the whole meteorological area attributed to this station it was decided to use an average rainfall of station 4004 and 4003 for meteorological area 4004.

#### 4.3.2.1 Temperature

Soil water frost, snow and heat transport are modelled with SWAP. Minimum and average temperatures determine soil temperature and conditions of frost and snow in the soil water model. Only for station 4001 (Hulice) minimum and maximum data were available. The linear relationships between average daily temperature and minimum and maximum temperature at Hulice were used to determine values for the other meteorological regions.

### 4.3.3 Soil – groundwater system

Soil physical parameters were assigned to the various soil types (table 4.6). When soils were a combination of different soils (table 4.1, paragraph 4.2.3) sand, silt, and clay fractions were averaged. This only changed fractions slightly as the soils were combined in the first place on similarities in these fractions. Top and bottom of layers and soil organic matter content (SOM) were available for each soil layer and inserted directly.

The CN ratio, sand, silt and clay fractions and pHKCL were only provided for the top layer. For the CN ratio it was assumed that the content in deeper horizonts would be twice as high. pHKCL is taken constant for the whole profile. Based on information provided by the catchment owner (email 06-12-2004), sand, silt and clay fraction were inserted uniformly for the cambisols and planosol (soils 2,3,7). For the fluvisols in the river valleys a medium or fine textured layer was inserted. Deeper layers were given the same texture class again as the topsoil.

No data were available on Aluminium-Ferro content. A constant of 80 (mmol/kg) was taken. Dry bulk densities (rho) were estimated using silt fraction and soil organic matter content using relationships based on measurements by Hoekstra and Poelman (1982).

*Table 4.6 Soil profiles*

| soilID | Texture class | top | bottom | rho | SOM | sand | silt | clay | pHKCl | CNratio |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Topsoil coarse | 0 | 20 | 1.4 | 2.8 | 63 | 26 | 11 | 6 | 10.3 |
| 2 | coarse | 20 | 100 | 1.5 | 0.9 | 63 | 26 | 11 | 6 | 20.6 |
| 2 | coarse | 100 | 700 | 1.6 | 0.5 | 63 | 26 | 11 | 6 | 20.6 |
| 3 | Topsoil medium | 0 | 3 | 1.4 | 3 | 27 | 54 | 19 | 5.5 | 10.5 |
| 3 | medium | 3 | 12.5 | 1.4 | 0.7 | 27 | 54 | 19 | 5.5 | 21 |
| 3 | medium | 12.5 | 100 | 1.5 | 0.5 | 27 | 54 | 19 | 5.5 | 21 |
| 3 | medium | 100 | 700 | 1.6 | 0.3 | 27 | 54 | 19 | 5.5 | 21 |
| 4 | Topsoil coarse | 0 | 3 | 1.4 | 3 | 55 | 28 | 17 | 5.5 | 10.5 |
| 4 | fine | 3 | 12.5 | 1.4 | 0.7 | 5 | 35 | 60 | 5.5 | 21 |
| 4 | fine | 12.5 | 100 | 1.5 | 0.5 | 5 | 35 | 60 | 5.5 | 21 |
| 4 | coarse | 100 | 700 | 1.6 | 0.3 | 55 | 28 | 17 | 5.5 | 21 |
| 6 | Topsoil medium | 0 | 5 | 1.1 | 10 | 57 | 24 | 19 | 5.5 | 11 |
| 6 | fine | 5 | 60 | 1.4 | 3.3 | 5 | 35 | 60 | 5.5 | 22 |
| 6 | medium | 60 | 700 | 1.6 | 0.5 | 57 | 24 | 19 | 5.5 | 22 |
| 7 | Topsoil medium | 0 | 20 | 1.4 | 2.8 | 25 | 58 | 17 | 5.8 | 10.3 |
| 7 | medium | 20 | 100 | 1.5 | 0.9 | 25 | 58 | 17 | 5.8 | 20.6 |
| 7 | medium | 100 | 700 | 1.6 | 0.5 | 25 | 58 | 17 | 5.8 | 20.6 |

For each soil type soil hydraulic properties (table 4.7) were taken from the European HyPress database (Wösten et al, 1999).

*Table 4.7 Soil hydraulic properties from HyPrES (Wösten et al, 1999)*

| | Soil texture | ThetaR | ThetaS | Ksat | Alpha | λ | n | m |
|---|---|---|---|---|---|---|---|---|
| Topsoils | Coarse | 0.025 | 0.403 | 60.000 | 0.0383 | 1.2500 | 1.3774 | 0.2740 |
| | Medium | 0.010 | 0.439 | 12.061 | 0.0314 | -2.3421 | 1.1804 | 0.1528 |
| | MediumFine | 0.010 | 0.430 | 2.272 | 0.0083 | -0.5884 | 1.2539 | 0.2025 |
| | Fine | 0.010 | 0.520 | 24.800 | 0.0367 | -1.9772 | 1.1012 | 0.9190 |
| | VeryFine | 0.010 | 0.614 | 15.000 | 0.0265 | 2.5000 | 1.1033 | 0.0936 |
| | Organic | 0.010 | 0.766 | 8.000 | 0.0130 | 0.4000 | 1.2039 | 0.1694 |
| SubSoils | Coarse | 0.025 | 0.366 | 70.000 | 0.0430 | 1.2500 | 1.5206 | 0.3424 |
| | Medium | 0.010 | 0.392 | 10.755 | 0.0249 | -0.7437 | 1.1689 | 0.1445 |
| | MediumFine | 0.010 | 0.412 | 4.000 | 0.0082 | 0.5000 | 1.2179 | 0.1789 |
| | Fine | 0.010 | 0.481 | 8.500 | 0.0198 | -3.7124 | 1.0861 | 0.0793 |
| | VeryFine | 0.010 | 0.538 | 8.235 | 0.0168 | 0.0001 | 1.0730 | 0.0680 |
| | Organic | 0.010 | 0.766 | 8.000 | 0.0130 | 0.4000 | 1.2039 | 0.1694 |

### 4.3.4 Land management

The different land covers (table 4.8) were simulated using default parameter sets for arable land, grassland and forest. Only for rape, winter wheat, spring barley and clover the Leaf Area Index (LAI) was adjusted for the Zelivka climatic region with the Wofost crop growth simulator (Boogaard et al., 1998) using climatic data from southern Germany. All other parameters like rooting depth and water and salt stress for arable, forest and grassland were derived from standard SWAP crop parameters.

*Table 4.8 Parameter sets for the distinguished land cover types*

| Land cover nr | Land cover type | Parameter set |
|---|---|---|
| 1 | Arable | Rotation winter wheat - rape - corn – w. wheat - potatoes – clover – s. barley |
| 9 | Grass | Natural grassland |
| 11 | Grass | Cultivated grassland |
| 17 | Forest | forest coniferous |
| 2 | Urban | not simulated by soil models |
| 5 | Water | not simulated by soil models |

#### 4.3.4.1 Rotations

Data on the occurrence of rotations with specific crops was available but not the exact location of this kind of rotation. Therefore the occurrence of each crop in the Zelivka area in all rotations over a period of 12 years (1998-2000) was calculated (table 4.9).

*Table 4.9 area percentage for crops in all rotations*

| Crops | yearly average area (%) | Crops | yearly average area (%) |
|---|---|---|---|
| Flax | 0.8 | Potatoes | 6.4 |
| Fig Peas | 0.8 | Clover | 8.0 |
| Poppy seed | 0.8 | Winter barley | 8.0 |
| Spring wheat | 0.8 | Rape | 8.7 |
| Oats | 2.3 | Corn silage | 9.5 |
| Rye | 4.0 | Spring barley | 14.3 |
| Hay | 19.0 | Winter wheat | 15.1 |

With this information a general rotation was created in which the most dominant crops were present (table 4.10). With winter barley modelled as winter wheat as well, winter wheat is the most dominant crop and therefore present twice in this rotation (including winter barley 23% of arable area).

As there is no information on the spatial distribution of certain rotations or on the presence of crops in a certain year it was decided to calculate the standard rotation each year 7 times each with a different crop in the starting year. In this way it is possible to simulate the non linearity of a rotation (consecutive crops under changing climatic circumstances) while at the same time the occurrence of a crop remains the same and consists each year of 1/7 potatoes, 2/7 winter wheat, 1/7 clover etc.

*Table 4.10 Original and modelled emergence and harvesting dates for arable crops*

| | | Original dates | | Modelled dates | |
|---|---|---|---|---|---|
| year | cropID | emergence | harvest | emergence | harvest |
| 1 | potatoes | 05-01 | 09-10 | 05-01 | 09-10 |
| 2 | w.wheat | 09-20 | 07-05 | 01-01 | 08-01 |
| 3 | rape | 08-25 | 07-10 | 01-01 | 08-01 |
| 4 | corn | 03-20 | 09-10 | 03-20 | 10-01 |
| 5 | w.wheat | 09-20 | 07-05 | 01-01 | 08-01 |
| 6 | clover | 03-20 | 09-10 | 01-01 | 12-30 |
| 7 | s.barley | 04-01 | 09-01 | 04-01 | 09-01 |

Hay was not included in the crop rotation but all agricultural plots which are undrained and have shallow groundwater tables according to the bottom boundary map (paragraph 4.2.6 Class1) were modelled as permanent hay lands (cultivated grassland). This is 13 % of total arable land.

In the Animo model it is, at present, only possible to model one crop every year. Emergence dates for the winter crops, winter wheat and rape, were therefore adjusted and start automatically at the first of January of a new year as can be seen in table 9. The development stage curve and harvesting dates have been adjusted slightly to compensate for the reduction of growing time in October until December.

### 4.3.4.2 Fertilizers

An analysis of historical fertilizer and manure applications with average data available for three periods (1988-1992, 1993-1996 and 1997-2000) resulted in values as given in table 4.11. Both manure and fertilizer use is decreasing in the last decade. As can be seen modelled periods differ slightly from the provided data periods. For an easy correspondence between the SWAP and Animo model it is best to model a complete crop cycle each period. Hence every period had to last 7 or a multiple of 7 years, whereas provided data was averaged over periods of 4 years.

*Table 4.11. Historical yearly average fertilizer applications (kg/ha)*

| | Period | Manure | | Fertilizer | | N Fixation | |
|---|---|---|---|---|---|---|---|
| | | N | P | N | P | N | P |
| Arable | 1947-1987 | 75 | 18 | 85 | 28 | 34 | 4 |
| | 1988-1994 | 60 | 15 | 52 | 10 | 34 | 4 |
| | 1995-2001 | 55 | 13 | 52 | 8 | 34 | 4 |
| Cultivated grassland | 1947-2001 | 60 | 15 | | | 17 | 4 |
| Natural grassland | 1947-2001 | | | | | 37 | 4 |
| Forest | 1947-2001 | | | | | 37 | 4 |

On arable land manure is applied in three applications spread over October. Fertilizer N and P are applied in three applications in April. Manure on cultivated grassland was applied the first of each month from April till September. No information was available on the differences in fertilizer and manure input for different crops. N and P inputs were therefore the same for all crops.

The 34 kg N fixation on arable land comes totally from clover (80 kg N/yr on 14% of arable land) and rape (40 kg N/yr on 14% of arable land). On grassland and forest a constant N fixation of 17 – 34 kg N/yr was applied depending on the availability of additional manure N. It is assumed that N fixation takes place during the whole growing season from April till October.

## 4.3.5 Surface water system

### 4.3.5.1 Diffuse sources

Output from the soil water module (SWAP) was used in the nutrient module (Animo) and input for the Surface Water Quantity module (SWQN). Outputs from Animo provided the diffuse source for the Soil Water Quality module (Nuswalite).

### 4.3.5.2 Point sources

Next to the diffuse nutrient sources two types of point sources were specified for the Zelivka watershed; waste water treatment plant discharges and direct discharges.

The discharge data from 23 Waste Water Treatment Plants (WWTP) over the period of 1994-2000 were analysed (table 12). N data is scarce and when large difference in N loads for the same area (related to SWQN node in table 4.12) occur trends in P concentrations were extrapolated to N concentrations. This is based on the assumption that P and N retention vary similarly over the years and no difference in retention capacity of N and P by waste water plants has taken place. Of course this can be questioned but no further specific information was available. Total N and P input were split into 75% mineral and 25 % organic. Average (daily) values were input to the surface water quality model and assigned to the nearest surface water nodes

*Table 4.12. Discharge from Waste Water Treatment Plants (kg/year)*

| N (kg/year) | Estimated/measured | | | | | | |
|---|---|---|---|---|---|---|---|
| SWQN node | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
| 19 | | | | 110 | | | |
| 79 | | 562 | | | | | |
| 80 | | 1519 | | | | | |
| 81 | | 558 | | | | | |
| 82 | | | | 108 | | | |
| 83 | | 321 | | | | | |
| 84 | | | | | | | |
| 165 | | 4889 | 4889 | 4889 | 4889 | | |
| 180 | | 4889 | | | | | |
| 190 | | 4889 | 4889 | 4889 | 4889 | | 4889 |
| 225 | | 1432 | 5010 | | | | |
| 245 | | 4847 | | | | | |
| 254 | | 3196 | | | | | |
| 486 | | 9829 | 14381 | | | | |
| 510 | | 535 | | | | | |
| 543 | | 47085 | 29300 | | | | |
| 704 | | 2425 | | 897 | | | |
| 706 | | 436 | | | | | |
| 708 | | 3206 | | | | | |
| 709 | | 446 | | | | | |
| 720 | | | | | | | |
| 724 | | | 1777 | | | | |
| 728 | | 1075 | | | | 4889 | |

| P (kg/year) | Estimated/measured | | | | | | |
|---|---|---|---|---|---|---|---|
| SWQN node | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
| 19 | | | 38 | 51 | | 5 | 21 |
| 79 | | 84 | 65 | 87 | 73 | 86 | 56 |
| 80 | | 255 | | 131 | 142 | 142 | 144 |
| 81 | | 148 | 141 | 111 | 95 | 70 | 126 |
| 82 | | | 33 | 2 | | 9 | 6 |
| 83 | | 60 | | | | 52 | 103 |
| 84 | | | 22 | 18 | | | |
| 165 | | 211 | 211 | 211 | 211 | 179 | 114 |
| 180 | | 211 | 179 | 163 | 193 | 217 | 205 |
| 190 | | 211 | 211 | 211 | 211 | 264 | 211 |
| 225 | | 114 | 244 | 133 | 101 | 90 | 45 |
| 245 | | 53 | | 230 | | 164 | 199 |
| 254 | | 119 | 112 | 130 | 268 | 119 | 133 |
| 486 | | 387 | 442 | 152 | 167 | 253 | 312 |
| 510 | | 8 | | | 93 | 81 | 69 |
| 543 | 6617 | 5301 | 2800 | 1000 | 1100 | 870 | 1740 |
| 704 | | 335 | 235 | 306 | 215 | 171 | 269 |
| 706 | | 50 | | | | | |
| 708 | | 168 | | 150 | 4 | 258 | 296 |
| 709 | | 31 | | | | | |
| 720 | | | | | 127 | | |
| 724 | | | 60 | 66 | 82 | 88 | 125 |
| 728 | | 159 | 136 | 130 | 95 | 211 | 95 |

| N (kg/year) | Model input | | | | | | |
|---|---|---|---|---|---|---|---|
| SWQN node | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
| 19 | 110 | 110 | 110 | 110 | 110 | 110 | 110 |
| 79 | 562 | 562 | 562 | 562 | 562 | 562 | 562 |
| 80 | 1519 | 1519 | 1519 | 1519 | 1519 | 1519 | 1519 |
| 81 | 558 | 558 | 558 | 558 | 558 | 558 | 558 |
| 82 | 108 | 108 | 108 | 108 | 108 | 108 | 108 |
| 83 | 321 | 321 | 321 | 321 | 321 | 321 | 321 |
| 84 | | | | | | | |
| 165 | 4889 | 4889 | 4889 | 4889 | 4889 | 4889 | 4889 |
| 180 | 4889 | 4889 | 4889 | 4889 | 4889 | 4889 | 4889 |
| 190 | 4889 | 4889 | 4889 | 4889 | 4889 | 4889 | 4889 |
| 225 | 1432 | 1432 | 5010 | 1432 | 1432 | 1432 | 1000 |
| 245 | 4847 | 4847 | 4847 | 4847 | 4847 | 4847 | 4847 |
| 254 | 3196 | 3196 | 3196 | 3196 | 3196 | 3196 | 3196 |
| 486 | 9829 | 9829 | 14381 | 5000 | 5000 | 6000 | 9000 |
| 510 | 535 | 535 | 535 | 535 | 535 | 535 | 535 |
| 543 | 47085 | 47085 | 29300 | 15000 | 15000 | 15000 | 15000 |
| 704 | 2425 | 2425 | 2425 | 897 | 897 | 897 | 897 |
| 706 | 436 | 436 | 436 | 436 | 436 | 436 | 436 |
| 708 | 3206 | 3206 | 3206 | 3206 | 3206 | 3206 | 3206 |
| 709 | 446 | 446 | 446 | 446 | 446 | 446 | 446 |
| 720 | | | | | | | |
| 724 | 1777 | 1777 | 1777 | 1777 | 1777 | 1777 | 1777 |
| 728 | 1075 | 1075 | 1075 | 1075 | 1075 | 4889 | 1075 |

| P (kg/year) | Model input | | | | | | |
|---|---|---|---|---|---|---|---|
| SWQN node | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
| 19 | 38 | 38 | 38 | 51 | 51 | 5 | 21 |
| 79 | 84 | 84 | 65 | 87 | 73 | 86 | 56 |
| 80 | 255 | 255 | | 131 | 142 | 142 | 144 |
| 81 | 148 | 148 | 141 | 111 | 95 | 70 | 126 |
| 82 | 33 | 33 | 33 | 2 | 2 | 9 | 6 |
| 83 | 60 | 60 | 60 | 60 | 60 | 52 | 103 |
| 84 | 22 | 22 | 22 | 18 | 18 | 18 | 18 |
| 165 | 211 | 211 | 211 | 211 | 211 | 179 | 114 |
| 180 | 211 | 211 | 179 | 163 | 193 | 217 | 205 |
| 190 | 211 | 211 | 211 | 211 | 211 | 264 | 211 |
| 225 | 114 | 114 | 244 | 133 | 101 | 90 | 45 |
| 245 | 53 | 53 | 53 | 230 | 230 | 164 | 199 |
| 254 | 119 | 119 | 112 | 130 | 268 | 119 | 133 |
| 486 | 387 | 387 | 442 | 152 | 167 | 253 | 312 |
| 510 | 8 | 8 | 8 | 8 | 93 | 81 | 69 |
| 543 | 6617 | 5301 | 2800 | 1000 | 1100 | 870 | 1740 |
| 704 | 335 | 335 | 235 | 306 | 215 | 171 | 269 |
| 706 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| 708 | 168 | 168 | 168 | 150 | 4 | 258 | 296 |
| 709 | 31 | 31 | 31 | 31 | 31 | 31 | 31 |
| 720 | 127 | 127 | 127 | 127 | 127 | 127 | 127 |
| 724 | 60 | 60 | 60 | 66 | 82 | 88 | 125 |
| 728 | 159 | 159 | 136 | 130 | 95 | 211 | 95 |

Direct discharge from 302 direct discharge sources was clustered for every subcatchment and assigned to the sub catchments additional storage node. An estimated number of inhabitants was available for each direct discharge source for which the datasheet provided average inhabitant specific emissions for N and P. P inhabitant specific emission was 2.6 g/inh/d in 1985, 3.0 g/inh/d in 1990, 2.4 g/inh/d in 1995 and 2.1 g/inh/d in 2000. Values for N remained constant over the whole period at 15 g/inh/d. The datasheets furthermore suggested that 50% of P and N of these direct discharge sources reached the watercourses. Therefore the N and P loads were divided by two. Finally total N and P input were again split into 75% mineral and 25 % organic. Average (daily) values were input to the surface water quality model.

#### 4.3.5.3 Erosion

A simplified approach was applied (paragraph 2.5). This approach is based on the RUSLE (Revised Unified Soil Loss Equation). A rough estimate of soil erosion was achieved by applying the procedure to the catchment with as the following input parameters for each 625 $m^2$ grid:

- nutrient emission from the soil sub model for nutrients (Animo);
- rock content as soil characteristics from the given database ( 5% for the whole catchment);
- the xyz-values of the DEM

The results of this estimation were changed during the calibration phase by adjusting one overall fitting parameter. This parameter was set to 0.2, similar to the fraction used for the Norwegian Vansjø-Hobøl catchment. It is assumed that not all P and N added to the surface water system as a result of erosion is released from the soil particles immediately but that most will be incorporated in the sedimentation.

#### 4.3.5.4 Input totals

Table 4.13 gives an indication of the different nutrient sources for the whole Zelivka catchment. As can be seen agricultural lands contribute most N to the surface water system. Point sources are an important contributor to the P input to surface waters.

*Table 4.13. Nutrient sources for the whole Zelivka catchment*

| | t N/a | t P/a |
|---|---|---|
| Point sources (incl. erosion) | 61.4 | 14.4 |
| Woodland and other non-agricultural land | 468 | 15 |
| Agricultural land | 1731 | 9.1 |
| | | |
| *Additional information regarding agric. land:* | | |
| Surface runoff all agric. land | 23 | 4.0 |
| Net surplus at soil surface: grassland | 76 | 60 |
| Net surplus at soil surface: arable land | 1745 | 554 |
| Root zone loss: grassland | 8 | 0.8 |
| Root zone loss: arable land | 1723 | 8.3 |

## 4.4 Simulation results

Measured data were most complete for the period 1996-2000. Results are given for the groundwater system and for the surface water system for this period. Figure 4.15 gives the measurements points for which results are presented.

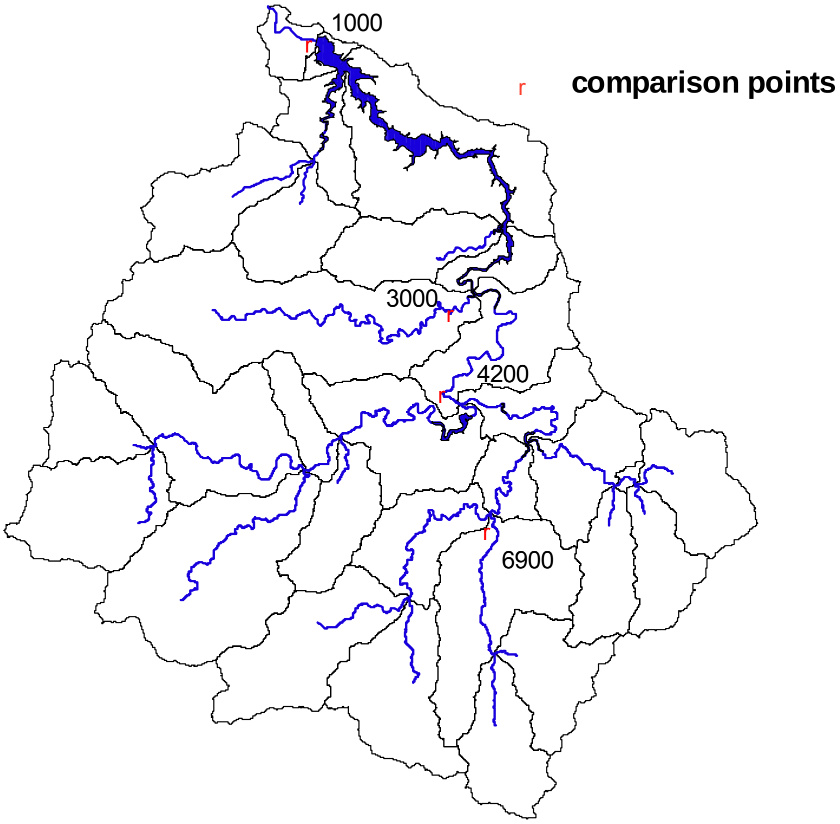



*Figure 4.15 Location of comparison points*

Appendix 9 gives a full scenario analysis for the Zelivka catchment in addition to the presented results in the following paragraphs.

### 4.4.1 Water

Water flow is simulated in the soil/groundwater system (Swap) and for the surface water system (Swqn). Figures 4.16 and 4.17 show yearly discharges of the surface water system compared to measured values for a point midstream and at the outlet.

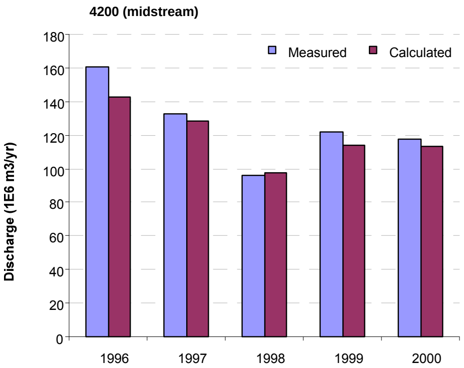



*Figure 4.16 Water discharge ($10^6$ $m^3$ $yr^{-1}$) from the surface water model and measured midstream*

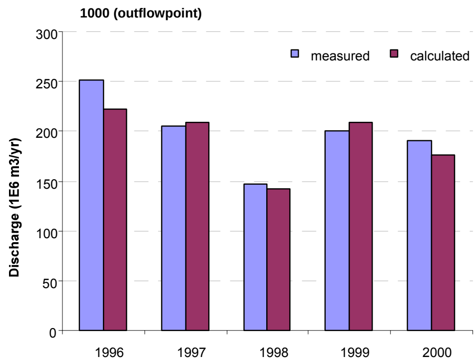



*Figure 4.17 Water discharge ( $10^6$ $m^3$ $yr^{1}$) from the surface water model and measured at the outlet*

The water discharges ($m^3$ $s^{-1}$) at the outlet of the entire catchment, midstream and of 2 sub catchments are given in table 4.14 and figure 4.18. Mean simulated values for the whole catchment and midstream are in good agreement with the measured ones. Only peakflows are not as high as measured. Largest deviations occur in subcatchment 3000 where overall modelled discharges are too high. This might be explained by attributing this whole catchment to meteorological regions 4002 which has a high measured precipitation in comparison two the neighbouring stations.

*Table 4.14 Statistics of the water discharge ($m^3$ $s^{-1}$) at the outlet(1000), midstream(4200) and from two subcatchments (3000,6900)*

| | Min. | 1stQu. | Median | Mean | 3rdQu. | Max. |
|---|---|---|---|---|---|---|
| 1000 - measured | 1 | 3.9 | 4.7 | 6.299 | 6.3 | 38 |
| 1000 - modelled SWQN | 3.799 | 4 | 4.929 | 6.665 | 7.905 | 29 |
| 4200 - measured | 0.432 | 1.722 | 2.684 | 3.978 | 4.722 | 56 |
| 4200 - modelled SWQN | 0.942 | 1.864 | 3.329 | 3.992 | 4.986 | 30 |
| 3000 - measured | 0.044 | 0.167 | 0.308 | 0.496 | 0.596 | 13.5 |
| 3000 - modelled SWQN | 0.141 | 0.305 | 0.608 | 0.721 | 0.922 | 5.6 |
| 6900 - measured | 0.156 | 0.443 | 0.62 | 0.769 | 0.896 | 12.0 |
| 6900 - modelled SWQN | 0.171 | 0.344 | 0.707 | 0.822 | 1.051 | 6.1 |

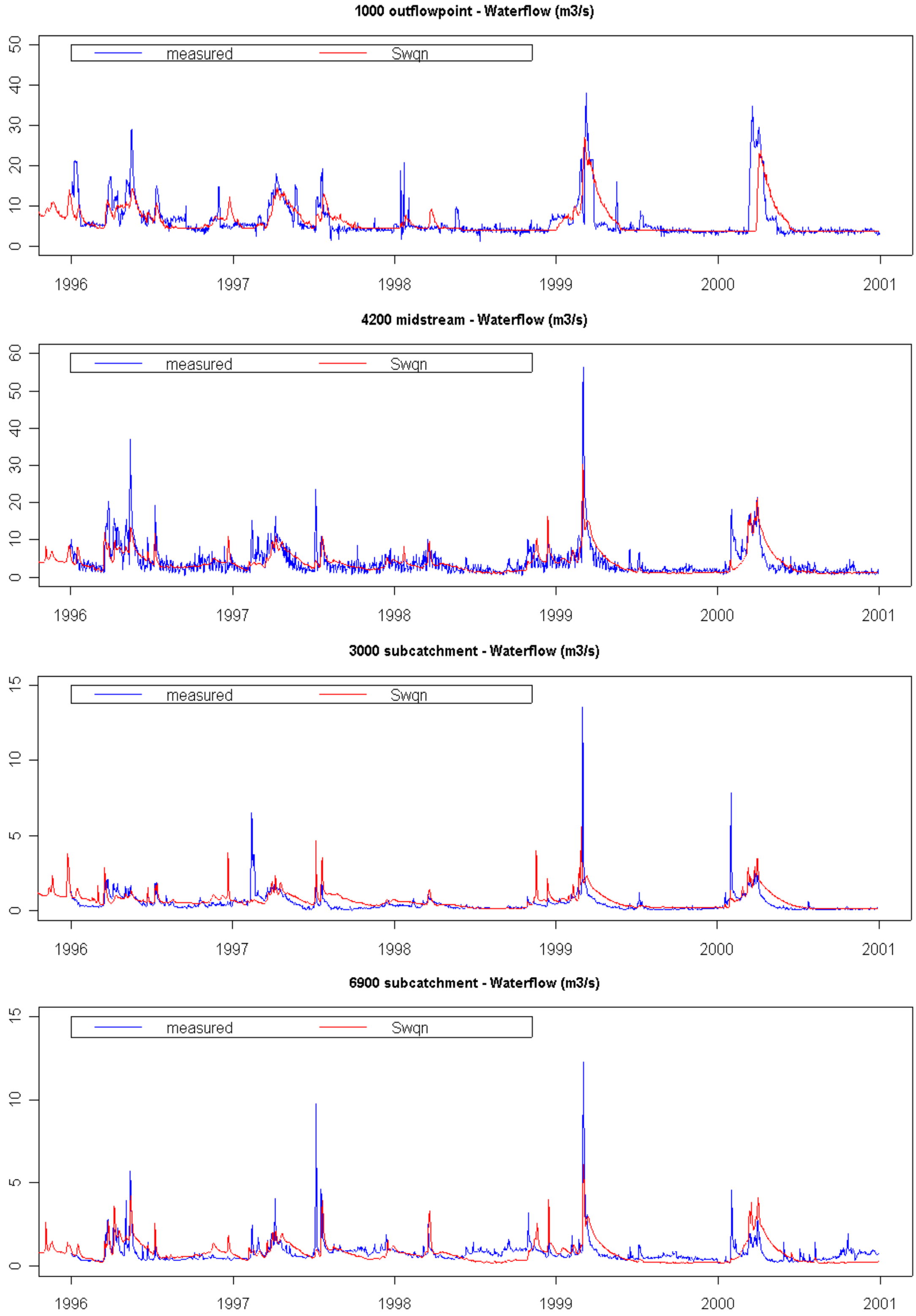



*Figure 4.18 Measured and simulated water discharge (m3 s-[1]) with the SWQN module of the NL-CAT modelling system*

At the outflow point, minimum calculated discharges are controlled by the pumping regime and correspond well with measured values. Timing of peak discharges is also quite accurate which indicates a correct modelling of the size and flood buffering capacity of the Zelivka storage reservoir.

At location 4200 midstream measured values are fluctuating due to the hydropower plant at Sedlice. These fluctuations are not calculated but short term averages do correspond well with measured values.

For all points it can be seen that calculated peak discharges are lower than modelled. Also the decline in calculated discharge after a peak event is slower than measured values. The modelled system reacts somewhat slower than in reality. This delay can already be seen in the groundwater model discharge output. The interflow through the soil might be of greater influence. A better soil hydraulic parameterisation with a quicker response in discharges could improve model results. But at present the necessary information on soil characteristics is not available.

Most peak discharges occur at the end of winter or early spring as a result of melting snow and ice. In combination with rain this can cause high peak flows. As can be seen from Figure 4.18 many of the peaks have been modelled, some are missed and sometimes the model calculates a peak discharge when in reality none occurred. In most cases calculated discharges are lower than measured. The occurrence of a peakflow depends on a delicate combination between precipitation, air temperature (determining snow or rain) and soil temperature (controlling instant snowmelt or accumulation). Although not always exact the model seems to be able to simulate frost and snow.

### 4.4.2 Nitrogen

Results are given for the groundwater nutrient system (Animo) and the surface water system (Nuswalite). Concentrations and loads for are presented.

#### 4.4.2.1 Soil- and groundwater system

In tables 4.15 and 4.16 the average N balance over the last 14 years of the soil nutrient model for all agriculture (including cultivated grassland) and nature (forest and grassland) plots are given.

*Table 4.15 Nitrogen balance for agriculture (kg ha$^{-1}$ yr$^{-1}$)*

| | Fertilizer | Manure | Deposition | Net crop uptake | discharge | seepage | volatili zation | Denitrifi cation | storage change |
|---|---|---|---|---|---|---|---|---|---|
| In | 59 | 69 | 12 | | | | | | |
| Out | | | | 105 | 27 | 3 | 2 | 21 | |
| Δ stor. | | | | | | | | | -19 |

*Table 4.16 Nitrogen balance for nature (kg ha$^{-1}$ yr$^{-1}$)*

| | Biological N fixation | Deposition | Net crop uptake | discharge | seepage | volatilization | Denitrification | storage change |
|---|---|---|---|---|---|---|---|---|
| In | 38 | 12 | | | | | | |
| Out | | | 13 | 6 | 1 | 0 | 19 | |
| Δ stor. | | | | | | | | 11 |

#### 4.4.2.2 Surface water system - concentrations

Results of a comparison between simulated and measured concentrations are given in Figure 4.19. Average concentrations agree well with measurements. The decreasing trend in minimum concentrations is present in calculated values as well.

For the outflow point measured concentrations seem to stabilise or even increase slightly in 1999 and 2000. Nutrient inputs and point sources have only decreased over this period so it is somewhat unclear what causes this fluctuation. Calculated concentrations do not show this trend.

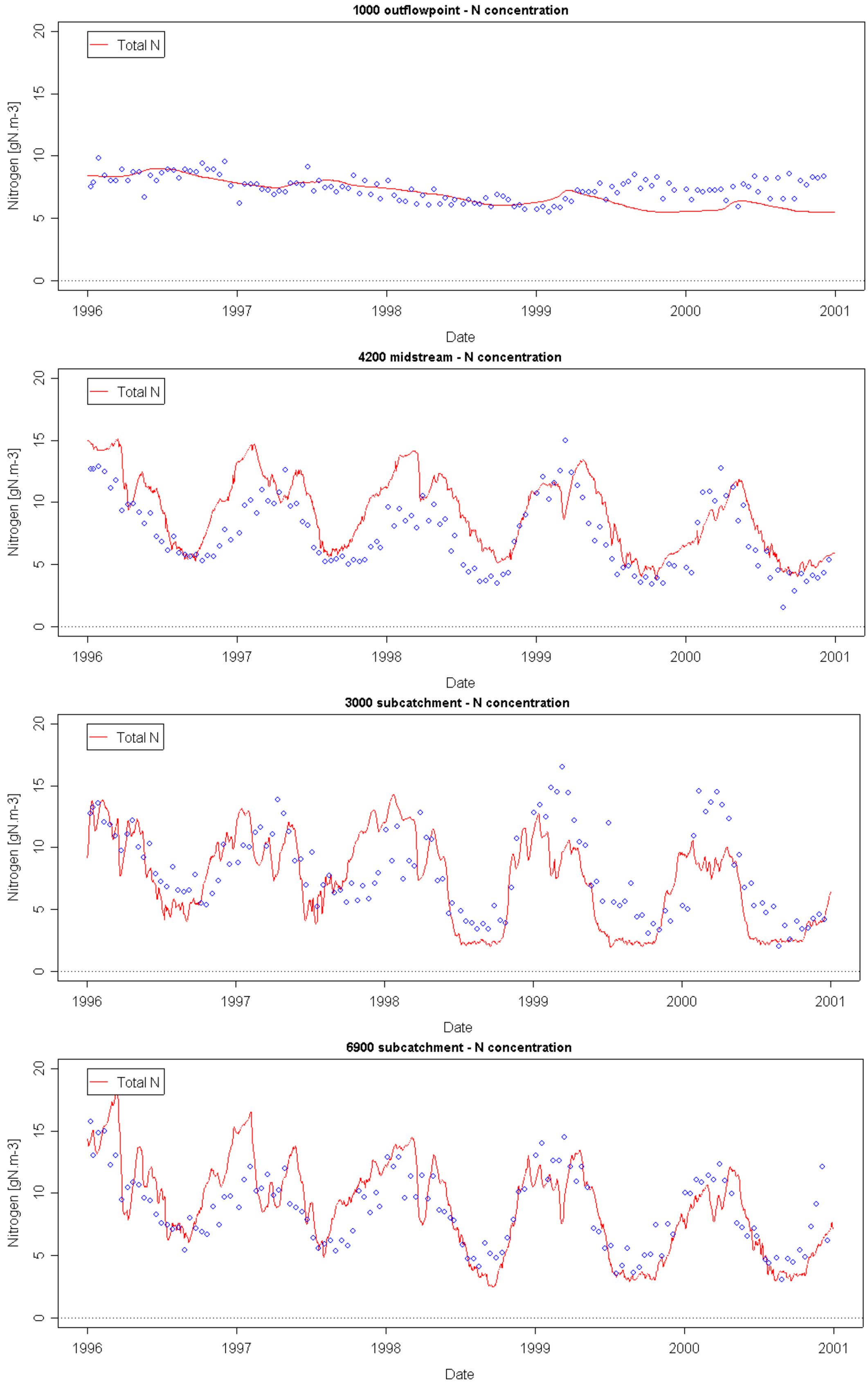



*Figure 4.19 Total Nitrogen concentrations (mg $l^{-1}$) calculated (red line) and measured (blue dots)*

#### 4.4.2.3 Surface water system – loads

Total loads are presented in figures 20 - 23. All loads are of the same order of magnitude and follow a similar trend as measured values with the exception of the year 1996 of point 6900.

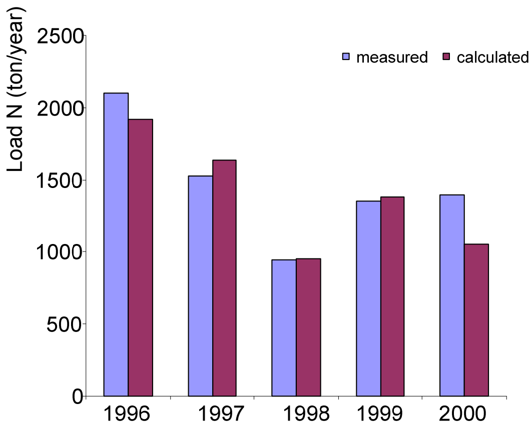



*Figure 4.20 Annual N loads for point 1000*

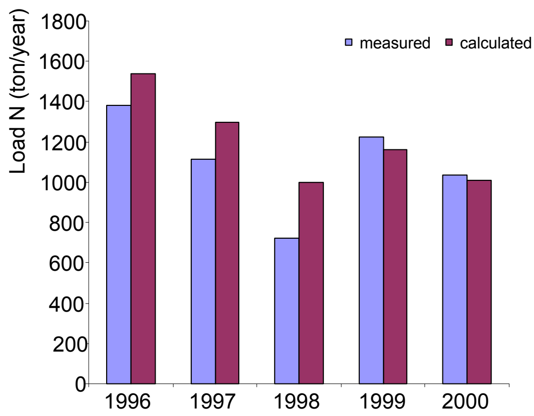



*Figure 4.21 Annual N loads for point 4200*

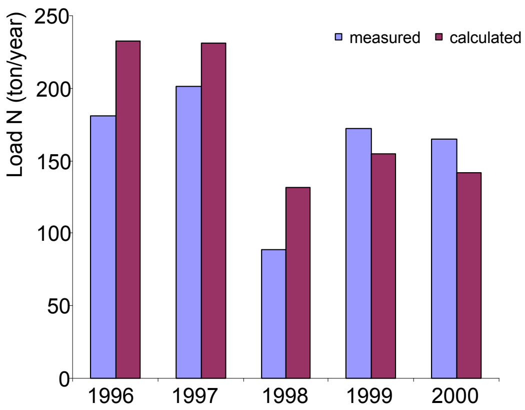



*Figure 4.22 Annual N loads for point 3000*

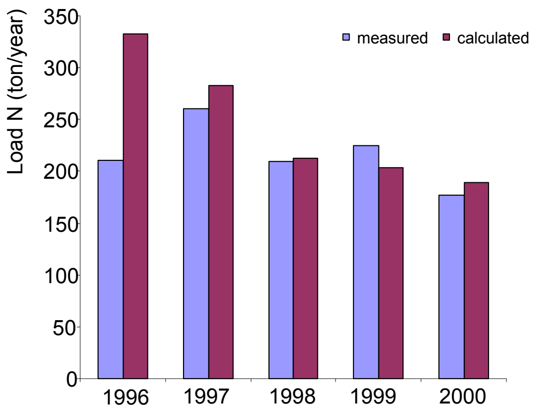



*Figure 4.23 Anual N loads for point 6900*

In Figure 4.24 daily fluctuations are presented.

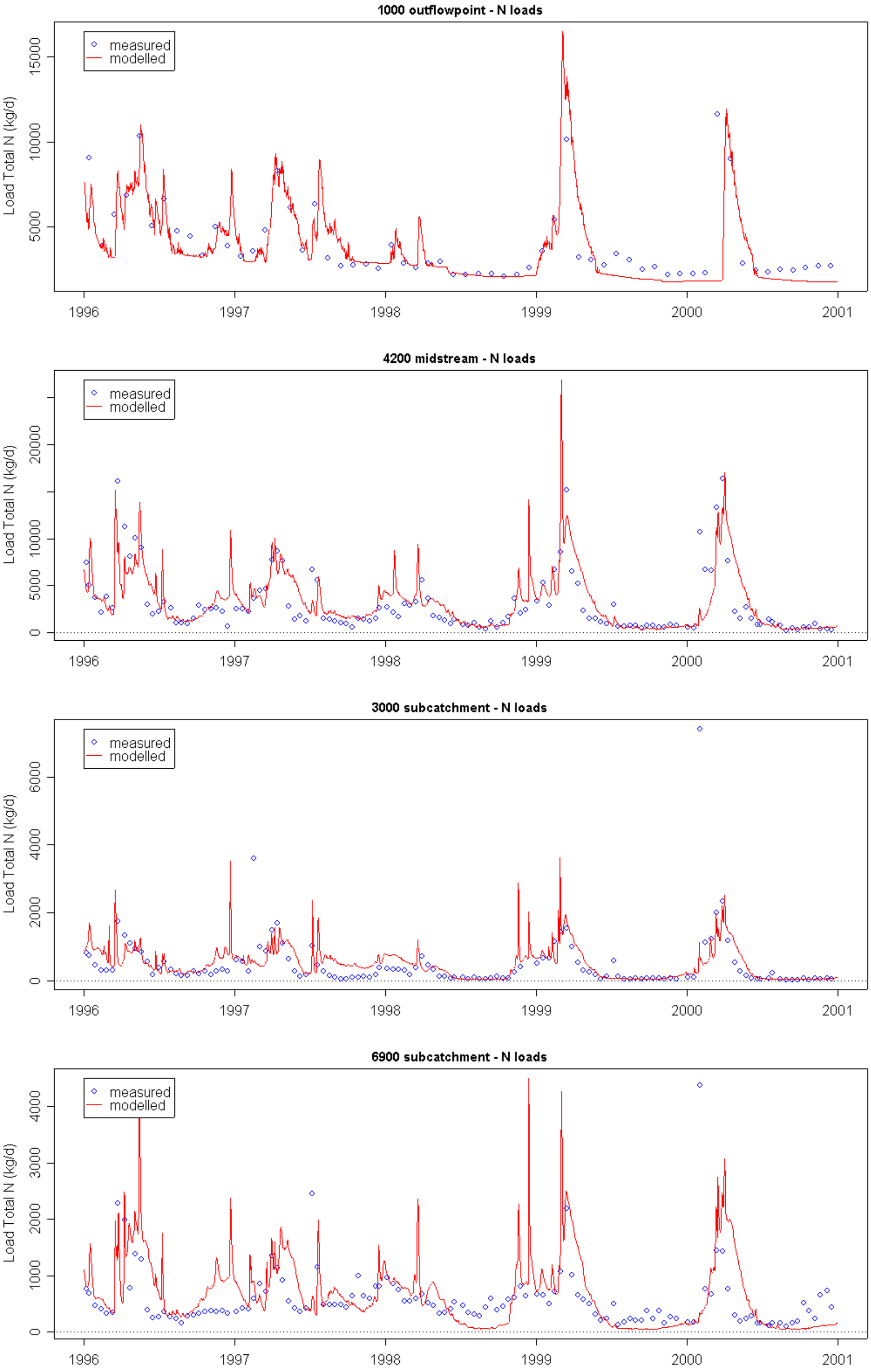



*Figure 4.24 daily fluctuations in N loads*

### 4.4.3 Phosphorus

#### 4.4.3.1 Soil- and groundwater system

In tables 4.17 and 4.18 the average P balance over the last 14 years of the soil nutrient model for all agriculture (including cultivated grassland) and nature (forest and grassland) plots are given.

*Table 4.17 Phosphorus balance for agriculture (kg ha$^{-1}$ yr$^{-1}$)*

| | Fertilizer | Manure | Deposition | Net crop uptake | discharge | Surface runoff | Δ storage P min | Δ storage Porg |
|---|---|---|---|---|---|---|---|---|
| In | 10 | 15.7 | 0.7 | | | | | |
| Out | | | | 16 | 0.1 | 0.1 | | |
| storage change | | | | | | | 10.5 | -0.5 |

*Table 4.18 Phosphorus balance for nature (kg ha$^{-1}$ yr$^{-1}$)*

| | Deposition | Mineralization and Background weathering | Net crop uptake | discharge | Surface runoff | Δ storage P min | Δ storage Porg |
|---|---|---|---|---|---|---|---|
| In | 0.7 | 4.2 | | | | | |
| Out | | | 0.6 | 0.2 | 0.0 | | |
| storage change | | | | | | 3.2 | 0.9 |

#### 4.4.3.2 Surface water system - concentrations

Daily fluctuation in P concentration is presented in Figure 4.25. No clear trend can be deduced in most of the measured values. Calculated concentrations are within the same reach as measured except for the extremes. High phosphorus concentrations in 1996 at the outflow point are not modelled and can not directly be explained by the data.

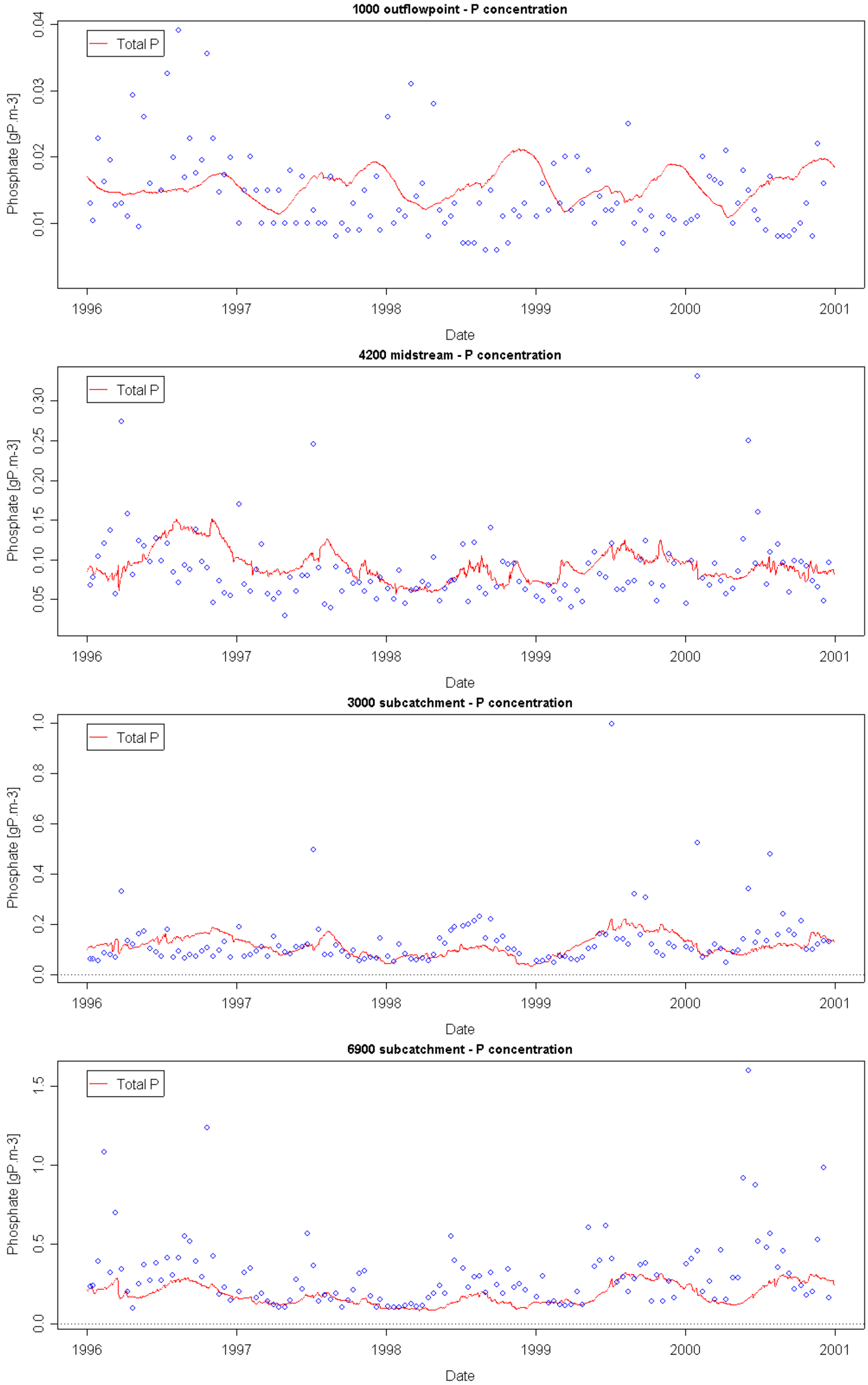



*Figure 4.25 Total Phosphorus concentrations (mg $l^{-1}$) calculated (red line) and measured (blue dots)*

#### 4.4.3.3 Surface water system – loads

Total phosphorus loads are presented in figures 4.26 – 4.29.

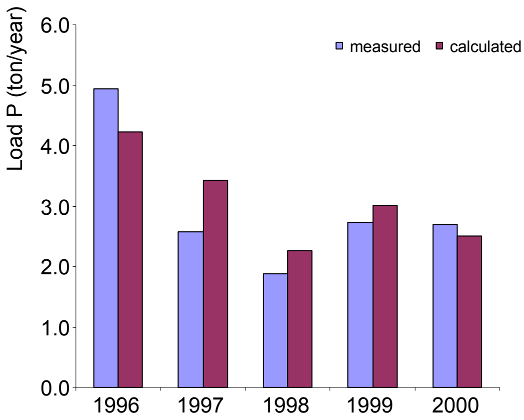



*Figure 4.26 Annual P loads for point 1000*

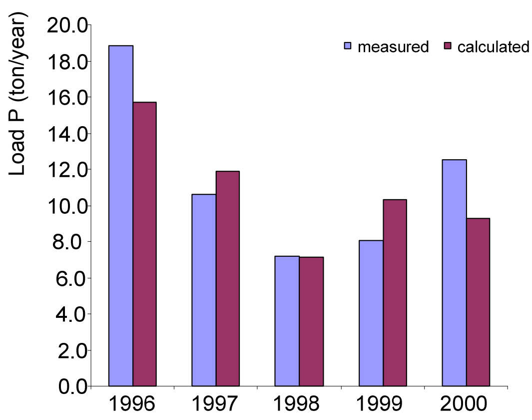



*Figure 4.27 Annual P loads for point 4200*

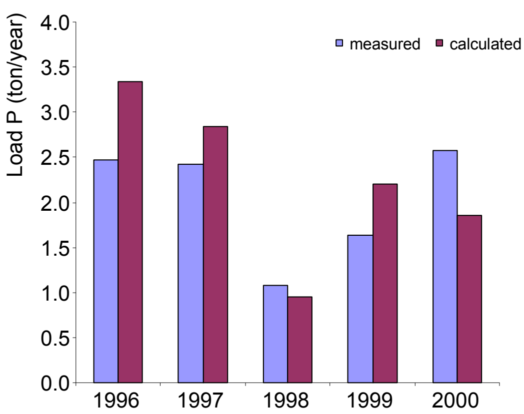



*Figure 4.28 Annual P loads for point 3000*

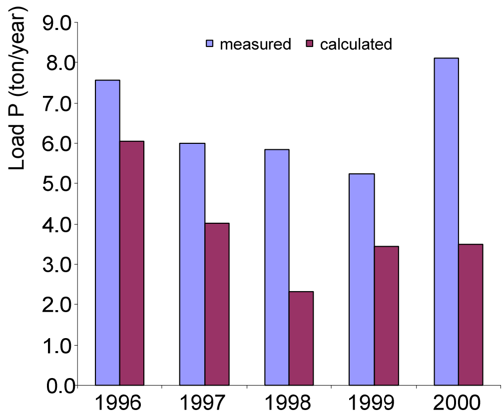



*Figure 4.29 Annual P loads for point 6900*

For points 1000, 4200 and 3000 measured and calculated values relate quite well. Only for point 6900 both discharges and P concentrations are lower than measured values which also results a structural underestimation of total P loads.
In 1999- 2000 point 3000 and 4200 show an opposite trend compared to measured values. For point 4200 calculated concentrations corresponds well with measured (Figure 4.25). But some outliers in the measured concentrations during periods with higher discharges could result in a high load estimate as can be seen in fig 4.27. The same is true for points 3000 and 6900.

The outlier in subcatchment 3000 (Figure 4.30) in the beginning of 2000 produces a load of 350 kg/d. To calculate total loads linear interpolation is applied. Only three measurements each month are available so this means that this 'measured' load represents about 10 days. Integrating the loads would mean an approximate total load of 350 * 10 * 0.5 = 1750 kg P represented by this single measurement point. This is about 70% of the total calculated load which gives an indication of the accuracy of calculating total loads from limited data.

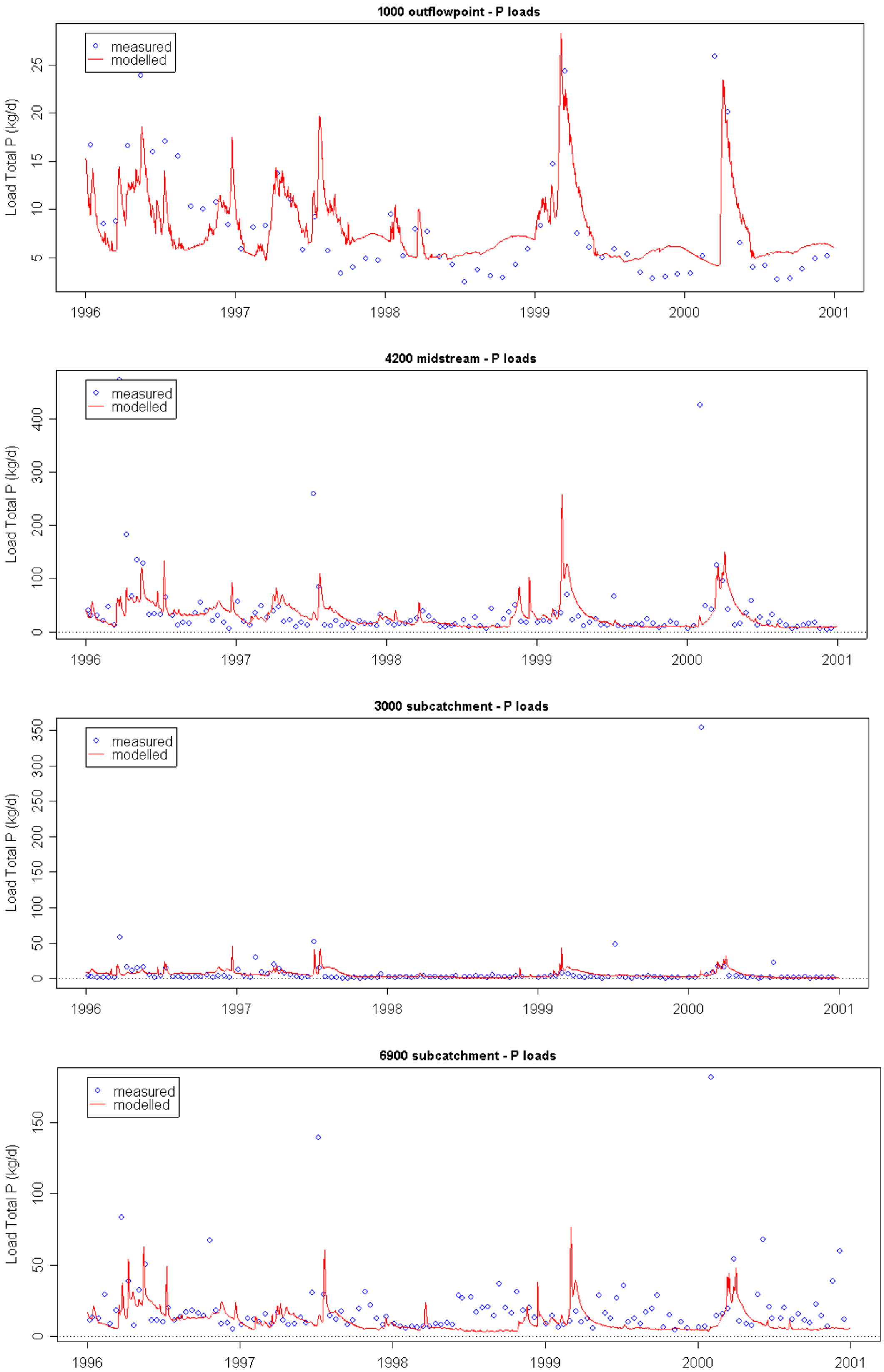



*Figure 4.30 Daily fluctuations in P loads*

### 4.4.4 Retention

Results are produced for different water bodies: groundwater and surface water (rivers, lakes and reservoirs). Retention may occur in both water bodies and is in general:

Retention = inflow – outflow

Retention in *the surface water system* is determined as difference in inflow (drainage + runoff + point sources + erosion) and outflow (discharge at outlet).

Retention in *the groundwater system* requires a slightly different approach. In this case the inflow is defined as the remaining nutrient surplus at the bottom of the root zone. Again it is the difference between inflow (additions + deposition + crop residues – grossUptake – volatilization) and outflow (drainage + runoff). This is equivalent to the change of storage for phosphorus and the sum of denitrification and change in storage for nitrogen.

For agriculture this gives an average retention in the groundwater system of 2 kg N $ha^{-1}$as the decrease in storage almost equals denitrification (table 15, paragraph 4.2.1). For nature retention is on average 30 kg N $ha^{-1}$. This large retention is caused mainly by the forest plots. As a result of the high retention in natural areas the total retention in the groundwater system is high. Table 4.19 shows the total results for the different (sub) catchments.

*Table 4.19 Retention in ton/year for surface and groundwater*

| | 1000 | | 4200 | | 3000 | | 6900 | |
|---|---|---|---|---|---|---|---|---|
| | t N/a | t P/a | t N/a | t P/a | t N/a | t P/a | t N/a | t P/a |
| Retention surface waters | 905 | 39.1 | 345 | 20 | 43.3 | 2.4 | 61.5 | 2.8 |
| Retention groundwater | 1695 | 836 | 1012 | 537 | 202 | 89.3 | 123 | 81.2 |

## 4.5 Concluding remarks

The agreement between daily simulated and daily measured loads at the catchment outlet is good but the model slightly underestimates the annual concentrations at the end of the modelling period (1999 and 2000). Possibly fertilization has increased which was not reflected in the data. The agreement between the annual measured and simulated loads is good.

The simulated N balance for the soils shows an excess of 29 kg $ha^{-1}y^{-1}$ of which 21 kg is denitrified. The biological net fixation was estimated at 22 kg $ha^{-1}y^{-1}$ and the net leaching to deeper groundwater was estimated at 3 kg $ha^{-1}y^{-1}$. The nitrogen transport to surface waters amounts to 28 kg $ha^{-1}y^{-1}$.
The total N inputs to surface waters are estimated at 2513 ton $y^{-1}$, of which 1658 ton $y^{-1}$ leaves the catchment at the outlet. The retention in surface waters is calculated at 36%, mainly caused by the large reservoirs in the catchment.

The simulated P balance shows an excess of 9.9 kg $ha^{-1}y^{-1}$ of which 9.6 is stored in the soil. The phosphorus transport to surface waters amounts to 0.22 kg $ha^{-1}y^{-1}$.
The total P inputs to surface waters are estimated at 44 ton $y^{-1}$, of which 4 ton $y^{-1}$ leaves the catchment at the outlet. The retention in surface waters is calculated at 91%.

## 4.6 Suggestions for improvement

Overall discharges, concentrations and loads correspond well with measured values.

What remains more or less a black box are the groundwater fluctuations as both important model input data on soil characteristics of the deeper layers and measurements are lacking. At present the hydrological module can only be checked by its discharges.

Model results do show the declining trend in nutrient outflow as a result of lower nutrient input. Still better results might be obtained when more detailed information on manure and fertilizer applications is available and a more specific discretisation and parameterisation of the crop rotations can be made.

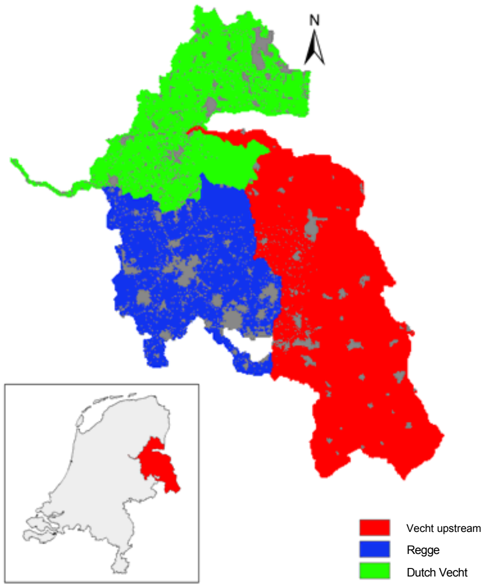
Most of the chemical parameters which describe the groundwater system are general values or estimates. Locally measured values will improve model results

# 5 The Vecht catchment

R. Smit, C. Siderius, M. Jeuken & M.Groenendijk

## 5.1 Introduction

The Vecht catchment is part of the Zwarte Water catchment which flows into the IJsselmeer, the big lake in the central north of the Netherlands. The catchment belongs to the Rhine basin.
The Vecht is a middle size rain river, which originates in Germany. The total length is 167 km, of which 60 km is situated in the Netherlands.




The size of the catchment is 3700 $km^2$, the elevation in the area ranges from 0 to 163 m in the south. The Vecht originates here but has already declined to 10 m above m.s.l. when it enters The Netherlands. The average rainfall in the catchment is 730 mm and ranges from 550 mm in dry years to 1100 mm in wet years. 35-40% of the precipitation runs off. The mean run off at the mouth of the Vecht is 50 $m^3/s$, at low water it is only 5 $m^3/s$ and under conditions of high water it can reach about 300 $m^3/s$.

The soils in the catchment are mainly sandy; most of the peat soils are situated in the northern part. The Dutch part of the catchment is used more intensive than the German part. Land use in the southern Dutch part is predominantly intensive animal husbandry, with growing of grass and maize. In the northern Dutch part as well as in Germany there is more arable land, with mainly potato growing.

The total population in the German part of the catchment is 54300. In the Dutch part of the catchment about 800000 people live with most cities situated in the southern part. The impervious area covers about 12% of the catchment.

The human pressure on the aquatic environment is high, both from cities and from intensive agriculture. Discharges from many of the sewage treatment plants are into relatively small waters. Most of the waters in the catchment, especially in the dutch part, have been strongly regulated by normalisation and dams. In large parts of the area water inlet from outside the catchment plays an important role for agriculture in the summer.

*Table 5.1General catchment informatiom*

| | Dutch part | German Part |
|---|---|---|
| Catchment Area | 2400 $km^2$ | 1300 $km^2$ |
| Elevation Range | 0-83 m | 10-163 m |
| Rainfall | 730 mm | |
| Soils | 16% peat<br>30% sand<br>54% loamy sand | |
| Land cover | 41% arable land<br>35% grassland<br>12% forest and nature<br>11% urban<br>1% open water | |
| Cities with over 50 000 inhabitants | Enschede (147 910)<br>Hengelo (77 480)<br>Almelo (65 170)<br>Emmen (56 025) | Lingen (52 500)<br>Nordhorn (52 000) |

## 5.2 Discretisation

The discretisation of the Vecht catchment consists of two parts:

1. Simplification of the surface water system for the models SWQN and NUSWALITE. First a division into subcatchments is made and secondly the watercourses are schematized.
2. Identification of unique units used for the models SWAP and ANIMO. Each unit has a unique combination of soil type, land cover, land management and other boundary conditions.

The soil models will be connected to the surface water models on the scale of the subcatchments. The water and nutrient fluxes will be added up for each subcatchment and assigned to a node of the surface water system within the subcatchment.

### 5.2.1 Delineation of subcatchments

With the ArcView interface for the SWAT model, AVSWAT (Luzio *et al.*, 2001) the catchment is schematized into 257 sub catchments and river segments. The data needed for this procedure are the DTM (Figure 5.2), a river network (Figure 5.3) and a mask of the catchment. This procedure gives only good results for areas with significant elevation differences. In the Netherlands these are very small, and therefore the results are poor. To solve this problem the DTM is manually adapted at places where the river network is not correctly followed. The areas of the subcatchments or water management units are known, and on the borders artificial walls are made to force the water into the right direction. The result is given in Figure 5.4. During further discretisation of the watercourses these subcatchments are found out to be too detailed. Therefore the subcatchments are aggregated into 35 subcatchments (Figure 5.5) which are used to connect the soil models to the surface water.

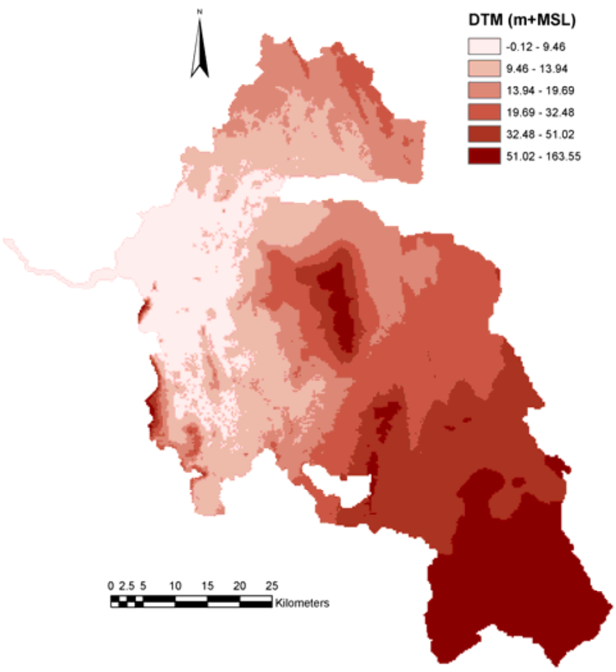



*Figure 5.2 Elevation map*

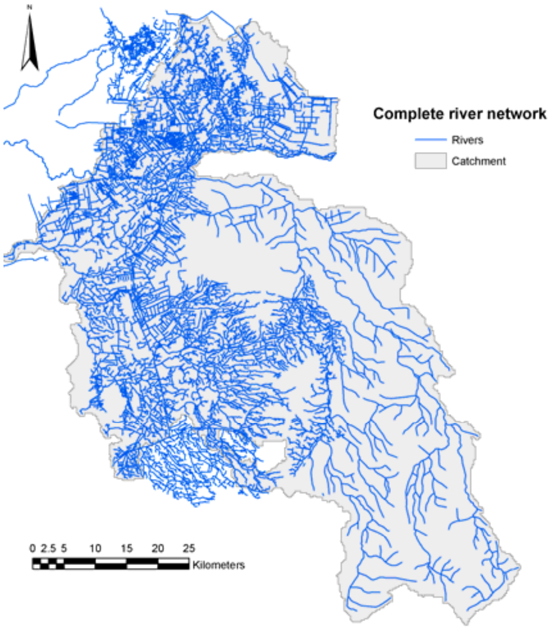



*Figure 5.3 Original river network*

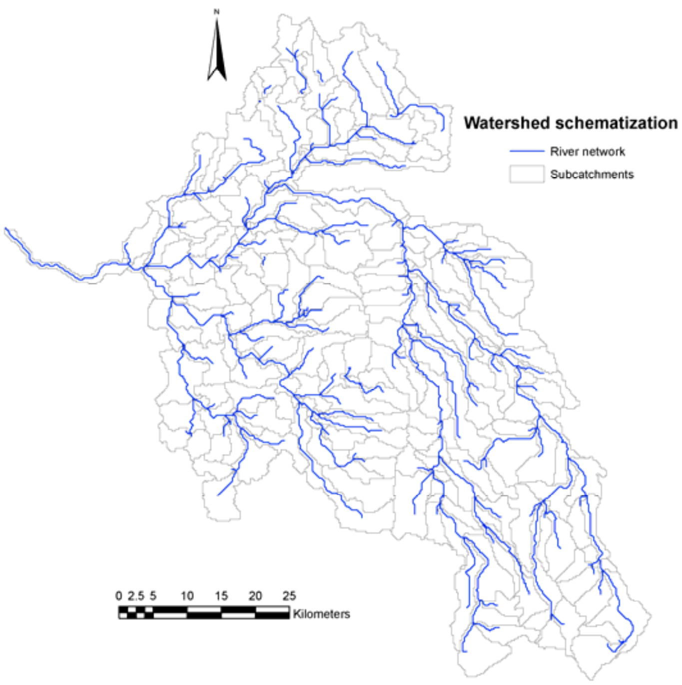



*Figure 5.4 Watersheds and river network generated with AVSWAT*

### 5.2.2 Surface water system

A discretisation of the GIOV model available for this study (Arcadis, 2000) is used. The main focus of this model is on peak discharges. Within the Euroharp project the total flows are needed so not only a proper modelling of peak discharges but also of base flow is important.
Figure 5.5 shows all the main watercourses used in the discretisation. Cross sections were derived from the GIOV database and transformed to trapezoid sections if not already available in this format. To incorporate the effect of the floodplains (which were not included in these trapezoid discretisation), an additional storage volume was added to all Vecht nodes with the dimensions of the floodplain. It is assumed that the floodplains have mainly a storage function and do not contribute significantly to the main flow. This means they fill up when the water level reaches the bottom level of the floodplain during peak flow and empty when the water level drops again, but water does not flow via these nodes to the adjacent Vecht node downstream. The Chezy resistance coefficient in the main Vecht watercourse is set to 40 for the main Vecht watercourse. The Chezy coefficient for all other watercourses was set to 30.

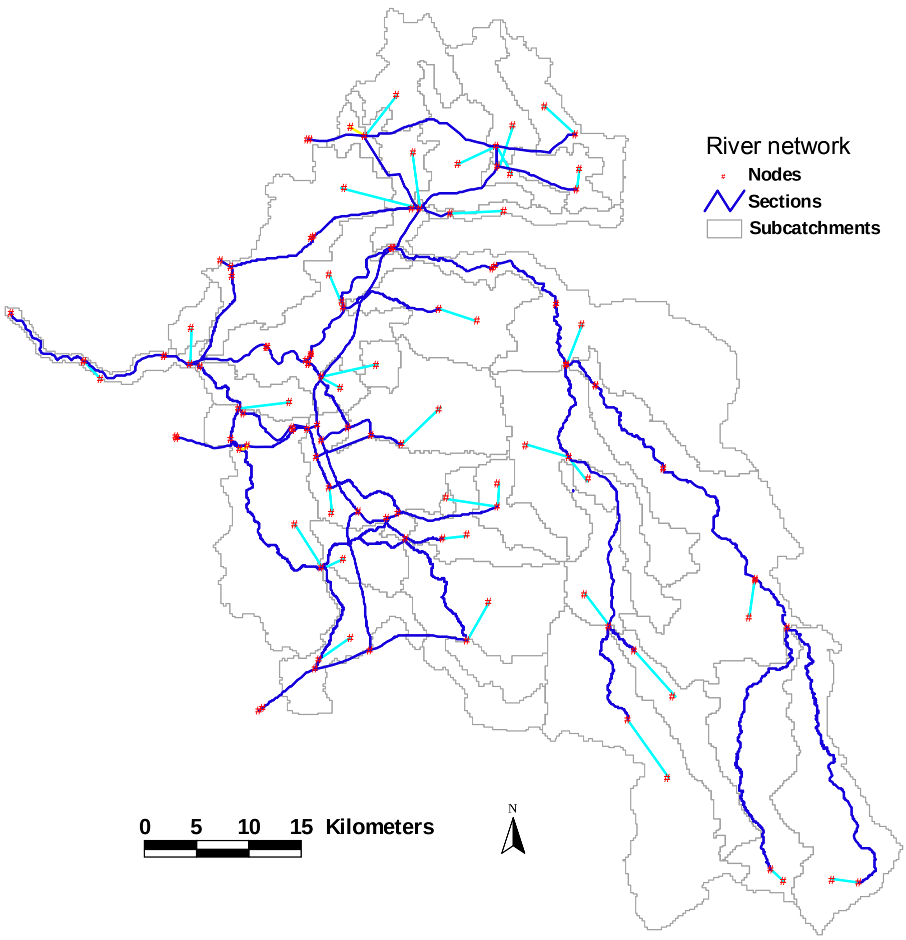



*Figure 5.5 Simplified river network*

The weirs in the Dutch part of the Vecht are all modelled with flexible crest heights to maintain a reference level upstream of the weir (Table 5. 1). The weirs in the German part of the Vecht and in the smaller channels and watercourses all have a fixed crest level. Resistance is set to 2 (-) representing broad crested weirs.

*Table 5.1 Weirs in the Vecht*

| Weir | Width (m) | Crest level (m + msl) | Target level summer (m + msl) | Target level winter (m + msl) |
|---|---|---|---|---|
| Vechterweerd | 36 | -1.2 | 1.25 | 1.00 |
| Vilsteren | 36 | 0.45 | 2.65 | 2.35 |
| Junne | 27 | 2.60 | 4.50 | 4.15 |
| Marienberg | 27 | 3.90 | 5.60 | 5.20 |
| Hardenberg | 27 | 5.05 | 7.00 | 6.80 |
| De Haandrik | 21 | 7.10 | 9.10 | 9.10 |
| Tinholt | 30 | 12 | - | - |
| Neuenhaus | 24 | 13 | - | - |
| Grasdorf | 26 | 15.5 | - | - |
| Brandlecht | 16 | 22.5 | - | - |
| Samern | 14 | 32 | - | - |

For each subcatchment an extra storage is determined by adding the total volume of all small watercourses not incorporated in the surface water discretisation within each subcatchment. The width of the extra storage is set similar to the width of the recipient surface water channel. An effective length for model calculations is calculated based on this width and the total volume. This creates very long watercourses with a proper storage but with an overestimated resistance when normal Chezy coefficients are being used. Therefore the resistance coefficient was multiplied width a correction factor ($f_{sw}$) using the following formula:

$$f_{sw} = \frac{Q_{tot}}{Q_{sw}} = \frac{L}{l_{\max}} \cdot \sqrt{\frac{L}{l_{\max}}}$$

$Q_{tot}$ : Discharge of total extra storage area ($m^3/d$)

$Q_{sw}$ : Discharge of the total length of all extra storage as calculated in the model discretisation ($m^3/d$)

$l_{\max}$ : Maximum length to the main watercourse in reality (m)

$L$ : total length of all watercourses in one subcatchment (m)

The additional volume is added as an extra storage to the most upstream node in each subcatchment. The total SWAP output of each subcatchment is added to the extra volume in each subcatchment.

### 5.2.3 Soil

Within the Euroharp project a map for the German part and a map for the Dutch part as in Figure 5.6 are provided. These maps have a different scale and classification. A harmonized map as shown in Figure 5.7 is used which covers the complete catchment and has also one classification (Stolte and Wösten, 1991). Only the Dutch part of this map was available digitally, the German part is digitized from a hard copy. The classification of this map consists of 25 units. For the discretisation into plots these are grouped into 3 classes (Table 5. 2 and Figure 5.8). These 3 classes are chosen based on the highest areal percentages in the catchment.

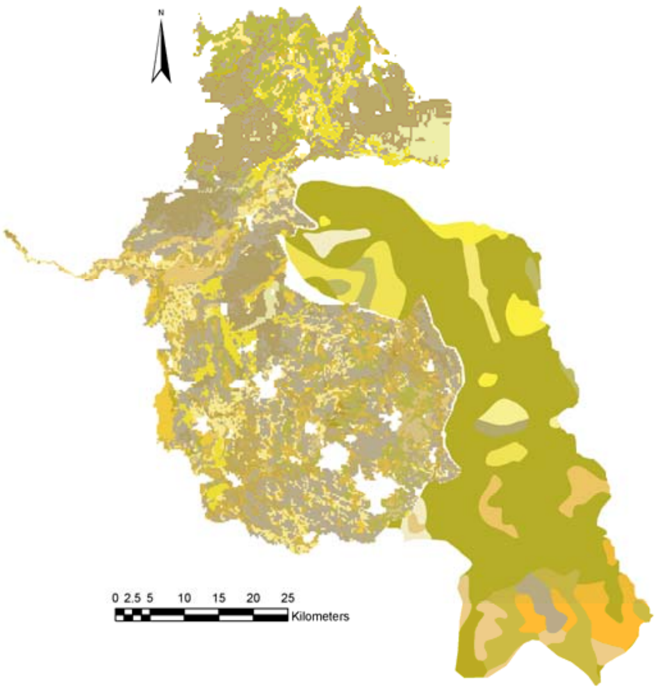



*Figure 5.6 German and Dutch soil map provided in Euroharp project*

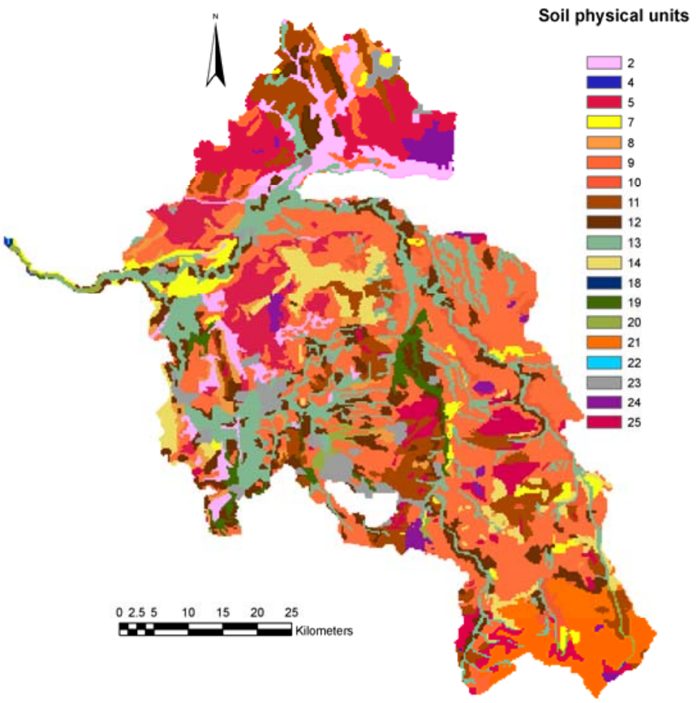



*Figure 5.7 Soil map (Stolte and Wösten, 1991)*

*Table 5.2 Soil classification*

| Soil class | Soil type | Area (%) | Soil class for modelling |
|---|---|---|---|
| 2 | Peat | 5.46 | 5 |
| 4 | Peat | 0.03 | 5 |
| 5 | Peat | 9.93 | 5 |
| 7 | Sand | 2.78 | 9 |
| 8 | Sand | 2.86 | 9 |
| 9 | Sand | 28.93 | 9 |
| 10 | Sand | 2.10 | 9 |
| 11 | Sand | 8.91 | 11 |
| 12 | Sand | 8.57 | 9 |
| 13 | Sand | 13.17 | 11 |
| 14 | Sand | 4.32 | 9 |
| 18 | Clay | 0.02 | 11 |
| 19 | Clay | 1.71 | 11 |
| 20 | Clay | 0.92 | 11 |
| 21 | Sand | 4.81 | 11 |
| 24 | Peat | 1.91 | 5 |
| 25 | Sand | 3.57 | 11 |

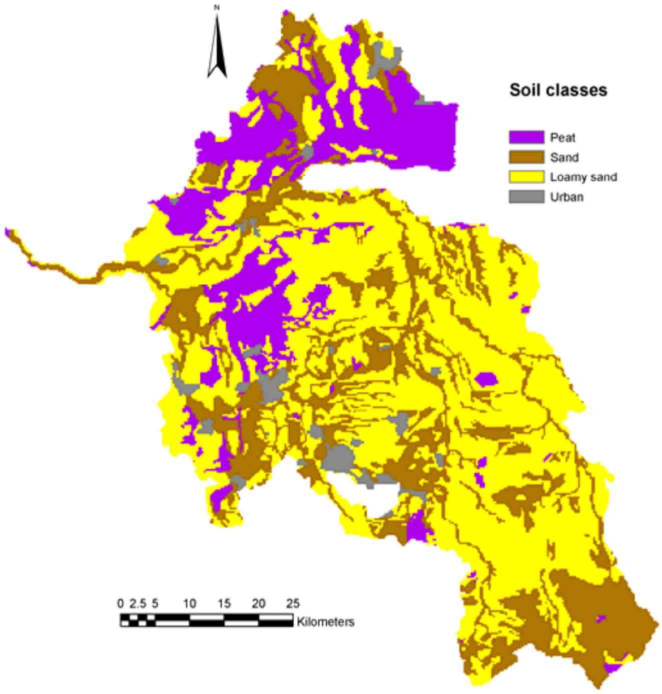



*Figure 5.8 Classified soil map*

## 5.2.4 Land cover

The Dutch part of the land cover map is based upon the LGN4 map. The German part is based upon the CORINE map. This German map contains one class for arable land with all different crops. For NL-CAT model simulations a more detailed division is needed where grassland, maize and the other arable crops are separate classes. This division is randomly made with the use of percentages for the different crops available for 5 regions in the German part of the catchment (Table 5. 3). The land use of the Dutch part of the Vecht is given in Table 5. 4. The Dutch and German part are both converted to maps with grid cells of 250 by 250 m and then combined together into one map (Figure 5.9).

*Table 5.3 Percentages arable land, grassland and maize in the German part of the Vecht catchment*

| District | Arable land (%) | Grassland (%) | Maize (%) |
|---|---|---|---|
| 3454 | 65.5 | 32.0 | 2.5 |
| 3456 | 50.3 | 48.8 | 0.9 |
| 5554 | 47.7 | 51.8 | 0.5 |
| 5558 | 71.1 | 26.5 | 2.4 |
| 5566 | 59.7 | 39.2 | 1.1 |

*Table 5.4 Percentages arable land, grassland and maize in the Dutch part of the Vecht catchment*

| District | Arable land (%) | Grassland (%) | Maize (%) |
|---|---|---|---|
| 5 | 75 | 22 | 3 |
| 6 | 43 | 44 | 12 |
| 7 | 27 | 55 | 18 |
| 8 | 7 | 69 | 24 |

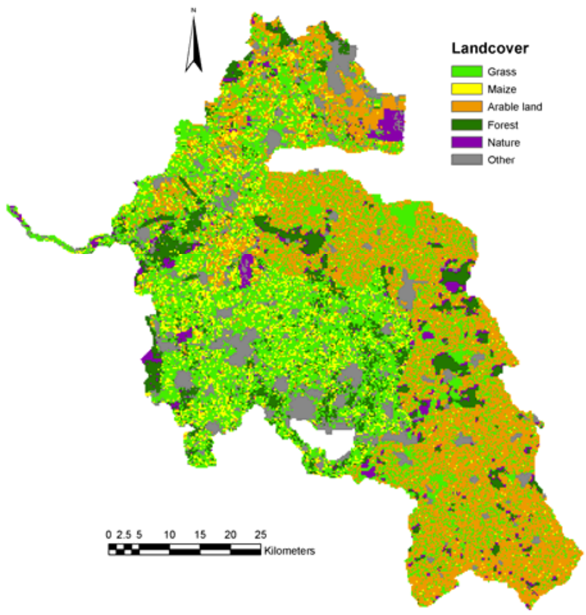



*Figure 5.9 Land cover map*

### 5.2.5 Land management

The land management map describes management actions as crop rotations, fertilization, grazing etc. for 12 different regions (Figure 5.10). Each region has a different amount of manure and fertilizer application.

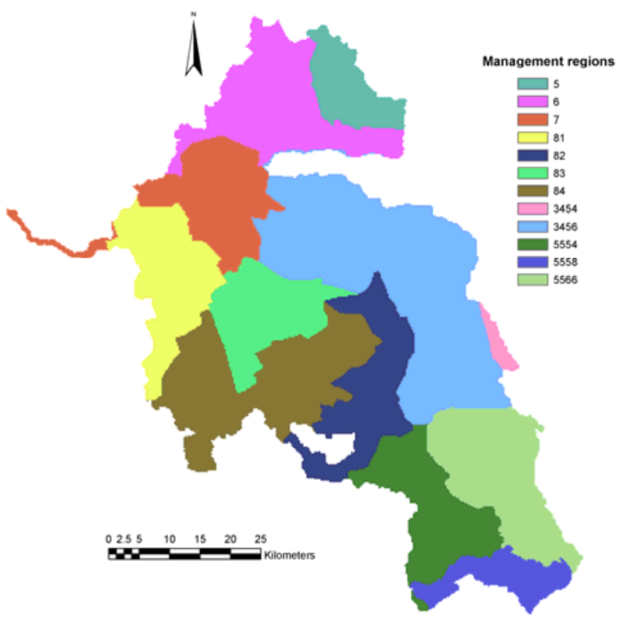



*Figure 5.10 Management regions*

### 5.2.6 Meteorology

For each management region (Figure 5.10) a meteostation with complete data for the simulation period is used for this whole region. The locations of the selected meteostations can be found in Figure 5.11.

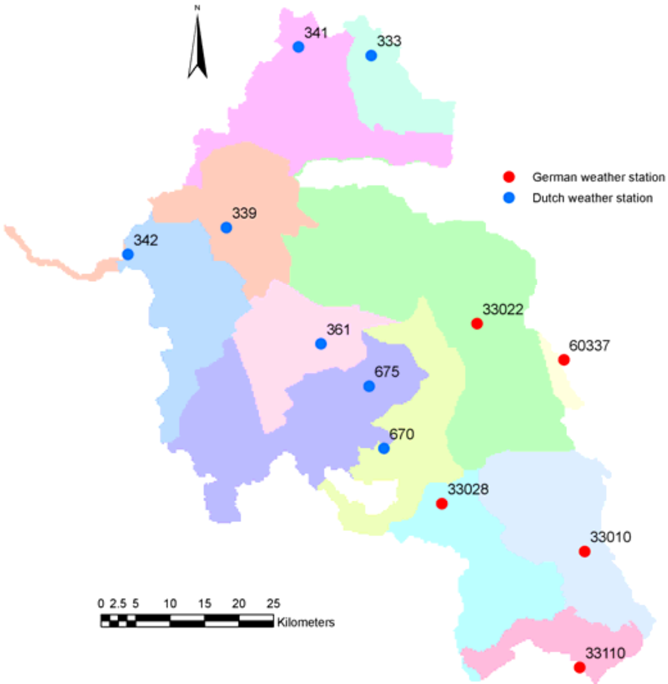



*Figure 5.11 Meteo stations*

In Table 5. 5 long term average precipitation for each meteostation is presented.

*Table 5.5 average annual rainfall for meteorological stations in the Vecht catchment*

| ID | Name | Elevation (m) | Average annual rainfall (mm) | periode |
|---|---|---|---|---|
| 333 | Emmen | 25 | 811 | 1971-2001 |
| 339 | Rheezerveen | 9 | 788 | 1971-2001 |
| 341 | Zweelo | 17 | 803 | 1971-2001 |
| 342 | Vilsteren | 5 | 791 | 1987-2001 |
| 361 | Tubbergen | 17 | 780 | 1971-2000 |
| 670 | Twenthe | 35 | 760 | 1974-2000 |
| 675 | Weerselo | 19 | 786 | 1971-2000 |
| 33022 | Nordhorn | 24 | 811 | 1961-2002 |
| 33028 | Gronau | 40 | 824 | 1961-2002 |
| 33010 | Steinfurt-Burgsteinfurt | 70 | 824 | 1961-2002 |
| 33110 | Billerbeck | 111 | 819 | 1961-2002 |
| 60337 | Emsbueren | 40 | 786 | 1961-2002 |

### 5.2.7 Boundary conditions

#### 5.2.7.1 Groundwater

For parameterization of the bottom boundary conditions the catchment is divided into areas with upward seepage (blue in Figure 5.12) and areas with downward seepage (red in Figure 5.12). These areas are based upon Dutch national SWAP and ANIMO calculations: STONE (Kroon *et al.*, 2001 and van Bakel *et al.*, 2003). Nation wide maps are available with the seepage fluxes and pressure heads. In the areas with upward seepage a positive flux is used to prescribe the bottom boundary conditions, in the other areas a negative flux is imposed. A classification into six groups is made to limit the amount of plots in the catchment (Figure 5.12 and chapter 3 parameterisation).

For the German part of the catchment no data was available. A closed bottom boundary with zero flux is assumed for this part of the catchment (light yellow in Figure 5.12).

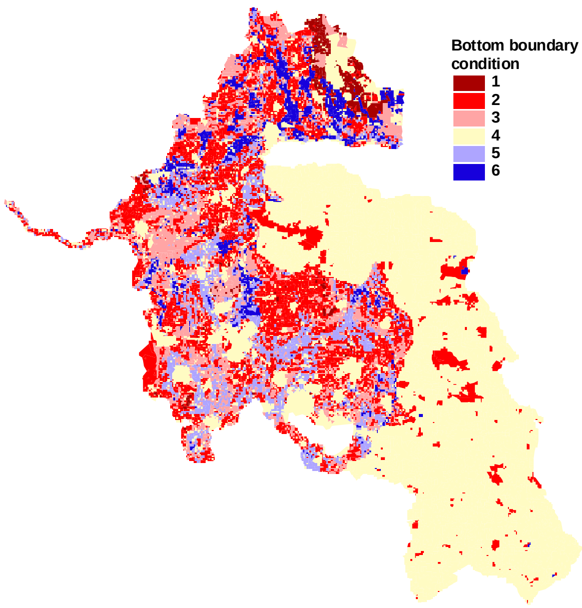



*Figure 5.12 Classes of the bottom boundary conditions*

#### 5.2.7.2 Drainage

For the discretisation and parameterization of the drainage system the nation wide maps from STONE (Kroon *et al.*, 2001) are used for the Dutch part of the catchment. For 3 different drainage systems the drain density and resistance are given on a 250 by 250 m grid. These 6 maps are simplified into a classification of 4 classes (Figure 5.13, parameterisation paragraph 5.3.4). For the German part of the catchment there is no data available. Average drainage characteristics of the Dutch part are used.

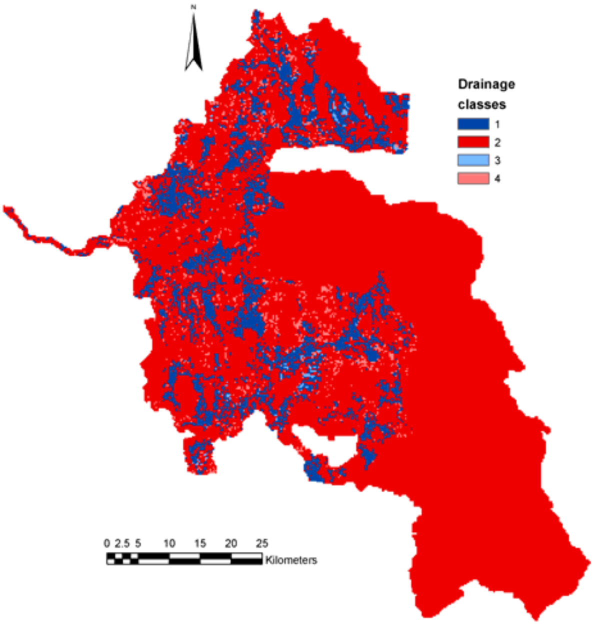



*Figure 5.13 Drainage classes*

### 5.2.8 Plots

Based upon the soil (Figure 5.8), land cover (Figure 5.9), land management (Figure 5.10), drainage (Figure 5.13) and groundwater (Figure 5.12) maps the plots are defined. An overlay of these maps results into 475 different combinations. A selection of the plots covering altogether 98% of the catchment are gave a reduction to 233 plots. Only these 233 plots are used for the calculations (Figure 5.14). The other 2% is assigned to the 233 plots with the Euclidean allocation Grid (identifies which cells are allocated to which source based on closest proximity) in ArcView – Spatial Analyst.

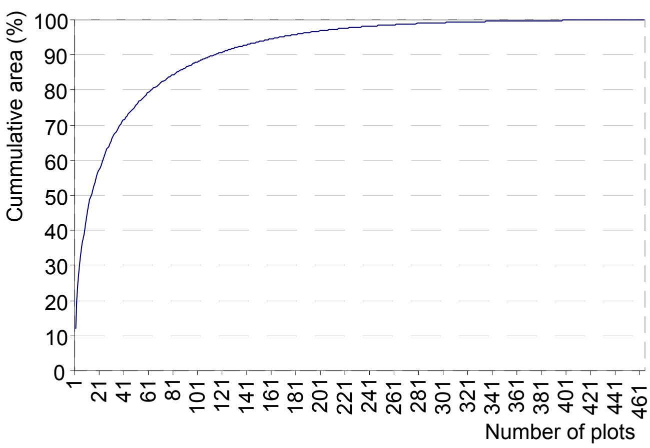



*Figure 5.14 Cumulative distribution of the plot area*

### 5.2.9 Suggestions for improvement

- Information on drainage and groundwater characteristics in the German part of the catchment could improve the model discretisation as only estimations could be used now.

- The information on the surface water system in the German part of the catchment is less detailed. This results in an underestimation of the extra storage.

- The smallest 2 % of plots are merged with the largest 98%. A 5% selection as is done in other catchments would further reduce calculation time without too much loss of information.

## 5.3 Parameterisation

### 5.3.1 Meteorology

The meteorological data is used from 12 different stations (Figure 5.11). The following parameters are needed for each day:

1. Minimum daily temperature ($^{\circ}$C)
2. Maximum daily temperature ($^{\circ}$C)
3. Daily precipitation (mm $d^{-1}$)
4. Reference evaporation (mm $d^{-1}$)

The temperature and reference evaporation are only available for station 670 (Figure 5.11) and are therefore used for the whole catchment.

The atmospheric deposition is a top boundary condition for the ANIMO model. In Figure 5.15 the deposition for the period 1990 till 2000 is given as used in the model for the whole catchment.

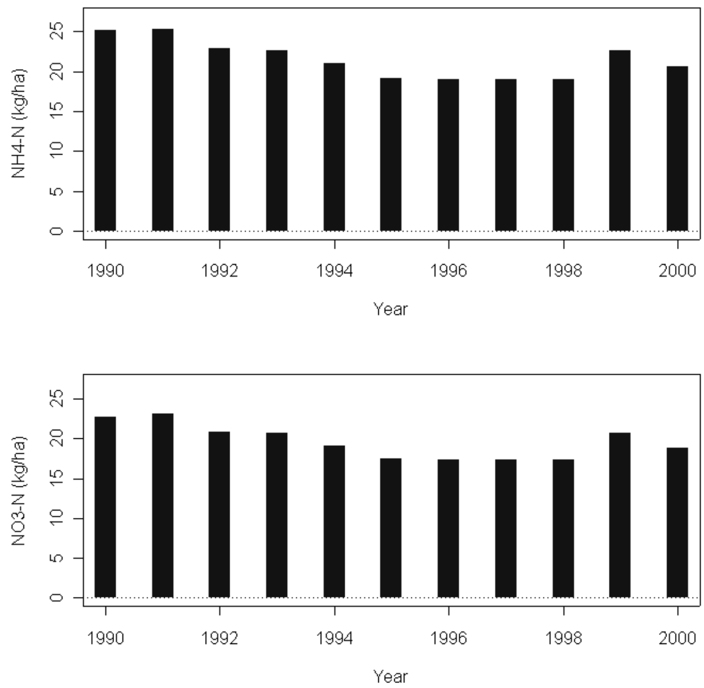



*Figure 5.15 Dry deposition of $NH_4N$ and $NO_3N$ (kg $ha^{-1}$)*

### 5.3.2 Land management

The land cover is defined based on the Dutch data for the 6 crops in Figure 5.8. These crops are also used for the German part of the catchment. Grass and nature have a LAI of 4 and a rooting depth of 35 cm and forest had a LAI of 3 and a rooting depth of 100 cm. The LAI and rooting depth of maize and arable land are a function of the crop development stage. The urban area is defined as a “crop” with no interception and evaporation.

#### 5.3.2.1 Dutch land management

The manure and fertilizer application rate for the Dutch part of the catchment is based on STONE (Kroon et al., 2001). In these national ANIMO calculations the N and P manure and fertilizer additions are given for every management region and different crops within a region. After several adjustments of the national STONE data to attune them to regional characteristics, the specific fertilization rates for the catchments have been uploaded to the Euroharp database and have been used in this study.

The differences in manure application between regions 81, 82, 83, and 84 (a subdivision of Dutch management region 8) had to be extrapolated to 1941 as in the Euroharp datasheet only a differentiation was made for the years 1990-2000 resulting in unrealistic developments in manure amounts between the periods 1940-1989 with average amounts for region 8 and 1990-2000 when regions 8 is subdivided.

Using the known average percentage of cattle, pig, poultry and grazing fractions in manure slurry over the years 1990-2000 the total historical manure amounts from the Euroharp database could be assigned to these fractions. With the characteristics of the different manure materials (Table 5. 6) the manure addition for each unique plot could be determined. It is assumed that the fractions did not change over time.

*Table 5.6 Description of the manure materials (FROR is the organic matter content, FRNH is the mineral $NH_4$N, FRNI is the mineral $NO_3$N and FRPO is the mineral P content, all in kg $kg^{-1}$)*

| id | name | FROR | FRNH | FRNI | FRPO |
|---|---|---|---|---|---|
| 1 | cattle slurry | 0.063 | 0.002 | 0 | 0.00078 |
| 2 | pig slurry | 0.063 | 0.0028 | 0 | 0.00185 |
| 3 | poultry slurry | 0.062 | 0.0095 | 0 | 0.0058 |
| 4 | grazing slurry | 0.062 | 0.0023 | 0 | 0.00065 |
| 5 | N-fertilizer | 0 | 0.5 | 0.5 | 0 |
| 6 | P-fertilizer | 0 | 0 | 0 | 1 |

Table 5.7 shows the average N and P input values for various periods for the Dutch management districts. A table with the historical application dates (on a ten-day basis) from 1940 till 2000 was used to divide the average yearly manure and fertilizer amounts over ten day periods.

*Table 5.7 Nitrogen and phosphorus annual fertilization rates for the Dutch management districts (kg $ha^{-1}$)*

| | Arable land | | | | Grassland | | | | Maize | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Manure | | Fertilizer | | Manure | | Fertilizer | | Manure | | Fertilizer | |
| period | N | P | N | P | N | P | N | P | N | P | N | P |
| 1941-1954 | 48 | 3 | 42 | 53 | 131 | 8 | 73 | 32 | 74 | 5 | 46 | 23 |
| 1955-1969 | 67 | 4 | 70 | 58 | 172 | 10 | 122 | 39 | 98 | 6 | 76 | 27 |
| 1970-1974 | 74 | 4 | 118 | 59 | 225 | 14 | 195 | 49 | 210 | 13 | 122 | 46 |
| 1975-1979 | 83 | 5 | 133 | 54 | 264 | 16 | 219 | 54 | 246 | 15 | 136 | 50 |
| 1980-1984 | 139 | 8 | 152 | 74 | 292 | 18 | 253 | 59 | 270 | 17 | 132 | 60 |
| 1985-1990 | 144 | 8 | 124 | 56 | 315 | 19 | 275 | 64 | 278 | 17 | 108 | 69 |
| 1991-1995 | 146 | 9 | 88 | 47 | 318 | 19 | 243 | 64 | 288 | 18 | 63 | 64 |
| 1996-2000 | 129 | 8 | 94 | 40 | 286 | 17 | 236 | 60 | 260 | 16 | 45 | 52 |

#### 5.3.2.2 German land management

German manure and fertilizer data were poor. Only average amounts for 1999 for a whole region without subdivision over crops or land use types were provided. Various assumptions based on Dutch trends and on a large amount of common sense were made to create reasonable input.

As a first step the average amounts were divided over the different land covers (arable, grass and maize) based on the area of each land cover in the district and a range for the application amounts.

To get some indication of the historical German fertilizer applications Dutch factors relating the historical amount to the 1999 amount were used to estimate German values. For N fertilizer amount this approach gave reasonable values (see Table 5.8).

*Table 5.8 Nitrogen and phosphorus fertilization rates for the German management districts (kg ha$^{-1}$)*

| | Arable land | | | | Grassland | | | | Maize | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Manure | | Fertilizer | | Manure | | Fertilizer | | Manure | | Fertilizer | |
| period | N | P | N | P | N | P | N | P | N | P | N | P |
| 1941-1954 | 35 | 2 | 27 | 22 | 118 | 7 | 42 | 28 | 48 | 3 | 25 | 17 |
| 1955-1969 | 41 | 3 | 46 | 23 | 135 | 8 | 69 | 31 | 63 | 4 | 41 | 21 |
| 1970-1974 | 81 | 5 | 73 | 32 | 221 | 13 | 111 | 48 | 97 | 6 | 65 | 29 |
| 1975-1979 | 101 | 6 | 82 | 34 | 276 | 16 | 125 | 58 | 122 | 7 | 73 | 34 |
| 1980-1984 | 121 | 7 | 102 | 42 | 331 | 19 | 143 | 70 | 146 | 8 | 69 | 43 |
| 1985-1990 | 121 | 7 | 83 | 34 | 331 | 19 | 155 | 73 | 146 | 8 | 57 | 48 |
| 1991-1995 | 109 | 7 | 56 | 27 | 298 | 17 | 136 | 64 | 132 | 8 | 33 | 41 |
| 1996-2000 | 88 | 5 | 61 | 22 | 240 | 14 | 134 | 56 | 106 | 6 | 24 | 31 |

For manure this approach gave unrealistically low values especially for arable land. Although the approach gives an indication of the fluctuations in manure application it probably underestimates the historical fertilization rates. The application rate in 1999 in the german part is much lower than in the Dutch part and has probably not increased as dramatic as in The Netherlands with its intensification in agriculture. This means the large increase in manure application can not be imposed on German values. Especially estimated amounts for 1940-1970 are then likely to be too low.

German manure application was therefore adjusted using the following assumptions

- 1941-1970 German applications are similar to Dutch
- 1970-1980 increase in application to 150% of 1999 value
- 1980-1990 stabilisation at 150%
- 1990-1999 decrease to 1999 value

Phosphorus fertilizer amounts were totally lacking, also for 1999, so there was no information to extrapolate from. For 1999, German phosphorus fertilizer amount was therefore estimated based on the relationship between Dutch and German nitrogen amount for arable, grass and maize (which was 50%-70% higher in the Netherlands in 1999). A historical trend in German P fertilizer was then applied based on the Dutch P trend. The differences to the 1999 values were reduced by 50% taking into account the lower intensification of agriculture. The same application dates as for N fertilizer were used.

### 5.3.3 Soil

The three used soil profiles are given in Table 5. 9. These parameters are needed for the models SWAP and ANIMO and are the calibrated values.

*Table 5.9 Soil profiles where 5 is peat, 9 is sand and 11 is loamy sand (Sand, Silt and Clay are given in %, SOM is the organic matter content also given in %, rho is the dry bulk density in g cm$^{-3}$ and AlFe is total Al/Fe content of dry soil in mmol kg$^{-1}$)*

| Soil | Depth | Horizon | Sand | Silt | Clay | SOM | pH KCl | CN-ratio | rho | AlFe |
|---|---|---|---|---|---|---|---|---|---|---|
| Peat | 0-20 | Aanp | 81 | 13 | 5 | 23 | 4.5 | 23 | 0.79 | 136.6 |
| | 20-50 | D1 | 78 | 15 | 6 | 38 | 4.3 | 31 | 0.51 | 138.6 |
| | 50-75 | D2 | 80 | 15 | 5 | 34 | 4.4 | 31 | 0.62 | 124.8 |
| | 75-100 | C11 | 90 | 7 | 3 | 25 | 4.4 | 28 | 0.72 | 87.4 |
| | 100-1300 | Gx | 84 | 12 | 3 | 25 | 4.4 | 30 | 0.72 | 87.4 |
| Sand | 0-25 | Ap | 85 | 12 | 3 | 4 | 4.6 | 17 | 1.36 | 68.8 |
| | 25-40 | B2 | 86 | 11 | 3 | 3 | 4.5 | 24 | 1.47 | 64.3 |
| | 40-50 | B3 | 88 | 10 | 3 | 2 | 4.5 | 24 | 1.14 | 60.9 |
| | 50-100 | C1g | 87 | 10 | 3 | 1 | 4.6 | 22 | 1.56 | 43.3 |
| | 100-1300 | C1gx | 87 | 10 | 3 | 1 | 4.6 | 30 | 1.57 | 41.6 |
| Clay | 0-20 | Ap | 83 | 14 | 4 | 6 | 4.0 | 17 | 1.30 | 77.5 |
| | 20-50 | B2 | 83 | 13 | 4 | 5 | 4.0 | 24 | 1.38 | 78.8 |
| | 50-100 | C1g | 80 | 14 | 7 | 1 | 4.4 | 20 | 1.54 | 62.4 |
| | 100-1300 | Dx | 79 | 14 | 7 | 1 | 4.3 | 30 | 1.55 | 46.5 |

For the German part the organic matter content for sand and clay soils was adjusted according to provided data. With very low values of about 0.1% of organic matter for the subsoil and deeper soil layers the provided organic matter content was lower than the default values for these soil types from the Stolte and Wösten (1991) classification. A lower organic matter content will influence leaching of nutrients. All other parameters were kept equal

### 5.3.4 Groundwater

Table 5.10 shows the four drainage classes of Figure 5.13 and their characteristics derived from the STONE database (Kroon *et al.*, 2001 and van Bakel *et al.*, 2003). The drainage is based upon areas with upwards and downwards seepage. Also a distinction is made between areas with and without drain tubes.

*Table 5.10 Properties of the drainage classes of Figure 5.13*

| **Drain class ID** | | **1** | **2** | **3** | **4** |
|---|---|---|---|---|---|
| Level 4 | Drain spacing (m) | | | 164 | 182 |
| | Bottom level (cm+s.s.) | | | -65 | -55 |
| | Drainage resistance (d) | | | 110 | 214 |
| | Infiltration resistance (d) | | | 110 | 214 |
| Level 3 | Drain spacing (m) | 172 | 212 | 90 | 90 |
| | Bottom level (cm+s.s.) | -55 | -65 | -80 | -80 |
| | Drainage resistance (d) | 100 | 266 | 100 | 100 |
| | Infiltration resistance (d) | 100 | 266 | 100 | 100 |
| Level 2 | Drain spacing (m) | 344 | 767 | 360 | 607 |
| | Bottom level (cm+s.s.) | -70 | -100 | -95 | -75 |
| | Drainage resistance (d) | 170 | 457 | 185 | 399 |
| | Infiltration resistance (d) | 170 | 457 | 185 | 399 |
| Level 1 | Drain spacing (m) | 1000 | 2331 | 826 | 2415 |
| | Bottom level (cm+s.s.) | -140 | -180 | -140 | -160 |
| | Drainage resistance (d) | 360 | 1535 | 460 | 1314 |
| | Infiltration resistance (d) | 360 | 1535 | 460 | 1314 |

The bottom boundary condition and the values for the average bottom flux of the 6 bottom boundary classes in Figure 5.12 are given in Table 5. 11.

*Table 5.11 Bottom boundary classification*

| id | Boundary condition | Average bottom flux (cm/d) |
|---|---|---|
| 1 | Flux specified | -0.079 |
| 2 | Flux specified | -0.043 |
| 3 | Flux specified | -0.022 |
| 4 | Zero flux | 0 |
| 5 | Flux specified | 0.063 |
| 5 | Flux specified | 0.108 |

### 5.3.5 Surface water system

#### 5.3.5.1 Diffuse sources

Output from the soil water module (SWAP) was used as input to the nutrient module (Animo) and the Surface Water Quantity module (SWQN). Outputs from Animo provided the diffuse source for the Soil Water Quality module (NUSWALITE).

#### 5.3.5.2 Point sources

Next to the diffuse nutrient sources two types of point sources were specified for the Vecht watershed; waste water treatment plant (WWTP) discharges and direct discharges. WWTP discharges were provided for Dutch and German plants, but for German plants only for the year 1999. A historical trend was assumed using Dutch values for 1992-2000. WWTP discharges are added to the nearest surface water node; water discharges to SWQN and nutrient loads to NUSWALITE.

According to Dutch information all rural inhabitants are not connected to WWTP but contribute to direct discharge. This assumption was used for the German part as well, but first an estimate of rural inhabitants in Germany had to be made. Based on the Dutch figures 10% of the population not living in cities are rural inhabitants, not connected to WWTP. Direct discharge is then calculated by multiplying inhabitants * Inhabitant N/P equivalent (Table 5. 12). The direct discharge is added to the extra storage nodes in NUSWALITE.

*Table 5.12 Direct discharge characteristics*

| Country | N inhabitant equivalent (gr/inh/d) | P inhabitant equivalent (gr/inh/d) | Area ($km^2$) | Rural inhabitants | Rural inh/$km^2$ |
|---|---|---|---|---|---|
| NL | 9.1 | 2.0 | 2033 | 27725 | 13.6 |
| GE | 11.0 | 1.85 | 1669 | 35419 | 21.2 |

#### 5.3.5.3 Input totals

Table 5.13 gives an indication of the different nutrient sources for the whole Vecht catchment. Agricultural lands contribute most N to the surface water system, though point sources from the 1.2 milion inhabitants are an important N contributor as wel. Point sources are a major contributor to the phosphorus load in the surface water.

*Table 5.13 Nutrient sources for the whole Vecht catchment*

| | t N/a | t P/a |
|---|---|---|
| Point sources | 1733 | 227 |
| Woodland and other non-agricultural land | 624 | 9 |
| Loss from all agricultural land | 8180 | 342 |
| | | |
| *Extra information regarding agric. land:* | | |
| Surface runoff all agric. land | 27 | 8 |
| Net surplus at soil surface: grassland | 24756 | 4978 |
| Net surplus at soil surface: arable land | 18906 | 1058 |
| Root zone loss: grassland | 3537 | 211 |
| Root zone loss: arable land | 4643 | 131 |

### 5.3.6 Suggestions for improvement

- The almost total lack of essential manure and fertilizer application data for the German part of the catchment will surely influence model results.

- Although it is not the most important source of nutrients to the surface water the direct discharge and waste water treatment plant discharge estimates could and should be improved with more information.

When calculating the total N discharge of all (estimated 500 000) people connected to WWTP in Germany using the inhabitant equivalent figures, WWTP in Germany should have a cleaning capacity of more than 85% to reach the provided WWTP discharge figures. Dutch WWTP cleaning capacity is on average 72%. When using this cleaning capacity of 72% and the German WWTP discharge figures only 250 000 people can be connected which means the discharge of about 250 00 people in Germany is 'lost' somewhere. Or the German direct discharge is underestimated and less people are connected to WWTP or the provided waste water treatment plant (WWTP) discharge figures are too low.

It is also possible that there is an error in the estimations because inhabitant N and P equivalent figures are national averages. It is unlikely that there is such a large difference in the P and N inhabitant equivalent between the bordering areas in The Netherlands and Germany. This N and P inhabitant equivalent is used to calculate the direct discharge to the surface water.

## 5.4 Simulation results

Measured data were most complete for the period 1996-2000. Results are given for the groundwater system and for the surface water system for this period. Figure 5.16 gives the measurements points for which results are presented.

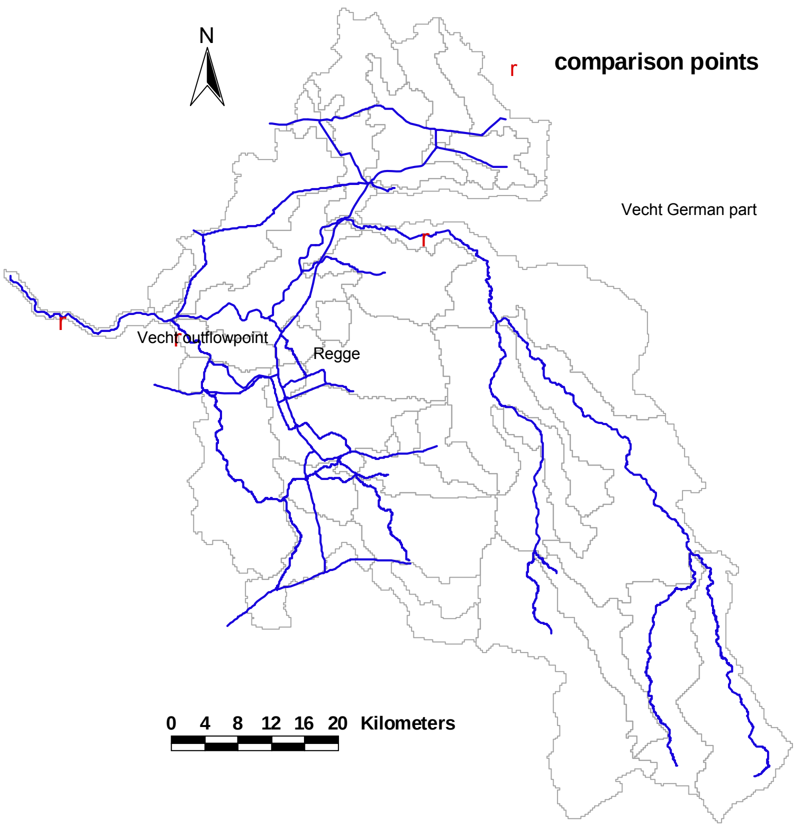



*Figure 5.16 comparison points*

### 5.4.1 Water

Water flow is simulated in the soil/groundwater system (Swap) and in the surface water system (Swqn). The yearly total simulated and measured water discharges at the outlet of the entire catchment, midstream and of the German part of the Vecht are given in figures 17, 18 and 19.

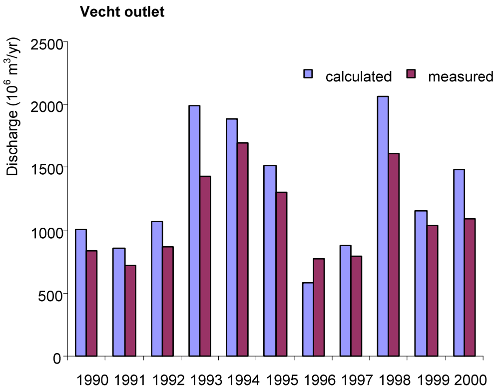



*Figure 5.17 Water discharge ($10^6$ $m^3$ $yr^{-1}$) from the surface water model and measured at the outlet*

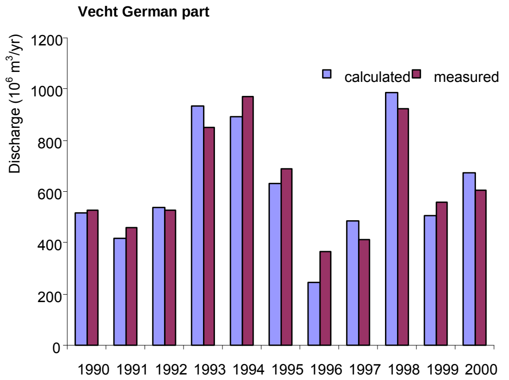



*Figure 5.18 Water discharge ( $10^6$ $m^3$ $yr^{-1}$) from the surface water model and measured midstream at the German border*

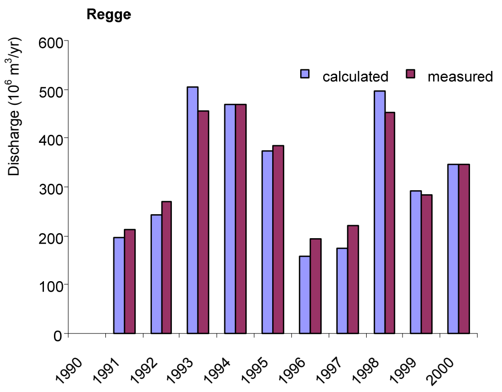



*Figure 5.19 Water discharge ($10^6$ $m^3$ $yr^{-1}$) from the surface water model and measured for the Regge*

Annual simulated values for the Regge and the German part of the Vecht are in good agreement with measured ones. Yearly simulated total discharges at the outlet (Figure 5.17) do show the same pattern as measured discharges but overall discharges seem to be overestimated, with the exception of the very dry year of 1996.

There is however some inconsistency in the measured discharge data. When subtracting the Regge discharge and German Vecht discharge from the total discharge at the outlet only a very small amount remains (Table 5. 12). But the whole northern Dutch part of the catchment is not included in the Regge and German Vecht discharges and has still to merge with the Vecht. This is an area as large as the Regge subcatchment (about 100.000 ha) which is likely to have a discharge in the same order of magnitude as the Regge subcatchment. But as can be seen in Table 5. 14 the residue is much lower than the Regge discharge. Some deviation is possible as both the north and the Regge catchment have outlet and inlet points to neighbouring catchments but discharge in or out of the catchment via these points is not enough to explain the difference (according to data provided by the waterboards). There are doubts about the reliability of the discharge data at the Vecht outlet during low discharges. However this could only partly explain the deviation as also during wet months and wet years the difference remains.

*Table 5.14 Yearly average measured discharges at the outlet, the Regge and the German part of the Vecht and the difference between Vecht minus Regge and German part in $m^3/s$*

| | Vecht (outlet) | Regge | German Vecht | Difference |
|---|---|---|---|---|
| 1991 | 22.8 | 6.7 | 14.5 | **1.6** |
| 1992 | 27.6 | 8.6 | 16.7 | **2.3** |
| 1993 | 45.3 | 14.5 | 26.9 | **3.9** |
| 1994 | 53.6 | 14.9 | 30.8 | **7.9** |
| 1995 | 41.5 | 12.2 | 21.9 | **7.3** |
| 1996 | 24.4 | 6.1 | 11.5 | **6.8** |
| 1997 | 25.3 | 7.0 | 13.0 | **5.3** |
| 1998 | 51.2 | 14.4 | 29.2 | **7.6** |
| 1999 | 32.8 | 9.0 | 17.7 | **6.0** |
| 2000 | 34.6 | 11.0 | 19.2 | **4.5** |
| 2001 | 37.6 | 11.8 | 19.5 | **6.3** |

In Table 5. 15 it can be seen as well that calculated mean discharges are higher than measured ones. Also maximum discharges are higher. The maximum modelled discharges have occurred at the end of October 1998 after extremely high rainfall. This discharge peak can also be seen in Figure 5.20 which shows the daily fluctuations in discharge for all three comparison points. As Table 5. 15 shows the overestimation of the discharge peak can already be seen in the output of the soil model (SWAP).

Except for the discharge extreme in 1998 most peaks are modelled well for both the German part of the Vecht and the outlet. At the Regge modelled peaks are somewhat lower than measured. This is due to the complicated hydrological situation with many bifurcations and weirs controlling the waterlevels. The model was calibrated on provided average waterdivisions at several points near the city of Almelo and the weirs at Hankate and Vroomshoop but it is likely that during high discharges more water is released via the Regge. However overall modelled daily discharges follow the measured discharges well as can be seen in Figure 5.20.

*Table 5.15 Statistics of the water discharge (m3 s-1) at the outlet*

| | Min. | 1stQu. | Median | Mean | 3rdQu. | Max. |
|---|---|---|---|---|---|---|
| Vecht - measured | 0.14 | 9.4 | 22.3 | 35.2 | 45.6 | 307 |
| Vecht - modelled SWAP | 2.75 | 10.9 | 24.6 | 41.4 | 51.7 | 1240 |
| Vecht - modelled SWQN | 1.92 | 12.7 | 25.5 | 41.4 | 52.9 | 416 |

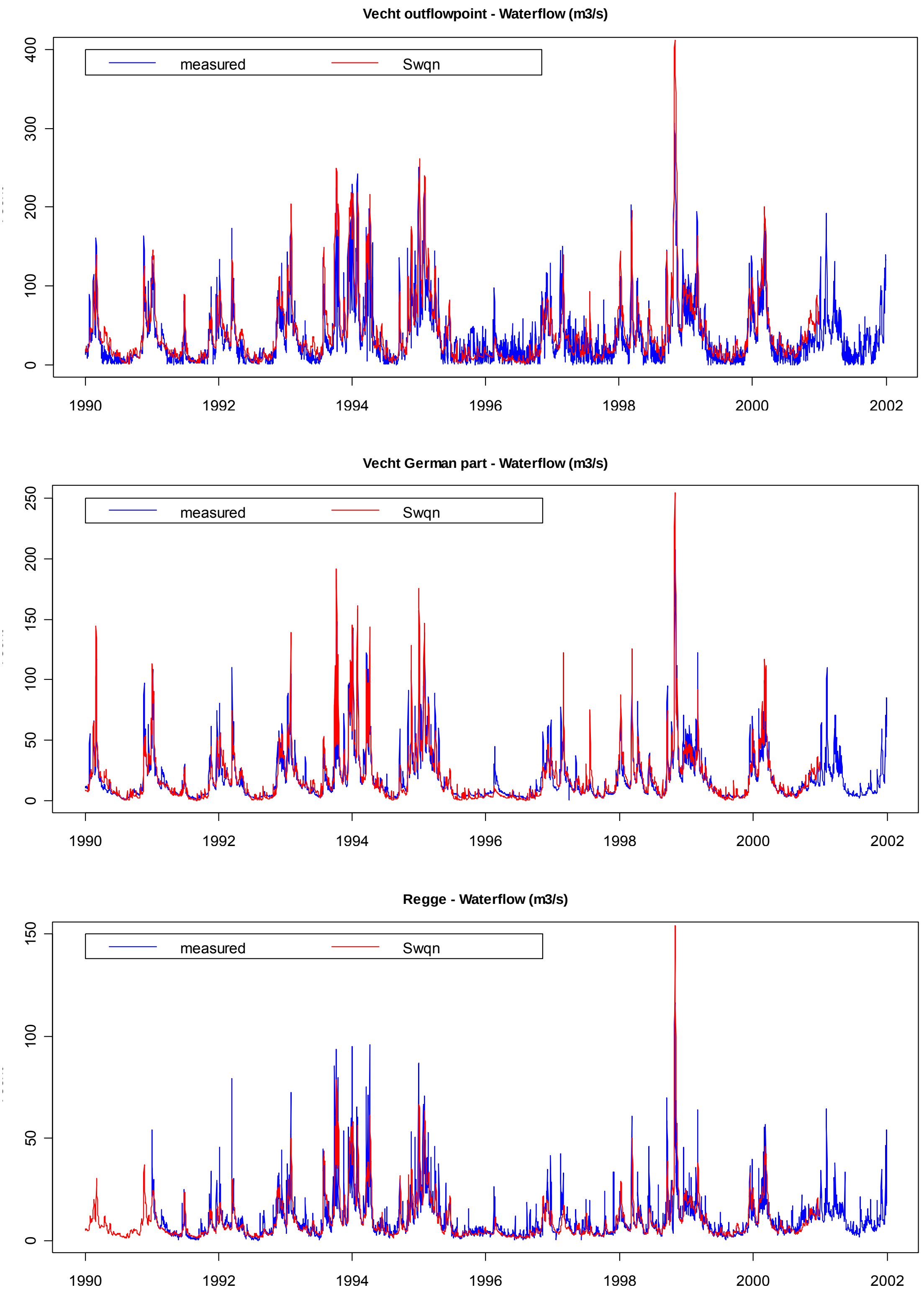



*Figure 5.20 Measured and calculated (SWQN) water discharge (m3 s-1)*

### 5.4.2 Nitrogen

Results are given for the soil water nutrient system (Animo) and the surface water system (Nuswalite). Concentrations and loads for all three comparison points are presented.

#### 5.4.2.1 Groundwater system

In tables 5.15 and 5.16 the average N balance over the last 5 years (1996-2000) of the soil nutrient model for arable, cultivated grassland and forest plots are given for The Netherlands and Germany.

On arable plots (table 16) the discharge of nutrients to the surface water model is almost similar for Dutch and German plots even though Dutch fertilizer and manure application is about 50% higher during this period. Most of the difference is buffered by a much higher denitrification in Dutch soils. This can be explained by the difference in organic matter content which is higher in the soils in the Dutch part of the catchment (paragraph 5.3.3).

*Table 5.16 Nitrogen balance for arable (kg ha$^{-1}$ yr$^{-1}$)*

| | | Fertilizer | Manure | Deposition | Net crop uptake | discharge | leakage - seepage | denitrification | Storage change |
|---|---|---|---|---|---|---|---|---|---|
| NL | In | 94 | 129 | 38 | | | | | |
| | Out | | | | 93 | 30 | -2 | 184 | |
| | Δ stor. | | | | | | | | -43 |
| GE | In | 61 | 88 | 38 | | | | | |
| | Out | | | | 90 | 32 | - | 69 | |
| | Δ stor. | | | | | | | | -3 |

For grassland plots (table 5.17) the higher manure and fertilizer application amounts do cause a higher discharge in the Dutch part of the catchment although denitrification is higher as well.

*Table 5.17 Nitrogen balance for grassland (kg ha$^{-1}$ yr$^{-1}$)*

| | | Fertilizer | Manure | Deposition | Net crop uptake | discharge | leakage-seepage | denitrification | Storage change |
|---|---|---|---|---|---|---|---|---|---|
| NL | In | 235 | 285 | 38 | | | | | |
| | Out | | | | 365 | 27 | 1 | 157 | |
| | Δ stor. | | | | | | | | 11 |
| GE | In | 133 | 240 | 38 | | | | | |
| | Out | | | | 289 | 20 | - | 75 | |
| | Δ stor. | | | | | | | | 10 |

As table 5.18 shows forest plots have hardly any discharge and all addition by deposition is 'lost' again through denitrification. The presence of more forest in the Dutch part of the catchment can also partly explain why nutrient concentration in surface water is almost similar to the German concentrations even though Dutch agricultural land receives much more N and P input.

*Table 5.18 Nitrogen balance for forest (kg ha$^{-1}$ yr$^{-1}$)*

| | Fertilizer | Manure | Deposition | Net crop uptake | discharge | leakage - seepage | denitrification | Δ storage |
|---|---|---|---|---|---|---|---|---|
| In | - | - | 38 | | | | | |
| Out | | | | 5 | 1 | 1 | 49 | |
| Δ stor. | | | | | | | | -16 |

### 5.4.2.2 Surface water system - N concentrations

In the calibration process the following parameters are changed for the nutrients in the surface water:

- Respiration loss during primary production;
- Mortality rate at 20 °C for aquatic plant roots during growth season;
- Mineralization rate of organic material;
- Denitrification rate of mineral N;
- Mineral phosphorus adsorption capacity;
- Sedimentation loss rate for mineral and organic P.

Appendix I shows the used parameters.

Results of a comparison between simulated and measured concentrations are given in Figure 5.21. Overall the measured fluctuations are resembled by simulated values as well. In the Regge not only the fluctuations but also the maximum and minimum concentrations correspond well with measured values. At the outlet modelled concentrations follow the same pattern as measured values but absolute concentrations are too low as Figure 5.21 shows. This underestimation of N concentration can already be seen in the German part. Only in the beginning of the 90ties modelled concentrations follow the measured values here. As described in paragraph 5.3.2 manure application amounts were 150% higher in 1990 than present values. This could indicate that the applied fertilizer amounts for recent years based on the provided 1999 German manure and fertilizer figures are too low.
Still, though, this does not give a full explanation for the underestimation of nitrogen concentrations in the Vecht, especially not for the period 1992-1994 when concentrations in the German Vecht and Regge are close to measured values. It might be possible that concentrations from the northern Dutch part of the catchment, not represented by the graphs in Figure 5.21, are too low. There are at present no figures available to check this assumption.

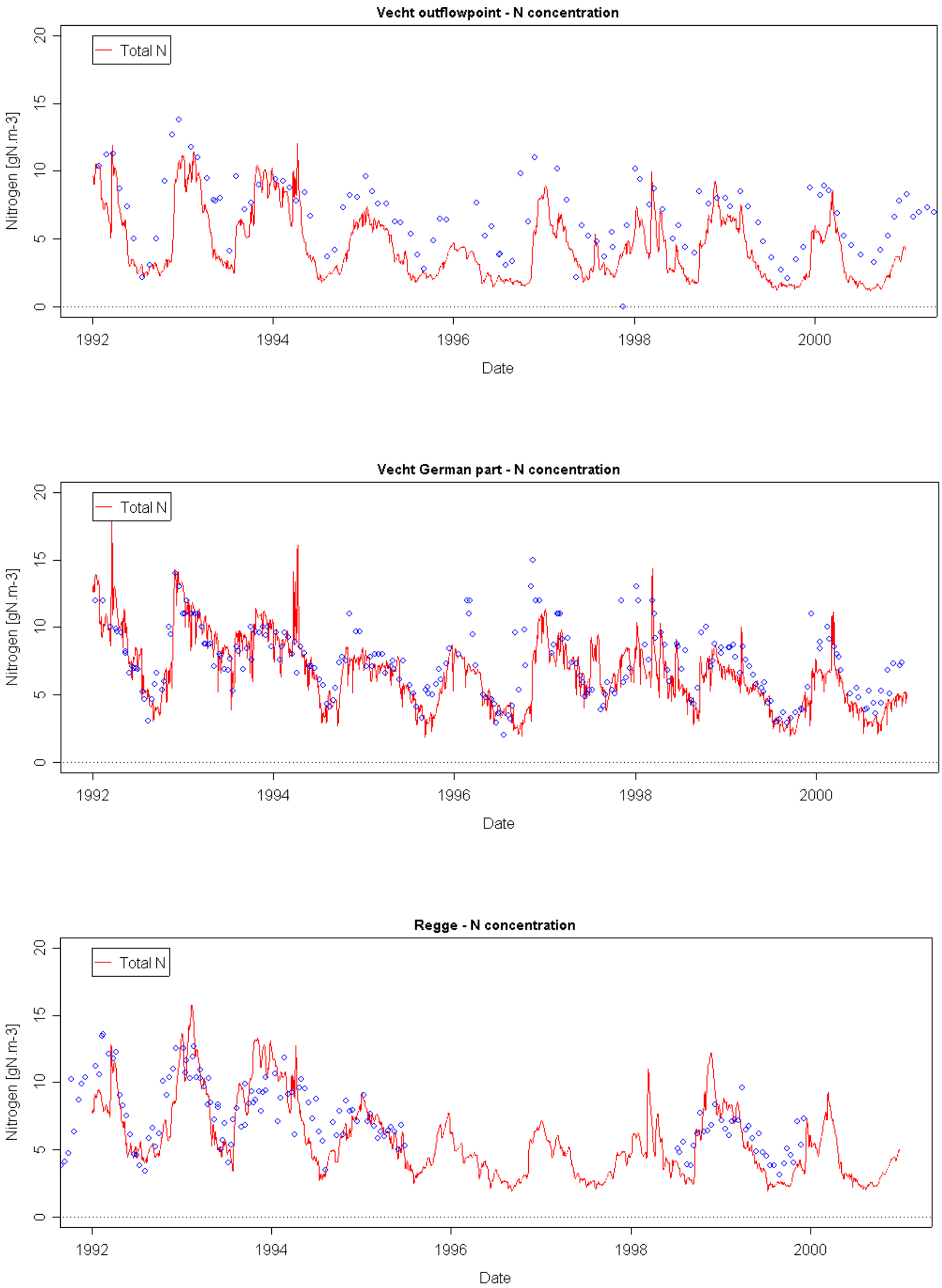



*Figure 5.21 Total Nitrogen concentrations (mg $l^{-1}$) calculated (red line) and measured (blue dots)*

#### 5.4.2.3 Surface water system – N loads

Total loads are presented in figures 5.22 – 5.24. At the outlet modelled loads follow the measured (calculated) loads quite well but this is largely due to the fact that the overestimated discharges counterbalance the underestimated concentrations. The pattern in German loads is simulated better. Until 1993 modelled loads follow measured loads nicely. After 1993 the total loads are somewhat too low compared to the measurements due to the underestimation of concentrations (figure 5.21). At the Regge loads are largely overestimated in 1993 and 1998, two years with high discharge and concentration peaks. It is likely that discharges are overestimated during extreme rainfall (Figure 5.20) but also the measured (calculated) loads can be questioned.
Only about 12 measurements per year are available to calculate total measured loads. This means single measurements have a large influence on yearly totals. When peaks are missed measured loads are underestimated. When one measurement is taken during a peak discharge with a rather high concentration interpolation of this single measurement over a whole month will overestimate total 'measured' loads. Interpretation of the difference between modelled and measured total loads should therefore be done with care.

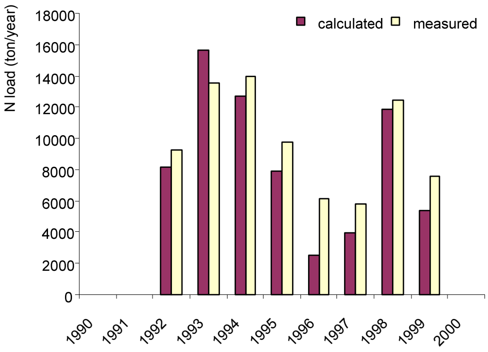



*Figure 5.22 Annual N loads at the outlet*

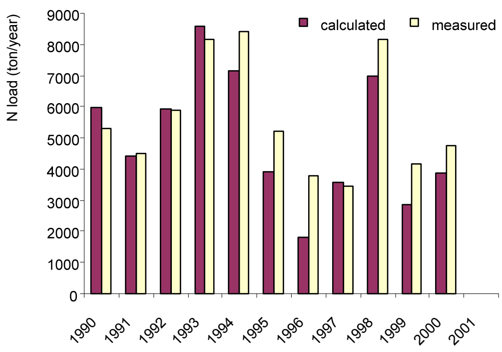



*Figure 5.23 Annual N loads for the German part of the Vecht*

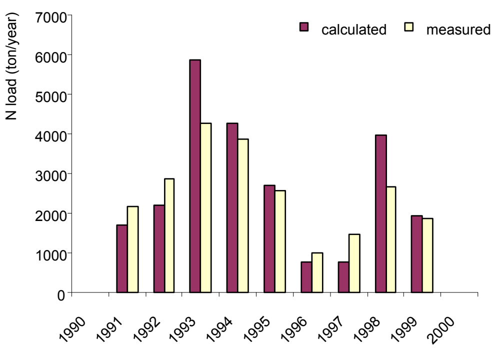



*Figure 5.24 Annual N loads for the Regge*

In Figure 5.25 daily fluctuations in N loads are presented.

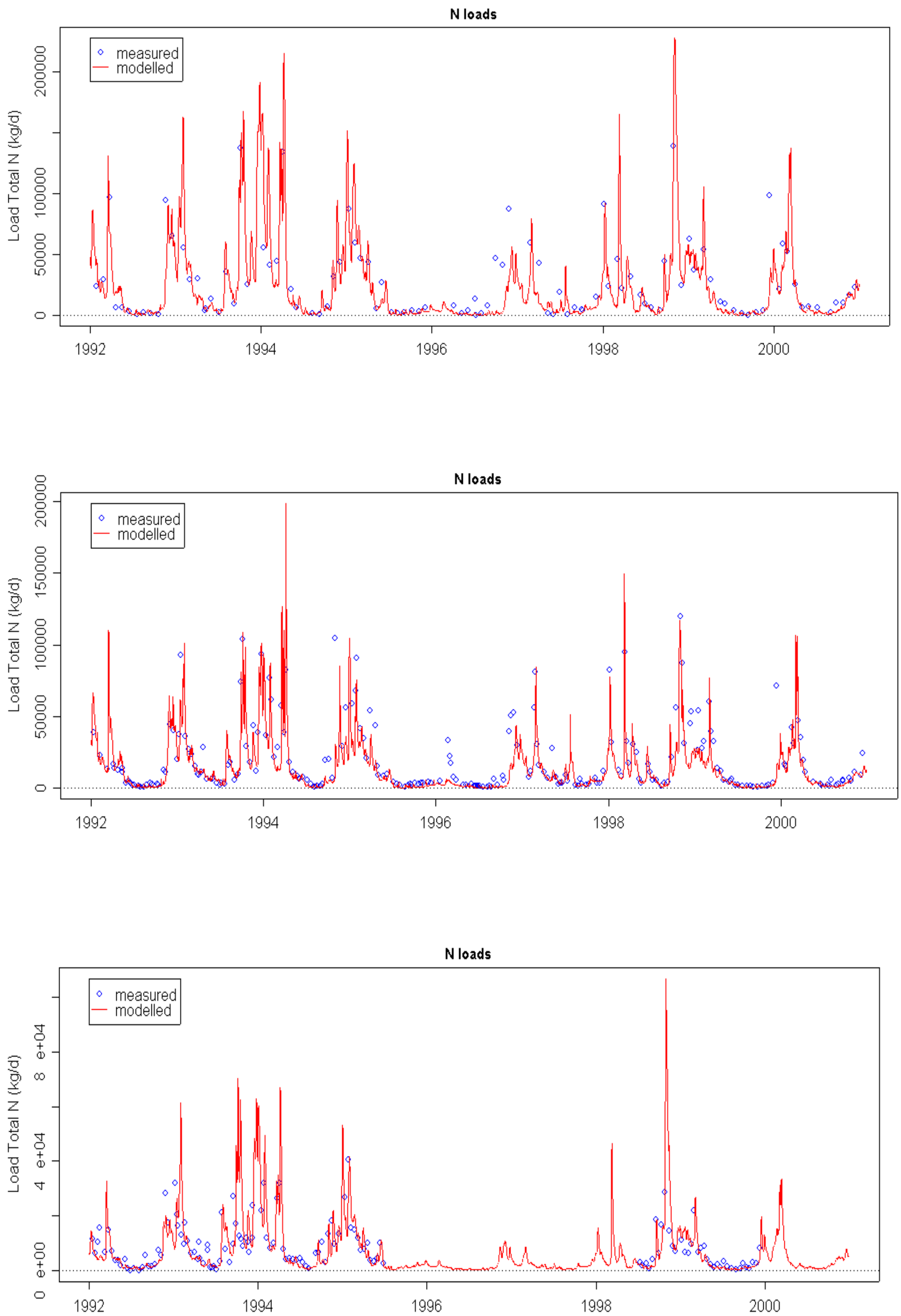



*Figure 5.25 Daily fluctuations of N loads (Outlet, German part and Regge)*

### 5.4.3 Phosphorus

#### 5.4.3.1 Groundwater system

In tables 5.19, 5.20 and 5.21 the average P balance over the last 14 years of the soil nutrient model for all agriculture (including cultivated grassland) and nature (forest and grassland) plots are given. A small decrease in storage can be seen on German arable lands and forests. Discharge is highest for German grasslands.

*Table 5.19 Phosphorus balance for arable (kg $ha^{-1}$ $yr^{-1}$)*

| | | Fertilizer | Manure | Deposition | Net crop uptake | discharge | leakage - seepage | Δ storage P mineral | Δ storage P organic |
|---|---|---|---|---|---|---|---|---|---|
| NL | In | 39.8 | 7.6 | 0 | | | | | |
| | Out | | | | 31.4 | 1.4 | -0.2 | | |
| | Δ stor. | | | | | | | 19.2 | -4.5 |
| GE | In | 22.4 | 5.4 | 0 | 31.0 | 0.7 | 0.0 | -6.3 | 2.3 |
| | Out | | | | | | | | |
| | Δ stor. | | | | | | | | |

*Table 5.20 Phosphorus balance for grassland (kg $ha^{-1}$ $yr^{-1}$)*

| | | Fertilizer | Manure | Deposition | Net crop uptake | discharge | leakage - seepage | Δ storage P mineral | Δ storage P organic |
|---|---|---|---|---|---|---|---|---|---|
| NL | In | 59.7 | 17.4 | 0.0 | | | | | |
| | Out | | | | 50.6 | 1.4 | -0.1 | | |
| | Δ stor. | | | | | | | 31.7 | 3.4 |
| GE | In | 55.8 | 13.8 | 0.0 | | | | | |
| | Out | | | | 39.0 | 1.8 | 0.0 | | |
| | Δ stor. | | | | | | | 23.6 | 5.2 |

*Table 5.21 Phosphorus balance for forest (kg $ha^{-1}$ $yr^{-1}$)*

| | Fertilizer | Manure | Deposition | Net crop uptake | discharge | leakage - seepage | Δ storage P mineral | Δ storage P organic |
|---|---|---|---|---|---|---|---|---|
| In | - | - | 0.0 | | | | | |
| Out | | | | 2.2 | 0.0 | -0.1 | | |
| Δ stor. | | | | | | | 0.5 | -2.7 |

#### 5.4.3.2 Surface water system - concentrations

Daily fluctuations of P concentrations are presented in Figure 5.26. No clear trend can be deduced in most of the measured values but modelled concentrations are within the same reach.

The peaks in the phosphorus concentrations in the German part of the Vecht are higher than measured values. This is probably due to high modelled groundwater levels in the German part of the Vecht where, as a result of limited data, averages had to be used for the bottom boundary conditions and drainage classes (paragraph 5.2.7). Phosphorus discharge from the soil column is high when groundwater levels are near soil level. As a result the P concentrations react fast to precipitation when the water table rises and discharges increases.

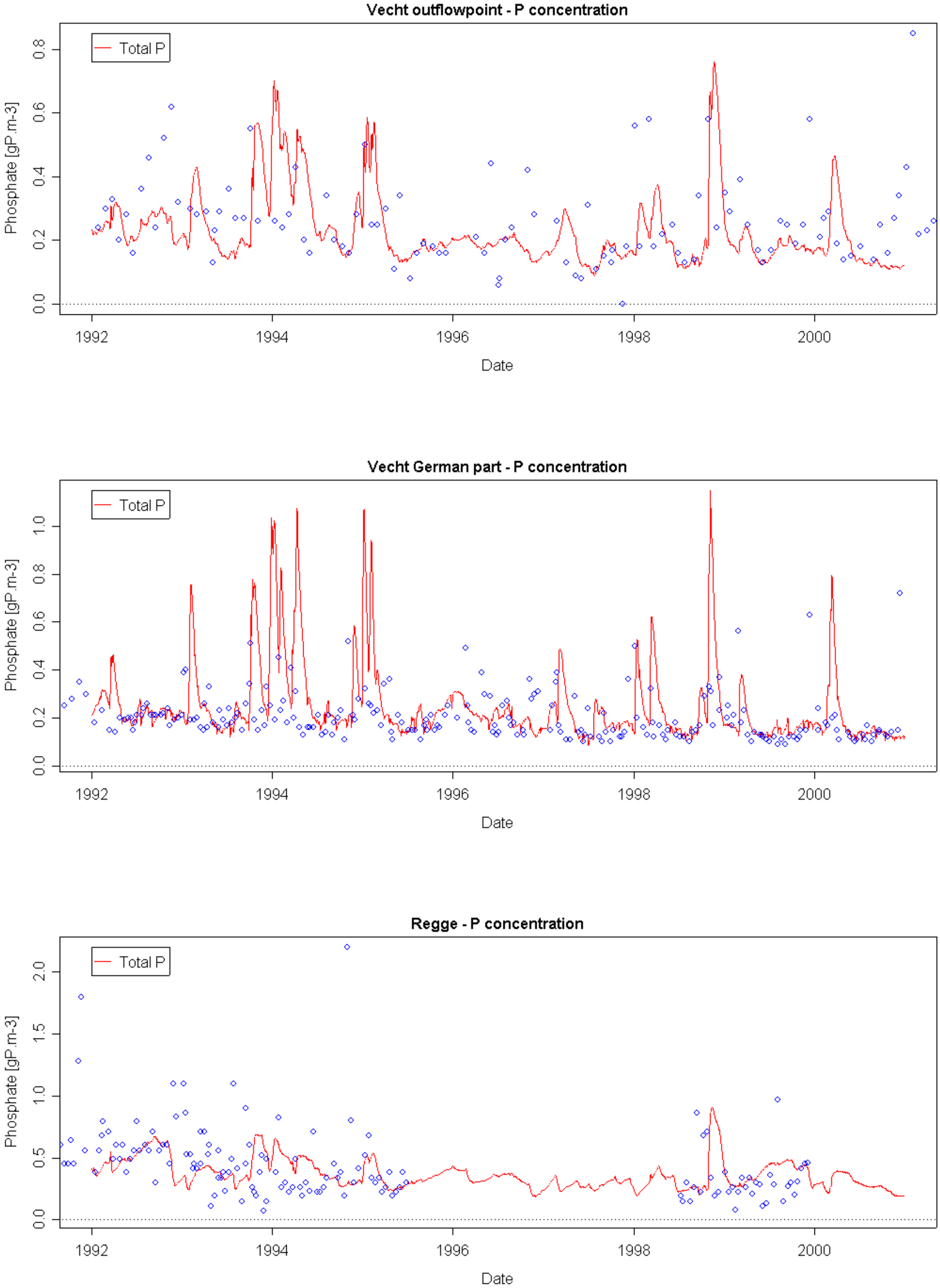



*Figure 5.26 Total Phosphorus concentrations (mg $l^{-1}$) calculated (red line) and measured (blue dots)*

#### 5.4.3.3 Surface water system – loads

Total phosphorus loads are presented in figures 5.27 – 5.29.

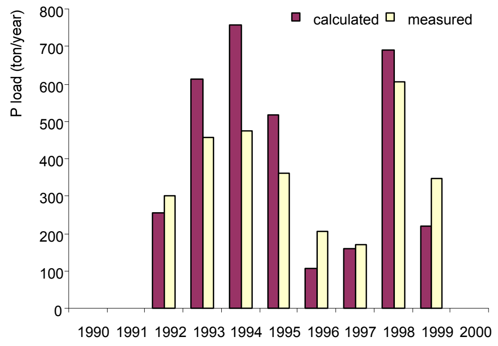



*Figure 5.27Annual P loads at the outlet*

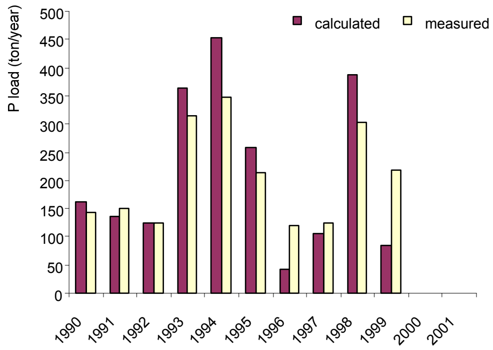



*Figure 5.28 Annual P loads for the German part of the Vecht*

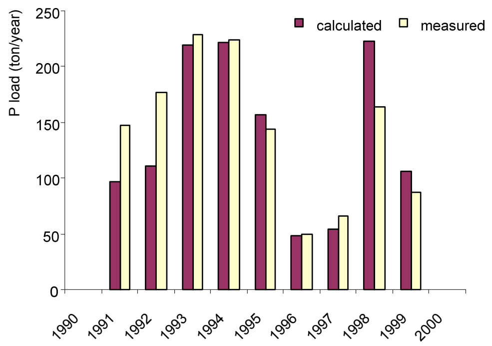



*Figure 5.29 Annual P loads for the Regge*

Figure 5.30 shows the daily fluctuations in P loads. The general pattern is similar between measured and modelled totals but large differences do occur. Phosphorus loads seem to be overestimated during the extreme rainfall period in at the end of October 1998 and the wet winter of 1993-1994 for the German part of the Vecht and at the outlet. But again 'measured' yearly loads are calculated with only a few concentration measurements so measured and 'calculated' values should be compared with care.

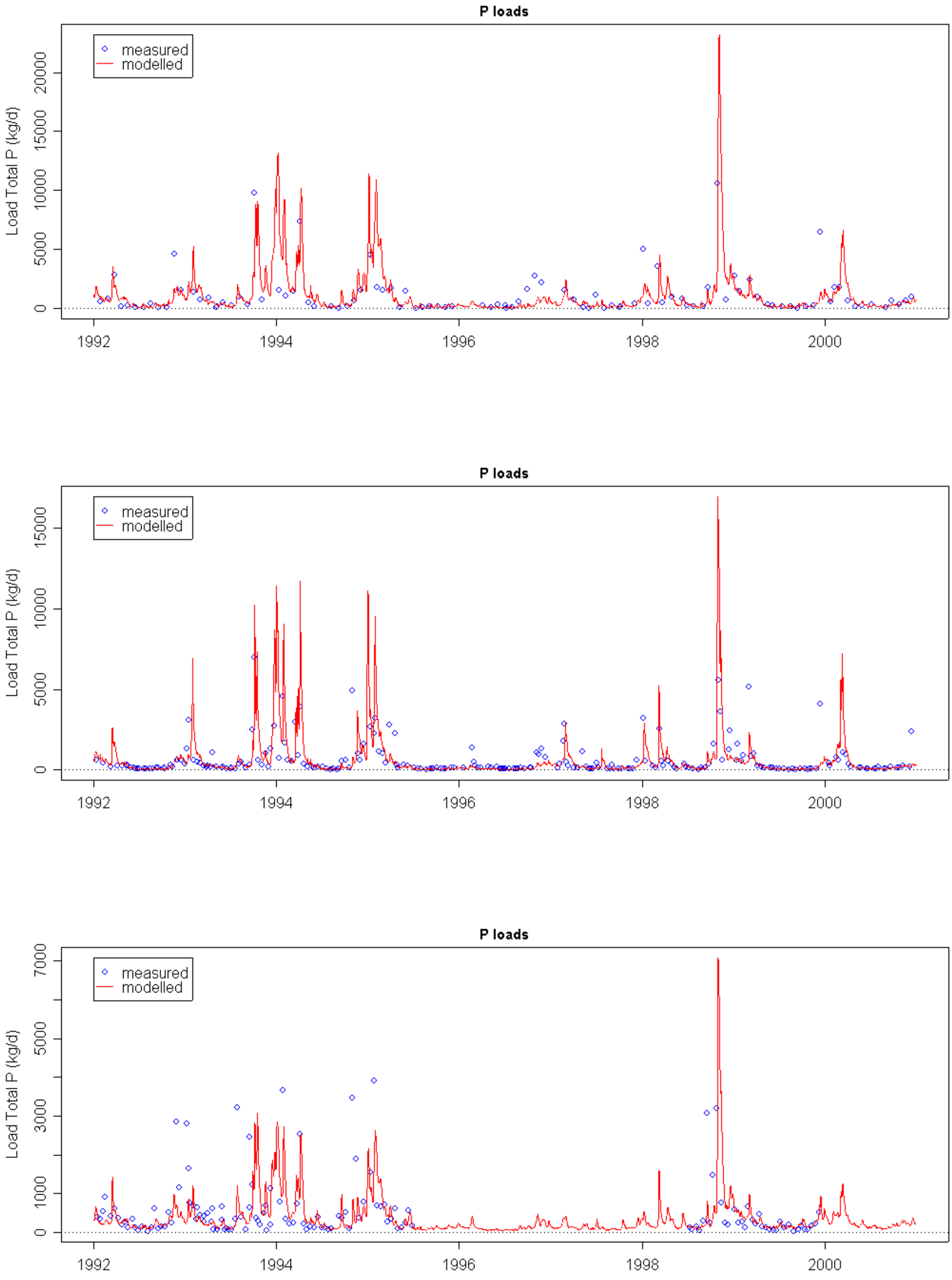



*Figure 5.30 Daily fluctuations of P loads (Outlet, German part and Regge)*

### 5.4.4 Retention

Results are produced for different water bodies: groundwater and surface water (rivers, lakes and reservoirs). Retention may occur in both water bodies and is in general:

Retention = inflow – outflow

Retention in *the surface water system* is determined as difference in inflow (drainage + runoff + point sources + erosion) and outflow (discharge at outlet).

Retention in *the groundwater system* requires a slightly different approach. In this case the inflow is defined as the remaining nutrient surplus at the bottom of the root zone. The outflow depends on the definition of the bottom boundary. When downward minus upward seepage (net seepage) is not considered to be a form of retention in the soil column, retention of the whole system is the difference between inflow (additions + deposition + crop residues – grossUptake – volatilization) and outflow (drainage + runoff + downward seepage – upward seepage). This is equivalent to the change of storage for phosphorus and the sum of denitrification and change in storage for nitrogen.
When the net downward seepage is assumed to be a form of retention, a loss term to deeper layers within the soil column from which it will not enter the surface water, retention is denitrification (for nitrogen) + change in storage + net seepage. The values in table 22 represent the second approach.

Denitrification is high at the agricultural lands, especially in the Netherlands as can be seen in table 5.16 (paragraph 5.4.2.1). As a result the total retention in the groundwater system is high. Table 5.22 shows the total results for the different (sub) catchments.

*Table 5.22 Retention in ton/year for surface and groundwater*

| | Vecht - outlet | | | | Vecht - Germany | | | | Regge | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N ton/a | % | P ton/a | % | N ton/a | % | P ton/a | % | N ton/a | % | P ton/a | % |
| Retention surface waters | 3862 | 37 | 255 | 43 | 776 | 17 | 57 | 28 | 1135 | 32 | 97 | 41 |
| Retention groundwater | 37701 | | 5601 | | | | | | | | | |

## 5.5 Concluding remarks

The agreement between daily simulated and daily measured nitrogen loads at the catchment outlet is good. The agreement between the annual measured and simulated loads is rather good, but the model underestimates the annual loads in in the dry years of 1996 and 1997. However waterdischarges and thereby also the loads at the outlet are questionable especially for dry years as they do not relate well to measured discharges upstream.
For the Regge subcatchment, for which the most detailed information was available, the agreement between daily simulated and daily measured loads is good. The model overestimates however the annual loads in the wetter years of 1993 and 1998.

The simulated N balance for all soils in the catchment shows an excess of 150 kg $ha^{-1}y^{-1}$ of which 122 is denitrified. The net seepage from deeper groundwater was estimated 1 kg $ha^{-1}y^{-1}$. The nitrogen transport to surface waters amounts to 29 kg $ha^{-1}y^{-1}$.
The total N inputs to surface waters are estimated at 13589 ton $y^{-1}$, of which 8836 ton $y^{-1}$ leaves the catchment at the outlet.

The agreement between daily simulated and daily measured phosphorous loads at the catchment outlet is reasonable. Annual measured and simulated loads show a similar trend, but the model overestimates the annual loads in the wetter years.
For the Regge subcatchment for which the most detailed information was available, the agreement between daily simulated and daily measured loads is reasonable although peak loads are underestimated. The agreement between the annual measured and simulated loads is very good for 6 out of 9 years, but the model overestimates the annual loads in the wet year of 1998 but underestimates the loads in the average years of 1991 and 1992.

The simulated P balance shows an excess of 20.7 kg $ha^{-1}y^{-1}$ of which 20.5 is stored in the soil. The net seepage from deeper groundwater was estimated at 0.2 kg $ha^{-1}y^{-1}$. The pophorus transport to surface waters amounts to 1.21 kg $ha^{-1}y^{-1}$. The total P inputs to surface waters are estimated at 730 ton $y^{-1}$, of which 422 ton $y^{-1}$ leaves the catchment at the outlet. The retention in surface waters is calculated at 44%.

## 5.6 Suggestions for improvement

Overall discharges, concentrations and loads correspond rather well with measured values. Still there are possibilities to improve the modelling of nutrient flows in the Vecht catchment. Model set-up as well as input data and control data could be improved.

Model setup

- During peak precipitation, discharge seems to be overestimated by the soil water model and consequently also the surface water model. Modelled german groundwater tables are quite shallow which could cause a quick reaction to precipitation. More information on German groundwater and drainage characteristics can improve model results. It is also possible that the current model setup underestimates the soil surface storage and water is discharged too quickly to the surface water system during extreme rainfall.

- Most of the chemical and physical parameters from the groundwater system are general values or estimates. Locally measured values will improve model results.

- Sensitivity and uncertainty analysis could provide insight in the most critical parts of the model chain.

Input data

- Model results do show the same fluctuations in nutrient concentrations as measured values, but absolute values are slightly underestimated in the German part of the Vecht and at the outlet. Better results will be obtained when more detailed information on manure and fertilizer applications is available especially for the German part of the catchment.

- Shallow groundwater levels in the German part of the catchment influence phosphorus discharge to the surface water system resulting in peaks in phosphorus concentrations. More information on German groundwater and drainage characteristics will improve model results.

- No information is available on the water intake during dry periods in summer.

Control data

- Measured discharge data from the different measurement points need to be compared. The measured discharges at the outlet of the Vecht seem to be too low compared to both measured discharges from measurement points upstream (the German part of the Vecht and the Regge) and modelled discharges.
- More water quality measurements are needed to get an accurate estimate of total loads. One measurement each month is not enough. Measured total loads can be highly under- or overestimated when only a few measurements can be used for the calculation.
- P-contents in soil and Nitrate –N concentrations in groundwater should be used to verify intermediate results.

# 6 The Ouse catchment

J. Kroes & C. Siderius

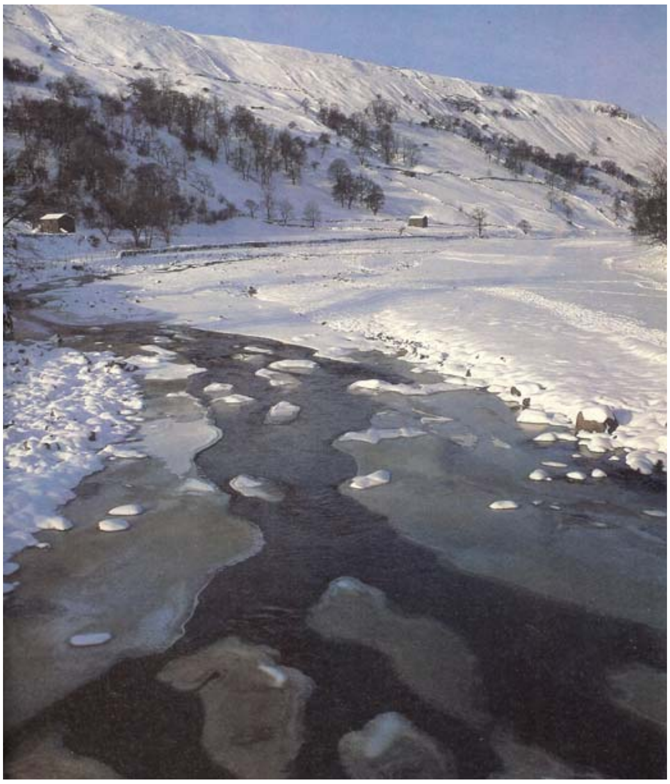
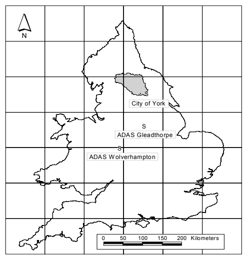


*Photo front page: The river SWALE in winter time (from: James Herrot's Yorkshire', published by Michael Joseph Ltd, 1979)*

## 6.1 Introduction

The Ouse catchment is a river basin in the North East of England. The River Ouse is formed by the confluence of the Rivers Swale, Ure and Nidd. Mean flow at the most downstream gauging station (upstream of York) is 49 $m^3s^{-1}$. Population density is low in the area and the land use consists mainly of arable land in the east and grassland and moorland in the West. Elevation ranges from 10 to 714 meters.

The Yorkshire Ouse is one of the principal river basins in the North east of England. The River Ouse is formed by the confluence of the Rivers Swale, Ure and Nidd. The Ouse flows south-east through the low lying land of the Vale of York to the catchment outflow at 10 m above ordnance datum. These rivers rise on the Pennies and North Yorkshire Moors to the north and west of the catchment draining predominantly moorland and agricultural areas with low population densities. The largest urban centre is the city of York (~105,000 inhabitants) on the River Ouse. Mean flow at the most downstream gauging station (upstream of York) is 49 $m^3s^{-1}$.


The dominant land-use across the catchment is tilled land (arable and mixed farming), interspersed with grassland (cattle and sheep grazing). Rough grazing moorland and heathland are found on the higher ground in the west of the catchment. The fertile Vale of York is used for arable production, wheat potatoes and sugarbeet.

Table 6.1 General Catchment information[3]

| | |
|---|---|
| Catchment Area | 3315 $km^2$ |
| Elevation Range | 5-680 m |
| Rainfall Range | 600-2000 mm $yr^{-1}$ |
| Run-Off | 520 mm $yr^{-1}$ |
| Soils | Sand Loams, Clay Loams, Clay and Peat |
| Arable Land | 29% |
| Grassland | 31% |
| Rough Grazing/ Moorland | 30% |
| Woodland/Forest | 4% |
| Open Water | 1% |
| Population within Ouse catchment. | ~ 264 000 |
| Urban centres with over 5000 inhabitants. | 7 |

[3] This information is retrieved from the Euroharp website:http://euroharp.org/map/img/eng.htm

## 6.2 Discretisation

### 6.2.1 Delineation of sub catchments

The Ouse catchment was divided into sub catchments using 3 maps:

- a DEM (Digital Elevation Model);
- the boundary of the catchment
- the locations of the rivers.

An overlay (figure 6.1) with clustering of areas <7 ha resulted in 27 sub catchments (figure 6.2).

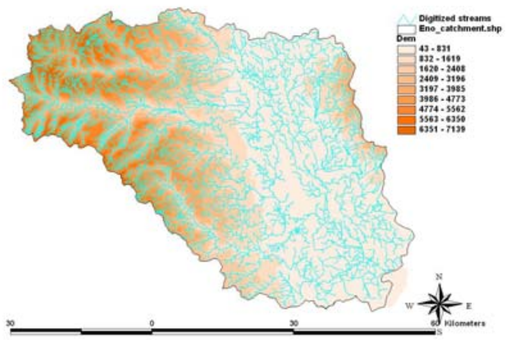



*Figure 6.1 Before watershed delineation*

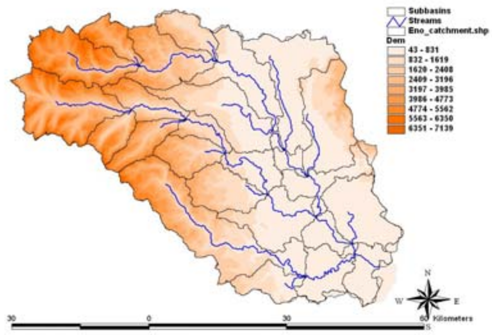



*Figure 6.2 After watershed delineation*

The 27 sub catchments have an average size of 12115 ha, with a minimum size of 671 and maximum size 36999 ha.

### 6.2.2 Derived surface water systems

The surface water system was schematised into sections, structures and nodes. Nodes are only relevant for the model descritization. Sections follow the course of original water course and the location of structures is identical to locations of surface water stations where monitoring data are available. In this way 103 sections, 103 nodes and 9 structures were distinguished (figure 6. 3).

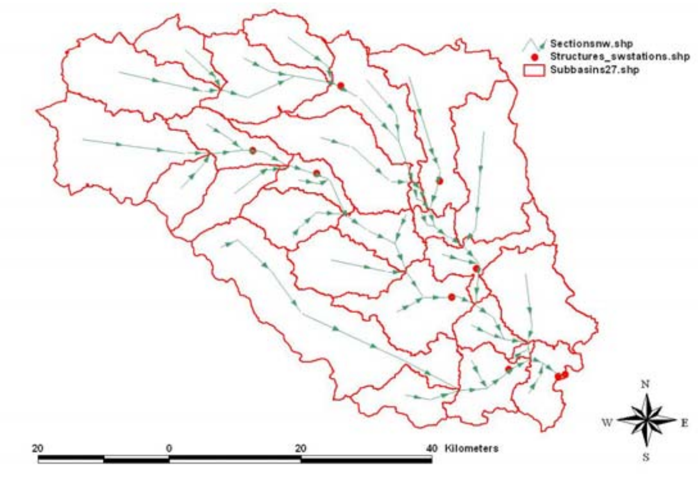



*Figure 6 3 The generalised surface water system*

### 6.2.3 Generalisation of the soil map

The available detailed map (figure 6.4a) was generalised using the EU/Hypress soil classification (Wosten *et al.*, 1999), which resulted in a map with 5 soil texture classes (figure 6.4b).

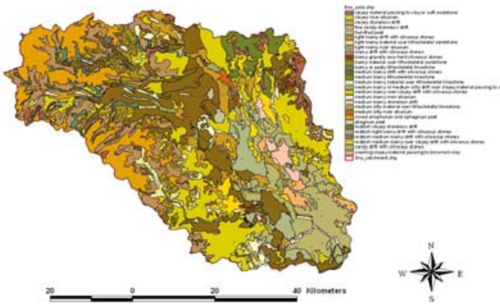



*Figure 6.4a Original soil map*

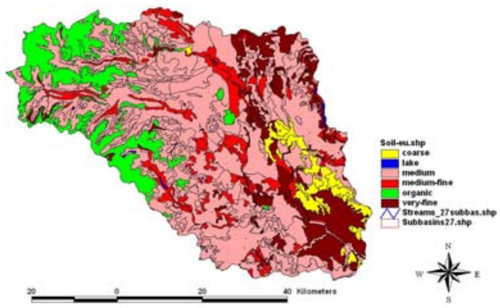



*Figure 6.4b Generalised soil map*

### 6.2.4 Generalisation of land cover and management

Land cover was given as a distribution within grids of a 1 km² size (figure 6. 5b). This distribution was generalised by selecting the dominant land use within each km² grid. Results of the distributions are given in table 6. 1 and figure 6.5a and 6.5b.

Table 6.1 Distribution of land use (km2 and as % of the total catchment area)

| | original data as distribution within grid | | dominant land use within grid | |
|---|---|---|---|---|
| land use | km2 | % | km2 | % |
| Arable | 973 | 29 | 1283 | 38 |
| Grass | 1022 | 31 | 1008 | 30 |
| Rough | 909 | 27 | 887 | 27 |
| Urban | 248 | 7 | 103 | 3 |
| Water | 26 | 1 | 2 | 0 |
| Wood | 168 | 5 | 63 | 2 |

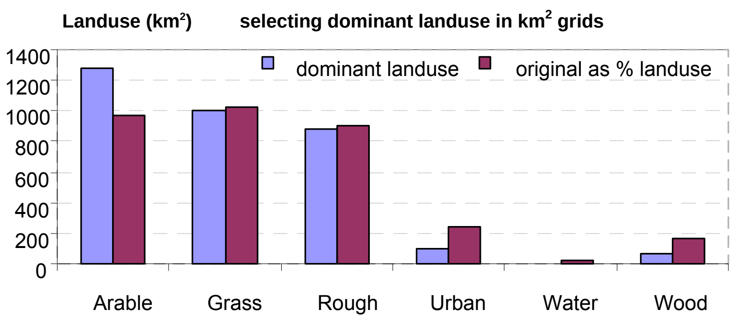



*Figure 6.5a Distribution of land use (km² and as % of the total catchment area)*

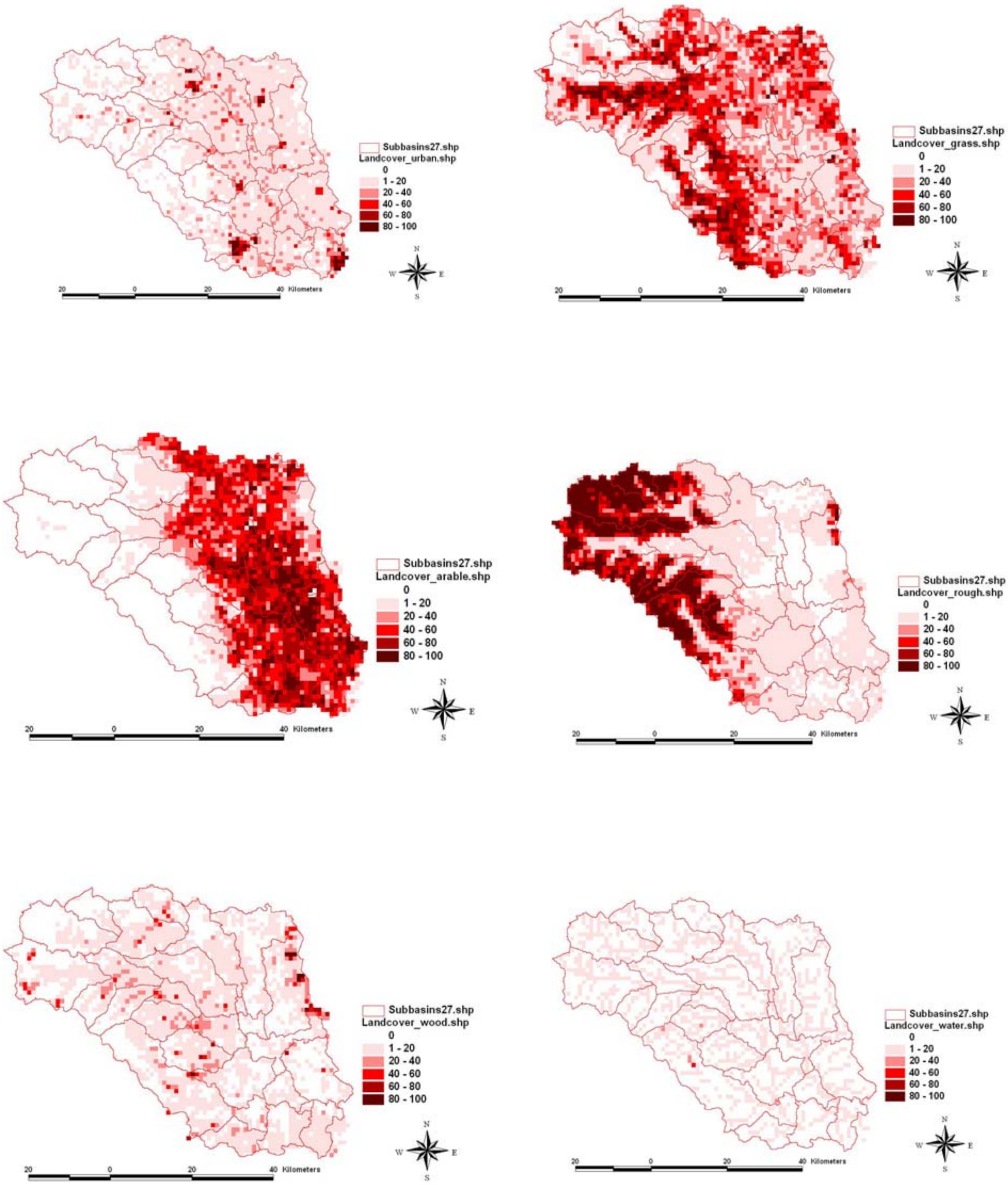



*Figure 6. 5b Distribution of land use within grid cells (% of a 1 km² grid cell)*

This resulted in the following land use map (figure 6. 6).

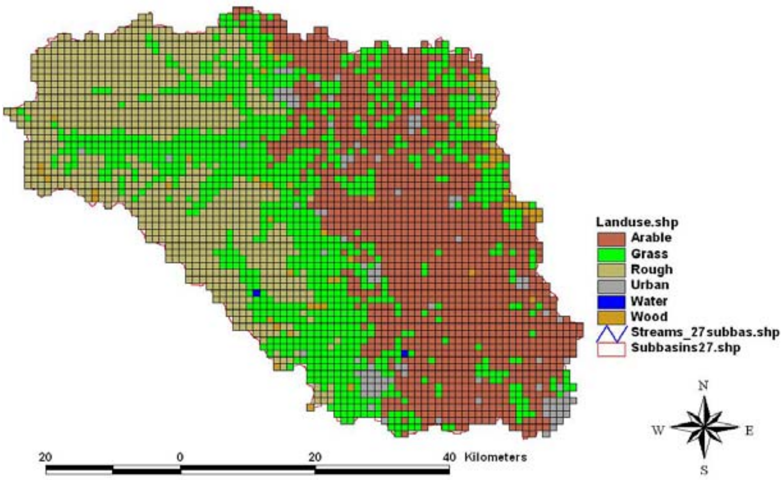



*Figure 6. 6 Generalised land cover map*

### 6.2.5 Meteorology

A proper meteorological data set is an important condition for any detailed discharge study. This is even more important if large spatial and temporal variation occur. In the English Ouse catchment there is a large variation in data.

#### 6.2.5.1 Precipitation

Precipitation data were available from 13 stations varying in altitude and location. Average annual rainfall showed a large variation, ranging from 573 – 1430 mm a-1 (table 6. 2).

Table 6. 2 Available weather stations with daily values for precipitation

| ID | Name | Coordinates.x | Coordinates.y | Elevation | Average Annual Rainfall |
|---|---|---|---|---|---|
| 3257 | LEEMING | 430600 | 489000 | 32 | 631 |
| 28904 | Brignall Rain Station | 407100 | 512200 | 209 | 818 |
| 47474 | Burtersett Rain Station | 389100 | 489300 | 291 | 1430 |
| 48001 | Bishopsdale Rain Station | 396100 | 483200 | 247 | 1388 |
| 49901 | Lumley Rain Station | 422400 | 470600 | 172 | 929 |
| 51718 | Arkengarth Rain Station | 400100 | 502900 | 282 | 1138 |
| 53530 | Crakehall Rain Station | 423800 | 490300 | 60 | 675 |
| 55222 | Osmotherly Rain Station | 445800 | 496800 | 147 | 740 |
| 56507 | Dunsforth Rain Station | 443500 | 464300 | 15 | 641 |
| 57427 | Scarhouse Rain Station | 406600 | 476600 | 331 | 1407 |
| 57788 | Gouthwaite Rain Station | 413900 | 468100 | 140 | 1141 |
| 58460 | Scargill Rain Station | 423500 | 453300 | 206 | 903 |
| 59792 | York Rain Station | 458200 | 452700 | 9 | 573 |

The weather station 58460 (Scargill Rain Station) lies far north of the area and is not taken into account. A first impression of influence areas of wheaterstations was achieved by creating Thiessen polygons (figure 6. 7). The final map with weather regions was created by assigning each subcatchment to a weather station using the following rules:

- In principal take the nearest station within a subcatchment;
- maintain results from the map with long term average rain fall data (Eno_long_term_rainfall_surface.shp);
- analyse results from Thiessen polygons.

The resulting map is given in figure 6. 8.

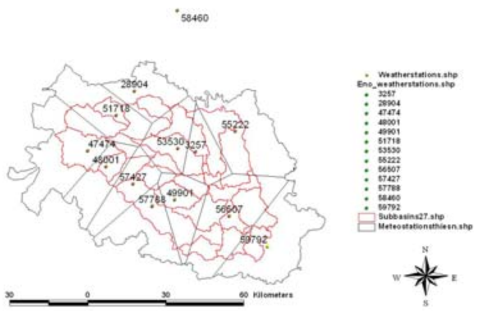



*Figure 6. 7 Weather station and Thiessen polygons to determine influence region*

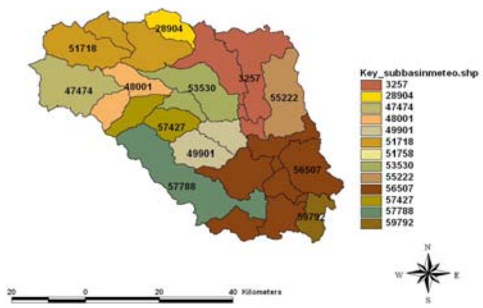



*Figure 6. 8 Weather regions*

Missing precipitation data were substituted by data from station 3257 ( LEEMING)

### 6.2.5.2 Evaporation

Meteorological data to determine evaporation were available for one station (3257 – Leeming). Wind speed, minimum and maximum temperature and the amount of sunshine hours were available for the period 1986-2000.

### 6.2.6 Boundary conditions

#### 6.2.6.1 Bottom boundary condition

The HOST classification (Boorman et al, 1995) was used to derive 2 different kinds of bottom boundary conditions:
- groundwater present and at > 2m; deepest drainage at 3.5 m
- groundwater present and at < 2m; deepest drainage at 1.50

Finally all peat areas are shallow drained with the drain level at 1.00 m below soil surface.

The resulting map for bottom boundary conditions is given in figure 6. 9.

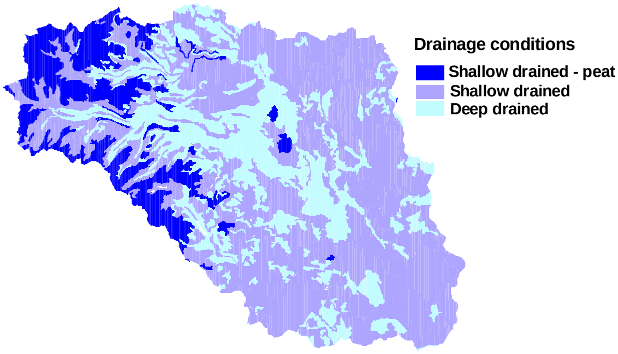



*Figure 6. 9 Generalised map with bottom boundary conditions*

#### 6.2.6.2 Lateral boundary condition

The discharge from the groundwater in the soil system to the surface water system is schematised in 3 routes: i) surface runoff with a very short residence time (within 1 day), ii) a very shallow rapid drainage system with a short residence time (a few days), iii) a drainage system with a longer residence time.

The latter drainage system has a representative drain spacing $L_i$ (m) which was derived by dividing the area of the subcatchement $A_{reg}$ (m$^2$) by the total length of the $i^{th}$ order channels, $l_i$ (m):

$$L_i = \frac{A_{reg}}{l_i}$$

The map with resulting representative drain spacing within each subcatchment is given in figure 6. 10.

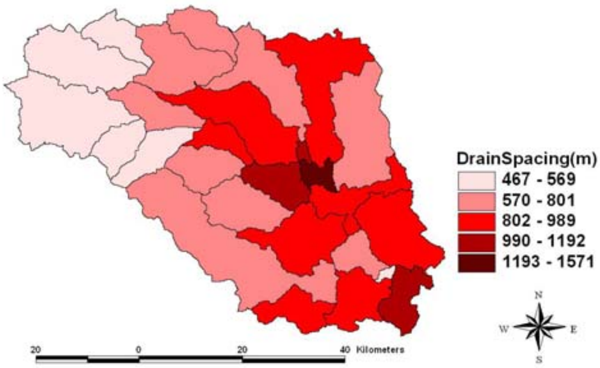



*Figure 6. 10 Drain spacing of the 3$^{rd}$ drainage system*

### 6.2.7 Calculation units

Unique Combinations were created using the following maps
- Sub catchments – 27 types
- Generalised soil map – 5 types
- Generalised land cover map – 6 types
- subsoil map HOST classes – 3 types
- occurrence of bypass flow – 2 types

The 5 maps were converted to 100 $m^2$ grids which is the output grid cell size and extent of the DEM. An overlay of these 5 maps resulted in 507 plots (or 323743 grids with a size of 100x100m) (figure 6. 11 and 12).

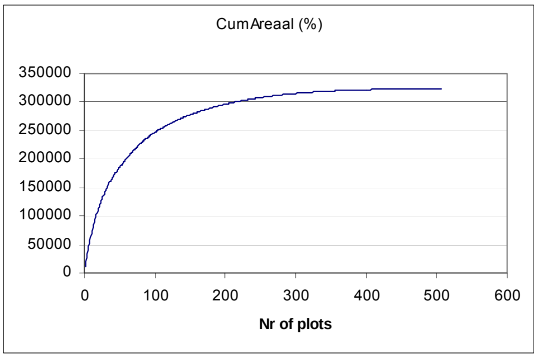



*Figure 6. 11 Cumulative frequency distribution of the size (ha) of calculation units (plots)*

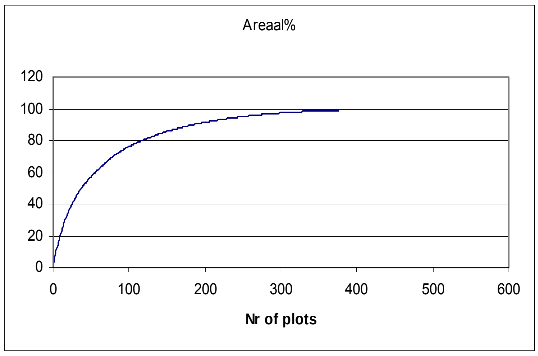



*Figure 6. 12 Cumulative frequency distribution of the size (%) of calculation units (plots)*

The number of calculation units was reduced from 507 to 246 plots (calculation units for Swap/Animo) as follows:

- Five plots with water were left out (lakes should be dealt with by surface water modelling);
- Small plots covering 5% of the area (and in size smaller than 2 $km^2$) could be assigned to nearest (figure 6. 11 and 12). Kriging was applied to find the nearest neighbouring plot.

A map with the final 246 calculation units is given in figure 6. 13.

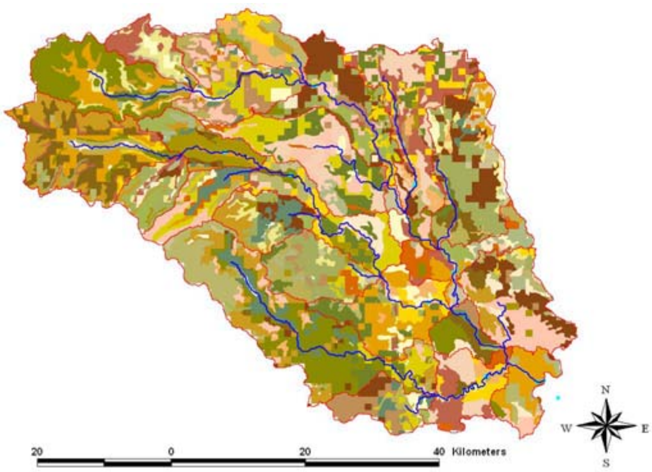



*Figure 6. 13 The calculation units*

## 6.3 Parameterisation

The study was carried out with the NL-Cat package which consists of the sub models:

- for soil hydrology: Swap version 3.0.3 (Kroes and Van Dam, 2003);
- for soil nutrients: Animo version 4.0.14 (Renaud *et al*, 2004. Groenendijk *et al*, 2005);
- for surface water quantity: SWQN version 1.0.7 (Smit *et al*, 2008);
- for surface water quality: NUSWALITE (SWQL) version 1.12 (Siderius *et al.*, 2008).

This chapter will explain how the different sub models were parameterised.

### 6.3.1 Meteorology

The Makkink equation (1957) was applied to determine evapotranspiration of a reference (grassland) crop. This equation requires values for minimum and maximum daily air temperature and global radiation. Radiation was derived from SunshineHours using a procedure given in Annex A. The procedure used measured air temperatures (figure 6.14), calculated global radiation (figure 6.15) and resulted in daily values for evapotranspiration (figure 6.16). The resulting evapotranspiration of the reference crop ranges between 480 mm in 1987 to 584 mm in 1989.

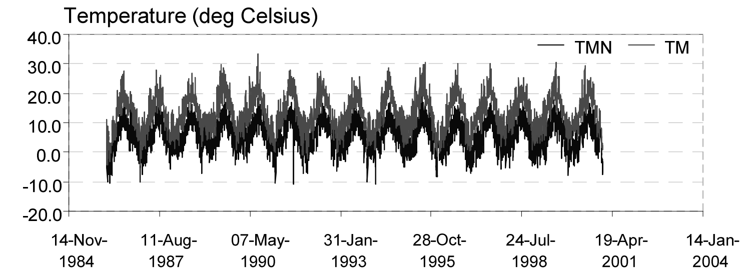



*Figure 6. 14 Daily average air temperature ($^oC$) at Leeming: minimum (TMN and maximum (MN) values*

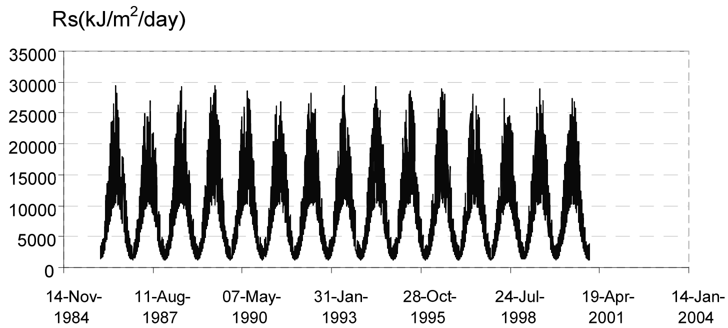



*Figure 6. 15 Daily global Radiation (kJ $m^{-2}$ $d^{-1}$) at Leeming*

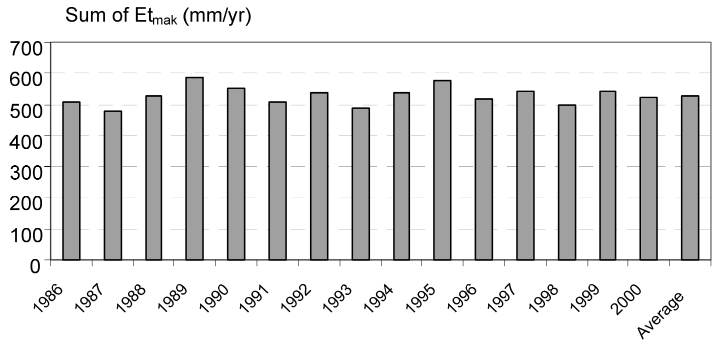



*Figure 6. 16 Annual sum of evapotranspiration (mm yr⁻¹) at Leeming*

### 6.3.2 Soil – groundwater system

Soil physical parameters were assigned to soil types and soil hydraulic properties (table 6. 3) were taken from the HyPress database (Wösten et al, 1999).

*Table 6. 3 Soil hydraulic properties from HyPrES (Wösten et al, 1999)*

| | Soil texture | ThetaR | ThetaS | Ksat | Alpha | λ | n | m |
|---|---|---|---|---|---|---|---|---|
| Topsoils | Coarse | 0.025 | 0.403 | 60.000 | 0.0383 | 1.2500 | 1.3774 | 0.2740 |
| | Medium | 0.010 | 0.439 | 12.061 | 0.0314 | -2.3421 | 1.1804 | 0.1528 |
| | MediumFine | 0.010 | 0.430 | 2.272 | 0.0083 | -0.5884 | 1.2539 | 0.2025 |
| | Fine | 0.010 | 0.520 | 24.800 | 0.0367 | -1.9772 | 1.1012 | 0.9190 |
| | VeryFine | 0.010 | 0.614 | 15.000 | 0.0265 | 2.5000 | 1.1033 | 0.0936 |
| | Organic | 0.010 | 0.766 | 8.000 | 0.0130 | 0.4000 | 1.2039 | 0.1694 |
| SubSoils | Coarse | 0.025 | 0.366 | 70.000 | 0.0430 | 1.2500 | 1.5206 | 0.3424 |
| | Medium | 0.010 | 0.392 | 10.755 | 0.0249 | -0.7437 | 1.1689 | 0.1445 |
| | MediumFine | 0.010 | 0.412 | 4.000 | 0.0082 | 0.5000 | 1.2179 | 0.1789 |
| | Fine | 0.010 | 0.481 | 8.500 | 0.0198 | -3.7124 | 1.0861 | 0.0793 |
| | VeryFine | 0.010 | 0.538 | 8.235 | 0.0168 | 0.0001 | 1.0730 | 0.0680 |
| | Organic | 0.010 | 0.766 | 8.000 | 0.0130 | 0.4000 | 1.2039 | 0.1694 |

The presence of disturbing soil layers (impermeable or gleyed < 1m) was derived from the HOST classification. HOST was also used to indicate the presence of groundwater, which determined the kind of lower boundary condition.

Soil chemical data were derived from Dutch databases relating soil chemical parameters to soil properties.

### 6.3.3 Land management

The different land covers were simulated using default parameter sets for arable land, grassland and wood land. Parameters for Rough and Urban were approached by natural grassland (table 6. 4). The land cover type Water was not simulated by the soil sub models

*Table 6. 4 Parameter sets for the distinguished land cover types*

| Land cover nr | Land cover type | Parameter set |
|---|---|---|
| 1 | Arable | potatoes only not-irrigated |
| 2 | Rough | natural grassland not-irrigated |
| 3 | Grass | cultivated grassland not-irrigated |
| 4 | Wood | forest coniferous not-irrigated |
| 5 | Urban | Urban (dominated by grassland) |
| 6 | Water | not simulated by soil models |

An analyses of historical fertilizer and manure applications resulted in average values as given in table 6. 5.

*Table 6. 5 Historical yearly average fertilizer applications (kg/ha)*

| | Arable land | grassland |
|---|---|---|
| fertilizer N | 119 | 153 |
| fertilizer P | 32 | 16 |
| Manure Slurry N | 49 | 115 |
| Manure Slurry P | 17 | 34 |
| Total | 217 | 318 |

The temporal distribution of fertilizer, manure and slurry is given in table 6. 6 for the crops arable land and grassland.

*Table 6. 6 Monthly fertilizer application (kg/ha) on arable and grassland*

| | fertilizer applications | | | | Manure applications | | | | Slurry Application | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | arable | | grassland | | arable land | | grassland | | arable land | | grassland | |
| month | N | P | N | P | N | P | N | P | N | P | N | P |
| 1 | 0 | 0.3 | 0 | 0.2 | 1 | 6 | 5.8 | 1.8 | 0.5 | 0.1 | 3.2 | 0.9 |
| 2 | 6 | 2.9 | 7.6 | 1.5 | 1.5 | 8.7 | 7.5 | 2.5 | 1 | 0.3 | 4.6 | 1.2 |
| 3 | 34.6 | 8.1 | 44.2 | 4 | 1.5 | 8.7 | 7.5 | 2.5 | 1 | 0.3 | 4.6 | 1.2 |
| 4 | 35.8 | 4.2 | 45.8 | 2.1 | 1.5 | 8.7 | 7.5 | 2.5 | 1 | 0.3 | 4.6 | 1.2 |
| 5 | 25.1 | 2.9 | 32 | 1.5 | 0.6 | 3.3 | 2.8 | 0.9 | 0.3 | 0.1 | 3.2 | 0.9 |
| 6 | 8.4 | 1 | 10.7 | 0.5 | 0.6 | 3.3 | 2.8 | 0.9 | 0.3 | 0.1 | 3.2 | 0.9 |
| 7 | 4.8 | 0.6 | 6.1 | 0.3 | 0.6 | 3.5 | 2.8 | 0.9 | 0.3 | 0.1 | 3.2 | 0.9 |
| 8 | 3.6 | 1.3 | 4.6 | 0.6 | 9.1 | 57.6 | 7.1 | 2.2 | 2.2 | 0.6 | 4.3 | 1.1 |
| 9 | 1.2 | 4.5 | 1.5 | 2.3 | 9.1 | 57.6 | 7.1 | 2.2 | 2.2 | 0.6 | 4.3 | 1.1 |
| 10 | 0 | 4.5 | 0 | 2.3 | 9.1 | 57.6 | 7.1 | 2.2 | 2.2 | 0.6 | 4.3 | 1.1 |
| 11 | 0 | 1.6 | 0 | 0.8 | 1 | 6 | 5.7 | 1.7 | 0.5 | 0.1 | 3.2 | 0.9 |
| 12 | 0 | 0.3 | 0 | 0.2 | 1 | 6 | 5.7 | 1.7 | 0.5 | 0 | 3.2 | 0.9 |
| total | 120 | 32 | 152.5 | 16.3 | 36.6 | 227 | 69.4 | 22 | 12 | 3.2 | 45.9 | 12.3 |

### 6.3.4 Surface water system

#### 6.3.4.1 Diffuse sources

Output from the soil water module (SWAP) was used in the nutrient module (Animo) and input for the Surface Water Quantity module (SWQN). Outputs from Animo provided the diffuse source for the Soil Water Quality module (NUSWALITE).

For erosion a simplified approach was applied (Walvoort, 2004). This approach is based on the RUSLE (Revised Unified Soil Loss Equation). A rough estimate of soil erosion was achieved by applying the procedure to the catchment with the following input parameters for each 100 $m^2$ grid:

- nutrient emission from the soil sub model for nutrients (Animo);
- rock content as soil characteristics from the given database;
- the xyz-values of the DEM

The erosion and Animo discharges were assigned to the most upstream surface water node in each catchment.

#### 6.3.4.2 Point sources

The discharge from 42 Waste Water Treatment Plants (WWTP) was assigned to the nearest surface water nodes. Average (daily) values were input to the surface water quality model (table 6. 7).

*Table 6. 7 Discharge from Waste Water Treatment Plants (g/d)*

| Surface water node | Organic N | Mineral N | Organic P | Mineral P |
|---|---|---|---|---|
| 8 | 0 | 69696 | 0 | 22376 |
| 9 | 0 | 4211 | 0 | 2628 |
| 10 | 0 | 12644 | 0 | 3909 |
| 18 | 0 | 13990 | 0 | 2190 |
| 21 | 0 | 9595 | 0 | 1051 |
| 26 | 0 | 111048 | 0 | 45552 |
| 31 | 0 | 2304 | 0 | 876 |
| 32 | 0 | 1994 | 0 | 876 |
| 33 | 0 | 109515 | 0 | 21900 |
| 37 | 0 | 2776 | 0 | 876 |
| 42 | 0 | 87991 | 0 | 22776 |
| 43 | 0 | 13027 | 0 | 3066 |
| 44 | 0 | 9080 | 0 | 2190 |
| 48 | 0 | 168997 | 0 | 45990 |
| 52 | 0 | 5344 | 0 | 1314 |
| 53 | 0 | 170980 | 0 | 45990 |
| 60 | 0 | 2472 | 0 | 876 |
| 61 | 0 | 2613 | 0 | 876 |
| 63 | 0 | 84540 | 0 | 21900 |
| 71 | 0 | 9689 | 0 | 2190 |
| 74 | 0 | 4355 | 0 | 1367 |
| 76 | 0 | 14397 | 0 | 4818 |
| 102 | 0 | 5971 | 0 | 2190 |
| Total | | 917228 | 0 | 257777 |

Discharge from 13 Industrial areas was assigned to the nearest surface water nodes.
Average (daily) values were input to the surface water quality model (table 6. 8)

*Table 6. 8 Industrial Area Discharges (g/d)*

| Name | Mineral N | Mineral P |
|---|---|---|
| MOORLAND POULTRY LTD*THE FACTO | 7036.8 | 86.3 |
| EDEN VALE FOOD INGREDIENTS | 102.8 | 21.8 |
| FARMERS GLORY LTD POULTRY FACT | 2686.5 | 597.0 |
| Glasshouses MILL TROUT FARM | 377.0 | 41.0 |
| Low Laithe Trout Farm | 87.2 | 9.9 |
| MARFIELD QUARRY LAGOON | 215.9 | 0.0 |
| WCF FOODS LTD | 1684.0 | 6130.8 |
| WEST TANFIELD FISH FARM | 308.9 | 7.6 |
| BARK TROUT FARM | 392.0 | 9.1 |
| TANCRED GRAVEL LIMITED | 215.9 | 0.0 |
| CHESSINGHAM LEISURE LTD | 4237.6 | 863.4 |
| ELDMIRE MILL (BUXTED CHICKEN L | 1329.6 | 863.4 |
| NUN MONKTON | 2933.9 | 889.3 |
| total | 21608.1 | 9519.7 |

Finally the direct discharge from people not connected to WWTP was estimated by assuming that 10% of people in rural areas are not connected. Rural area was determined by the population density from a 1 $km^2$ grid map. Grids with more than 400 inhabitants per $km^2$ were supposed to be towns and villages in which all inhabitants are connected to WWTP. Dutch N and P inhabitant equivalent values (9 gr/inh/d for N and 2 gr/inh/d for P) were used. In the end the total N and P discharge was split into a 25% organic and a 75% mineral fraction. This direct discharge sources was assigned to the most upstream surface water node in each catchment.

### 6.3.4.3 Input totals

Table 6. 9 gives an indication of the different nutrient sources for the Ouse catchment. As can be seen point sources are a relatively small component of the nitrogen load to the surface water but important for the phosphorus load.

*Table 6. 9 Nutrient sources for the whole Ouse catchment*

| | t N/a | t P/a |
|---|---|---|
| Point sources | 382 | 113 |
| Woodland and other non-agricultural land | 1830 | 48 |
| Loss from all agricultural land | 5050 | 99 |
| | | |
| *Extra information regarding agric. land:* | | |
| Surface runoff all agric. land | 333 | 13 |
| Net surplus at soil surface: grassland | 10674 | 2794 |
| Net surplus at soil surface: arable land | 14006 | 2672 |
| Root zone loss: grassland | 1329 | 38 |
| Root zone loss: arable land | 3388 | 49 |

### 6.3.5 Suggestions for improvement

- No extra storage was added to the surface water discretisation. It is expected that the surface water will quickly reach the main rivers due to the large gradients in elevation. In the valley an extra storage and, thus, delay could however have some effect on the processes of denitrification and sedimentation in the surface water.

- Only one arable crop, potatoes, is modelled. In reality a rotation of crops will be applied.

- No information was available on groundwater levels. The groundwater system can therefore only be calibrated on surface water discharges on (sub) catchment scale.

- The estimation of the direct discharge source of inhabitants not connected to waste water treatment plants is primarily based on Dutch averages as local figures and parameters were lacking. Especially the estimation of number of people not connected could be improved. A different estimate of people not connected or inhabitant equivalent N or P constants will mainly have an effect on phosphorus concentrations during dry periods as for nitrogen drainage loads are most dominant.

## 6.4 Simulation results

In the following paragraphs the results are given of the calibration of discharges, concentrations and loads. Figure 6. 17 shows the location of the used measurement point along the surface water system.

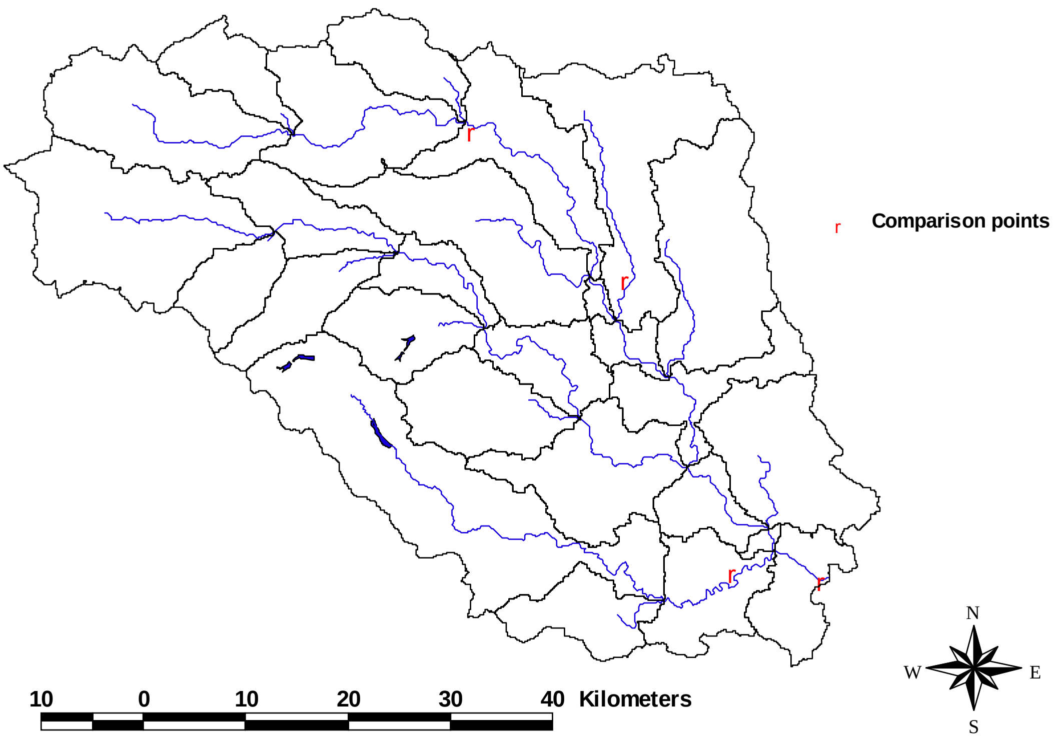



*Figure 6. 17 Comparison points for measured and modelled surface water concentrations and loads*

#### 6.4.1.1 Water

Water flow is simulated for the soil/groundwater system (SWAP) and for the surface water system (SWQN). Results are compared to measured values at the outlet (figure 6.18). Measured water discharges were used from 4 outlet points within the Ouse catchment for the period 1990-1994. The mean measured discharge is 1560 $Mm^3$ $a^{-1}$. The modelled mean discharge is 1531 $Mm^3$ $a^{-1}$.

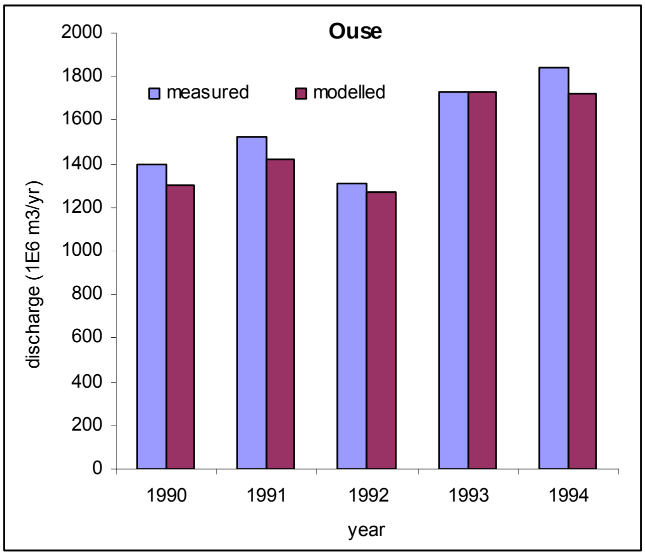



*Figure 6.18 Water discharge ($Mm^3$ $a^{-1}$) at the outlet modelled and measured*

The water discharge ($m^3$ $s^{-1}$) at the outlet of the entire catchment and out of the 4 sub-catchments (Nidd, Swale, Ure and Wiske) is given in table 6. 10 and figure 6.19.
Mean simulated values for the catchment are in good agreement with measured ones. Most peak discharges are modelled properly as well mostly especially for the Ouse river, although maximum modelled values are somewhat higher than measured. Another difference can be seen at the end of the dry summer period when measured discharges do increase after rainfall while modelled discharges are still at base level.

Largest deviations in mean discharge occur in the subcatchments of Nidd and Wiske. For the Wiske subcatchment it was reported that discharges higher than 2 $m^3$ $s^{-1}$ are not reliable. Because of these doubts about the accuracy of the discharge data the Wiske catchment was not used in further concentration and loads analyses.

*Table 6.10 Water discharge ($m^3$ $s^{-1}$) at the outlet of (sub) catchments*

| Subbasin | Min. | 1stQu. | Median | Mean | 3rdQu. | Max. |
|---|---|---|---|---|---|---|
| Ouse - measured | 4.0 | 12.6 | 24.4 | 49.4 | 60.9 | 552.1 |
| Ouse - modelled SWQN | 1.8 | 6.9 | 22.7 | 47.2 | 50.0 | 665.7 |
| Nidd - measured | 1.0 | 2.2 | 3.7 | 7.9 | 9.4 | 80.2 |
| Nidd - modelled SWQN | -1.1 | 0.8 | 3.4 | 8.0 | 8.2 | 130.0 |
| Swale - measured | 1.3 | 4.1 | 7.1 | 14.8 | 17.4 | 206.9 |
| Swale - modelled SWQN | 0.2 | 1.0 | 4.1 | 10.4 | 9.3 | 179.8 |
| Ure - measured | 0.5 | 2.9 | 7.1 | 16.8 | 20.2 | 332.7 |
| Ure - modelled SWQN | 0.3 | 1.6 | 5.5 | 15.7 | 14.4 | 359.4 |
| Wiske - measured | 0.1 | 0.3 | 0.5 | 3.6 | 1.3 | 113.5 |
| Wiske - modelled SWQN | 0.0 | 0.1 | 0.4 | 1.2 | 1.4 | 18.8 |

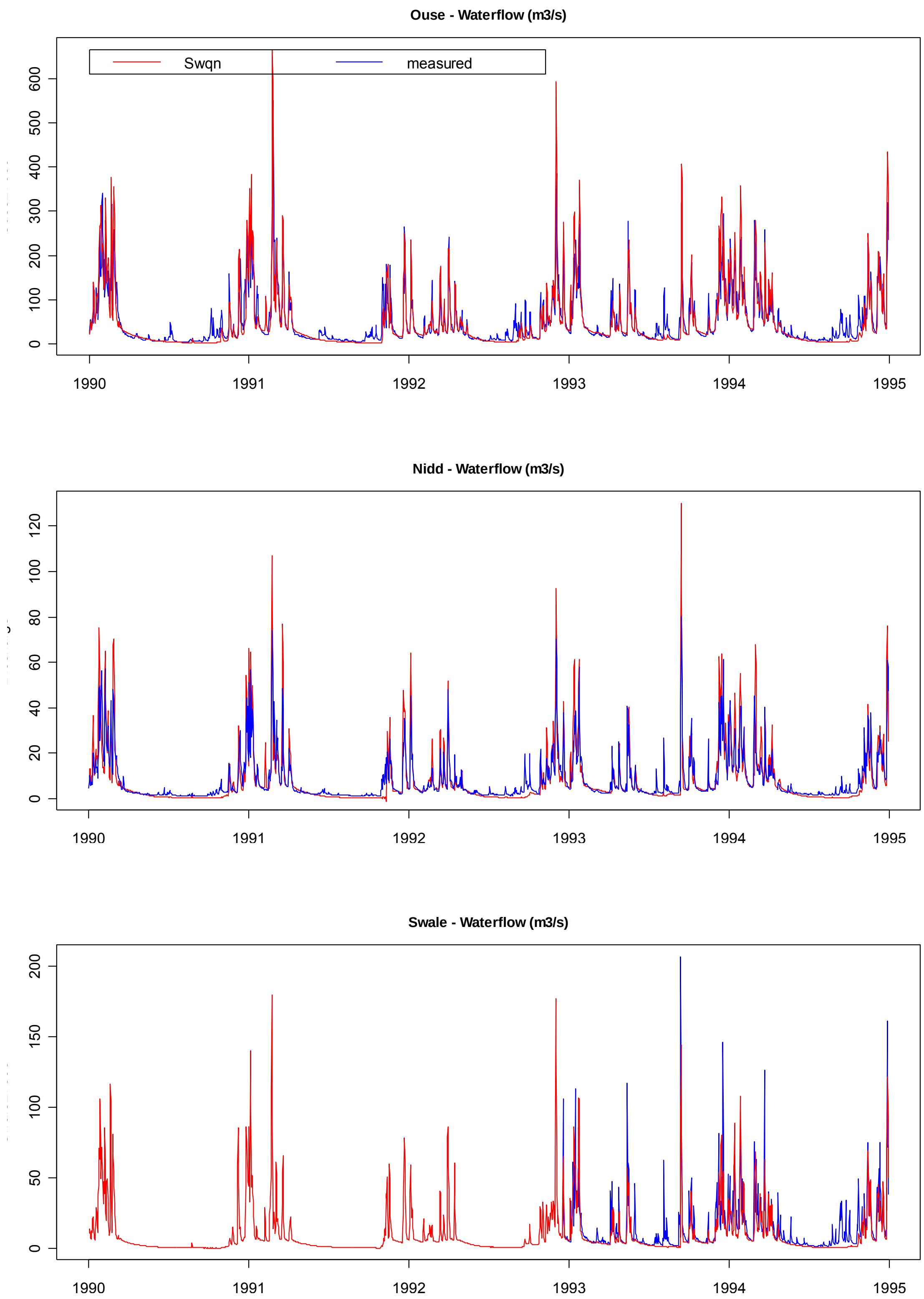



*Figure 6.19 Water discharge ($m^3$ $s^{-1}$) modelled (SWQN) and measured*

### 6.4.2 Nitrogen

Results are given for the groundwater system (Animo) and the surface water system (NUSWALITE). Nitrogen measurements were available from 3 points, Nidd, Swale and Wiske, for the period 1990 - 1994. Next to the concentrations in the Swale and Nidd River the modelled concentrations in the Ouse near the outlet are presented as well.

#### 6.4.2.1 Groundwater system

In tables 6.11 the average N balance over the last 14 years of the soil nutrient model for all agriculture (including cultivated grassland) plots is given. There is slight decrease storage, normal for plots under agricultural use.

*Table 6.11 Nitrogen balance for agriculture (kg ha$^{-1}$ yr$^{-1}$)*

| | Fertilizer | Manure | Deposition | Net crop uptake | discharge | seepage | volatilization | Denitrification | Δ storage |
|---|---|---|---|---|---|---|---|---|---|
| In | 134 | 83 | 62 | | | | | | |
| Out | | | | 164 | 23 | - | 2.4 | 97 | |
| Δ stor. | | | | | | | | | -7 |

Table 6.12 shows the nitrogen balance for nature areas, a combination of forest plots and natural grasslands. With no fertilizer or manure input but still a rather large discharge and denitrification the storage depletion is high for these nature areas, which are mainly peat lands.

*Table 6.12 Nitrogen balance for nature (kg ha$^{-1}$ yr$^{-1}$)*

| | Fertilizer/ Manure | Deposition | Net uptake | crop | discharge | seepage | volatilization | denitrification | Δ storage |
|---|---|---|---|---|---|---|---|---|---|
| In | 0 | 78 | | | | | | | |
| Out | | | 0 | | 25 | - | 0 | 87 | |
| Δ stor. | | | | | | | | | -35 |

#### 6.4.2.2 Surface water system – N concentrations

In the calibration process the following parameters are changed for the nutrients in the surface water:

- Respiration loss during primary production;
- Mortality rate at 20 $^{o}$C for roots during growth season;
- Mineralization rate of organic material;
- Denitrification rate of mineral N;
- Mineral phosphorus adsorption capacity;
- Sedimentation loss rate for mineral and organic P.

Appendix 4 shows the used parameters.

Measurements were analysed as concentrations. Results of a comparison between simulated and measured concentrations are given in figure 6.20. Average concentrations in Nidd agree relatively well with measurements, for Swale and Wiske the agreement is less.

As only few concentration measurements were available for the calibration period a proper calibration on concentration and loads was difficult. However the measurements do give an indication about the range of concentrations and seasonal fluctuations
Concentrations in the subcatchments of Nidd and Swale are both within the same range as measured concentrations. In the Nidd River measured concentrations are somewhat on the low side during the summer period. For Swale the few measurements give no clear indication if the modelled seasonal fluctuations are correct.

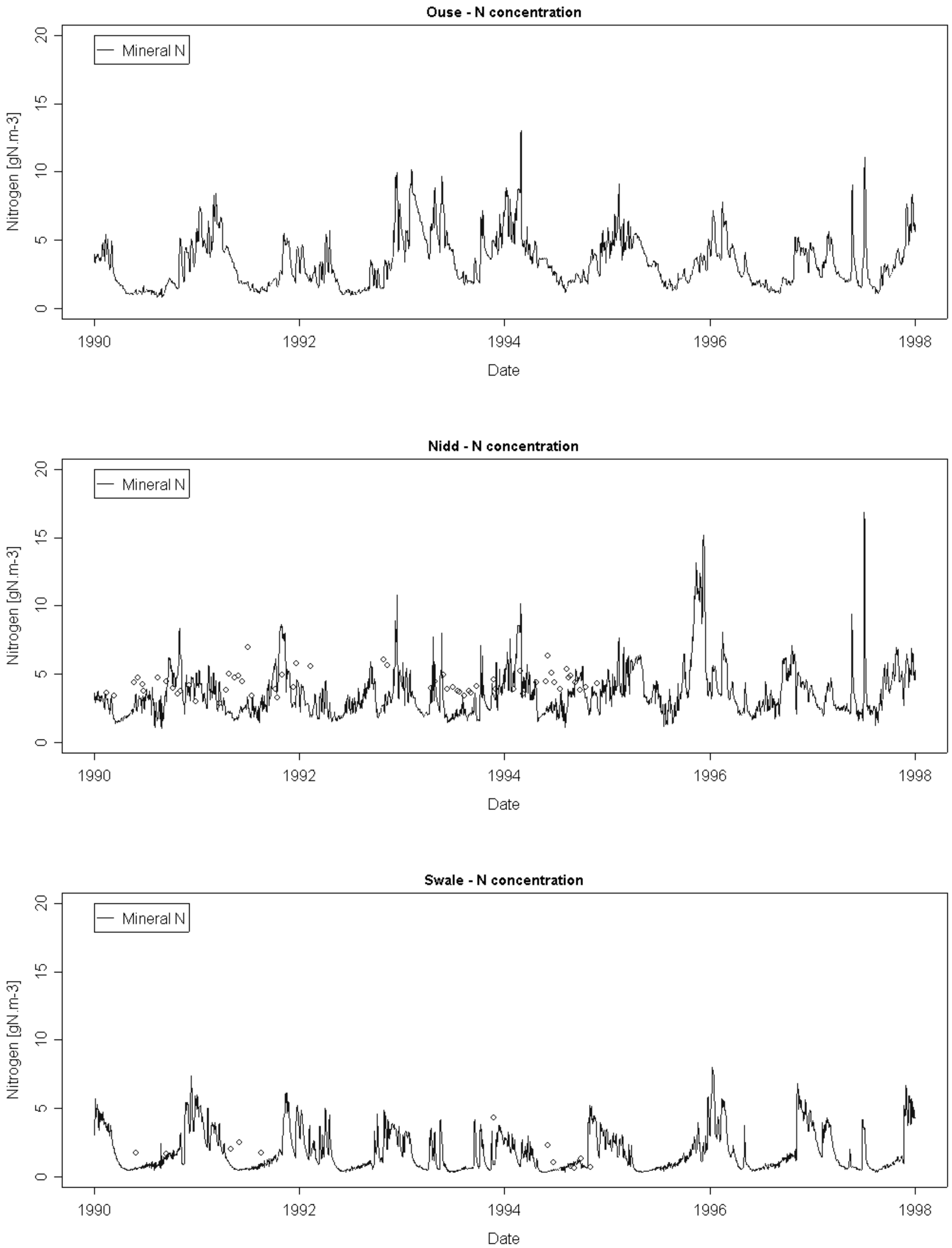



*Figure 6.20 Mineral nitrogen concentrations (g m⁻³) in the surface water measured (blue dots) and simulated (blue line)*

### 6.4.2.3 Surface water system – N loads

Daily fluctuations in N loads are shown in figure 6.21.

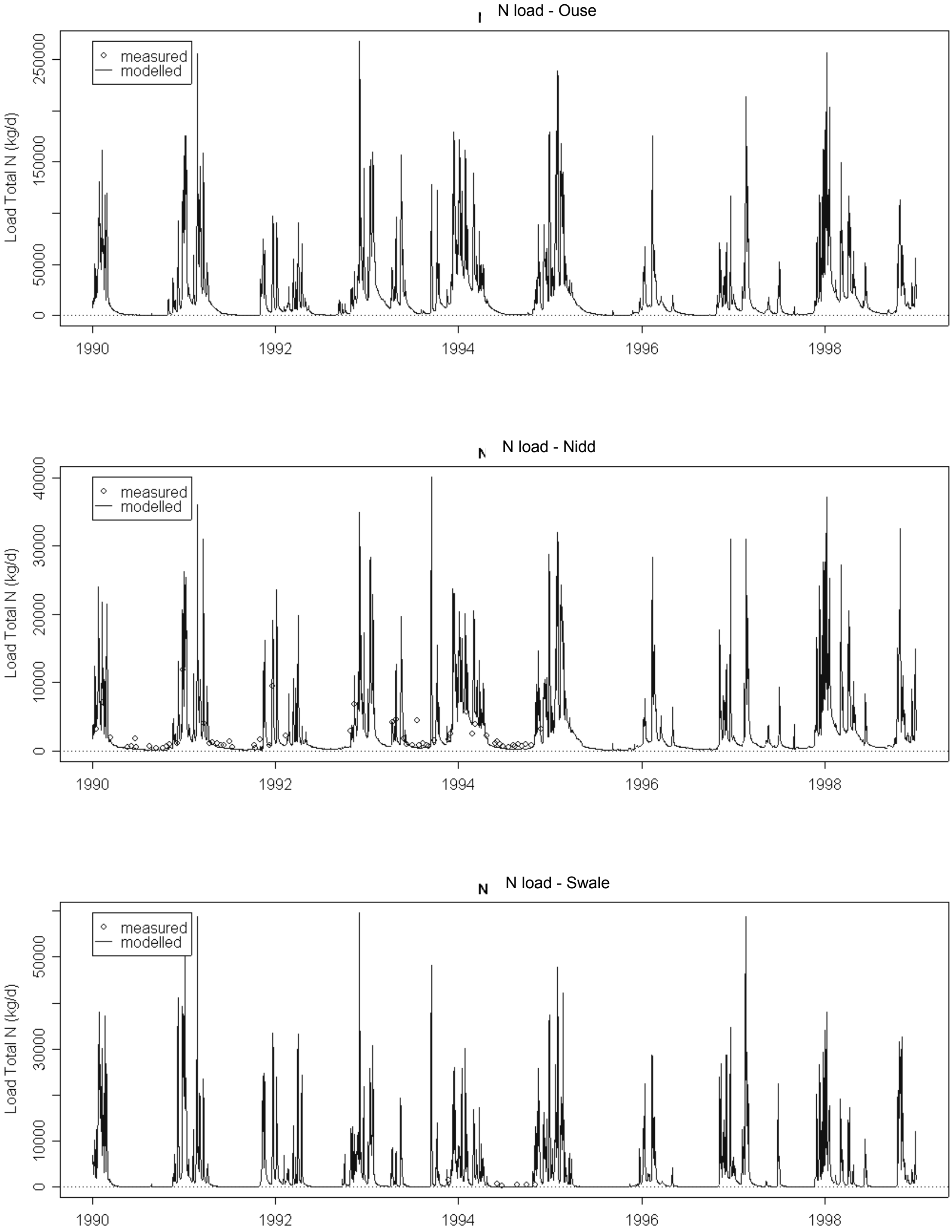



*Figure 6.21 Nitrogen discharge ($kg\ d^{-1}$)*

### 6.4.3 Phosphorus

Results are given for the groundwater system (Animo) and the surface water system (Nuswalite).

#### 6.4.3.1 Groundwater system

In tables 6.13 and 6.14 the average N balance over the last 14 years of the soil nutrient model for all agriculture (including cultivated grassland) and nature (forest and grassland) plots are given. On arable land there is a small decrease in mineral phosphorus while organic phosphorus increase. Net retention of phosphorus is therefore positive for agricultural lands (

*Table 6.13 Phosphorus balance for arable land (kg ha$^{-1}$ yr$^{-1}$)*

| | Fertilizer | Manure | Deposition | Net crop uptake | discharge | Δ storage P mineral | Δ storage P organic |
|---|---|---|---|---|---|---|---|
| In | 30 | 4.8 | 1.0 | | | | |
| Out | | | | 23 | 0.44 | | |
| Δ stor. | | | | | | -1.1 | 13 |

On nature areas, without any fertilization, there is a large decrease in mineral phosphorus and only a slight increase in organic phosphorus.

*Table 6.14 Phosphorus balance for nature (kg ha$^{-1}$ yr$^{-1}$)*

| | Fertilizer | Manure | Deposition | Net crop uptake | discharge | Δ storage P mineral | Δ storage P organic |
|---|---|---|---|---|---|---|---|
| In | 0 | 0 | 1.6 | | | | |
| Out | | | | 15 | 0.51 | | |
| Δ stor. | | | | | | -15 | 1 |

#### 6.4.3.2 Surface water system – P concentrations

Modelled phosphorus concentrations for Swale and Nidd show the same fluctuations as measured concentrations. For the Nidd River minimum concentrations are modelled well, maximum modelled concentrations ate a bit too low. For the Swale River modelled minimum concentrations are somewhat higher than the measured values.

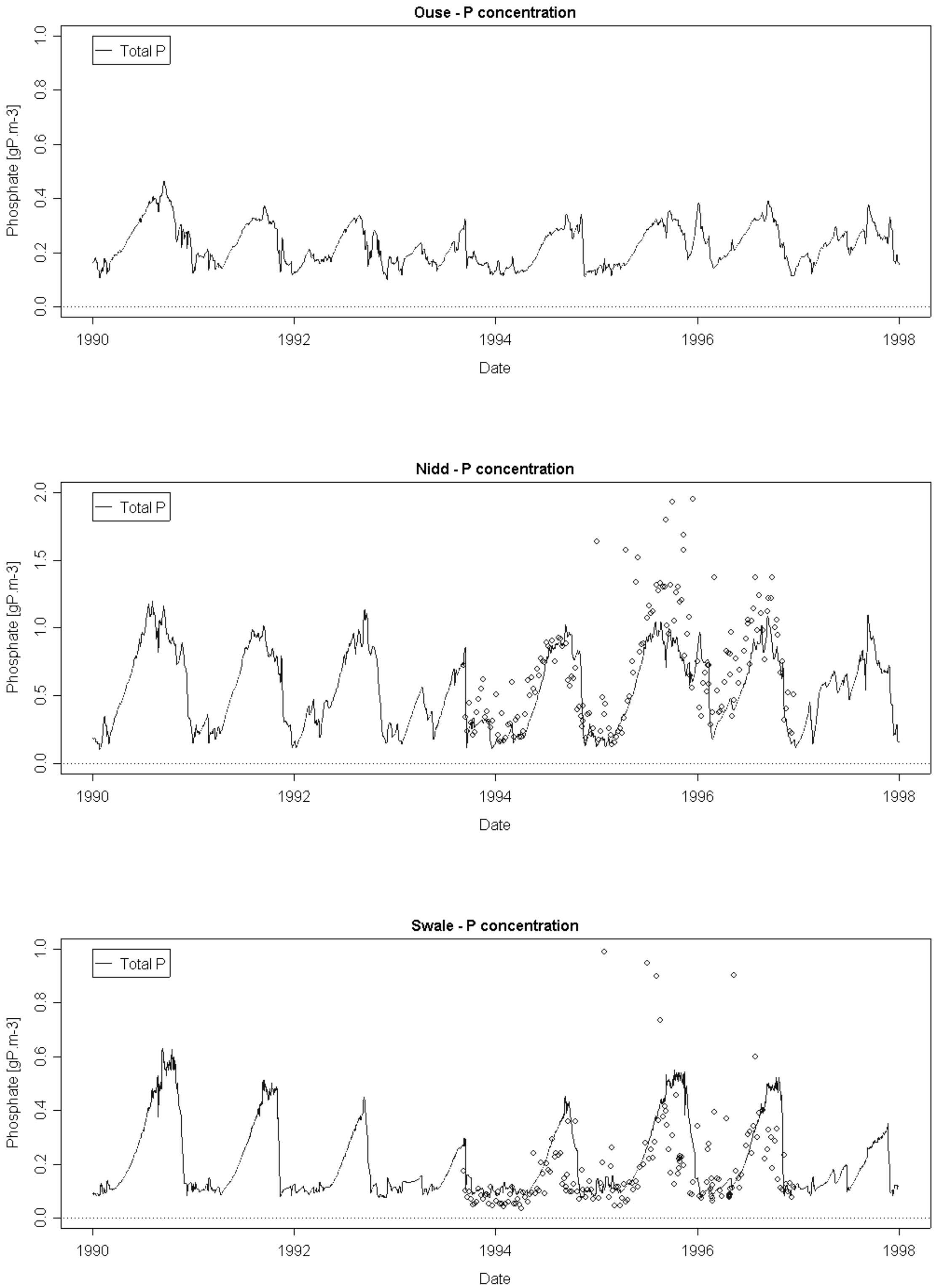



*Figure 6.22 Phosphorus concentrations (g m$^{-3}$ or mg l$^{-1}$) in the surface water measured (blue dots) and simulated (blue line)*

### 6.4.3.3 Surface water system – P loads

Daily modelled and measured loads are shown in figure 6.23.

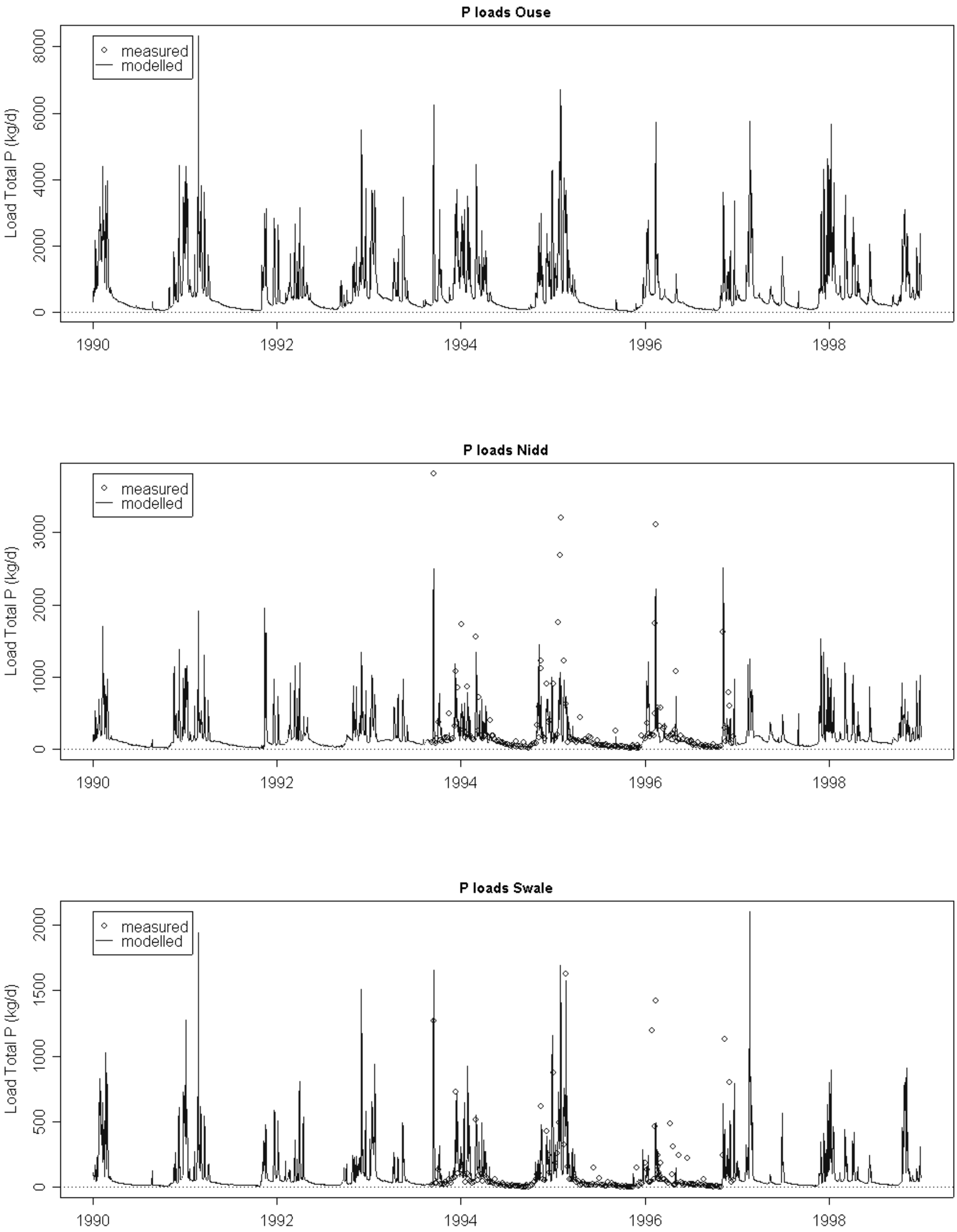



*Figure 6.23 Phosphorus discharge (kg d⁻¹)*

### 6.4.4 Retention

Results are produced for different water bodies: groundwater and surface water (rivers, lakes and reservoirs). Retention may occur in both water bodies and is in general:

Retention = inflow – outflow

Retention in *the surface water system* is determined as difference in inflow (drainage + runoff + point sources + erosion) and outflow (discharge at outlet).

Retention in *the groundwater system* requires a slightly different approach. In this case the inflow is defined as the remaining nutrient surplus at the bottom of the root zone. The outflow depends on the definition of the bottom boundary. When downward minus upward seepage (net seepage) is not considered to be a form of retention in the soil column, retention of the whole system is the difference between inflow (additions + deposition + crop residues – grossUptake – volatilization) and outflow (drainage + runoff + downward seepage – upward seepage). This is equivalent to the change of storage for phosphorus and the sum of denitrification and change in storage for nitrogen.
When the net downward seepage is assumed to be a form of retention, a loss term to deeper layers within the soil column from which it will not enter the surface water, retention is denitrification (for nitrogen) + change in storage + net seepage. The values in table 6.15 represent the second approach.

As a result the total retention in the groundwater system is high. Table 6.15 shows the total results for the different (sub) catchments. Retention in the surface water system is low. As the residence time of the water is very low sedimentation of Phosphorus and denitrification of Nitrogen can hardly take place. Most N and P retention takes places in the groundwater system.

*Table 6.15 average retention in ton/year for surface and groundwater for 1996-2000*

| | Ouse | | | | Swale | | | | Nidd | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N ton/a | % | P ton/a | % | N ton/a | % | P ton/a | % | N ton/a | % | P ton/a | % |
| Retention surface waters | 156 | 2 | 19 | 7 | 3.6 | 0.3 | 3.5 | 9 | 35 | 3 | 7.4 | 10 |
| Retention groundwater | 15217 | | 1367 | | | | | | | | | |

## 6.5 Concluding remarks

No measured loads for the catchment outlet were available. For the tributaries, Nidd, Swale and Wiske, limited data on concentrations were available. Average concentrations in Nidd agree relatively well with measurements, for Swale and Wiske the agreement is less.

The simulated N balance shows an excess of 113 kg $ha^{-1}y^{-1}$ of which 97 is denitrified. There was no net leaching to deeper groundwater estimated. The nitrogen transport to surface waters amounts to 22 kg $ha^{-1}y^{-1}$. The total N inputs to surface waters are estimated at 6921 ton $y^{-1}$, of which 6789 ton $y^{-1}$ leaves the catchment at the outlet. The retention in surface waters is calculated at 2%.

Daily modelled phosphorous concentrations and loads for Nid and Swale show similar fluctuations over the year to the measurements, but for the Nidd tributary the model slightly underestimates concentrations and loads.

The simulated P balance shows an excess (fertilization – crop yield) of 12.4 kg $ha^{-1}y^{-1}$ of which 12.0 kg $ha^{-1}y^{-1}$ is stored in the soil. The phosphorus transport to surface waters amounts to 0.44 kg $ha^{-1}y^{-1}$.
The total P inputs to surface waters are estimated at 259 ton $y^{-1}$, of which 239 ton $y^{-1}$ leaves the catchment at the outlet. The retention in surface waters is calculated at 8 %.

## 6.6 Suggestions for improvement

- The modelling of the fast responding water discharge after a dry period could be improved as some of the measured peaks during this period are not simulated by the model. The model responds well when the soil is wet but when the groundwater levels have dropped after a dry period rain is first used to raise the groundwater table. As a result the modelled surface water discharges do not increase after the first rains in contrast to measured discharges. This could be the result of the chosen model concept and discretisation in which there is no infiltration from the surface water into the soil column. Furthermore gleyed layers, which are not explicitly modelled, might have a large impact on discharges during a dry period. In reality groundwater levels might remain closer to the soil surface and rain is drained quicker by the fast reacting shallow drainage systems. Groundwater level measurements a lacking to check this.

- Biological nitrogen fixation was not taken into account for any of the soils. The depletion of the nitrogen store in the soil of unfertilized fields was calculated at 35 $kgha^{-1}$ $yr^{-1}$. To compensate for the simulated depletion an assumption of the biological N fixation rate between reasonable limits would be sufficient.

# 7 The Enza catchment

D. Walvoort

## 7.1 Introduction

This report gives the results of modelling nutrient loss from the land to the surface water system in the Enza catchment. The Enza is a tributary of the Po-river, in the Northern part of Italy.

Appendix 10 gives a full scenario analysis for the Enza catchment in addition to the presented results in the following paragraphs.

## 7.2 Discretisation

### 7.2.1 Introduction

The aim of schematisation is to divide the Enza catchment into a number of unique relatively homogenous spatial units. It is assumed that the variation between units is much greater than the variance within units. The number of units should not be too great, otherwise calibration will take too much cpu time. On the other hand, the number of units should not be too small either, otherwise important details might get lost.

The procedure is as follows. First, GIS-maps representing subcatchment delineation, meteorology, soil types, land use and management, and the surface water system are prepared. Second, these maps are combined to obtain a map with unique spatial units. In this report, these spatial units will be referred to as 'unique combinations' (UCs).

### 7.2.2 Delineation of sub catchments

Subcatchment delineations were provided by the catchment data holder (Figure 7.1). Each subcatchment is referred to by the name of the surface water monitoring station near its outlet. As has been decided at the EuroHarp meeting in Réggio Emilia (Italy), the most northern subcatchment will be left out of consideration as it is affected by the river Po.

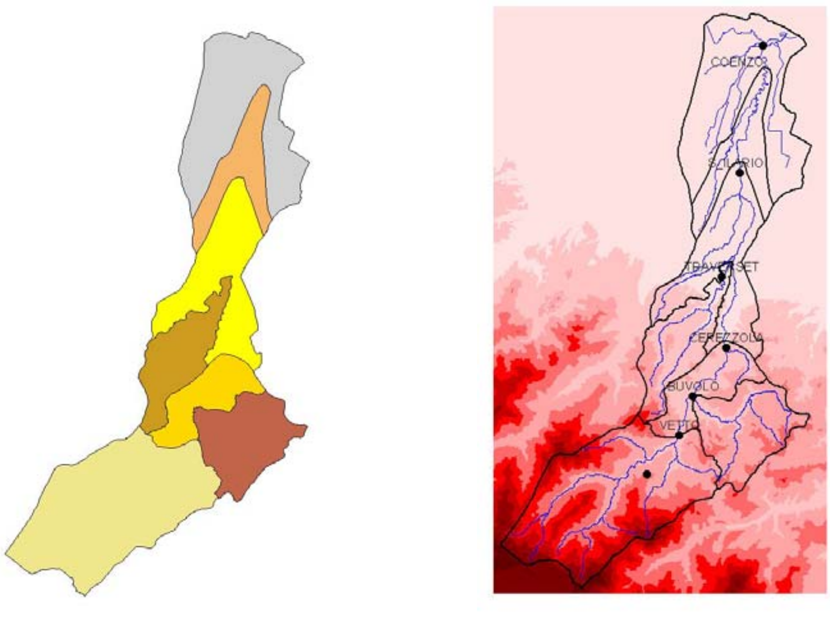



*Figure 7.1 Subcatchments discerned in the Enza catchment (left). Right figure: idem, but superimposed on the digital elevation model. The surface water system (lines) and monitoring stations (dots) are also given.*

### 7.2.3 Derived surface water system for modeling

The discretisation of the surface water system has been provided by the catchment data holder (figure 7.1, right)

### 7.2.4 Spatial interpolation of soil units

The Work Package 2 (Joint Research Centre, 2002–2004) soil map contains 8 major soil units (figure 7.2, left). At several places near the catchment border, soil information is missing. Missing values have been filled up by means of nearest neighbour interpolation. The resulting soil map is given in figure 7.2 (right map).

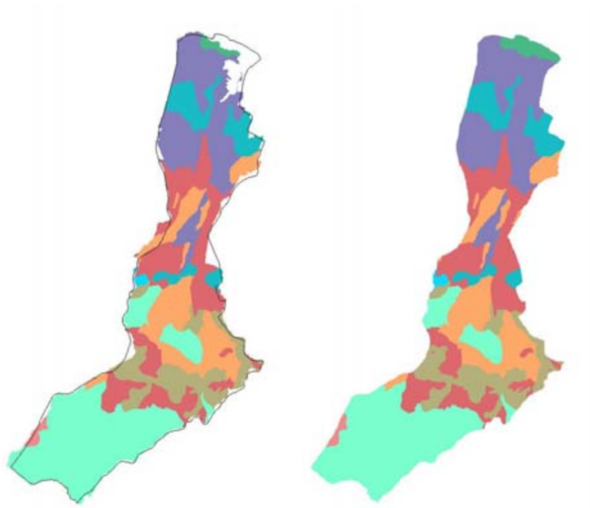


*Figure 7.2 Original (left) and interpolated soil map (right).*

### 7.2.5 Generalisation of land cover and management

Both land cover and land management data were provided. However, the catchment data holder's advice is to use the land management data only. These data are more coherent with official statistics tables and also more crop specific. In addition to land cover (crop type), the land management database also contains information on management practices.

The Work Package 2 land management units are given in figure 7.3 (Joint Research Centre, 2002–2004). Apart from urban area and surface water, this map contains 6 map units. Map units CORN, SGBT, and WWHT refer to the same crop rotation scheme shifted by a lag of 1 or 2 years. Figure 7.4 shows the spatial coverage of these variants for a single year. In order to reduce the total number of UCs it seems attractive to cluster these variants. However, clustering may

introduce problems due to the non-linearity of NL-CAT. Therefore, CORN, SGBT, and WWHT have been treated as separate map units.
The original WP land cover map has been converted to a 100 by 100 m grid by means of an adapted majority filter. The resulting spatially generalised land management map is given in figure 7.3 (right map).

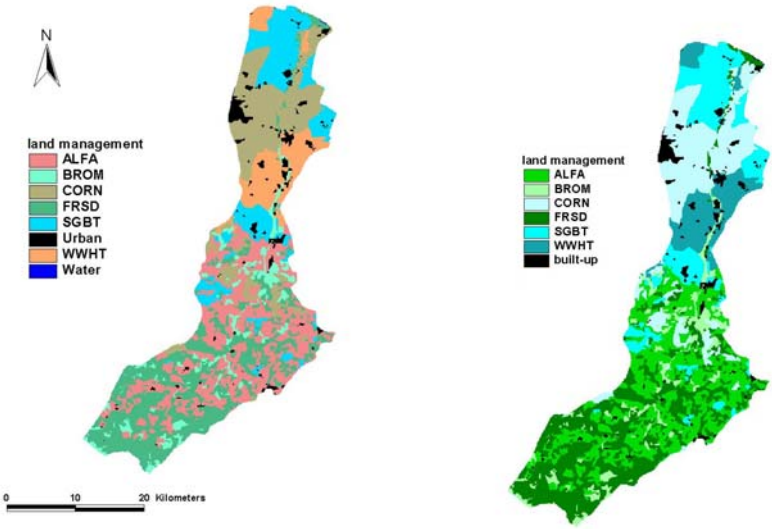



*Figure 7.3 Original (left) and generalised (right) land management maps.*

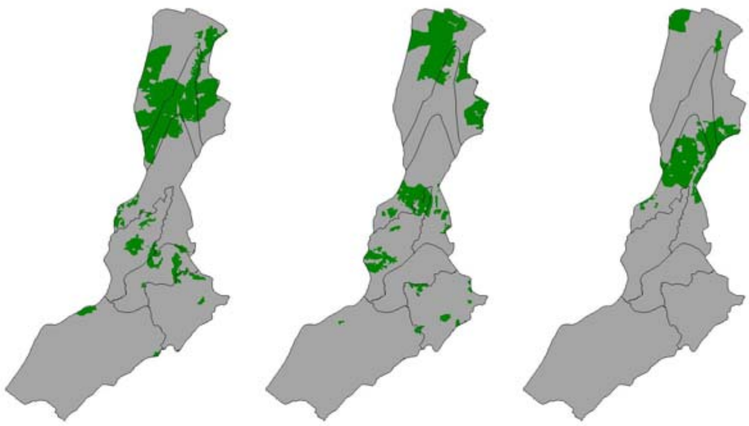


*Figure 7.4 Spatial distribution of the crop rotation scheme CWS (left), SCW (middle), and WSC (right) for a particular year (C: corn, S: sugarbeet, W: winter wheat).*

### 7.2.6 Meteorology

Meteorology is one of the principal driving forces of the NL-CAT model. It is therefore disconcerting that the official meteorological data set provided by WP2 for the Enza catchment was far from complete and contained many errors (many outliers, and physically unrealistic and even impossible values). Most of these errors were corrected by the catchment data holder. However, the spatial representativeness of the remaining (incomplete) time-series remained an issue of concern. This is particularly true for the validation period.

During the EuroHarp Dublin meeting, the ADAS researchers kindly offered a new meteorological dataset for the Enza catchment which has been generated by an in-house algorithm (ADAS, 2002). Meteorological time-series were available for each subcatchment. Hence, in the Enza discretisation, meteorological districts coincide with subcatchments (figure 7.1)

### 7.2.7 Bottom boundary condition

A zero flux bottom boundary has been assumed for the entire Enza catchment. There is no evidence for a regional flux.

### 7.2.8 Derivation of unique combinations

In order to limit the computational burden, NL-CAT will only be applied to a limited number of UCs. Each UC represents a unique combination of soil, land use, hydrology, and meteorology. In order to derive these UCs, an overlay operation has been applied to the generalised soil map, the generalised management map, and the meteorological district map. Each UC has been assigned a unique identifier, the so called 'plot id'. Figure  gives the cumulative spatial coverage as function of plot id. In this figure, the UCs have been sorted by area in decreasing order. To reduce the total number of UCs, all UCs that do not significantly contribute to the total catchment area will be removed. Note that this approach is rather 'quick and dirty'. Ideally, selection should also depend on the attributes of a UC. As a rule of thumb, all UCs that contribute less than five percent to the total subcatchment area will be removed. In Figure , these UCs are represented by open circles. The UCs that will be retained are given by closed circles.

Combining the UCs for all subcatchments in figure 7.5 gives figure 7.6. From the 160 UCs (figure 7.7, left), only 81 will be retained. Removal of UCs leads to gaps on the map. These have been reclassified by means of nearest neighbour interpolation conditioned on the retained plots (figure 7.7, middle and right). Removing all UCs resembling built-up area or water bodies, and UCs affected by the Po river yield a total of 69 UCs. This generalisation of the UC map, also affects the underlying soil map and land management map (*i.e.*, these maps will be further generalised).

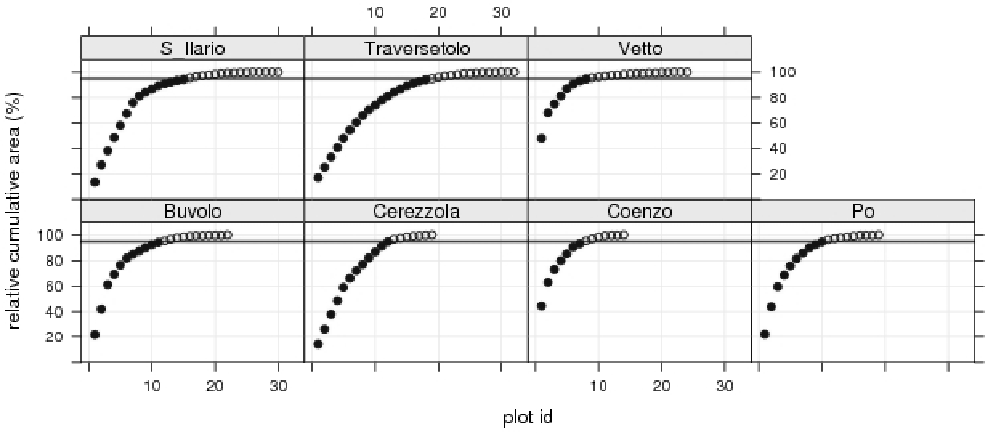



*Figure 7.5 Cumulative spatial coverage as function of UC (plot id) and subcatchment. The UCs are sorted by area (greatest areas first). The red line represents the threshold value below which UCs are retained.All UCs that are retained are indicated by solid dots, UCs that have to be replaced are represented by open circles.*

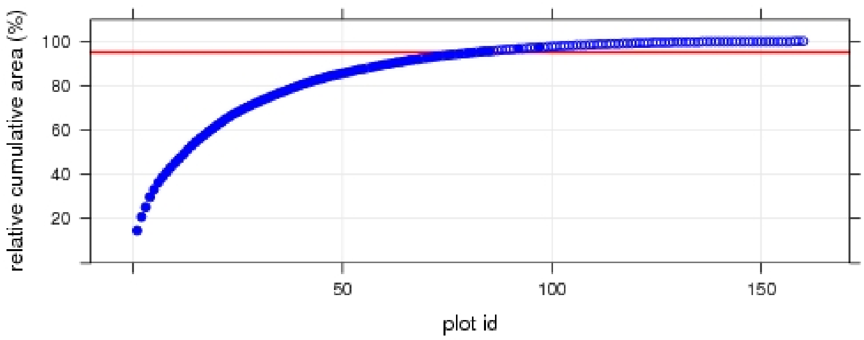



*Figure 7.6 As figure 7.5, but then for the entire catchment.*

*Figure 7.7 Original UCs (left), retained UCs (middle), and location of reclassified UCs (right).*

## 7.3 Parameterisation

### 7.3.1 Introduction

This section describes how the NL-CAT model has been parameterised.

### 7.3.2 Meteorology

As has been said before, the quality of the original meteorological data set was disappointingly low. Data outside physically realistic bounds were common and several fields were mixed-up (*i.e.*, contained wrong time-series). Although the corrected datasets seem to be of better quality, the spatial representativeness of the meteorological data remains doubtful. Therefore, the meteorological data set kindly provided by the ADAS-researchers has been used. The SWAP module of NL-CAT requires at least data on rainfall and Makkink evaporation.

*Rainfall*

Rainfall data have been spatially aggregated to subcatchment scale.

*Evaporation*

Since data on evaporation were not available, a crude estimate has been made by means of the Hargreaves equation (Allen *et al.*, 1998). Evaporation according to Hargreaves is based on the maximum and minimum daily temperature. As a final step, Hargreaves evaporation has to be converted to the reference evaporation according to Makkink. The latter can be directly used as input for SWAP. For this purpose, a linear model has been derived that relates Hargreaves evaporation to Makkink evaporation. This model has been calibrated on data for meteorological station De Bilt in the Netherlands (Heijboer & Nellestijn, 2002).

### 7.3.3 Soil

*Soil physics*

The WP2 database (Joint Research Centre, 2002–2004) doesn't provide information on soil water retention and soil hydraulic conductivity. Therefore these characteristics have been estimated by means of soil texture. Wösten *et al.* (1999) provide data on the Mualem-van Genuchten parameters as function of soil texture. These data were based on several thousands of European soil samples (including Italy). SWAP uses the Mualem--van Genuchten parameters to estimate soil water retention and hydraulic conductivity.

Gas diffusion coefficients have been predicted by means of a random forest classifier (Breiman, 2001) that has been trained on texture data obtained from the STONE data base (Kroon *et al.* 2001, Wolf *et al.*, 2003).

*Soil chemistry*

No data were available on pH-KCl, the C/N ratio and the total Al+Fe contents of the soil. Therefore, these soil properties have been predicted by means of soil profile information residing in the STONE (version 2.1) database (Kroon *et al.* 2001, Wolf *et al.*, 2003). Random forest models (Breiman, 2001) have been derived to predict pH-KCl, the C/N ratio and total Al+Fe by means of soil texture and soil organic matter content. Each random forest consisted of 1000 trees. The performance of each random forest has been evaluated by means of out-of-bag validation. The validation results are reasonable for pH-KCl and Al+Fe, and meagre for C/N (table 7.1). Based on these models and the WP2 database, pH-KCl, C/N and total Al+Fe-contents have been predicted for the Enza catchment.

*Table 7.1 Explained variance based on out-of-bag validation.*

| property | Explained variance (%) |
|---|---|
| pH−KCl | 72 |
| Al+Fe | 71 |
| C/N | 61 |

### 7.3.4 Land management

Five main classes of land-management are discerned:

- 1 year of winter wheat, followed by four years of alfalfa;
- 1 year of corn, followed by 1 year of wheat and 1 year of sugarbeets
- permanent grassland (cultivated, but no grazing)
- deciduous forest
- built-up area

The JRC-database served as the primary source of information for parameterising land management. However, in some cases it was necessary to retrieve data from other sources like the dbSWAN database (Walvoort, 2003). The data in the dbSWAN database originate from several sources like STONE (Kroon *et al.* 2001, Wolf *et al.*, 2003), the SWAP manual (Kroes & van Dam, 2003), the SWAP sample sets, and the ANIMO manual (Groenendijk *et al.*, 2003).

### 7.3.5 Surface water system

According to the catchment data holder, rainfall will generally leave the Enza catchment via the surface water system in less than 1.0 to 1.5 days. For this reason it is not worth the effort to parameterise the surface water modules of NLCAT. Instead, a simpler model has been used consisting of a series of interconnected reservoirs, each reservoir resembling a subcatchments (NL-CAT-lite version). The inputs to the reservoirs are from the soil system, point sources and surface erosion.

## 7.4 Calibration

### 7.4.1 Introduction

In this section, simulation results obtained with NL-CAT will be confronted with observations. Residual variation will be reduced by fine tuning parameters that are hard to quantify a priori, but that significantly affect model response. However, one should be careful not to end up with meaningless parameters.

### 7.4.2 Flow rates

For the Enza-catchment, only a limited number of meteorological time-series were provided. For example, only data for the meteorological stations at Parma and Selvanizza were available for the validation period. These stations are not representative for the Enza as a whole. Selvanizza lies in the far South at relatively high altitude, whereas Parma is in the North-West, well outside the catchment. Mountainous areas like the Enza region are often characterised by a large spatial and temporal variability in local climatic conditions. It will therefore be hard, if not impossible, to accurately model catchment hydrology for all UCs.

Therefore, it was first tested whether there is sufficient rainfall to generate the observed flow rates. The results are given in figure 7.8. It can be concluded that only in the lower reaches of the river system, total upstream rainfall intensity is greater than observed flow rates. In the upstream areas, however, the amount of rainfall is insufficient to produce observed flow rates. The situation becomes even worse when evaporation is also taken into account.

In figure 7.9, simulated versus observed annual flow has been given. As expected, simulated flow rates are too small, particularly in the upper reaches. In the lower reaches, some years are simulated quite well. However, the years 1992 and 1994 are problematic. These years also have the greatest relative shortages in the upper reaches.

In figure 7.10, observed and daily flow rates are given for the Coenzo station (*i.e.*, the outlet of the Enza catchment). The following issues are notable:

- As has been expected, simulated flow rates are lower than observed flow rates;
- Simulated flow rates are more flattened out (less peaky) compared to observed flow rates. This is probably due to the lack of detailed meteorological data, and the presence of preferential flow (a process that is implemented in later versions of NL-CAT). Simulated flow rates can be given a more peaked appearance by reducing drainage resistances or by modifying van Genuchten parameters. However, drainage resistances are already quite low, and further lowering didn't have a significant effect.
- Observed flow peaks don't always coincide with rainfall peaks.

It can be concluded that insufficient information is available about the spatial and temporal variation in rainfall. This has been acknowledged by the catchment data holder during the Dublin meeting. This will result in rainfall shortages in part of the catchment, and discharge peaks in 'dry' periods. This issue can't be solved by calibration. Calibration might even be dangerous, as one may end up with unrealistic parameters estimates.

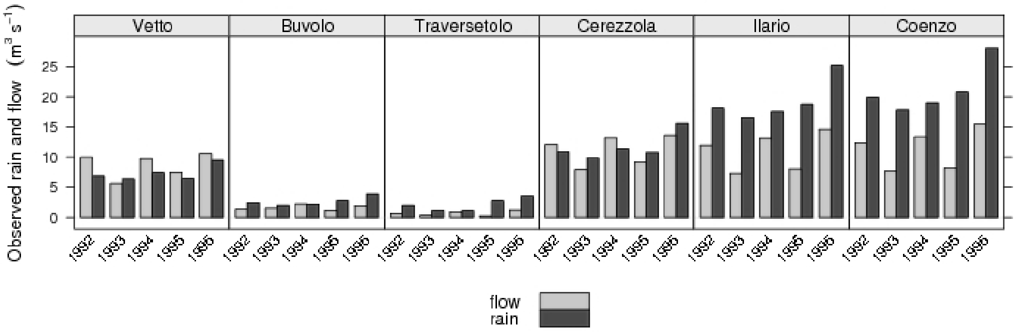



*Figure 7.8 Observed rainfall (m3 s$^{-1}$) versus observed flow rates (m3 s−1). Left to right corresponds to the down-stream direction.*

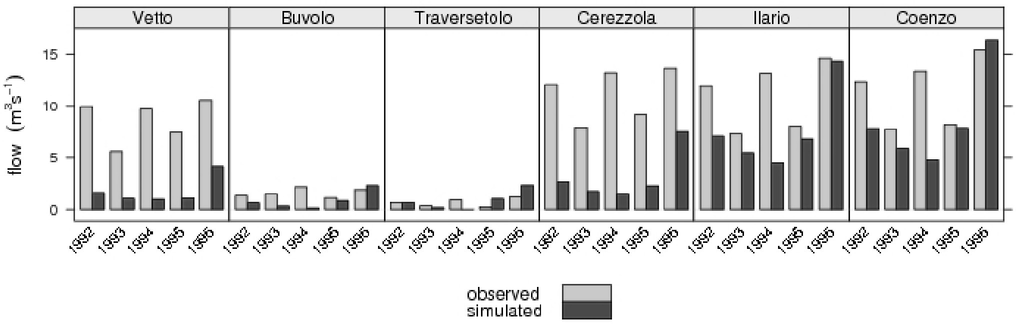



*Figure7.9 Simulated versus observed flow rates (m3 s−1). Left to right corresponds to the down-stream direction.*

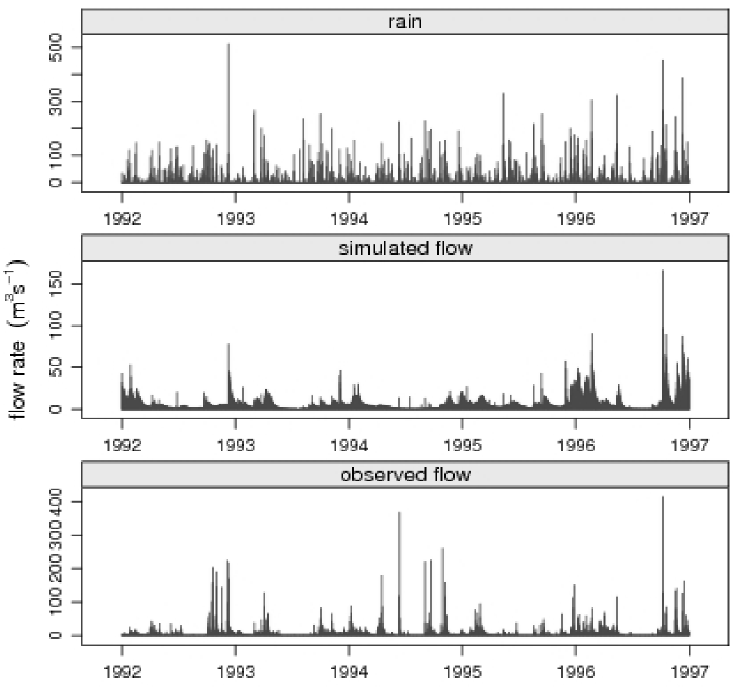



*Figure 7.10 Simulated versus observed daily flow rates and rainfall intensities (m3 s−1).*

### 7.4.3 Organic matter

In figure 7.11, the soil organic matter distribution as function of time is given. The total amounts of organic matter seem to be quite stable in time (no trend) indicating that the initialisation period for ANIMO was sufficiently long.

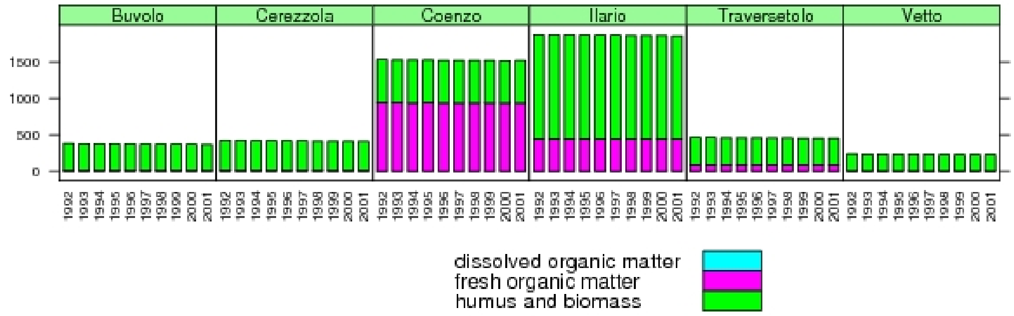



*Figure 7.11 Soil organic matter distribution (Mg/ha)*

### 7.4.4 Nutrients

In the previous section it was concluded that it is difficult, if not impossible, to accurately model catchment hydrology. Since nutrient concentrations and nutrient loads depend on catchment hydrology, it will also be cumbersome to predict nutrient loss to the surface water system. In the sections below, the results for nitrogen and phosphorus are given.

*Nitrogen*

As has been expected, the simulation results for nitrogen are disappointing. Nitrate and ammonium concentrations are generally too high. An import reason for this is the underestimation of flow rates. The nitrate and ammonium loads are generally also too high, in particularly in 1995.

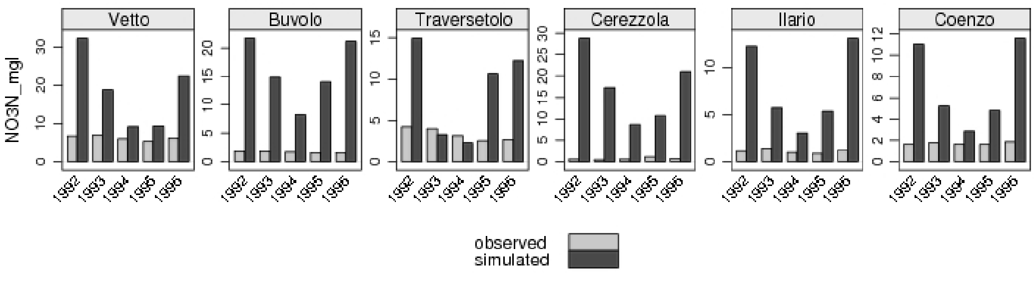



*Figure 7.12 Observed versus simulated nitrate (mg $l^{1}$).*

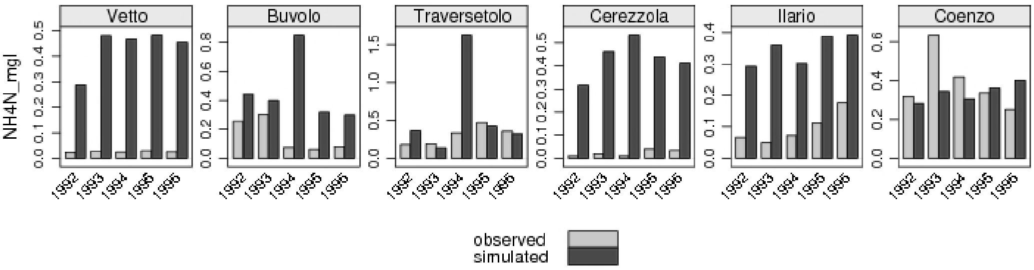



*Figure 7.13 Observed versus simulated ammonium (mg $l^{1}$).*

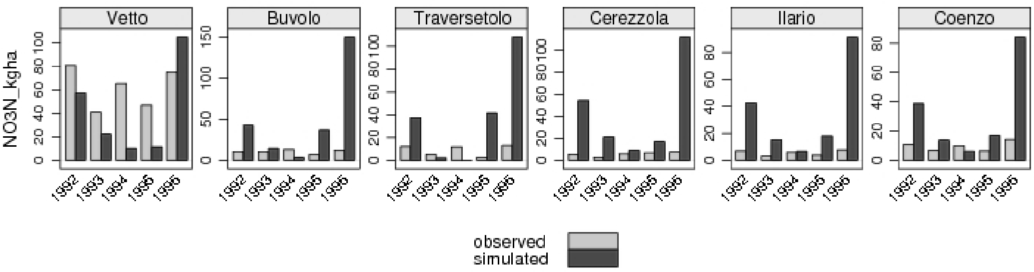



*Figure 7.14 Observed versus simulated nitrate (kg $ha^{-1}$ $a^{-1}$).*

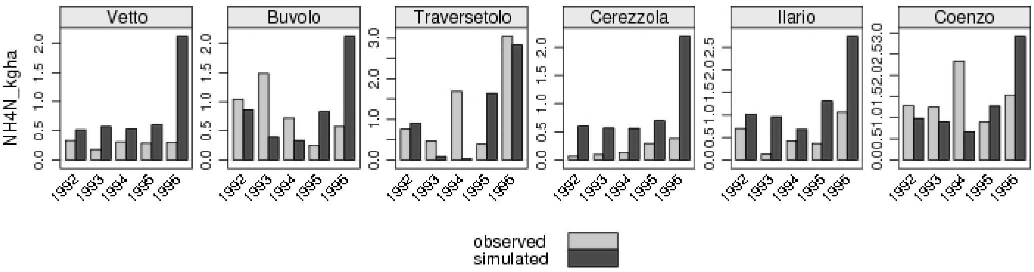



*Figure 7.15 Observed versus simulated ammonium (kg $ha^{-1}$ $a^{-1}$).*

*Phosphorus*

Total phosphorus concentrations are generally predicted too high in the upstream areas. For the lower reaches, the concentrations are generally a bit lower. The predicted total phosphorus loads are generally too low. One of the reason is again that it was hard to model catchment hydrology. Another reason is that (river) bank erosion has been ignored. Bank erosion is an important process resulting in large amounts of particulate phosphorus in the surface water during flood events. However, flood events can only be modelled correctly if sufficient meteorological data are available.
Surface erosion has been modelled by means of the PUSLE component of NL-CAT. This resulted only in an additional input of 0.07 kg $ha^{-1}$ $a^{-1}$ of particulate P.

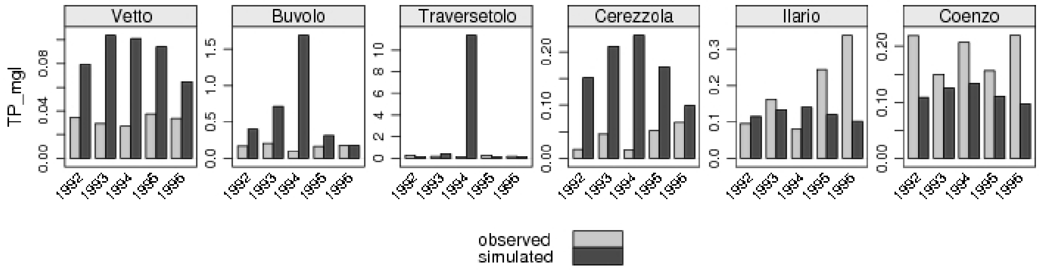



*Figure 7.16 Observed versus simulated total phosphorus (mg l$^{1}$).*

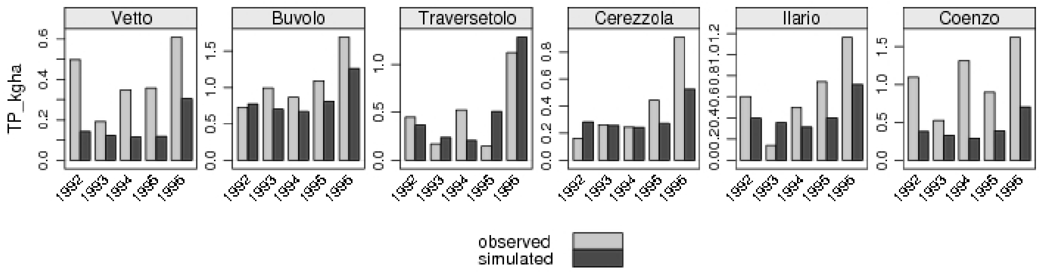



*Figure 7.17 Observed versus simulated total phosphorus (kg ha$^{-1}$ a$^{-1}$).*

## 7.5 Concluding remarks

The agreement between daily simulated and daily measured loads at the catchment outlet is poor. The agreement between the annual measured and simulated loads is poor. Main reason is the incomplete meteorological data which wsa not representative for the whole catchment.

The simulated N balance shows an excess of 112 kg ha$^{-1}$y$^{-1}$ and a denitrification of 125 kg ha$^{-1}$y$^{-1}$. The biological net fixation was estimated at 44 kg ha$^{-1}$y$^{-1}$ and the net leaching to deeper groundwater was estimated at ???? kg ha$^{-1}$y$^{-1}$. The nitrogen transport to surface waters amounts to 31 kg ha$^{-1}$y$^{-1}$. The total N inputs to surface waters are estimated at about 2800 ton y$^{-1}$, all of which leaves the catchment at the outlet as surface water retention was expected to be negligible and therefore not modelled.

Also for phosphorous agreement between measured and simulated loads is poor. In addition to insufficien meteorological data, erosion could not be taken into account properly. Bank erosion is an important process resulting in large amounts of particulate phosphorus in the surface water during flood events. However, flood events can only be modelled correctly if sufficient meteorological data are available.

The simulated P balance, averaged for all soils in the catchment, shows an excess of (fertilization – crop yield) 18.9 kg ha$^{-1}$y$^{-1}$ of which 18.6 kg ha$^{-1}$y$^{-1}$ is stored in the soil. The phosphorus transport to surface waters amounts to 0.38 kg ha$^{-1}$y$^{-1}$. The total P inputs to surface waters are estimated at 35 ton y$^{-1}$.

# 8 The Vansjø-Hobøl catchment

M.H.J.L. Jeuken

## 8.1 Introduction

This report is the result of the modelling efforts by Alterra on the Vansjø-Hobøl catchment in Norway within the EuroHarp project. The catchment is 690 $km^2$ in size and situated in the south of Norway, in the neighbourhood of its capital Oslo. The outlet of the catchment is located in the city of Moss. Dominant land use is forest. Average precipitation in the area is 810 mm/year. The soil type is predominantly clay. There is ca. 120 $km^2$ of agricultural land, of which more than two thirds is used to produce grains using 120 to 145 kg nitrogen and 22 to 25 kg phosphorus fertilisation.
The runoff of the catchment flows through 959 km of streams and 48 $km^2$ of lakes in which two measurements stations are located. One station is located in the Hobøl River, and has an upstream catchment of almost half the entire catchment. The other is located just after the biggest lake in the catchment, Lake Vansjø, at a dam in Moss. For both stations more than ten years of flow and quality data were available.
During the process of modelling many choices have been made on parameter settings and interpretation of data. Most of these choices will be described here, as well as the final results.
I would like to thank the catchment owner of the Vansjø-Hobøl catchment for providing their data and the tour around the catchment. I also would like to thank my colleagues for their kind assistance on the various problems that came to my path during this research.

*Figure 8.1 A stubble field in the catchment in March*

## 8.2 Discretisation

The catchment owners of Vansjø-Hobøl have provided detailed information on the catchment, such as maps and data sheets describing soil types, land cover, land management, rivers, lakes, and other properties of the catchment. It was not possible to use all these data directly; an interpretation of data prior to model input is always necessary. The NLCat modelling system distinguishes two main parts in the soil/water system: the soil system and the surface water system. In order to model the soil system of the catchment with NLCat it is necessary to divide the catchment into a discrete number of areas containing the same unique combination (UC) of parameters for the ANIMO and SWAP models. This elementary unit or plot does not necessarily have to consist of one continuous area. The same UC of parameters can be found in different parts of the catchment.

The UC's were determined by combining maps concerning soil types, land management, land cover, and meteorological conditions. Direct use of the maps and data provided for soil (345 types) and land use (538 types) alone however, would result in a huge number of UC's (345 x 538 = 185610 combinations at the most). Although not all combinations may be found in the catchment, enough would remain, even before other factors would be included. Therefore, it is necessary to reduce the number of types. Grouping of soil and land use types is based on similarity in certain parameters. The final parameterisation of these new types will be discussed in chapter 8.3.

Furthermore, the maps provided seem to originate from different sources. These sources used different base maps to digitalise their data with tiny differences in the borders of fields, roads, buildings, forests, lakes, and so forth. As a consequence, creating overlays with these maps results in the creation of numerous tiny and irrelevant plots. Therefore, after simplification all maps were transformed to the 100m-grid of the elevation map before making overlays.

Finally, as not all maps covered the entire catchment, gaps were filled up based on data from the land cover map.

### 8.2.1 Generalisation of land cover

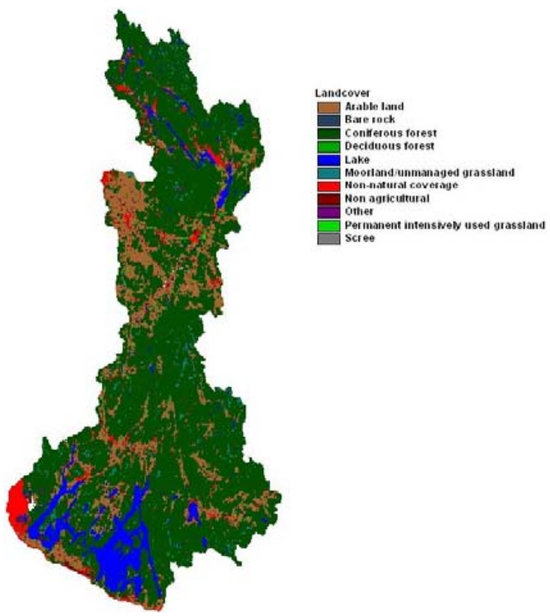



*Figure 8.2 Map showing land cover of the Vansjø-Hobøl catchment*

The land cover map (Figure 8.2) was used to fill up the gaps in the soil and land management maps. The only adaptation made was the transformation of the original shape file to the 100m-grid of the elevation map as discussed above.

### 8.2.2 Delineation of subcatchments

The catchment of Vansjø-Hobøl was divided into subcatchments by AV-SWAT using a DEM (Digital Elevation Model), the locations of the rivers, the boundary of the catchment and a given main outlet point (Figure 8.3a). The intended subcatchment size was 250ha, which resulted in ca. 250 subcatchments (Figure 8.3b). However, AV-SWAT did not come with a result at once. Some of the river segments ran over local 'bumps', especially in the irregularly shaped Lake Vansjø. AV-SWAT did not manage to look beyond them, so we had to adjust some of the rivers and the DEM manually. Eventually AV-SWAT did not manage to connect some small areas at the edge of the catchment boundaries to any river segment, so they were left out. During the calibration the small catchments were clustered. An overlay with clustering of subcatchments on basis of the river id's resulted in 9 subcatchments Figure 8.4.

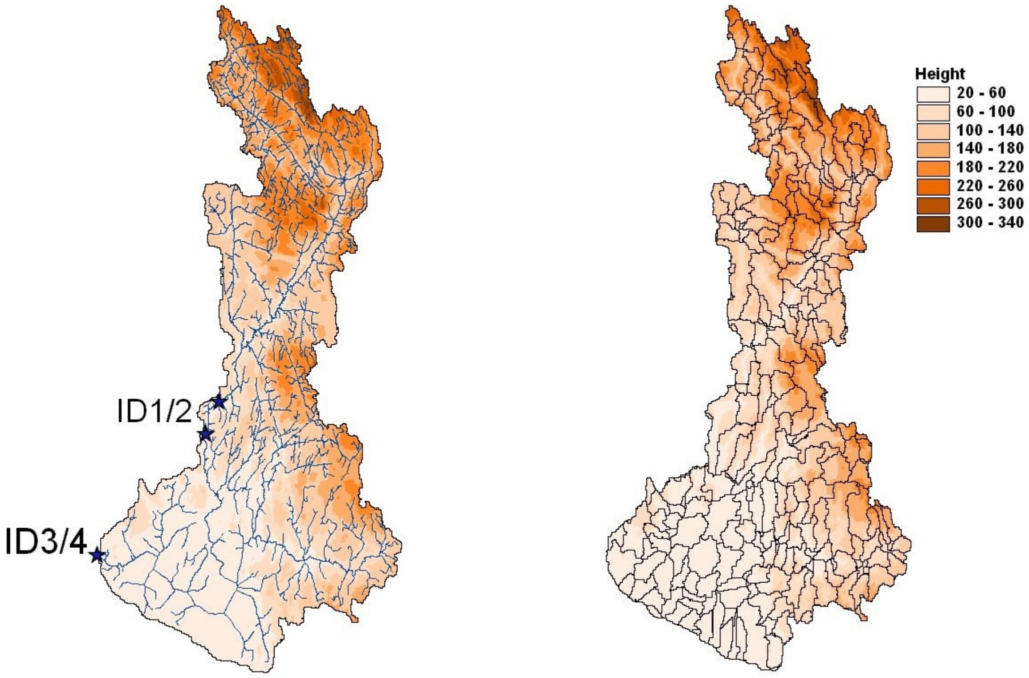



*Figure 8.3a Rivers, DEM and the location of the surface water measurement stations; and 8.3b subcatchments*

### 8.2.3 Derived surface water system

The river map contained 959 km of streams divided into 2846 segments. There was also a map with 34 lakes. All river segments had a classified width and depth, except streams through lakes (128 km). The width of these segments was determined by dividing the total area of each lake by the total length of streams within it. Lakes for which no depth was given were considered to be 0.50m deeper than the connecting streams. As can be seen from Table 8.1, Lake Vansjø makes up 75% of the entire surface water in the catchment, and 85% of the total volume.

*Table 8.1 Area and volume of the surface water system*

| | Area | | Volume | |
|---|---|---|---|---|
| | ha | % | $10^6$ $m^3$ | % |
| Lake Vansjø | 3600 | *75%* | 266 | *85%* |
| Deep lakes | 569 | *12%* | 40 | *13%* |
| Shallow lakes | 381 | *8%* | 3 | *1%* |
| Rivers and streams | 216 | *5%* | 2 | *1%* |
| Total | 4766 | | 311 | |

With an annual average discharge of 304 mln. $m^3$ (from 1991 until 1995), the residence time is circa 10½ months in Lake Vansjø, but only 2½ days for rivers and streams. The main rivers and lakes of the surface water system were descritisized into larger sections, based on the provided dimensions. The remaining river sections were aggregated per subcatchment into added storage basins to represent the finer watercourses (Figure 8.4).

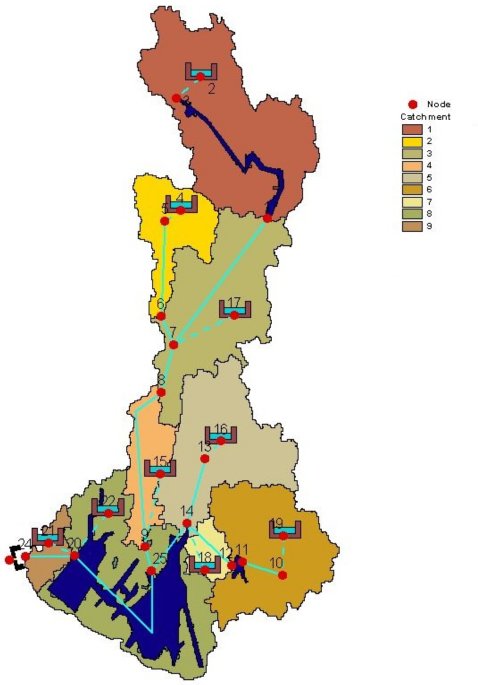



*Figure 8.4 The generalised surface water system*

*Figure 8.5 Dam at Moss*

### 8.2.4 Generalisation of the soil map

The soil data sheets provide data for 345 soil profiles. However, this data does not cover the entire area, but only circa 100 km$^2$ of the catchment (see Figure 8.6a). It seems that the profiles were only determined for arable land. Furthermore the occurrence of the profiles is far from normally distributed. The four most common profiles cover more than 50% of the described area and the fifteen most common profiles describe more than 75% of the described area. This doesn't mean that the smaller profiles should be neglected. Some profiles for small areas that are significant different from the more common types could add up to a significant area with their own soil profile.

A close look at the data learns that two special groups could be determined: peat or moorland profiles that are rich in organic matter (> 30%), and shallow profiles (< 30 cm). The remaining profiles consist of a top layer (0–25 cm) and a deeper layer (25–40/95 cm on average 25–65 cm). It was decided that these layers could best be categorised by their clay content: clay (> 30%), light clay (10–30%) and sand (< 10%). In table 8.2 the occurrence of all combinations of top and deeper layers are shown. Some combinations do not occur or are seldom, so the number of types can be reduced to four: clay, light clay on clay, light clay and sand. Applying these new soil types leads to the simplified map.

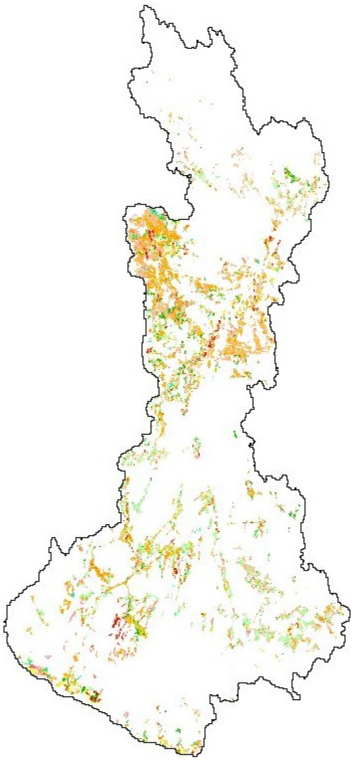
*Table 8.2 Occurrence of upper and lower soil combinations*

| Area [km$^2$] | top layer | | |
|---|---|---|---|
| | clay | light clay | sand |
| on clay | 30.0 | 12.3 | - |
| on light clay | *0.3* | 28.3 | *3.3* |
| on sand | - | *1.4* | 10.7 |

After labelling the soil profiles with the six new soil types and dissolving the map by this field, the shape file is converted to the 100m-grid of the elevation map. In order to get a covering soil map, the soil map is combined with the land cover map. For every land cover type it had to be decided what soil profile type should be applied. This leads to the introduction of one real new type, two 'temporary' soil types ('arable' and 'grass') on which decisions will be made later, and two 'imaginary' soil types ('surface water' and 'other') for which no soil profile is needed in the end. This resulted in a covering soil map (Figure 8.6b) with a total of ten soil types (table 8.3).

*Table 8.3 Occurrence of upper and lower soil combinations*

| Profile | ID | Description | Area [km$^2$] |
|---|---|---|---|
| 1 | CC | Clay | 30.3 |
| 2 | LC | light clay on clay | 11.7 |
| 3 | LL | light clay | 31.8 |
| 4 | MO | peat/moorland | 13.8 |
| 5 | SS | Sand | 12.2 |
| 6 | UD | Shallow | 11.9 |
| 7 | FO | Forest | 481.0 |
| 8 | AR | 'arable' | 9.3 |
| 9 | GR | 'grass' | 1.8 |
| 10 | OT | 'other' | 36.8 |



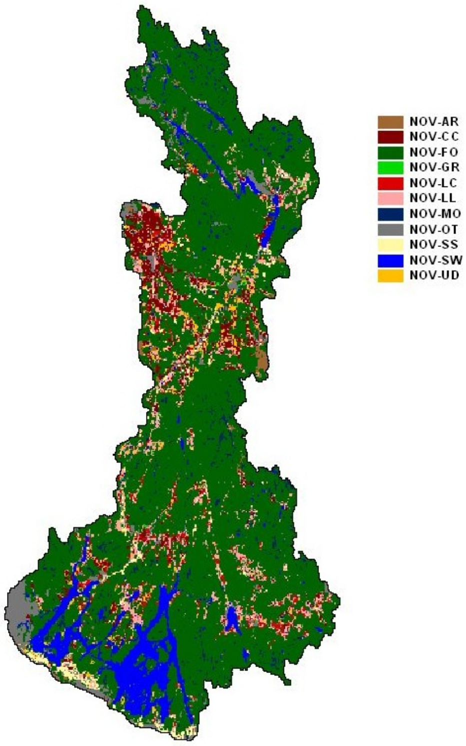



*Figure 8.6a Original soil map* *and 8.6b Completed soil map*

### 8.2.5 Generalisation of land management

The land management data sheet also contains a lot of data. No less than 538 management types are given on a farm level for circa 85 km² of the catchment. It was not possible to use all these farms individually, because combining these land management types with the soil types would result in to many UC's.

Detailed yearly crop rotations of nine different crops were given for all these farms, as well as very detailed fertilizing events (7171 in total). This all seems very thorough gathered date at first sight, but a closer look learns there is a lot of repetition. The most common event for example is the addition of 120 kg nitrogen and 22 kg phosphorus mineral fertiliser per hectare on the first or forth of may, which happens 3954 times. This doesn't seem very likely. We did find some relationship between the cultivated crop and fertiliser application, but found too many exceptions. Complete reverse engineering would take too much effort. Furthermore most farms are made up of multiple fields throughout the catchment. It is very unlikely that such a farm cultivated the same crop in a certain year on all fields, which the data suggests. So it was decided to take this data not too strictly, but find a way to somehow aggregate the land management types.

The four most common crops are all grains but with their own characteristic properties. For Spring Barley the soil is ploughed in spring instead of autumn. Winter Wheat, Rye and Triticale differ because of autumn sowing (see table 8.4). Spring wheat differs from oats because animal fertilization is applied, whilst with other grains only mineral fertiliser is applied (table 8.5).

*Table 8.4 Characteristics of crops in the Vansjø-Hobøl catchment*

| | Area | Timing of events | | | Standard | Off take [kg/ha] | | |
|---|---|---|---|---|---|---|---|---|
| | % | Plough | Sow | Harvest | Yield | Dry mat. | N | P |
| *Grains* | | | | | | | | |
| Oats | 44.5 | Oct | May | Aug | 4086 | 3473 | 72 | 13 |
| Spring Barley | 25.1 | **Apr** | May | Aug | 3878 | 3296 | 68 | 12 |
| Spring Wheat | 13.7 | Oct | May | Sept | 4325 | 3676 | **87** | 13 |
| Winter Wheat | 8.9 | Sept | **Sept** | Aug | 4567 | 3882 | 91 | 14 |
| Rye | 0.6 | Sept | **Sept** | Aug | 4531 | 3851 | 79 | 14 |
| Triticale | 0.3 | Sept | **Sept** | Aug | 3771 | 3205 | 72 | 12 |
| *Turnip* | | | | | | | | |
| Turnip rape | 2.5 | Apr | May | Sept | **1653** | **1504** | **56** | 12 |
| *Grasses* | | | | | | | | |
| Rye grass | 2.7 | Apr | **May** | **3 times** | **4923** | **4923** | **158** | **15** |
| Timothy | 1.8 | Apr | **May** | **3 times** | **5182** | **5182** | **166** | **16** |
| Median | | Sep/Oct | May | Aug/Sept | 4092 | 3514 | 78 | 13 |

*Table 8.5 Fertiliser applied to crops in the Vansjø-Hobøl catchment*

| Crop | Mineral N kg/ha | Organic N kg/ha | Mineral P kg/ha | Organic P kg/ha |
|---|---|---|---|---|
| Oats | 120 | - | 22 | - |
| Spring Barley | 118 | 4 | 21 | 1 |
| Spring Wheat | 124 | 46 | 15 | 9 |
| Winter Wheat | 160 | - | 23 | - |
| Rye | 150 | - | 24 | - |
| Triticale | - | - | - | - |
| Turnip rape | 49 | 114 | 5 | 28 |
| Rye grass | 69 | 149 | <1 | 41 |
| Timothy | 142 | 54 | 19 | 21 |

Because the differences are small, and the crops other than the grains make up only 7% of all cultivation, it was decided to model only one average grain-like crop with weighted parameters of all crops. The only difference taken into account was the application of organic fertiliser. Some farms nearly don't apply organic fertiliser, which seems to be related to the crops cultivated. Oats, Spring Barley, Winter Wheat and Rye seldom receive organic fertiliser. The farms were divided into two groups: the ones cultivating the mentioned mineral-fertiliser-only crops for at least nine out of the ten years taken in consideration (A), and the other farms (B). This divides the land management area in two nearly equal groups (see Figure 8.7).

Like the soil map also the land management map had to be combined with the land cover map to get a complete map. Arable land for which no land management was provided was modelled as grassland. This led to a catchment covering land management map with a total of six land management types (Table 8.6; Figure 8.7).

*Table 8.6 Land management types*

| ID | Description | Area [km$^2$] |
|---|---|---|
| A | Grains, mineral fertilisation | 36.3 |
| B | Grains, mineral and organic | 48.7 |
| C | Intensively used grassland | 23.1 |
| D | Extensively used grassland | 12.0 |
| E | Forest | 471.3 |
| F | Other | 35.7 |

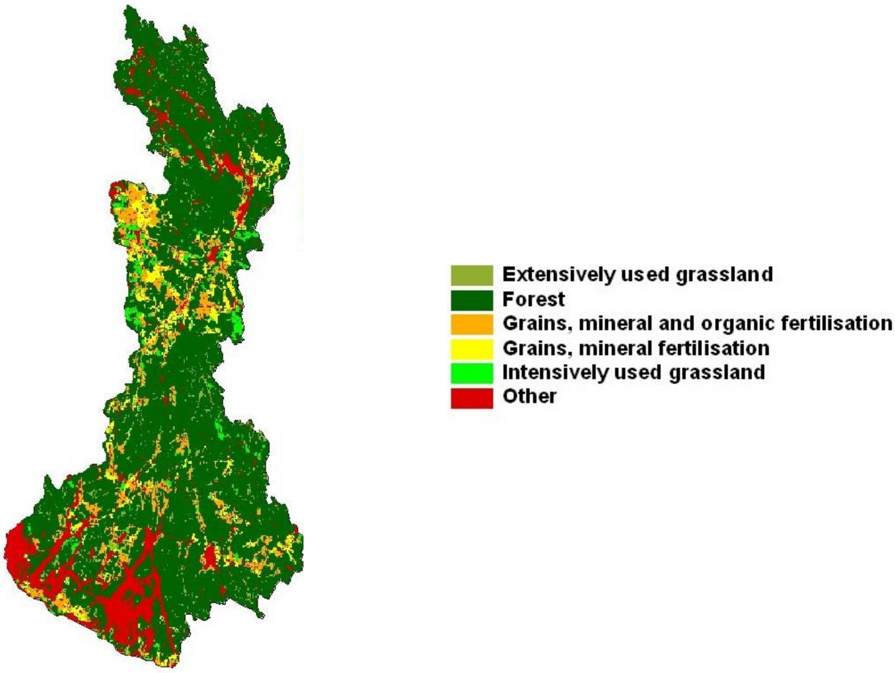



*Figure 8.7 Complete land management map*

### 8.2.6 Meteorology

Meteorological data was provided for eleven stations inside and outside the catchment, covering the period from 1970 until 2002. After a first selection of usable data, it was determined how many (nearly) complete years (>350 days) were available for each station and each parameter needed for the models during the period 1991 until 2000 (table 8.7). From this table it can be seen that a complete set of rainfall data is available from five stations, but a complete set of temperature, humidity and wind speed is only available from one station, and for solar radiation no complete set is available. So, apart from rainfall the choices on which data to use were not very hard. Solar radiation measurements were taken from Ås-NLH, and air temperature, humidity and wind speed measurements were taken from Rygge.

Deciding on which rainfall to use was a bit more difficult. Kalnes was considered to be too far outside the catchment. Long term averages given for the other stations showed little differences with a 66 mm/y range (814–880 mm/y). A closer look at the averages over the modelled period as shown in Table 8.7 learns however that the range is now doubled to 132 mm/y (823–955 mm/yr). Therefore it is important to distinguish different meteo regions.

*Table 8.7 Comparison of average rainfall at meteorological stations*

| Year | Igsi i Hobøl | Rygge | Moss | Fløter |
|---|---|---|---|---|
| 1991 | 764 | 705 | 661 | 919 |
| 1992 | 756 | 772 | 727 | 899 |
| 1993 | 802 | 825 | 734 | 892 |
| 1994 | 788 | 848 | 711 | 856 |
| 1995 | 810 | 792 | 670 | 916 |
| 1996 | 722 | 673 | 685 | 764 |
| 1997 | 651 | 680 | 735 | 746 |
| 1998 | 839 | 795 | 850 | 939 |
| 1999 | 1169 | 1171 | 1171 | 1307 |
| 2000 | 1258 | 1312 | 1280 | 1313 |
| Average | 856 | 857 | 823 | 955 |
| *average given* | *829* | *829* | *814* | *880* |

We choose to assign each subcatchment to a meteo station. Subcatchment 9 was assigned to Moss at first, but the Moss region was considered to small for a meteo region on its own. Finally the area is divided into three regions, were region 1 is assigned to Rygge, region 2 to Fløter, and region 3 to Igsi i Hobøl (Figure 8.8).

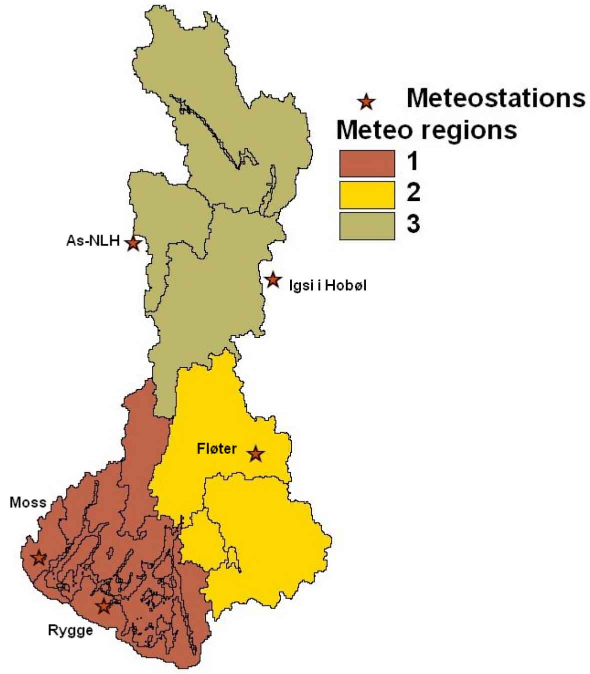



*Figure 8.8 Meteorological regions*

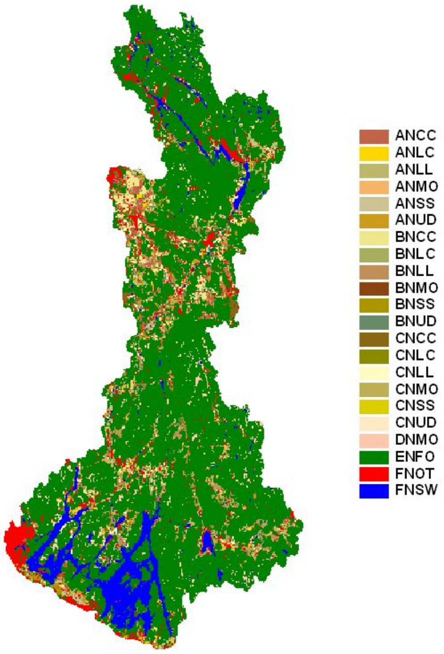
### 8.2.7 Boundary conditions

No information was available about the deeper groundwater levels and conditions. Therefore the bottom boundary was considered closed. Little information was provided on lateral drainage. Information was provided on the location of drainage tubes (all cultivated land, except the sandy soils), and their standard properties (drain spacing 8m, drain depth 0.8m). Density of gullies and smaller ditches was not known. Some general assumptions had to be made. Because all differences in lateral drainage are coupled to soil type, no extra plots had to be distinguished.

*Figure 8.9 A drainage tube in the catchment*

### 8.2.8 Calculation units

Because all properties of the plot will be linked either to soil type or land use the UC plot map is determined by the overlay of the soil and land management maps. Some of the resulting UC's are so seldom that adjustments were made to group them with other UC's. This leads to the final 21 plots as show in Figure 8.10.




| Plot | Description | Area (ha) | % |
|---|---|---|---|
| ANCC | grains mineral fertilizer on clay | 1031 | 1.6% |
| ANLC | grains mineral fertilizer on light clay on clay | 395 | 0.6% |
| ANLL | grains mineral fertilizer on light clay | 1137 | 1.8% |
| ANMO | grains mineral fertilizer on peat | 131 | 0.2% |
| ANSS | grains mineral fertilizer on sand | 465 | 0.7% |
| ANUD | grains mineral fertilizer on shallow profile | 471 | 0.8% |
| BNCC | grains mineral and organic fertilizer on clay | 1490 | 2.4% |
| BNLC | grains mineral and organic fertilizer on light clay on clay | 646 | 1.0% |
| BNLL | grains mineral and organic fertilizer on light clay | 1534 | 2.4% |
| BNMO | grains mineral and organic fertilizer on peat | 64 | 0.1% |
| BNSS | grains mineral and organic fertilizer on sand | 580 | 0.9% |
| BNUD | grains mineral and organic fertilizer on shallow profile | 556 | 0.9% |
| CNCC | intensively used grassland on clay | 1344 | 2.1% |
| CNLC | intensively used grassland on light clay on clay | 106 | 0.2% |
| CNLL | intensively used grassland on light clay | 545 | 0.9% |
| CNMO | intensively used grassland on peat | 17 | 0.0% |
| CNSS | intensively used grassland on sand | 144 | 0.2% |
| CNUD | intensively used grassland on shallow profile | 157 | 0.3% |
| DNMO | extensively used grassland on peat | 1199 | 1.9% |
| ENFO | Forest | 47134 | 75.2% |
| FNOT | Other | 3565 | 5.7% |

*Figure 8.10 Final UC map*

## 8.3 Parameterisation

The study was carried out with the NL-Cat package, which consists of the sub models:

- SWAP version 3.0.3 (Kroes et al, 2003) for soil hydrology;
- ANIMO version 4.0.18 (Groenendijk et al, 2005) for soil nutrients;
- SWQN version 1.0.9 (Smit et al, 2005) for surface water quantity;
- NuswaLite version 1.12 (Jeuken et al, 2005) for surface water quality.

The models SWAP and ANIMO can only run one soil profile at a time. Parameters for SWAP and ANIMO were set in a *dbSWAN* database to allow multiple runs of these models to cover all plots. After running the soil models a *plot-area-to-surface-water* conversion table is used to generate the boundary conditions for the surface water models. These models cover the entire system at once, and further parameters for the surface water models were put directly into their input files. This chapter will explain how the different sub models were parameterised.

### 8.3.1 Meteorology

The metrological data was sufficient to model the transpiration and evaporation within SWAP with the Penman-Monteith equation. Potential soil evaporation is reduced to maximum Darcy flux and to maximum Black (1969). The soil evaporation coefficient of Black is set to 0.15 $cm.d^{-1/2}$. The minimum amount of rainfall to reset Black time is set to 0.5 $cm.d^{-1}$.

### 8.3.2 Soil physical

The model SWAP has a lot of optional processes. For modelling in the Norwegian catchment no hysteresis (wetting and drying curves), similar media scaling or preferential flow was applied. Heat transport was modelled, using the numerical method with a damping depth of 50 cm. Soil water frost, snow accumulation and melt were modelled using a snow coefficient of 0.3.

*Figure 8.11 Snow and frost play an important role in the catchment*

Soil hydrological parameters were fitted on the given retention curves of the soils in the catchment (Appendix 8, Table 1). The information on moorland was however not sufficient, so parameters from a standard Dutch peat soil were used.
Maximum ponding depth was set to 0.25 cm, runoff/inundation resistance was set to 0.3 d, and the exponent in the runoff/inundation relation was set to 1.5. The basic drainage module was applied using multilevel drainage resistance. The parameters of the drainage per soil type are found in (Appendix 8, Table 2).

### 8.3.3 Soil chemical

The model ANIMO was used to model the C, N and P cycles is the soil system. Apendix 8, Table 3 shows soil parameters used in ANIMO. Soil density, organic matter, sand silt and clay fraction and pHKCl were based on averages of the given soil profiles. AlFe-content was related on clay content, based on a relationship laid between them in a Dutch database with soil types. In Appendix 8, Table 4 the initial phosphorus sorption definition is shown. The PoxAlFe is the fraction of the sorption complex that is occupied. These values are representative for soils

enriched by years of cultivation. For forest we used other values because of the more natural conditions.
The oxygen diffusion parameters determine the amount of oxygen in the soil profile, and thus determine the speed of mineralization, nitrification and denitrification. The values for the different soil types are given in Appendix 8 as well as are several other ANIMO parameters.

### 8.3.4 Land management

Crops have an important influence on both the moisture conditions as well as the nutrients in the soil profile. Transpiration by plants was modelled by SWAP, crop uptake is modelled by ANIMO. Parameterisation of both models is discussed here.
All grains were combined into one average crop type. As a result no crop rotation was necessary. Parameterisation of this grain was based on default parameters used for wheat, with additional information from the data sheets when available. These provided sowing and harvesting dates, standard yield under normal crop growth conditions, dry matter, nitrogen and phosphorus off-take at harvest and dry matter remaining after harvest. This data was used to make estimates of the net and gross nutrient uptake during the growing season (Appendix 8, Table 7). For grasses no specific information was available, so default values with some expert judgement were used (Appendix 8, Table 8). Maximum rooting depth allowed by the soil profile was set to 1m.

The amount of manure for grains was determined by calculating the weighted average amount of manure applied for both grain land management types. Type A, intended to consist of mineral fertilizer only, still contains some organic fertilizer because some of the plots included one year with organic fertilizer. New materials with specific dissolved, organic matter and nutrient fractions had to be defined to model the specific nutrient contents of the manure types applied in the catchment (Appendix 8, Table 9). For grassland no data was available, so we made an educated guess of the amount ourselves. For both intensively and extensively used grassland we introduced 1.0 LSU (life stock unit) per ha. We used the know composition of the cattle slurry from the catchment data, and the equivalent of 30000 kg of slurry resulted in 46.8 kg nitrogen and 8.8 kg phosphorus per ha. For intensively used grassland we added the same amount as 'normal' slurry, as well as 150 kg nitrogen per ha of mineral fertilizer. Based on the resulting phosphorus soil depletion we had to add 12 kg of mineral phosphorus fertiliser per ha to keep enough phosphorus available for the growth of grass. The final figures are summarised in table 8.8.

*Table 8.8 .Application of manure in different land use types*

| | Grains, Mineral Fertilizer | | Grains, Mineral and Organic Fertilizer | | Intensively Used Grassland | | Extensively Used Grassland | |
|---|---|---|---|---|---|---|---|---|
| [kg/ha/y] | N | P | N | P | N | P | N | P |
| Mineral Fertilizer | 122.2 | 21.4 | 120.9 | 18.5 | 150.0 | 12.0 | - | - |
| Cattle Pasture | - | - | - | - | 46.8 | 8.8 | 46.8 | 8.8 |
| Cattle Slurry | 2.3 | 0.4 | 10.5 | 1.9 | 46.8 | 8.8 | - | - |
| Pig Slurry | 1.0 | 0.3 | 10.8 | 2.8 | - | - | - | - |
| Poultry Slurry | 0.4 | 0.2 | 4.2 | 1.8 | - | - | - | - |
| Total | 126.0 | 22.3 | 146.5 | 25.1 | 93.6 | 29.6 | 46.8 | 8.8 |

### 8.3.5 Surface water system

The dimensions of the surface water system were discussed before in paragraph 8.2.2. The inflow boundary condition of the surface water consists of the runoff calculated by SWAP and the nutrient losses calculated by ANIMO. Both models give aerial results for each plot. To calculate the absolute loads to the surface water of the subcatchments we used the area of the plots residing in each subcatchment. Parameterisations of the management of structures will be discussed later on in paragraph 8.4.1.2.

*Figure 8.12 Lake Vansjø*

### 8.3.6 Additional point sources

The total flow discharge from point sources is less than 0.5% of the total water balance, and thus neglected. For N and P loads from point sources long-term averages were calculated from the information provided and aggregated to surface water nodes. Total load from point sources is 39.4 ton N and 2.5 ton P per year for the whole catchment.

### 8.3.7 Erosion

Erosion was not included in the original modelling tool, because it is not a great source of nutrients in the Netherlands. However, it came out that this source could not be ignored in less level areas, such as the Vansjø-Hobøl catchment. A simplified approach was used based on the RUSLE (Revised Unified Soil Loss Equation, Appendix 1). A first rough estimate of soil erosion was achieved by applying the procedure to the catchment with nutrient emission from the soil sub model for nutrients, rock content as soil characteristics from the given database and the xyz-values of the DEM as input parameters for each 100 m$^2$ grid.

The first estimate was changed during the calibration phase by modifying the management factor. Because this factor works through the result linear, it was possible to apply it afterwards without repeating the whole procedure. The final erosion applied was 56.8 ton N and 20.0 ton P per year for the whole catchment. Combined with the loads resulting from the soil models as presented in the next chapters, it is possible to determine the contribution of the various nutrient sources .

## 8.4 Simulation results

In the following discussion of the modelling results from the models, measurement points 1 and 2 at Hobølelva v/Kure are revered to as the *subcatchment*, and measure point 3 at Mosselva as the *total catchment* (Figure 8.3a).

### 8.4.1 Calibration

The calibration of the model was done on the measurement from 1991 until 1995 in two major steps. First surface water flow was calibrated, then nutrient concentrations and loads, because nutrient loads depend on the flow results. Flow was mainly calibrated by adjusting parameters from SWAP, while for nutrients both ANIMO and NuswaLite were adjusted. The details and results of both steps will be discussed in this chapter.

#### 8.4.1.1 Soil results

Since there are no measurements of runoff flow and nutrients at the physical border between the soil system and the surface water system, it was not possible to calibrate the soil model results directly on the measurements from the surface water stations. A comparison is of course still possible, but one should consider that there are processes between these results and the measurements. The differences are smallest when comparing flow results with measurements, especially for the subcatchment, and big when comparing nutrient loads with measurements from the whole catchment, because of other nutrient sources and retention in the surface water, especially in Lake Vansjø.
While calibrating SWAP on the measurements it had to be considered that an additional ca. 5% of net runoff is generated within the subcatchment due to direct precipitation en evaporation to the surface water. This is even 10% for the total catchment due to Lake Vansjø. First evaporation was adjusted to obtain a good over-all balance of the system especially for forest, a 'crop' that isn't very common to SWAP. Adjusting drainage resistances in SWAP and flow resistances in SWQN to model the correct pattern of peaks and 'background' discharges followed. Final results can be found in table 29 to table 31 for the various land uses in the catchment. Differences in precipitation are due to different occurrence of the crops in the meteorological regions. The discharges at the measuring point react very fast to rainfall. Therefore the soil had to produce runoff very fast, because the surface water only slows it down. This was achieved mainly by generating high surface runoff. The final results of this calibration will be discussed in chapter 8.4.1.2.

Calibrating ANIMO was slightly harder because of other nutrient sources and retention in the surface water. These factors work contrarily. Calibrating extra retention in the surface water can compensate an overestimation of nutrient runoff calculated by ANIMO and vice versa. Therefore it was very important to judge the ANIMO-results by their own right on validity. This was done by looking closely at the nutrient balances of the soil in detail. Most important balance entries to look at are crop off take, denitrification, soil depletion or enrichment and runoff. A summary of these balances grouped by land management type can be found in can be found in table 8.9 to table 8.11.

The modelled nitrogen crop off take is a bit too low (72 versus 78 kg/ha given). A comparison between the grains balances shows that the extra manure does not lead to extra crop off take. Additional nitrogen leads to more denitrification and runoff, while additional phosphorus leads to extra soil enrichment. The phosphorus crop off take is calculated well.

*Table 8.9 Simulated soil balances for grains plots (averages for 1991-2000)*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| grains mineral fertilizer | | 3630 | ha | grains mineral and organic fertilizer | | 4870 | ha |
| *Water balance* | | | *mm* | *Water balance* | | | *mm* |
| Input | | Output | | Input | | Output | |
| Precipitation | 857.2 | Interception | 28.0 | Precipitation | 869.9 | Interception | 27.9 |
| | | Transpiration | 202.7 | | | Transpiration | 202.8 |
| | | Evaporation | 73.1 | | | Evaporation | 73.1 |
| Infiltration | 0.0 | Surface runoff | 241.5 | Infiltration | 0.0 | Surface runoff | 252.5 |
| | | Subsurface runoff | 313.2 | | | Subsurface runoff | 314.8 |
| Upward seepage | 0.0 | Downward seep. | 0.0 | Upward seepage | 0.0 | Downward seep. | 0.0 |
| Storage Change | 1.2 | | | Storage Change | 1.2 | | |
| | 858.4 | | 858.5 | | 871.1 | | 871.2 |
| *Nitrogen balance* | | | *kg/ha* | *Nitrogen balance* | | | *kg/ha* |
| Input | | Output | | Input | | Output | |
| Deposition | 8.3 | Volatilization | 0.4 | Deposition | 8.4 | Volatilization | 2.7 |
| Fertilizer | 122.2 | Crop offtake | 72.3 | Fertilizer | 120.9 | Crop offtake | 72.4 |
| Manure | 3.7 | Denitrification | 71.2 | Manure | 25.0 | Denitrification | 82.2 |
| Infiltration | 0.0 | Surface runoff | 2.5 | Infiltration | 0.0 | Surface runoff | 2.6 |
| | | Subsurface runoff | 25.5 | | | Subsurface runoff | 31.8 |
| Upward seepage | 0.0 | Downward seep. | 0.0 | Upward seepage | 0.0 | Downward seep. | 0.0 |
| Soil depletion | 37.8 | | | Soil depletion | 37.4 | | |
| | 171.9 | | 171.9 | | 191.7 | | 191.7 |
| *Phosphorus balance* | | | *kg/ha* | *Phosphorus balance* | | | *kg/ha* |
| Input | | Output | | Input | | Output | |
| Deposition | 0.2 | Crop offtake | 14.1 | Deposition | 0.2 | Crop offtake | 14.1 |
| Fertilizer | 21.4 | | | Fertilizer | 18.5 | | |
| Manure | 0.9 | | | Manure | 6.6 | | |
| Infiltration | 0.0 | Surface runoff | 0.2 | Infiltration | 0.0 | Surface runoff | 0.2 |
| | | Subsurface runoff | 0.6 | | | Subsurface runoff | 0.7 |
| Upward seepage | 0.0 | Downward seep. | 0.0 | Upward seepage | 0.0 | Downward seep. | 0.0 |
| | | Soil enrichment | 7.5 | | | Soil enrichment | 10.2 |
| | 22.4 | | 22.4 | | 25.2 | | 25.2 |

*Table 8.10 Simulated soil balances for grass plots (averages for 1991-2000)*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| intensively used grassland | 2313 | | ha | extensively used grassland | | 1199 | ha |
| | | | | | | | |
| *Water balance* | | | *mm* | *Water balance* | | | *mm* |
| Input | | Output | | Input | | Output | |
| Precepitation | 868.6 | Interception | 0.0 | Precepitation | 891.6 | Interception | 0.0 |
| | | Transpiration | 367.3 | | | Transpiration | 214.2 |
| | | Evaporation | 57.8 | | | Evaporation | 57.3 |
| Infiltration | 0.0 | Surface runoff | 225.8 | Infiltration | 0.0 | Surface runoff | 589.4 |
| | | Subsurface runoff | 219.1 | | | Subsurface runoff | 30.8 |
| Upward seepage | 0.0 | Downward seep. | 0.0 | Upward seepage | 0.0 | Downward seep. | 0.0 |
| Storage Change | 1.3 | | | Storage Change | 0.1 | | |
| | 869.9 | | 870.0 | | 891.7 | | 891.8 |
| | | | | | | | |
| *Nitrogen balance* | | | *kg/ha* | *Nitrogen balance* | | | *kg/ha* |
| Input | | Output | | Input | | Output | |
| Deposition | 8.3 | Volatilization | 10.8 | Deposition | 8.5 | Volatilization | 5.4 |
| Fertilizer | 150.0 | Crop offtake | 199.5 | Fertilizer | 0.0 | Crop offtake | 63.8 |
| Manure | 93.6 | Denitrification | 25.5 | Manure | 46.8 | Denitrification | 16.3 |
| Infiltration | 0.0 | Surface runoff | 2.7 | Infiltration | 0.0 | Surface runoff | 11.9 |
| | | Subsurface runoff | 5.7 | | | Subsurface runoff | 0.9 |
| Upward seepage | 0.0 | Downward seep. | 0.0 | Upward seepage | 0.0 | Downward seep. | 0.0 |
| | | Soil enrichment | 7.6 | Soil depletion | 43.0 | | |
| | 251.9 | | 251.9 | | 98.3 | | 98.3 |
| | | | | | | | |
| *Phosporus balance* | | | *kg/ha* | *Phosporus balance* | | | *kg/ha* |
| Input | | Output | | Input | | Output | |
| Deposition | 0.2 | Crop offtake | 29.0 | Deposition | 0.2 | Crop offtake | 9.1 |
| Fertilizer | 12.0 | | | Fertilizer | | | |
| Manure | 17.6 | | | Manure | 8.8 | | |
| Infiltration | 0.0 | Surface runoff | 0.2 | Infiltration | 0.0 | Surface runoff | 1.9 |
| | | Subsurface runoff | 0.4 | | | Subsurface runoff | 0.2 |
| Upward seepage | 0.0 | Downward seep. | 0.0 | Upward seepage | 0.0 | Downward seep. | 0.0 |
| | | Soil enrichment | 0.2 | Soil depletion | 2.2 | | |
| | 29.7 | | 29.7 | | 11.1 | | 11.1 |

*Table 8.11 Simulated soil balances for forest and total catchment (averages for 1991-2000)*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| forest | | 47134 | ha | total catchment | | 62711 | ha |
| | | | | | | | |
| *Water balance* | | | *mm* | *Water balance* | | | *mm* |
| Input | | Output | | Input | | Output | |
| Precipitation | 883.5 | Interception | 205.9 | Precipitation | 878.9 | Interception | 158.6 |
| | | Transpiration | 145.2 | | | Transpiration | 154.3 |
| | | Evaporation | 49.0 | | | Evaporation | 55.6 |
| Infiltration | 0.0 | Surface runoff | 25.2 | Infiltration | 0.0 | Surface runoff | 73.7 |
| | | Subsurface runoff | 458.1 | | | Subsurface runoff | 437.0 |
| Upward seepage | 0.0 | Downward seep. | 0.0 | Upward seepage | 0.0 | Downward seep. | 0.0 |
| Storage Change | 0.0 | | | Storage Change | 0.2 | | |
| | 883.5 | | 883.6 | | 879.2 | | 879.2 |
| | | | | | | | |
| *Nitrogen balance* | | | *kg/ha* | *Nitrogen balance* | | | kg/ha |
| Input | | Output | | Input | | Output | |
| Deposition | 8.4 | Volatilization | 0.0 | Deposition | 8.4 | Volatilization | 0.7 |
| Fertilizer | 0.0 | Crop offtake | 1.2 | Fertilizer | 22.0 | Crop offtake | 19.3 |
| Manure | 0.0 | Denitrification | 2.7 | Manure | 6.5 | Denitrification | 14.0 |
| Infiltration | 0.0 | Surface runoff | 0.2 | Infiltration | 0.0 | Surface runoff | 0.9 |
| | | Subsurface runoff | 7.7 | | | Subsurface runoff | 10.8 |
| Upward seepage | 0.0 | Downward seep. | 0.0 | Upward seepage | 0.0 | Downward seep. | 0.0 |
| Soil depletion | 3.4 | | | Soil depletion | 8.7 | | |
| | 11.8 | | 11.8 | | 45.6 | | 45.6 |
| | | | | | | | |
| *Phosphorus balance* | | | *kg/ha* | *Phosphorus balance* | | | kg/ha |
| Input | | Output | | Input | | Output | |
| Deposition | 0.2 | Crop offtake | 2.3 | Deposition | 0.2 | Crop offtake | 4.9 |
| Fertilizer | 0.0 | | | Fertilizer | 3.1 | | |
| Manure | 0.0 | | | Manure | 1.4 | | |
| Infiltration | 0.0 | Surface runoff | 0.0 | Infiltration | 0.0 | Surface runoff | 0.1 |
| | | Subsurface runoff | 0.2 | | | Subsurface runoff | 0.3 |
| Upward seepage | 0.0 | Downward seep. | 0.0 | Upward seepage | 0.0 | Downward seep. | 0.0 |
| Soil depletion | 2.3 | | | Soil depletion | 0.6 | | |
| | 2.5 | | 2.5 | | 5.2 | | 5.2 |

### 8.4.1.2 Water

The calibration of surface water flow was mainly done by adjusting SWAP parameters. This was, however, not sufficient for a proper modelling of the discharges downstream of Lake Vansjø. These discharges are clearly influenced by the management strategies of the electric power plant at the dam in Moss. Due to trade secret, no information on the management strategies was provided. At first only a dam was modelled at the end of the lake, but a closer look learned that the discharges are more or less discrete around ca. 1 $m^3/s$, ca. 8 $m^3/s$, and ca. 15 $m^3/s$. This behaviour is not characteristic for a normal dam, so it was imitated by a combination of four structures at the outlet point of the catchment. First there is a pump with a capacity of 1 $m^3/s$, which starts pumping if the level in the lake reaches 24.51m. If the runoff of the catchment is

higher than 1 $m^3/s$, the water level will rise, and at first run over a weir with a crest level of 25.00m. If the runoff is high enough and the level still raises, at 25.01m a second pump starts with an extra discharge of 7 $m^3/s$. If even this doesn't stop the raising of the water, a third pump will start with another extra discharge of 7 $m^3/s$. The most extreme runoff peeks will just run over the weir. If the runoff lowers and the water level drops below 24.96, the third pump stops pumping. At 24.95m the second pump stops, and eventually if levels drop to 24.50m even the first pump stops but this does seldom happen.
An average yearly water balance is presented in table 8.12. Yearly totals tend to be a little too high. This was caused by adaptations in the drainage system of some plots after the calibration of evaporation on basis of the total yearly water balance.

*Table 8.12 Surface water balances (averages for 1991-2000)*

| Total catchment | 68000 | | ha | Subcatchment | | | 30000 ha |
|---|---|---|---|---|---|---|---|
| *Water balance* | | | *$10^6$ $m^3$* | *Water balance* | | | *$10^6$ $m^3$* |
| Input | | Output | | Input | | Output | |
| Runoff | 320.3 | Outflow | 359.7 | Runoff | 135.8 | Outflow | 139.6 |
| Precipitation | 68.6 | Evaporation | 29.9 | Precipitation | 5.7 | Evaporation | 2.5 |
| Storage change | 0.7 | | | Storage change | 0.6 | | |
| | 389.6 | | 389.6 | | 142.1 | | 142.1 |
| *Nitrogen balance* | | | *ton* | *Nitrogen balance* | | | *ton* |
| Input | | Output | | Input | | Output | |
| Runoff | 712.1 | Outflow | 423.6 | Runoff | 327.4 | Outflow | 318.1 |
| Point sources | 39.4 | Biomass loss | 158.3 | Point sources | 31.9 | Biomass loss | 67.3 |
| Erosion | 56.8 | Denitrification loss | 229.9 | Erosion | 34.1 | Denitrification loss | 12.4 |
| Storage Change | 3.5 | | | Storage Change | 4.4 | | |
| Total | 811.9 | Total | 811.9 | Total | 397.9 | Total | 397.9 |
| *Phosporus balance* | | | *ton* | *Phosporus balance* | | | *ton* |
| Input | | Output | | Input | | Output | |
| Runoff | 22.9 | Outflow | 9.6 | Runoff | 10.1 | Outflow | 18.0 |
| Pointsources | 2.5 | Biomass loss | 7.9 | Pointsources | 1.7 | Biomass loss | 3.4 |
| Erosion | 20.0 | Sedimentation loss | 24.0 | Erosion | 13.0 | Sedimentation loss | 3.3 |
| | | Storage Change | 3.9 | | | Storage Change | 0.1 |
| Total | 45.4 | Total | 45.4 | Total | 24.8 | Total | 24.8 |

Discharges at the catchment outlet were very difficult to model in detail. The approach with structures does not always react as in reality, but the result is satisfying. The results of the calibration on discharges can be found in Figure 8.13 and Figure 8.14. Results are presented on both a normal and a logarithmic scale. On a normal scale peaks can be seen more clearly, and on a logarithmic scale it is possible to see the 'background' flow. The results are very reasonable for both measuring points. During some winters peak discharges tend to come a bit too early, especially 1995. This might be due to premature snowmelt in the model.

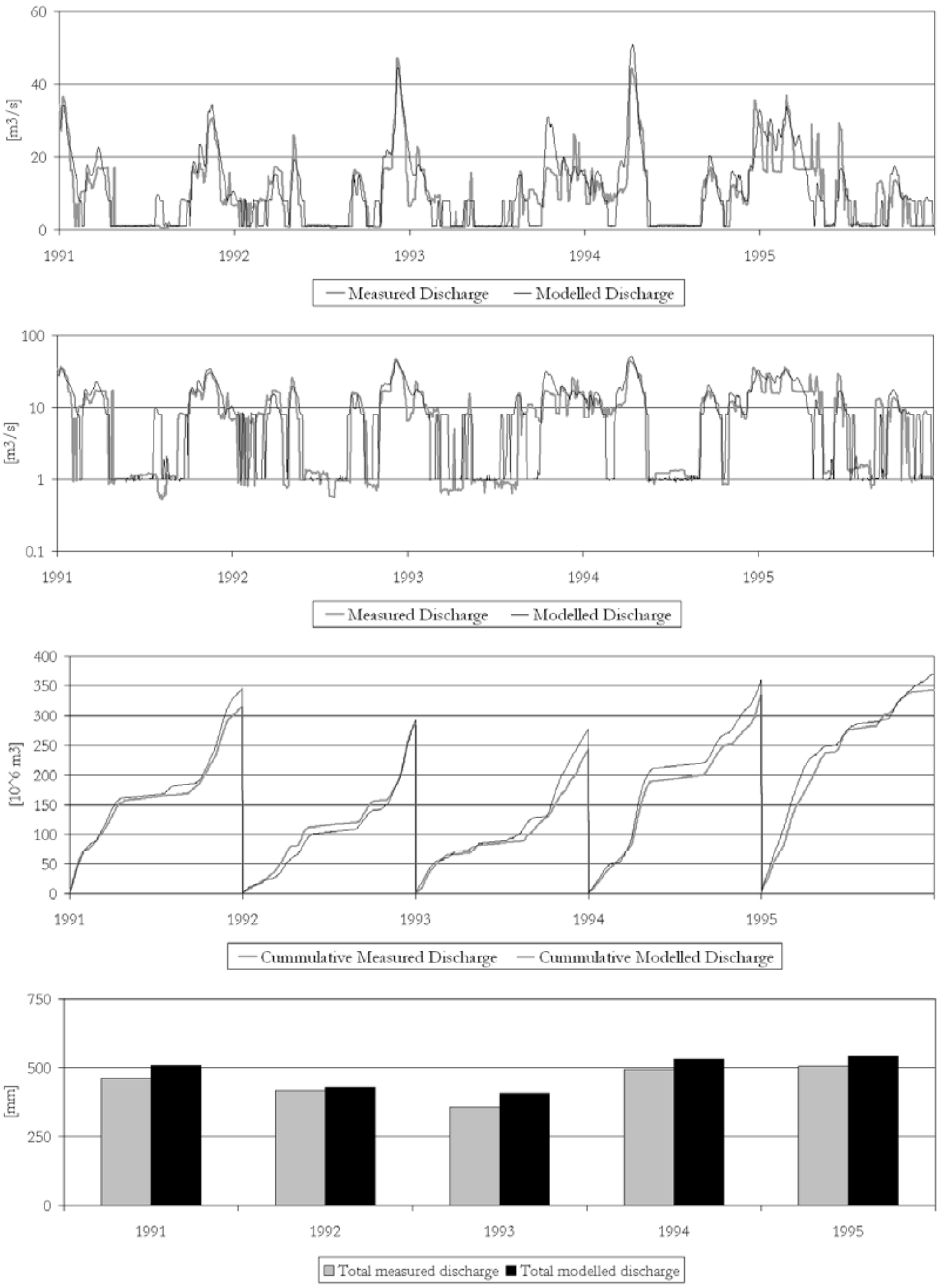



*Figure 8.13 Calibrated discharges from total catchment*

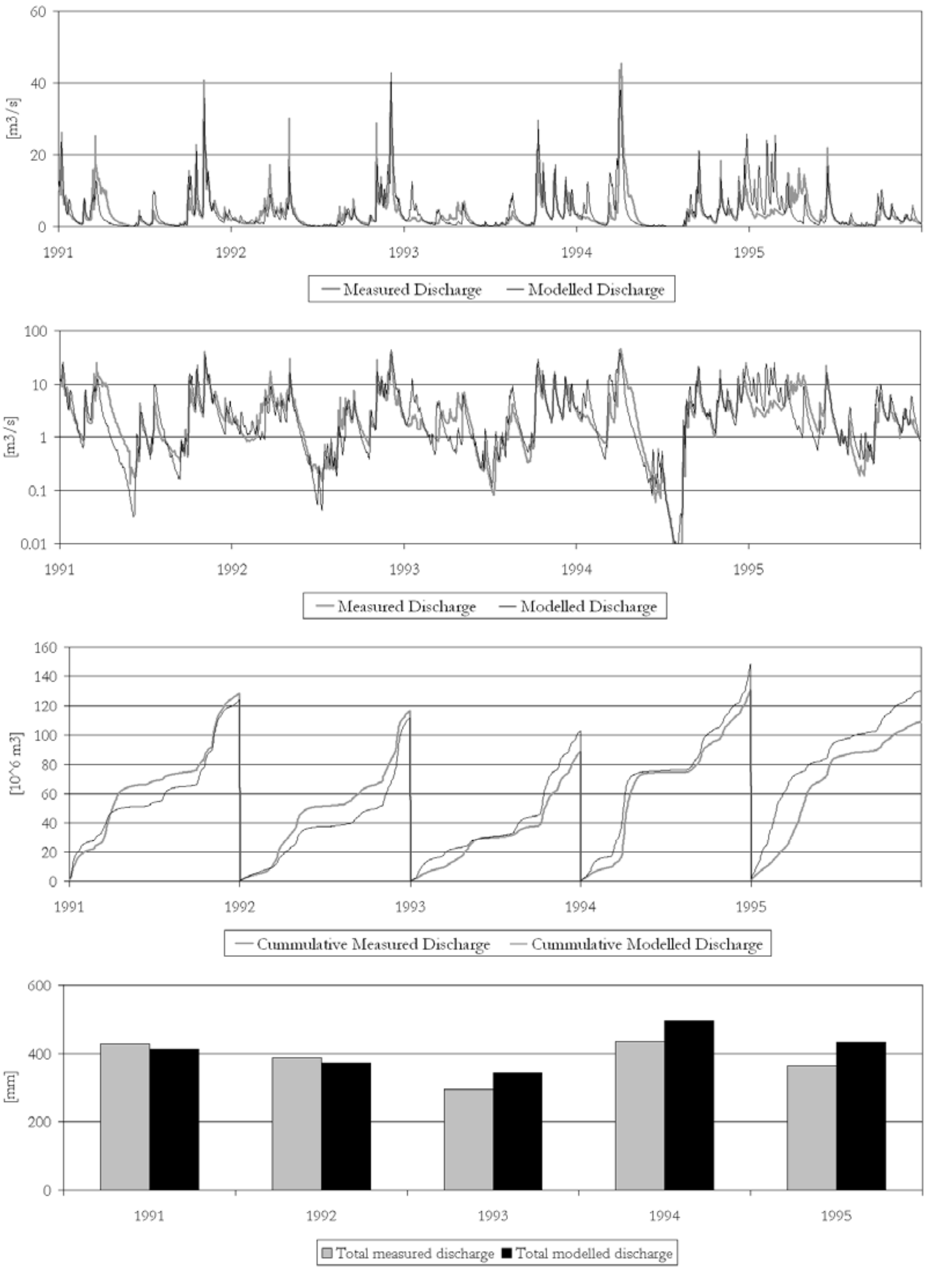



*Figure 8.14 Calibrated discharges from subcatchment*

#### 8.4.1.3 Nitrogen

Nitrogen concentrations at both measuring points are low compared to most Dutch surface waters (0.5-3 mg/l). Seasonal variations at the outlet can be seen very clearly (figure 8.15). This is mainly due to the buffering effect of Lake Vansjø. During spring and summer primary production processes demand nitrogen, which is released again during autumn and winter. Nitrogen concentrations at the measuring point from the subcatchment have a less clear seasonal change (figure 8.16). Due to residence time, retention processes mainly take place in the lake, and less in the upper streams in the catchment. This made it possible to judge the runoff as calculated by ANIMO, because it has to be at least higher than the measured outflow from the subcatchment minus point sources and estimated erosion loads. Concentrations from the entire catchment are much lower due to the retention in lakes. To reproduce the seasonal changes we had to adjust the parameters for biomass growth. To adjust the total retention losses from the catchment we adjusted the denitrification parameter.

As can be seen from Figure 8.15 and Figure 8.16 we achieved reasonable results. For the subcatchment it was difficult to model the peaks in the discharges because we had no clear idea what caused them. We dismissed erosion because opposite of phosphorus, nitrogen erosion plays a less important role due to the lower nitrogen content of soils. Calibration resulted in a higher base concentration to compensate the peaks and achieve reasonable loads on a yearly basis. For the whole catchment we reproduced the concentrations very well. Loads are presented on linear and logarithmic scales to judge on both peak and background runoff loads. The final retention calculated by us is 20% of the total loads to the surface water for the subcatchment, and 48% of the total loads to the surface water for the whole catchment.

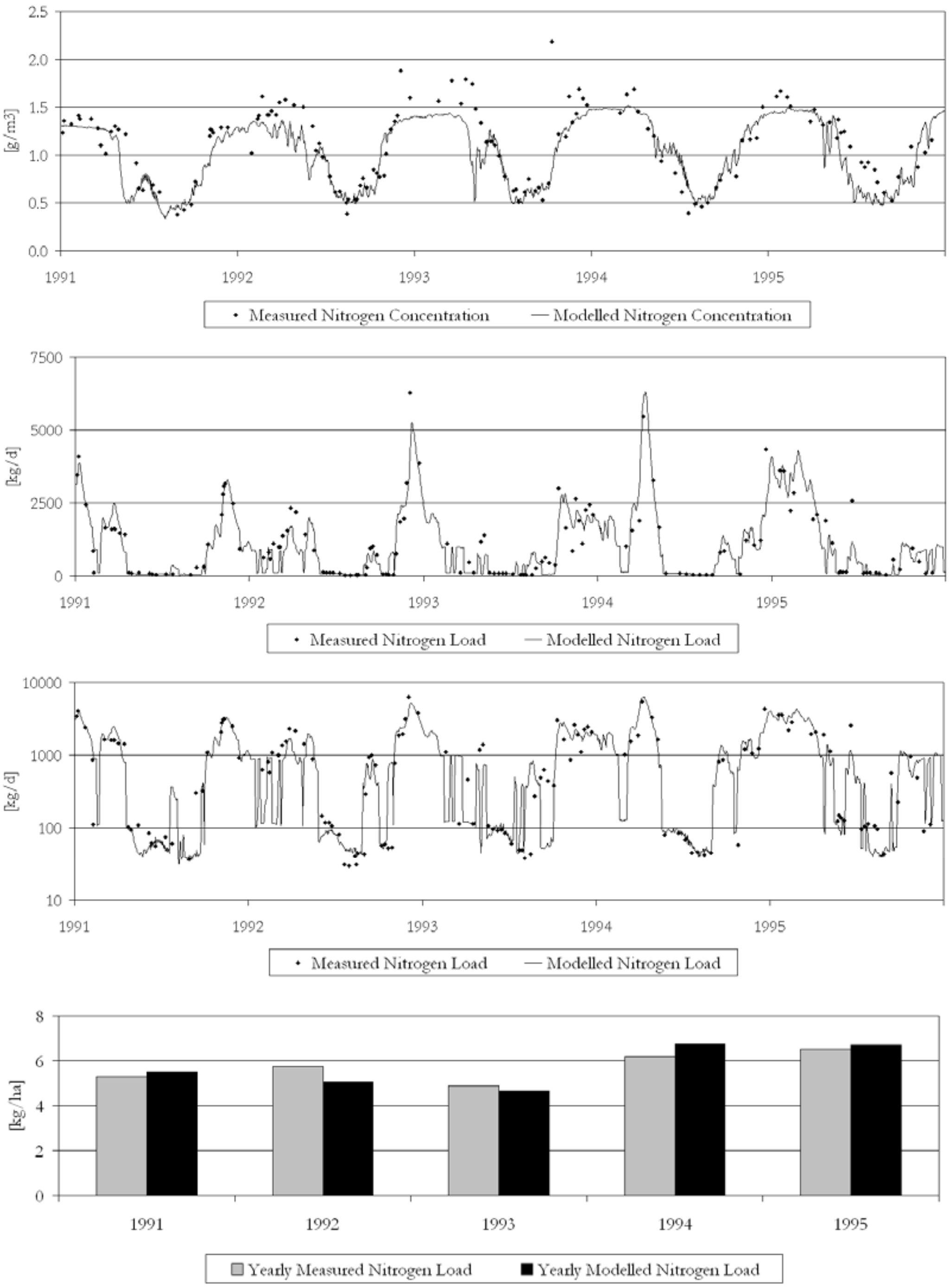



*Figure 8.15 Calibrated nitrogen concentrations from total catchment*

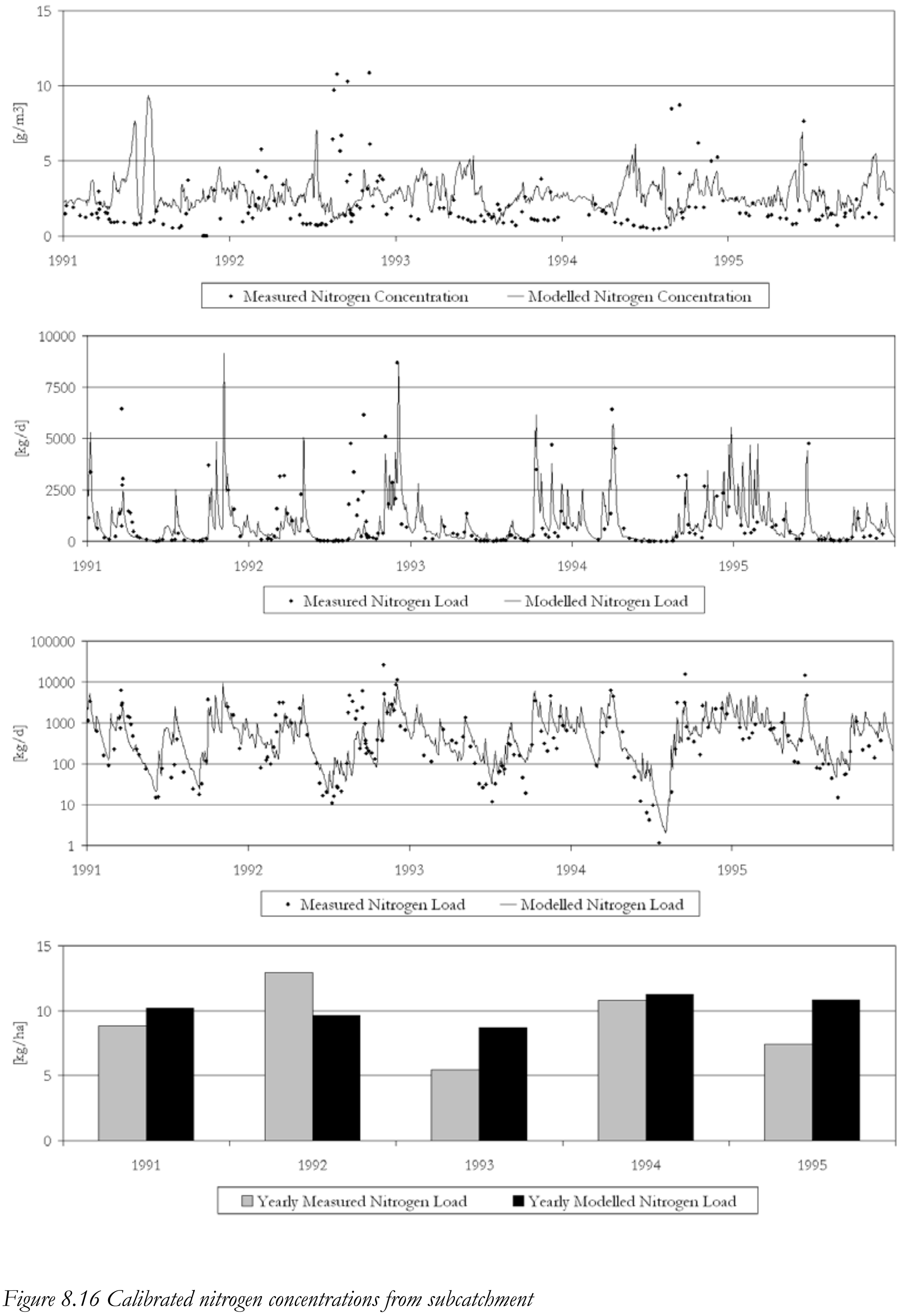



*Figure 8.16 Calibrated nitrogen concentrations from subcatchment*

*Figure 8.17 Sampling station in Norway, however not in the Vansjø-Hobøl catchment*

#### 8.4.1.4 Phosphorus

Phosphorus was more troublesome than nitrogen. The comparison of modelled phosphorus discharge from the soil column to measured concentrations in the surface water revealed that an additional process, erosion, was the most important source for phosphorus load to the surface water. Because of our limited experience on this subject it was harder to judge if our erosion calculations were reasonable, also because overestimation could be compensated with more retention. Seasonal patterns in the phosphorus concentrations were even harder to distinguish (Figures 8.18 and 8.19). For the whole catchment the seasonal pattern of phosphorus concentration was contrarily to that of nitrogen, although the primary production processes have the same effect on phosphorus as nitrogen. We managed to follow the pattern reasonably by adjusting sorption parameters.

The modelled loads were reasonable on a yearly basis, but we didn't manage to achieve good results for the subcatchment for 1994 and 1995. In our model the subcatchment is typical for the total runoff that enters Lake Vansjø. In 1994 and 1995 the load to the lake is lower than in 1992. However the load from the entire catchment in 1994 and 1995 is higher than in 1992. We do not have any information that could explain this difference. The final retention calculated by us is 27% of the total loads to the surface water for the subcatchment, and 70% of the total loads to the surface water for the whole catchment.

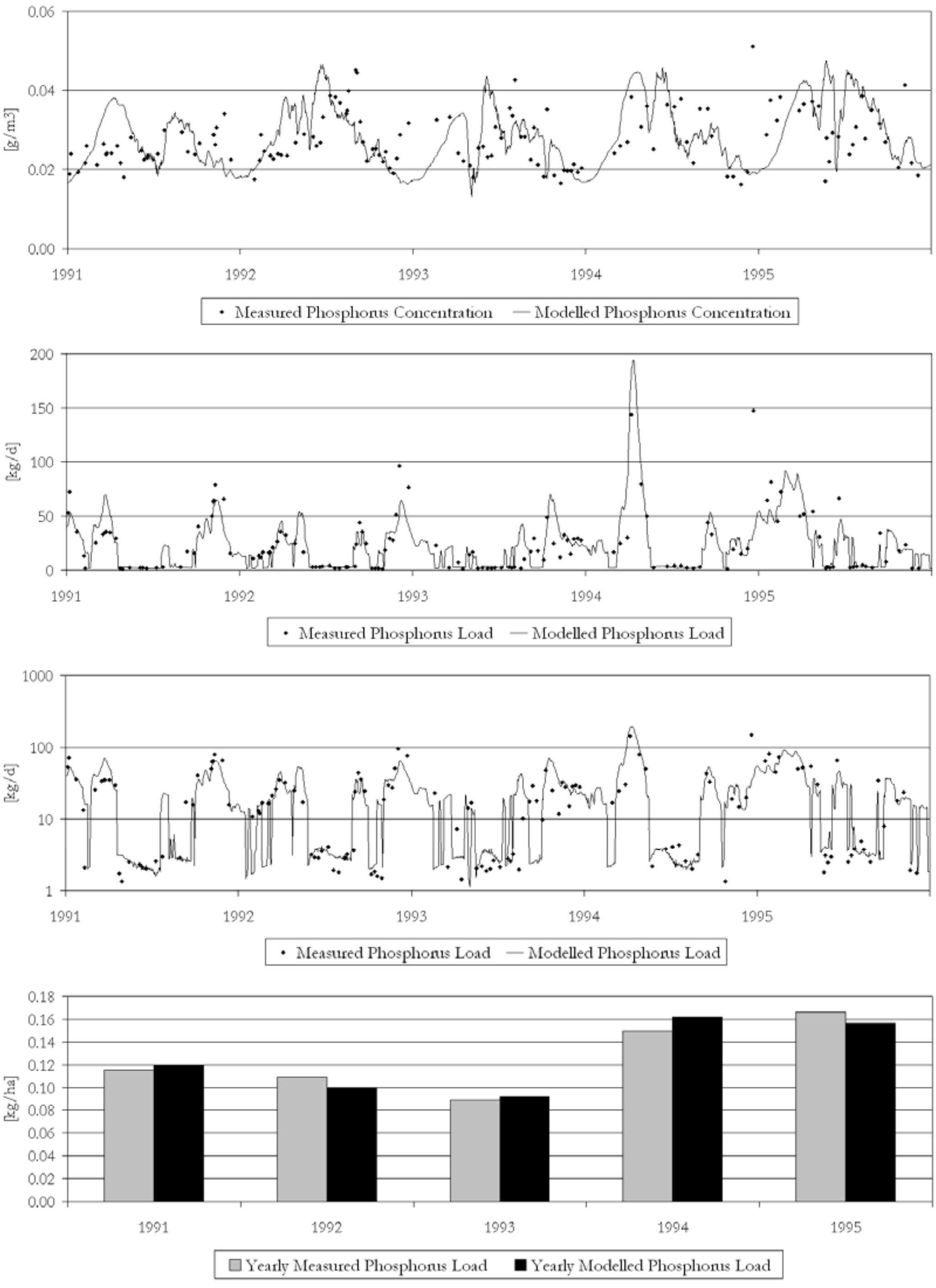



*Figure 8.18 Calibrated phosphorus concentrations from subcatchment*

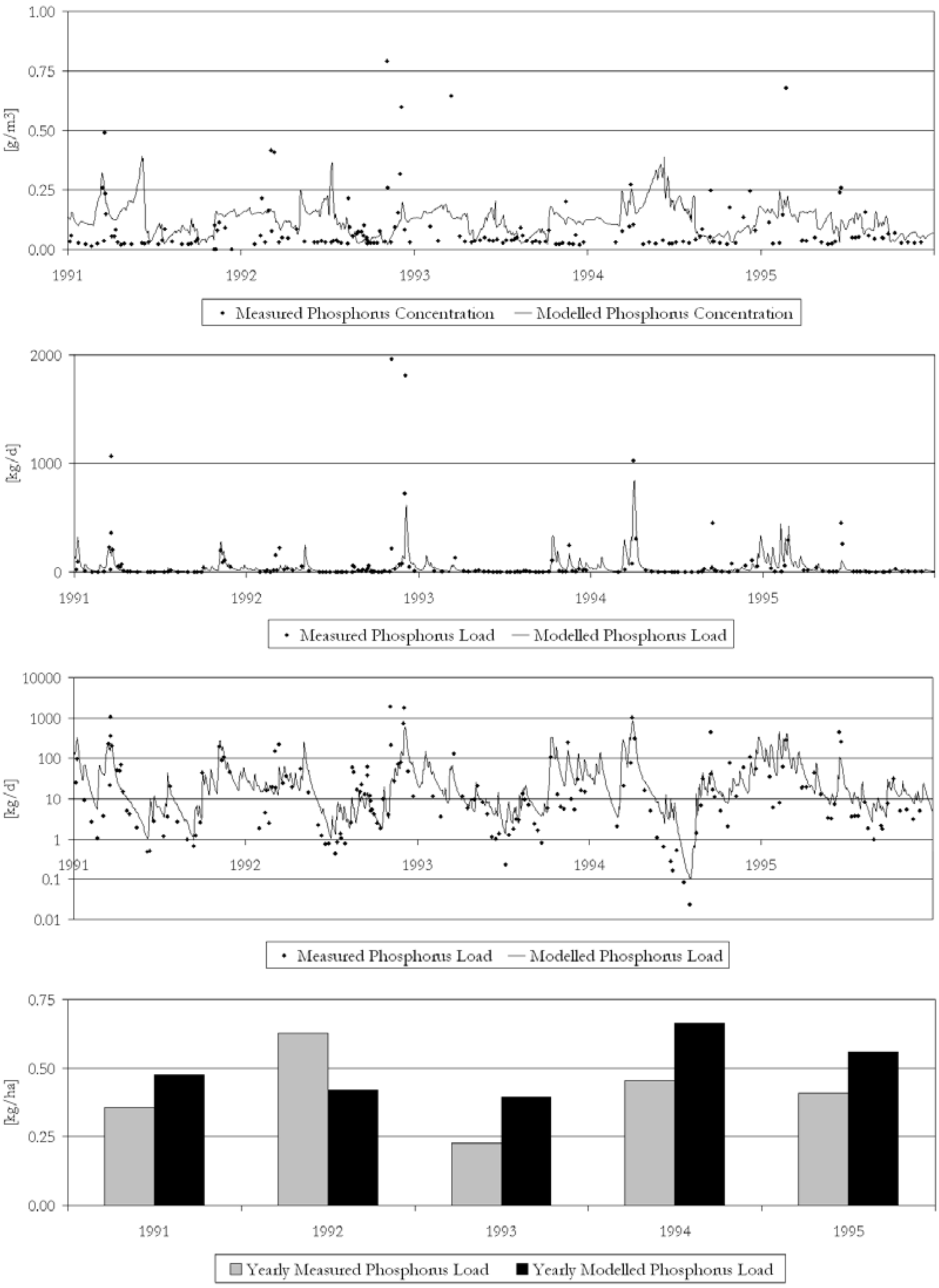



*Figure 8.19 Calibrated phosphorus concentrations from subcatchment*

### 8.4.2 Validation

The validation of the model was done on the measurement from 1996 until 2000. Measurements show high runoff in 1999 and 2000, which was expected because of higher precipitation in these years. As can be seen in figure 8.20 and figure 8.21 the models managed to predict the discharges very well, although they were calibrated on less extreme years. Nitrogen was predicted fine as well as can be seen from figure 8.22 and figure 8.23, although the yearly loads from the subcatchment are a little too high. For phosphorus we didn't manage to model the peak runoff in 2000 because we overestimated the retention that year, but all other results look fine (figure 8.24 and figure 8.25). Overall we can conclude that the model predicted the measurements from the validation period very well despite the fact that the validation period contained two meteorological extreme years.

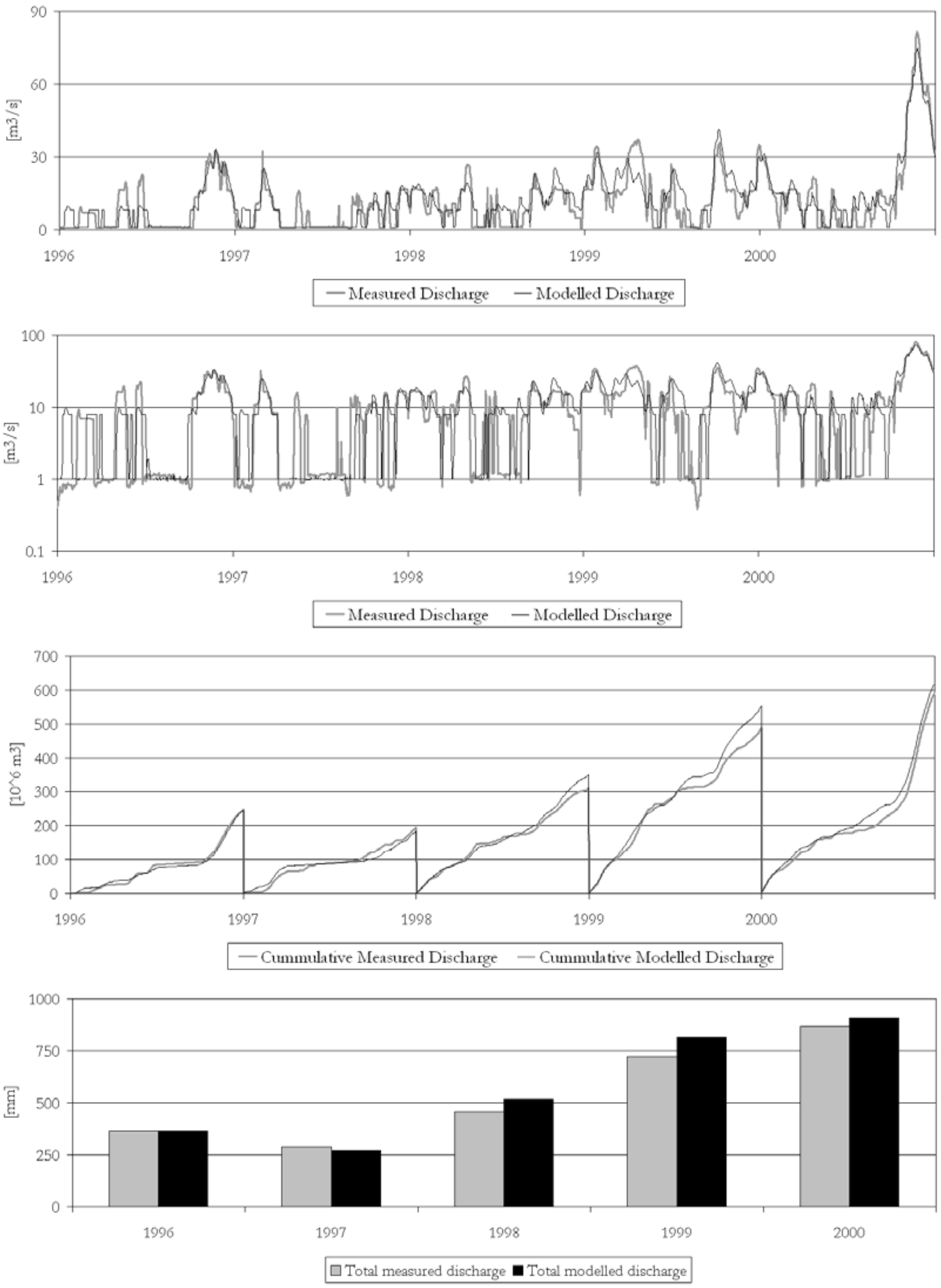



*Figure 8.20 Validation of modelled discharges from total catchment*

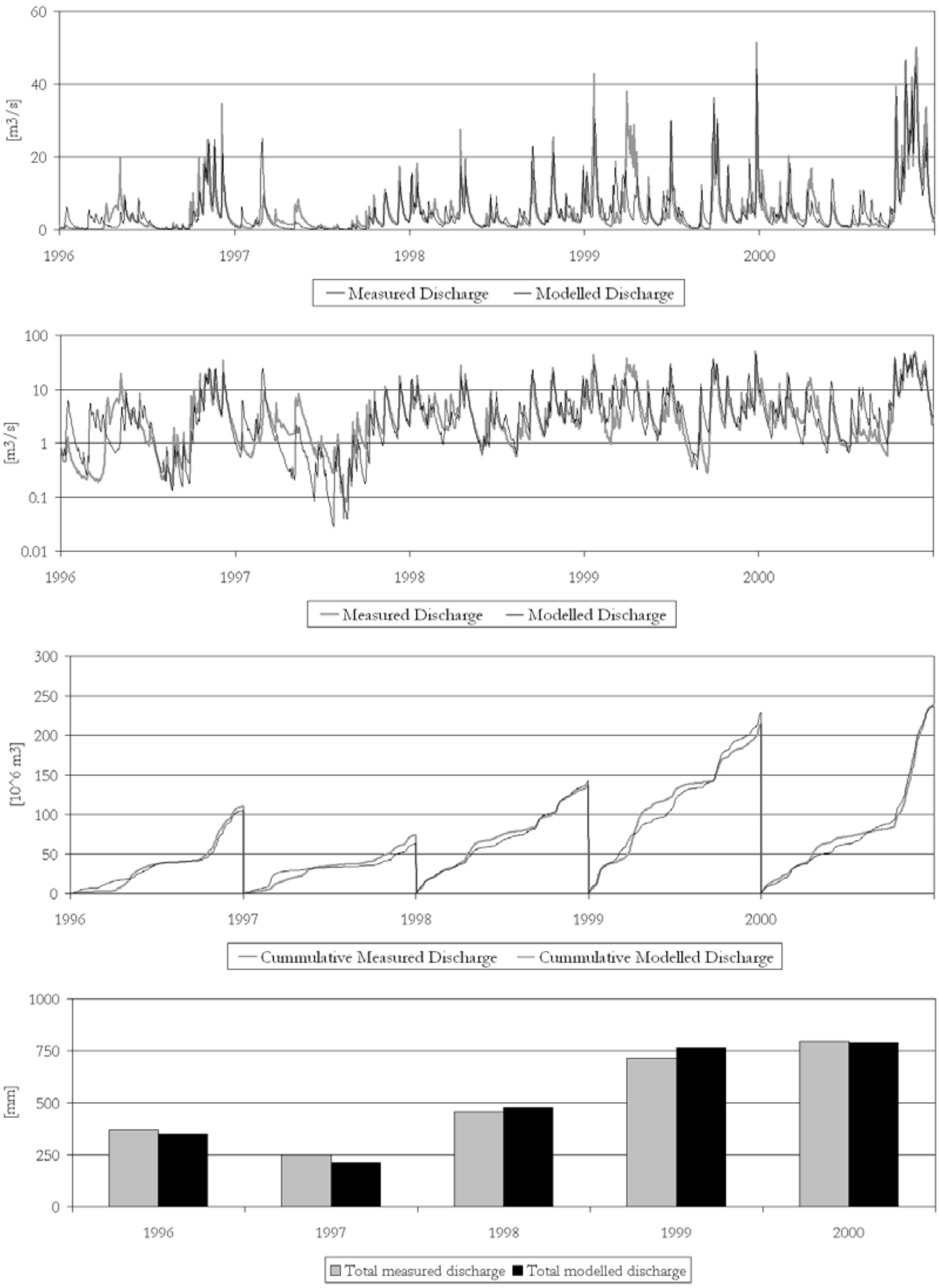



*Figure 8.21 Validation of modelled discharges from subcatchment*

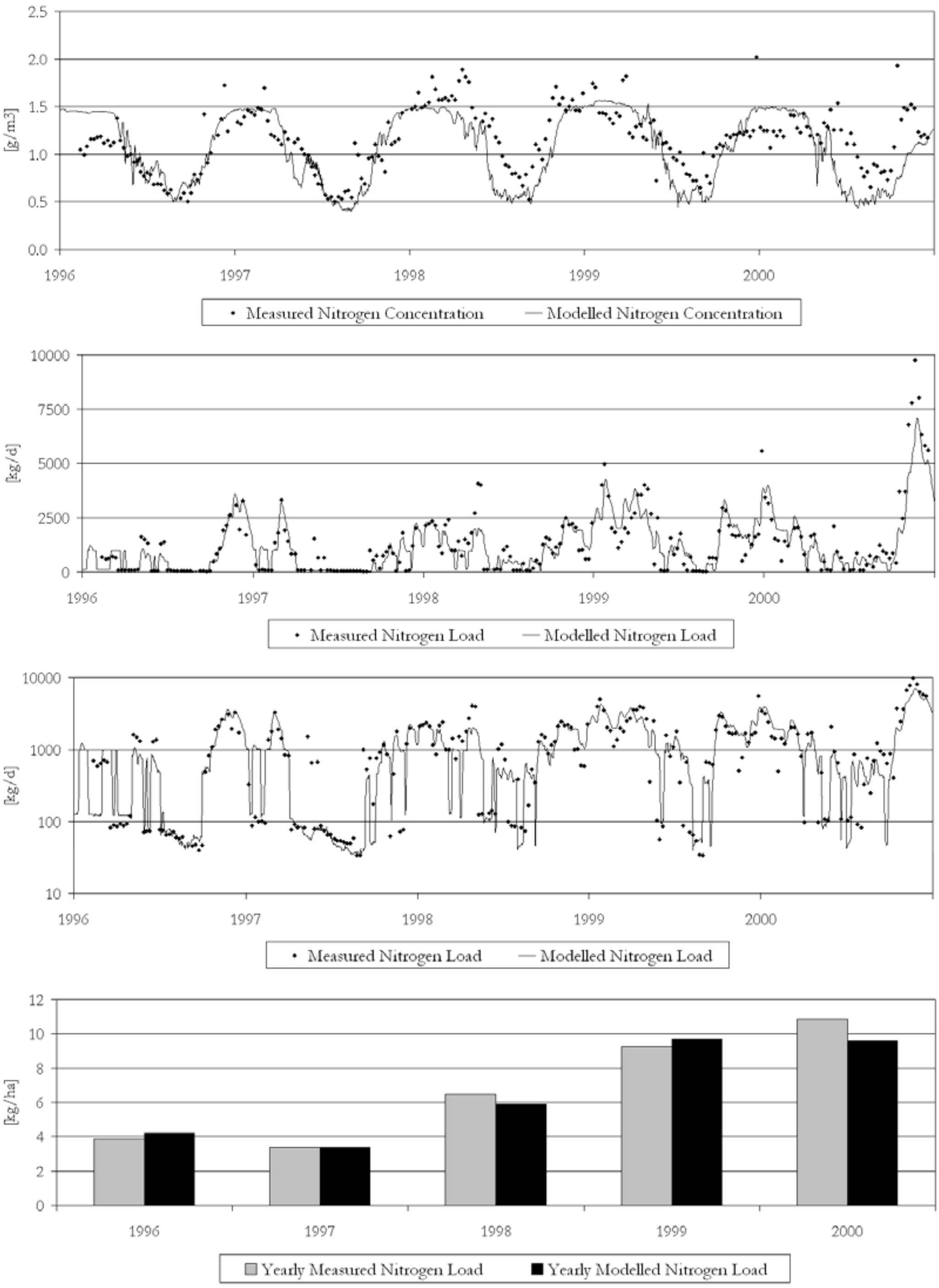



*Figure 8.22 Validation of modelled nitrogen concentrations from total catchment*

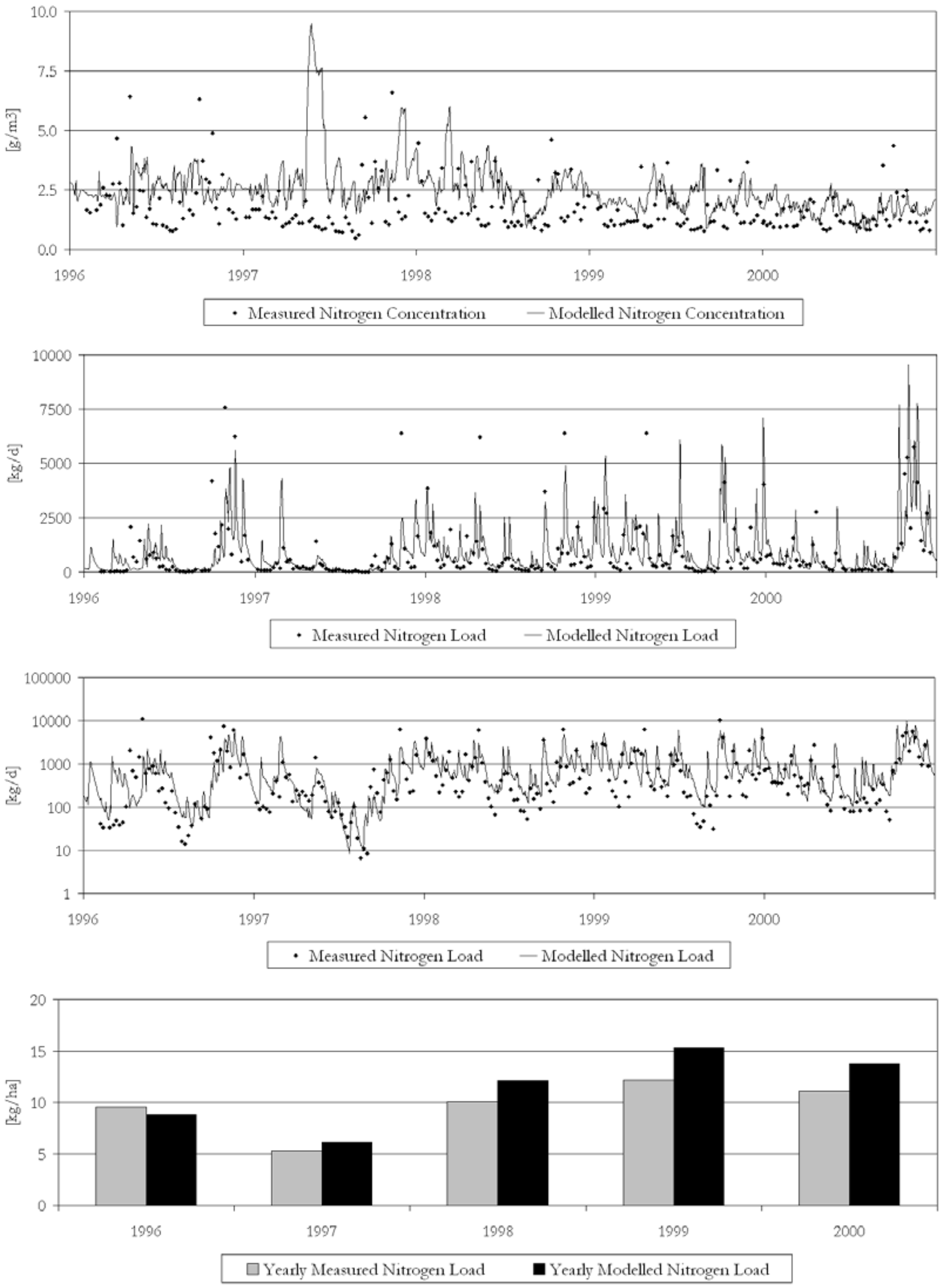



*Figure 8.23 Validation of modelled nitrogen concentrations from subcatchment*

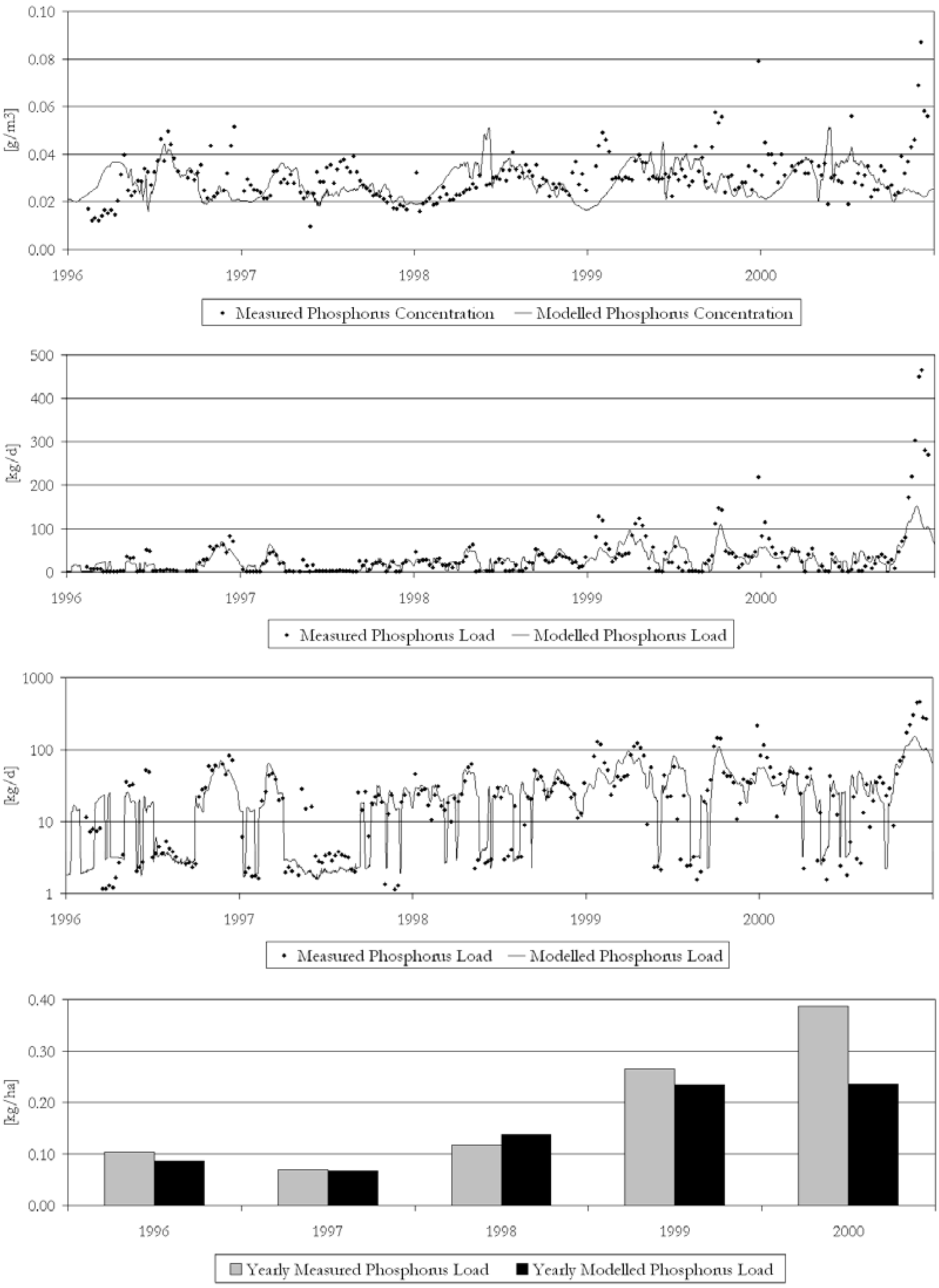



*Figure 8.24 Validation of modelled phosphorus from total catchment*

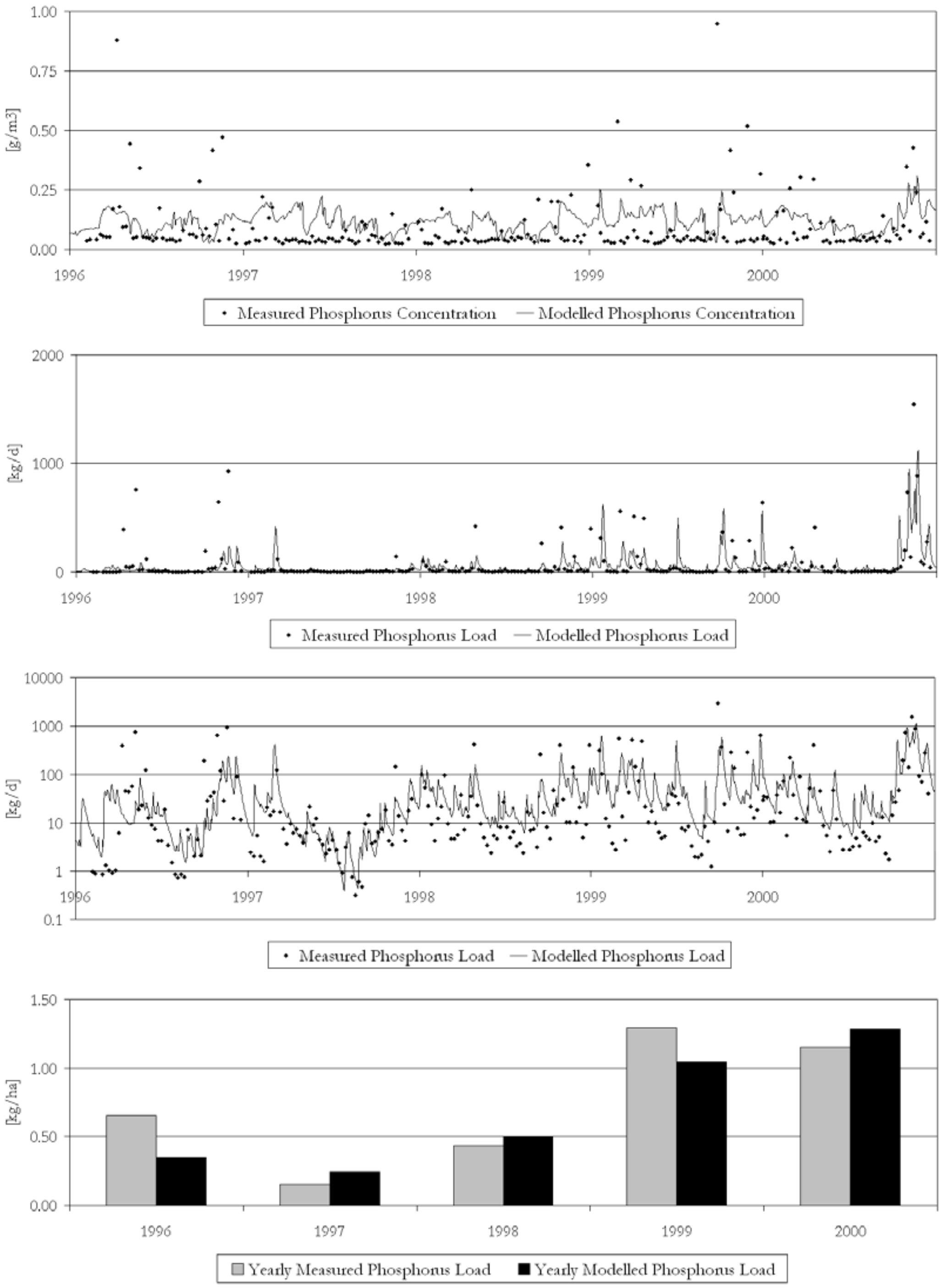



*Figure 8.25 Validation of modelled phosphorus from subcatchment*

## 8.5 Concluding remarks

The agreement between daily simulated and daily measured loads at the catchment outlet is very good. The agreement between the annual measured and simulated loads is very good, but the model overestimates the annual loads, especially for phosphorous, in the wet year 2000.

The simulated N balance shows an excess of 66 kg $ha^{-1}y^{-1}$ and a denitrification of 69 kg $ha^{-1}y^{-}$. The biological net fixation was estimated at 30 kg $ha^{-1}y^{-1}$ with no net leaching to deeper groundwater. The nitrogen transport to surface waters amounts to 28 kg $ha^{-1}y^{-1}$. The total N inputs to surface waters are estimated at 796 ton $y^{-1}$, of which 417 ton $y^{-1}$ leaves the catchment at the outlet. The retention in surface waters is calculated at 49%.

The simulated P balance, averaged for all soils in the catchment, shows an excess of (fertilization – crop yield) 8? kg $ha^{-1}y^{-1}$. Soil storages is almost equal at 8.1 kg $ha^{-1}y^{-1}$. The phosphorus transport to surface waters amounts to 1.29 kg $ha^{-1}y^{-1}$. The total P inputs to surface waters are estimated at 45 ton $y^{-1}$, of which 9 ton $y^{-1}$ leaves the catchment at the outlet. The retention in surface waters is calculated at 79 %.

# 9 Discussion and conclusions

*Overall conclusions*

The integrated modelling approach presented in this study simulates solute transport, accumulation and transformation processes in soil, groundwater and surface waters, and allows the analysis of scenarios and the testing of complex management measures intended to protect and improve freshwater ecology.

Nutrient transport is closely related to hydrological pathways. A detailed hydrologically based nutrient transport model gives a valuable insight in the different processes leading to the surface water load on both field and catchment scale.

It is shown, as an example, that with one of the quantification tools involved in the EUROHARP project, NL-CAT, the fate of nutrients applied on agricultural land in soils can be determined together with the nutrient losses from agricultural. The nutrient losses can vary remarkably within European catchments as a result of nutrient application rates, landscape, soil type and climatic and hydrological conditions.

*Data*

The preceding catchment chapters show that the NL-CAT package is very well capable of modelling the nutrient loads in the surface water and the contribution to these loads from diffuse sources. An exception is the Enza catchment where inaccurate or missing data restricted a proper modelling of the soil water discharges and consequently also of nutrient flow, surface water flow and quality.

The accuracy of data is therefore, not surprisingly, a decisive factor. However, although the NL-CAT requires a large amount of input data, many missing or incomplete data can be substituted by regional values (for example crop growth), be approximated by using general characteristics that are measured (e.g. soil hydraulic parameters derived from a European database using texture classes) or be estimated based on expert judgement. Still, the modelling of the six catchments learns that several data is irreplaceable or would greatly improve the modelling result. That is:

1. Precipitation data
2. Manure and fertilizer input data
3. Groundwater level and concentration data

Ad 1.
A lack of precipitation data, be it missing values or only one or few meteorological stations, becomes a problem in large hilly areas. A meteorological station is often only representative for a small area at the same elevation. In the Zelivka catchment the Thiessen polygon method was used at first dividing the influence area of each station on the basis of distance from the station. Test runs however showed that runoff in the area attributed to the highest situated meteostation was overestimated. Precipitation had to be corrected using a neighbouring station but this affected local variation.
In the Zelivka catchment data from four stations were available. In the Enza catchment, data from only one station, situated outside the catchment could be used. Precipitation from this station was for certain areas not even enough to balance drainage discharge, even without

evapotranspiration. As a result soil drainage modelling failed and consequently also soil nutrient flow and surface water modelling.

Ad 2.
A proper knowledge of the intensity of agriculture and the amount of fertilizer and manure application is essential. The modelling of the Dutch Regge part of the Vecht catchment shows that when sufficient data is available a proper match can be reached between measured and modelled concentrations. However for the German part only manure and fertilizer application data for 1997 were available. Despite large scale interpolation and expert judgement to derive correct historical application values and trends, concentrations in the surface water were still underestimated.

Ad 3.
Not only input data is essential but also data to calibrate on. The load on surface water could not be verified directly but only by comparison with surface water concentrations downstream which are influenced by transport, point sources and retention processes. Groundwater measurements were lacking everywhere or available for only one single location. Information on both groundwater concentrations and levels is important. The groundwater level not only influences the drainage of water but also the denitrification rate and this denitrification rate is largely responsible for the nitrogen retention in the soil column.

*Processes*

Denitrification in groundwater can be a major part of the total loss. Assessment of the denitrification amounts is still very uncertain as the detailed empirical information of the catchments is lacking. Biological N-fixation can be expected in unfertilized fields and was not accounted for in most of the model simulations. The process is highly variable and depends on the meterological circumstances, the land use and the land management. The occurrence of clover and other N-binding botanical species is difficult to predict. Ignoring this source revealed itself in the depletion of the organic nitrogen stores in soils as was the case for e.g. the Ouse catchment. In the Zelivka catchment the process itself was described by an annual addition of nitrogen to soils, based on arguments to close the N soil balance.
Independent validation of specific individual processes like denitrification, phosphorus sorption/desorption and kinetics (by detailed laboratory and field studies) is important to improve the reliability and plausibility of the model results

*Results reliability*

A statistical analysis has been performed within the Euroharp project on all results from every catchment by every model institute. Tables 9.1 and 9.2 show the RMSE for both concentrations and loads for the NL-CAT application in all six catchments. For the core catchments (Ouse, Enza and Vansjø-Hobøl) the RMSE values are validation results. For the other non-core catchments the RMSE is based on the calibration period.

The RMSE values should be interpret together with the model results presented in the preceding chapters to get a better insight in their true meaning. Many aspects already mentioned in the catchment chapters are reflected in these RMSE values. Annual RMSE is, as expected, better than sub annual. Of the non-core catchments the Vecht has the highest annual discharge RMSE, as a result of the overestimation of discharges or, as suggested in paragraph 5.4.1, the underestimation by the measurements at the outlet. Of the core catchments the Ouse has the worst performance on discharges but performs better on nitrogen concentrations and loads for which the Enza catchment has the highest RMSE.

*Table 9.1 Root mean squared error (RMSE) on concentrations for each subcatchment, annual and sub annual*

| | flow_m3s | TP_mgl | MRP_mgl | SRP_mgl | DIN_mgl | TN_mgl |
|---|---|---|---|---|---|---|
| Annual Ouse | 8.15 | 0.1982 | 0.0816 | 0.1269 | 0.7433 | |
| Subannual Ouse | 30.90 | 0.3146 | 0.1402 | 0.1771 | 1.6529 | |
| Annual Enza | 2.07 | 0.0855 | 0.0153 | | 7.0487 | |
| Subannual Enza | 16.54 | 1.0412 | 0.0473 | | 4.5261 | |
| Annual Vansjø-Hobøl | 1.14 | 0.0054 | | | | 0.1691 |
| Subannual Vansjo_Hobol | 5.51 | 0.0121 | | | | 0.2828 |
| Annual Zelivka | 0.48 | | | | | |
| Subannual Zelivka | 3.59 | 0.0072 | | 0.0077 | 1.0959 | 1.1420 |
| Annual Odense | 0.45 | | | | | |
| Subannual Odense | 2.30 | 0.0827 | | 0.0857 | 2.2634 | 2.1855 |
| Annual Vecht | 8.84 | | | | | |
| Subannual Vecht | 22.44 | 0.1568 | 0.1868 | 0.1445 | 3.6065 | 3.3478 |

*Table 9.2 Root mean squared error (RMSE) on loads for each subcatchment, annual and sub annual*

| | flow_m3s | TP_kgha | MRP_kgha | SRP_kgha | DIN_kgha | TN_kgha |
|---|---|---|---|---|---|---|
| Annual Ouse | 8.15 | 1.0189 | 0.3147 | 0.7274 | 3.6416 | |
| Subannual Ouse | 30.90 | 0.0040 | 0.0015 | 0.0024 | 0.0464 | |
| Annual Enza | 2.07 | 1.2745 | 0.1096 | | 26.5639 | |
| Subannual Enza | 16.54 | 0.0461 | 0.0017 | | 0.1911 | |
| Annual Vansjø-Hobøl | 1.14 | 0.0696 | | | | 0.6608 |
| Subannual Vansjo_Hobol | 5.51 | 0.0006 | | | | 0.0098 |
| Annual Zelivka | 0.48 | 0.0067 | | | | 1.6438 |
| Subannual Zelivka | 3.59 | | | | | |
| Annual Odense | 0.45 | 0.1077 | | | | 4.6303 |
| Subannual Odense | 2.30 | 0.0013 | | 0.0013 | 0.0526 | 0.0541 |
| Annual Vecht | 8.84 | 0.2414 | | | | 6.4110 |
| Subannual Vecht | 22.44 | 0.0026 | 0.0022 | 0.0022 | 0.0722 | |

Another analysis to express the accuracy of prediction is to use the Nash-Suttcliffe's model efficiency (NSE) (Nash and Suttcliffe, 1970).[4] Its optimal value is 1. Values smaller than 0 indicate that the model is less efficient than simply using the average observation ($\overline{O}$) as prediction. In table 9.3 the NSE values for all catchments for three process based models used in the Euroharp project are shown. Model efficiency is high except for the SWAT application in Norway (Vansjo-Hobol) and the NL-CAT application in the Vecht regarding discharges. As is explained in chapter 5 (The Vecht catchment) and mentioned above as well, measured discharges at the outlet of the Vecht catchment seem to be too low compared to measured discharges upstream taking into account catchment area and precipitation. In the case of clear errors in measured data a high NSE should of course be considered questionable. Also in the Enza catchment were input data on precipitation inconsistent or insufficient (chapter 7).

[4] $NS = \frac{\sum_{i=1}^{n}(O_i - \overline{O})^2 - \sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2}$ where $\overline{O}$ is given by: $\overline{O} = \frac{1}{n}\sum_{i=1}^{n} O_i$

*Table 9. 3 Individual model efficiency (Nash-Suttcliffe: NSE) scores NL-CAT and two other process based models used in the Euroharp project*

| | | flow_m$^3$s | TP_kgha | TN/DIN_kgha |
|---|---|---|---|---|
| Ouse | NL-CAT | 0.8 | - | 0.7 |
| | TRK | 1.0 | - | - |
| | SWAT | 1.0 | - | 0.7 |
| Enza | NL-CAT | - | - | - |
| | TRK | - | - | 0.5 |
| | SWAT | 0.8 | - | 0.8 |
| Vansjø-Hobøl | NL-CAT | 0.9 | 0.67 | 1.0 |
| | TRK | 1.0 | - | 0.9 |
| | SWAT | 0.6 | 0.03 | 0.1 |
| Zelivka | NL-CAT | 0.8 | 0.5 | 0.8 |
| | TRK | - | - | - |
| | SWAT | - | - | - |
| Odense | NL-CAT | 0.9 | 0.7 | 0.8 |
| | TRK | - | - | - |
| | SWAT | - | - | - |
| Vecht | NL-CAT | 0.15 | 0.7 | 0.4 |
| | TRK | 0.9 | - | 0.7 |
| | SWAT | - | - | - |

More information on the evaluation of the different models in the various catchments can be found in Kronvang *et al.*, 2008 and Schoumans *et al.*, 2008.

*Loads and concentrations*

The modelling of the catchments has learned that it is best to calibrate on concentrations first rather than on loads. Concentrations are measured; loads are derived from them by multiplying the concentration with discharge. Discharges fluctuate more than concentrations and its effect is thus more visible when comparing measured and modelled loads visually. Possible errors in concentrations do not become visible.

*Time*

Time spend on modelling one catchment ranged from three months (Zelivka and Odense) to almost six months (Vecht), with data collection not included. There is definitely a learning curve as the Zelivka and the Odense catchment were modelled at the end. Also the accuracy of data is determining with the Vecht catchment as one of the most problematic.

*Model procedure*

The modelling sequence in the NL-CAT package goes from SWAP-ANIMO to SWQN and finally NuswaLite. Feedback however is necessary. The groundwater model could not be calibrated without the surface water model as only surface water discharges were available. The same is true for nutrients. No groundwater quality measures were available. Furthermore the discretisation of SWAP and Animo consists of so many different plots that possible abnormalities are sometimes only noticed in the surface water quality model when discharges from the different plots are merged together. A correction sometimes involves not only rerunning Animo but also SWAP and SWQN. Taking this into account it is important to take deliberate steps in the beginning but at the same time work quickly to the final concentrations and loads of Nuswalite.

*Applicability*

Models that include explicit or implicit decription of agricultural practices such as land use and intensity of land use management (manure application, fertilization) have the potential ability to predict the impact of management strategies on nutrient losses to surface waters. Most of the Euroharp models are able to predict changes in nutrient losses due to changes in fertilizer application or the effect of livestock numbers. The NL-CAT modelling system simulates water flows and nutrients dynamics and transports at a detailed level and soil management measures as tillage timing and tillage depth can be imposed to the model.
In principle the impact of water management strategies on nutrient losses from agricultural land to surface waters can only be determined by models which contain a hydrological component. Four of the nine EuroHarp models did not have an explicit hydrological module simulating river flow (REALTA, NOPOLU, NLES-CAT, and source apportionment) and are therefore not suitable for (independent) exploration of the effect of water management scenarios such as hydrotechnical measures. The NL-CAT modelling system is able to simulate different aspects of operational surface water management as well as interventions in the ydrological infrastructure.

*Modellers*

Finally the experience of the modeller plays an important role. The expert judgement of the modeller is of utmost importance especially with respect to estimation of missing data. When standardized procedures for data handling, filling gaps in time serees and spatial discretization are missing the model results depend for a considerable part on the modellers' intuition. Exchange of models and modellers between different research groups could possibly contribute to the objectification of the application of distributed catchment models.

# Literature

ADAS, 2002. EveNFlow Model Documentation. ADAS - Environment Modelling and GIS Group, Wolverhampton, UK (version June 2002)

Allen, R.G., L.S. Pereira, D. Raes & M. Smith. 1998. Crop evapotranspiration - guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations (FAO), Rome

Anthony, S.G., P. Quinn & Lord, E. I. 1996. Catchment scale modelling of nitrate. Aspects of Applied Biology 46, 23-32.

Allen, R.G., M. Smith, A. Perrier & L.S. Pereira. 1994. An update for the definition of reference evapotranspiration. ICID Bulletin 43 (1994) 2

Arcadis, 2000. Grensoverschrijdend Instrumentarium Overijsselse Vecht. SOBEK modellering. Waterschap Velt en Vecht. Technical Report 10302/OA9/563/0001361b, RIZA. Arcadis Heidemij Advies.

Behrendt, H., P. Huber, M. Ley, D. Opitz, O. Schmoll, G. Scholz & R. Uebe. 1999. Nährstoff-bilanzierung der Flußgebiete Deutschlands. UBA-texte, 75/99, 288 S.

Bergström, S., 1995. The HBV model. In Singh, V. P. (ed.) Computer Models of Watershed Hydrology, Water Resources Publications, Littleton, Colorado, pp. 443-476.

Bouraoui F., B. Grizzetti, G. Adelsköld, H. Behrendt, I. de Miguel, M. Silgram, S. Gómez, K. Granlund, L. Hoffmann, B. Kronvang, S. Kværnø, A. Lázár, M Mimikou, G. Passarella, P. Panagos, H. Reisser, B. Schwarz, C. Siderius, A.S. Sileika, A.A.M.F.R. Smit, R. Sugrue, M. VanLiedekerke & J. Zaloudik (2009). Basin characteristics and nutrient losses: the EUROHARP catchment network perspective. J. Environ. Monit., 2009, **11**, 515-525

Boogaard, H.L., C.A. Van Diepen, R.P. Rötter, J.M.C.A. Cabrera & H.H. Van Laar, 1998. User's guide for the WOFOST 7.1 crop growth simulation model and WOFOST Control Center 1.5, Technical document 52, DLO Winand Staring Center, Wageningen.

Boorman, D.B., J.M. Hollis, & Lilly, A., 1995. Hydrology of soil types: a hydrologically-based classification of the soils of the United Kingdom, Report no. 126. Institute of Hydrology, Wallingford, 137 p.

Borgvang, S.A. & J.S. Selvik, eds. Development of HARP Guidelines - Harmonised Quantification and Reporting Procedure for Nutrients. SFT Report 1759/2000. ISBN 82-7655-401-6. 179 pp.

Breiman, L., 2001. Random forests. Machine Learning 45:5–32

Bruin, H.A.R. de, 1981. The determination of (reference crop) evapotranspiration from routine weather data. Comm. Hydrol. Research TNO, Den Haag, Proc. and Inform. 28:25-37.

Dam, J.C. van, 2000. Field-scale water flow and solute transport. SWAP model concepts, parameter estimation and case studies. Ph.D.-thesis, Wageningen University, Wageningen.

Dijk, T.A. van, 2002. Resultaten akkerbouw en volle grondsgroenten 2002. NMI Wageningen. European Environment Agency/IFEN (2000). Technical report N°51. Calculation of nutriment surplus from agricultural sources. Statistics spatialisation by means of CORINE Land Cover. Application to the case of Nitrogen.

Dijk, W. van, 2003. Adviesbasis voor de bemesting van akkerbouw en vollegrondsgroentengewassen. Praktijkonderzoek Plant en Omgeving B.V.. Publicatienummer 307.

FAO, 1998, Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56, Rome.

Groenendijk, P., M. van Elswijk, J. Huygen, J.G. Kroes, A.J. Otjens, A.A.M.F.R. Smit, A.A. Veldhuizen & J.G. Wesseling. 1999. MultiSwap as application of the Framework Integrated Water management. Winand Staring Centre, Wageningen. Techn. Doc. 60. (in Dutch)

Groenendijk, P. & J.G. Kroes, 1999. Modelling the nitrogen and phosphorus leaching to groundwater and surface water with ANIMO 3.5. Report 144. Winand Staring Centre, Wageningen.

Groenendijk, P., L.V. Renaud & J. Roelsma, 2005, Prediction of Nitrogen and Phosphorus leaching to groundwater and surface waters; Process descriptions of the ANIMO 4.0 model. Report 983. Alterra, Wageningen

Heijboer, D. & J. Nellestijn. Klimaatatlas van Nederland, 2002. De normaalperiode 1971-2000. Elmar, Rijswijk, the Netherlands.

Hejzlar J., S. Anthony, B. Arheimer, H. Behrendt, F. Bouraoui, B. Grizzetti, P. Groenendijk, M.H.J.L. Jeuken, H. Johnsson, A. Lo Porto, B. Kronvang, Y. Panagopoulos, C. Siderius, M. Silgram, M. Venohrd & J. Žaloudíka (2009). Nitrogen and phosphorus retention in surface waters: an inter-comparison of predictions by catchment models of different complexity. J. Environ. Monit., 2009, **11**, 584-593

Hoekstra, C. & J.N.B. Poelman, 1982. Dichtheden van gronden gemeten aan de meest voorkomende bodemeenheden in Nederland, STIBOKA, Wageningen

Jeuken, M.H.J.L, 2004a, Description of input files for SWQN (version 1.07). Internal note, Alterra, Wageningen

Jeuken, M.H.J.L, 2004b, Short description of NuswaLite (version 1.12). Internal note, Alterra, Wageningen

Johnsson, H., M. Larsson, K. Mårtensson, & M Hoffmann,. 2002. SOILNDB: A decision support tool for assessing nitrogen leaching losses from arable land. Environmental Modelling & Software 17: 505-517.

Joint Research Centre. EuroHarp: Data for Core Catchments, 2002–2004. URL http://viso.ei.jrc.it/euroharp nov/index cc.htm.

Kirk McClure Morton ,2001. The Lough Derg and Lough Ree Catchment Monitoring and Management System. Final Report.

Kolk, J.W.H. van der & J. Drent, 1996. NUSWA – a mathematical model to predict the fate of nutrients in surface water systems. Internal Report 402, DLO-Winand Staring Centre, Wageningen.

Kroes, J.G. & J.C. van Dam, 2003. Reference manual SWAP version 3.0.3. Alterra, Wageningen. Report 773.

Kronvang B., H. Behrendt, H. E. Andersen, B. Arheimer, A. Barr, S. A. Borgvang, F. Bouraoui, K. Granlund, B. Grizzetti, P. Groenendijk, E. Schwaiger, J. Hejzlar, L. Hoffman, H. Johnsson, Y. Panagopoulos, A. Lo Porto, H. Reisser, O. Schoumans, S. Anthony, M. Silgram, M. Venohr & S. E. Larsen (2009). Ensemble modelling of nutrient loads and nutrient load partitioning in 17 European catchments. J. Environ. Monit., 2009, **11**, 572-583

Kronvang, B., S.E. Larsen., J.P. Jensen & H.E Andersen, 2003 Catchment Report: River Odense, Denmark, trend analysis, retention and source apportionment, EUROHARP report No. 2-2003, NIVA report SNO 4740-2003, Oslo, Norway, 20 pp (In Print).

Kroon, T., P. Finke, I. Peereboom & A. Beusen, 2001. Redesign STONE: De nieuwe schematisatie voor STONE: de ruimtelijke indeling en toekenning van hydrologische en bodemchemische parameters. RIZA rapport 2001.017, RIZA, Lelystad.

Lewis, D.R. & M.B. McGechan, 2002. A review of field scale phosphorus dynamics models. Biosystems Engineering 82(4): 359-380.

Luzio, M. Di, R. Srinivasan & J. Arnold, 2001. ArcView Interface for SWAT2000. User's Guide. Blackland Research center and Grassland, soil and water research laboratory, USA

Makkink, G.F., 1957. Testing the Penman formula by means of lysimeters. Journ. Int. of Water Eng.,11:277-288.

McGechan, M.B. & D.R. Lewis, 2002. Sorption of phosphorus by soil, part 1: principles, equations and models. Biosystems Engineering 82(1):1-24.

Milieu- en Natuurplanbureau, 2002. Minas en milieu. Balans en verkenning. Report 718201005, RIVM, Bilthoven.

Milieu- en Natuurplanbureau, 2004. Mineralen beter geregeld. Evaluatie van de werking van de Meststoffenwet 1998-2003. Report 500031001, RIVM, Bilthoven.

Nash, J. and J.Sutcliffe, 1970. River flow forecasting through conceptual models part 1 – a discussion of principles. Journal of Hydrology, 10, 282-290.

Neitsch S.L., J.G. Arnold, J.R Kiniry & J.R. Williams, 2001. Soil and Water Assessment Tool – Theoretical Documentation - Version 2000, Blackland Research Center – Agricultural Research Service, Texas – USA

OSPAR, 2000. Guideline 8: Principles for Source Apportionment for Quantifying Nitrogen and Phosphorus Discharges and Losses (Reference Number: 2000-1; 00/9/2 Add.8 and 00/20/1, § 9.5a)

Overbeek, G.B.J., et al., 2001. Computing the pollution of soils and groundwater in the Netherlands for the fifth environment exploration with the model STONE; model approach and calculation results. Report 408129020, RIVM, Bilthoven (in Dutch).

Pettersson, A., B Arheimer & B. Johansson, 2001. Nitrogen concentrations simulated with HBV-N: new response function and calibration strategy. Nordic Hydrology 32(3):227-248.

Renaud, L.V., J. Roelsma & P. Groenendijk 2004. User's guide of the ANIMO 4.0 nutrient leaching model. Wageningen, Alterra, Green World Research. Alterra Report 224. 154 pp.

Rijtema P.E., M.F.R. Smit, D. Boels, S.T. Abdel Gawad & D.E. El Quosy, 1991. Formulation of the Water Distribution Model WATDIS. Reuse of Drainage Water Project Report 23. Drainage Research Institute, Cairo, Egypt and The Winand Staring Centre, Wageningen, The Netherlands

Schoumans, O.F. & P. Groenendijk, 2000. Modeling Soil Phosphorus Levels and Phosphorus Leaching from Agricultural Land in the Netherlands. Journal of Environmental Quality 29: 111-116.

Schoumans, O.F. & M. Silgram (eds.), 2003. Review and literature evaluation of nutrient quantification tools. EUROHARP report 1-2003, NIVA report SNO 4739-2003, Oslo, Norway, 120 pp.

Schoumans, O.F., 2004. Quick scan van de milieukundige effecten van een aantal voorstellen voor gebruiksnormen. Report 730.6, Alterra, Wageningen.

Schoumans O.F., M. Silgram, P. Groenendijk, F. Bouraoui, H.E. Andersen, B. Krongvang, H. Behrendt, B. Arheimer, H. Johnsson, Y. Panagopoulos, M. Mimikou, A. Lo Porto, H. Reisser, G. Le Gall, A. Barr & S.G. Anthony (2009a). Description of nine nutrient loss models: capabilities and suitability based on their characteristics. J. Environ. Monit., 2009, **11**, 506-514.

Schoumans O.F., M. Silgram, D.J.J. Walvoort, P. Groenendijk, F. Bouraoui, H.E. Andersen, A. Lo Porto, H. Reisser, G. Le Gall, S. Anthony, B. Arheimer, H. Johnsson, Y. Panagopoulos, M. Mimikou, U. Zweynert, H. Behrendt & A. Barr (2009b). Evaluation of the difference of eight model applications to assess diffuse annual nutrient losses from agricultural land. J. Environ. Monit., 2009, **11**, 540-553

Siderius C., M.H.J.L. Jeuken, P. Groenendijk, L.P.A. van Gerven & A.A.M.F.R. Smit, 2009. Process description of NUSWALITE: A simplified model for the fate of nutrients in surface waters. Report 1226.2, Alterra, Wageningen

Silgram M., S.G. Anthony, A.L. Collins, J. Strőmqvist, F. Bouraoui, O. Schoumans, A. Lo Porto, P. Groenendijk, B. Arheimer, M. Mimikou & H. Johnsson (2009a). Evaluation of diffuse pollution model applications in EUROHARP catchments with limited data. J. Environ. Monit., 2009, **11**, 554-571

Silgram M., O. F. Schoumans, D.J.J. Walvoort, S.G. Anthony, P. Groenendijk, J. Stromqvist, F. Bouraoui, B. Arheimer, M. Kapetanaki, A. Lo Porto & K. Mårtensson (2009b). Subannual models for catchment management: evaluating model performance on three European catchments. J. Environ. Monit., 2009, **11**, 526-539

Simmelsgaard, S.E., K. Kristensen, H.E. Andersen, R. Grant, J.O. Jørgensen & H.S. Østergaard, 2000. An empirical model for calculation of root zone nitrate leaching. DJF rapport Markbrug no. 32, Danmarks JordbrugsForskning, 67 pages (in Danish)

Smit, A.A.M.F.R. & S.T. Abdel Gawad, 1992. Irrigation water distribution in the Nile Delta: A model approach. In: Proceedings of a workshop on water management in irrigated agriculture, Abdel Gawad S.T. and M.F.R. Smit (Eds.), 91-107, Cairo, Egypt.

Smit, A.A.M.F.R., C. Siderius & L.P.A. van Gerven, 2009. Process description of Surface Water; a simplified hydraulic model. Report 1226.1, Alterra, Wageningen.

Stolte, J. & J.H.M. Wösten, 1991. Soil physical discretisation of the catchment area of the river Vecht. Report 45, The Winand Staring Centre.

Swedish, EPA, 1997. Nitrogen from land to sea. Main report. Swedish Environmental Protection Agency, Report 4801, Nordstedts tryckeri AB, Stockholm.

Vagstad, N., H.K. French, H.E. Andersen, H. Behrendt, B. Grizzetti, P. Groenendijk, A. Lo Porto, H. Reisser, C. Siderius, J. Stromquist, J. Hejzlar & J. Deelstra (2009). Comparative study of model prediction of diffuse nutrient losses in response to changes in agricultural practices. J. Environ. Monit., 2009, **11**, 594-601

Van Bakel, P.J.T., T. Kroon, J.G. Kroes, J. Hoogewoud, R. Pastoors, H.Th.L. Massop & D.J.J. Walvoort, 2003. Reparatie Hydrologie voor STONE 2.1. Alterra, Wageningen.

Vinten, A.J.A., 1999. Predicting Nitrate Leaching from Drained Arable Soils Derived from Glacial Till, J. Environment. Qual. 28: 988-996.

Walvoort, Dennis J.J., 2003. User's Manual dbSWAN, Linking Soil Models and Databases. Internal note, Alterra, Wageningen, October 31, 2003

Wolf, J., A.H.W. Beusen, P. Groenendijk, T. Kroon, R. Rötter & H. van Zeijts, 2003. The integrated modeling system STONE for calculating nutrient emissions from agriculture in the Netherlands. Environmental Modelling & Software 18: 597-617

Wösten, J.H.M., A. Lilly, A. Nemes & C. Le Bas, 1999, Development and use of a database of hydraulic properties of European soils, Geoderma 90 (1999) 169-185

Wu, L. & M.B. McGechan, 1998. A Review of Carbon and Nitrogen Processes in Four Soil Nitrogen Dynamics Models. J. Agric. Engng Res. 69: 279-305.

# Appendix 1 Implementation of the USLE for NL-CAT

D. Walvoort

## 1 Introduction

In order to quantify the amounts of P and N added to the surface water system via erosion, the NLCat model has been extended with a simple erosion module. This module is based on the modified and revised Universal Soil Loss Equation (MUSLE, rep. RUSLE). A brief description of this module is given below.

## 2 Formulation of the RUSLE equation

The RUSLE gives the sediment generation E (Mg) for each plot:

$$E = RKLSCP.r$$

Its parameters will be described below.

### 2.1 Rainfall and run-off factor R

The rainfall and run-off factor is given by:

$$R = 11.8(Q_r * q_r^{\max})^{0.56}$$

where $Q_r$ is the daily volume of run-off ($m^3$) generated for each plot, and qmax
r is the peak run-off rate(m3/s):

$$q_r^{\max} = \frac{pQ_r}{24 * 3600}$$

where p is assumed to be 0.1.

### 2.2 Soil erodibility factor K

The soil erodibility factor has been computed according to Williams (1995):

$$K = b_1 b_2 b_3 b_4$$

where

$$b_1 = 0.2 + 0.3e^{-25.6 f_{sand}(1 - f_{silt})}$$

$$b_2 = \left( \frac{f_{silt}}{f_{clay} + f_{silt}} \right)^{0.3}$$

$$b_3 = 1 - \frac{25 f_{oc}}{100 f_{oc} + e^{3.72 - 295 f_{oc}}}$$

$$b_4 = 1 - \frac{0.7(1 - f_{sand})}{1 - f_{sand} + e^{-5.51 + 22.9(1 - f_{sand})}}$$

where $f_{sand}$ is the sand (50 − 2000µm) fraction, $f_{silt}$ is the silt (2 − 50µm) fraction, $f_{clay}$ is the clay (< 2µm) fraction, and $f_{oc}$ is the organic carbon fraction.

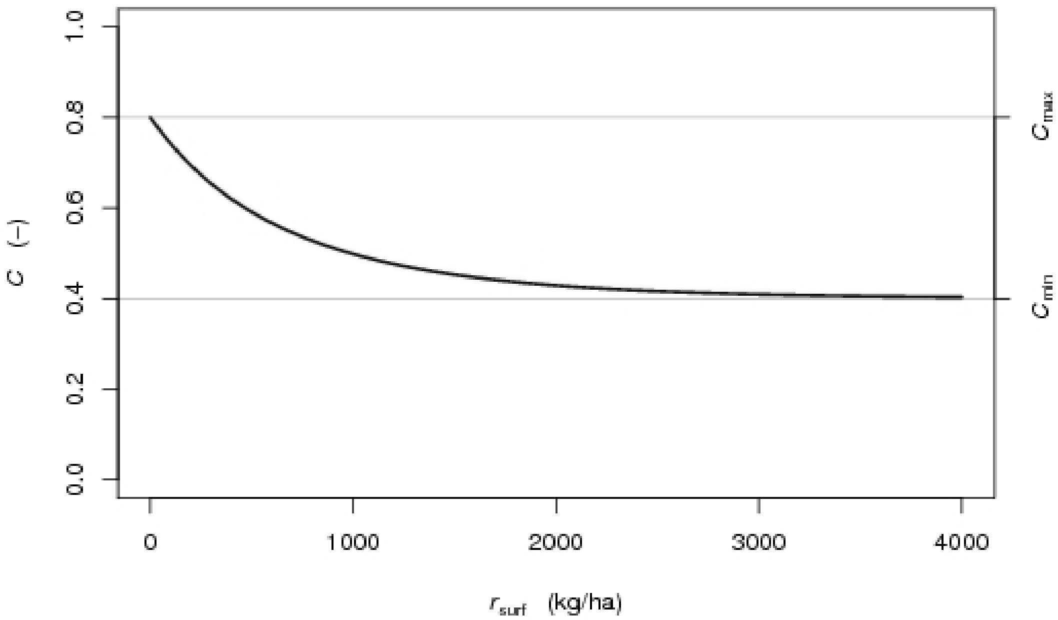



Figure 1: C-factor as function of the amount of residue on the soil surface

## 2.3 Soil cover factor C

The C factor is computed by means of:

$$\log_e C = \log_e \left( \frac{C_{\max}}{C_{\min}} \right) e^{(-0.00115 r_{surf})} + \log_e C_{\min}$$

where $r_{surf}$ is the amount of residue on the soil surface (kg/ha), $C_{max}$ is the maximum C-factor ($C_{max}$ = 0.8), and $C_{min}$ is the minimum C factor. The latter is a function of the average annual C factor for the land cover. A graphical representation is given in Figure 1. This expression has to be adjusted since no information on $r_{surf}$ is available. The following expression will be used in NL-Cat:

$$\log_e C = \log_e \left( \frac{C_{\max}}{C_{\min}} \right) e^{\left( \frac{f_c}{f_c - 1} \right)} + \log_e C_{\min}$$

where $f_c$ is the soil cover fraction (-). $C_{min}$ will be a function of crop type, e.g., row crops will have a greater $C_{min}$ than grass. This expression is given in Figure 2. In NL-Cat, the following values are used for $C_{min}$: $C_{min}$ = 0.4 for grass and nature, and $C_{min}$ = 0.6 for arable land. The soil cover fraction has been estimated by means of (Kroes and van Dam, 2003, p.39):

$f_c$ = LAI/3

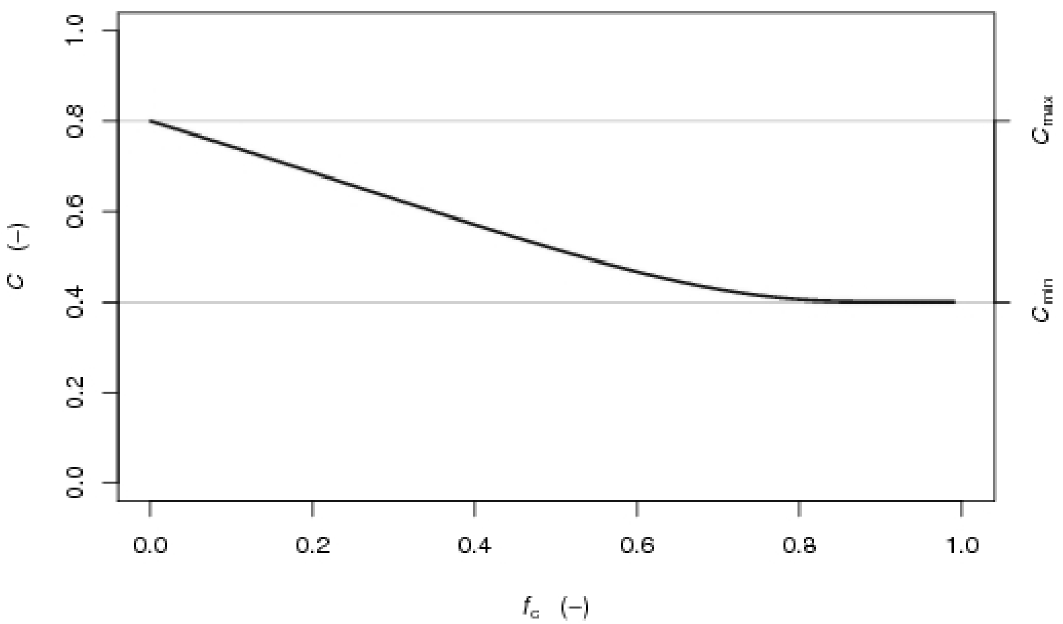



Figure 2: C-factor as function of soil cover fraction fc

## 2.4 Slope length and steepness factor *LS*

The slope length and steepness factor *LS* is a function of slope length *L* (m), and slope angle α (rad)
(SWAT User's manual, 2000).

$$LS = \left(\frac{L}{L_0}\right)^m \left(b_0 + b_1 \sin\alpha + \mathrm{b}_2 \sin^2\alpha\right)$$

Where $L_0$ = 22.1, m = 0.6(1 − e−35.835_), $b_0$ = 0.065, $b_1$ = 4.56, $b_2$ = 65.41. $L_0$ and $\alpha_0$ refer to a reference slope, i.e., a 9% slope of length 22.1 m.

To incorporate the impact of flow convergence, the slope length factor *L* has been replaced by the
upslope contributing area. The latter can be expressed as flow accumulation *F*, i.e., the number of upstream grid cells times the grid size (Mitasova, 1999):

$$LS = (1+m)\left(\frac{F}{F_0}\right)^m \left(\frac{\sin\alpha}{\alpha_0}\right)^n$$

$F_0$ = 22.1, $a_0$= 0.09, $m$ = 0.6, and $n$ = 1.3. Or alternatively (Engel, 2003):

$$LS = \left(\frac{F}{F_0}\right)^m \left(\frac{\sin\alpha}{\alpha_0}\right)^n$$

$F_0$ = 22.13, $a_0$= 0.0896, $m$ = 0.4, and $n$ = 1.3 The latter has been implemented in NL-CAT.
LS varies from 0.1 to 5 in the most frequent farming contexts in West-Africa, and may reach 20 in mountainous areas.

## 2.5 Coarse fragment factor r

The coarse fragment factor r is given by:

$$r = e^{-5.3 f_{rock}}$$

where frock is the fraction of rock in the first soil layer (-).

## 3 Amounts of particulate N and P due to hill-slope erosion

The amount of particulate $P_{part}$ (Mg) is estimated by means of:

$$P_{part} = P \frac{E}{\rho D}$$

where $P$ is the amount of P in the top soil (kg/m$^2$), $D$ is the thickness of the top soil (m), $\varrho$ is the dry bulk density of the top soil (kg/m$^3$), and $E$ is the sediment yield (Mg). Likewise, the amount of
particulate N (Mg) is given by:

$$N_{part} = N \frac{E}{\rho D}$$

where $N$ is the amount of N in the top soil (kg/m$^2$).

The amounts of N and P in the top soil are extracted from the following output files of ANIMO: *sorbed-N.Out, *solid-N.Out, *sorbed-P.Out, *solid-P.Out, and *precip-P.Out.

## References

B. Engel. Estimating soil erosion using RUSLE (Revised Universal Soil Loss Equation) using ArcView. http://pasture.ecn.purdue.edu/ engelb/agen526/gisrusle/gisrusle.html, 2003.

J.G. Kroes and J.C. van Dam. Reference Manual SWAP version 3.0.3. Wageningen University & Research Centre, version 3.0.3 edition, December 2003.

H. Mitasova. Modeling soil detachment with RUSLE 3d using GIS. http://skagit.meas.ncsu.edu/ helena/gmslab/erosion/usle.html, 1999.

# Appendix 2 Reference evaporation according to Makkink

Reference-evaporation $E_{Mak}$ (kg m$^{-2}$ d$^{-1}$ or mm d$^{-1}$) is calculated according to Makkink (1957):

$$\lambda_E E_{Mak} = C_1 R_s \frac{\Delta_v}{\Delta_v + \gamma} + C_2$$

Where: $\lambda_E$ is latent heat of vaporization (J kg$^{-1}$), $\Delta_v$ is the slope of the vapor pressure curve (dimensionless), $\gamma$ is psychometric constant (Pa $^o$C$^{-1}$), $R_s$ is the global solar radiation (J m$^{-2}$ d$^{-1}$), $C_1$ and $C_2$ are constants.
De Bruin (1981) found values of $C_1$ = 0.65 and $C_2$ = 0.0.

Global radiation ($R_s$) is calculated according to FAO (FAO, 1998) based on relative sunshine duration and latitude of the monitoring station.

Other parameters are determined according to Swap 3.0.3 (Kroes and Van Dam eds, 2003):

- latent heat of vaporization $\lambda_E$ (MJ kg$^{-1}$):

$$\lambda_E = 2.501 - 0.002361\, T$$

where: $T$ is average day temperature ($^o$C)

- psychrometer constant $\gamma$ (Pa $^o$C$^{-1}$):

$$\gamma = 0.00163 \frac{P_{atm}}{\lambda_E}$$

Where: $P_{atm}$ is atmospheric pressure at soil surface (kP$_a$)

- slope of the vapor pressure curve $\Delta_v$ (-):

$$\Delta_v = \frac{2504\, e^{\frac{17.27\,T}{237.3+T}}}{\left(T + 237.3\right)^2}$$

Where: $T$ is the average day temperature ($^o$C)

- Average day temperature $T$ ($^o$C) is derived from daily minimum and maximum temperature (respectively $T_{min}$, $T_{max}$) and length of the day according to:

$$T = f\ T_{max} + (1 - f) T_{min}$$
$$with \quad f = 0.025 L_{day} + 0.15$$

Where: length of day ($L_{day}$ in hrs) is determined from the latitude.

# Appendix 3 NuswaLite parameters for the Odense catchment

*Living Biomass Parameters*

NitrogenDMRatio= 0.1
PhosphorusDMRatio= 0.005
LightExtCoef= 0.23
RespirationRate= 0.25

MortalityRate= 0.015
Q10MortalityRate= 0.0

ConcNitrCritUpt= 0.00001
ConcNitrMonod= 1
ConcPhosCritUpt= 0.00001
ConcPhosMonod= 0.1
InflowCFB=0.0

*Parameters*

Latitude=55.29

MineralizationRate=0.5
Q10Mineralization=0.047

DenitrificationRate=0.2
Q10Denitrification=0.045

BulkDensity = 300000
LinSorptionNMin=0.0001
LinSorptionNMax=0.0001
LinSorptionNDayMax=240

LinSorptionPMin=0.0060
LinSorptionPMax=0.006
LinSorptionPDayMax=30

SedimentSinkSpeed=0.04

# Appendix 4  NuswaLite parameters for the Zelivka catchment

*Living Biomass Parameters*

NitrogenDMRatio= 0.1
PhosphorusDMRatio= 0.005
LightExtCoef= 0.8
RespirationRate= 0.2

MortalityRateFloat= 0.05

RootStartSeason = 100
RootEndSeason = 300
MortalityRateRootSeason = 0.005
MortalityRateRootWinter = 0.01
Q10MortalityRate= 0.05

DepthMortalityRate= 0.75

Q10MortalityRate= 0.05

ConcNitrCritUpt= 0.00001
ConcNitrMonod= 10
ConcPhosCritUpt= 0.00001
ConcPhosMonod= 0.1
InflowCFB=1

*Parameters*

Latitude=49.72

MineralizationRate=0.30
Q10Mineralization=0.047

DenitrificationRate=0.003
Q10Denitrification=0.045

BulkDensity = 300000
LinSorptionNMin=0.0001
LinSorptionNMax=0.0001
LinSorptionNDayMax=240

LinSorptionPMin=0.005
LinSorptionPMax=0.01
LinSorptionPDayMax=90

SedimentSinkSpeed=0.15

# Appendix 5 NuswaLite parameters for the Vecht catchment

*Living Biomass Parameters*

NitrogenDMRatio= 0.1
PhosphorusDMRatio= 0.005
LightExtCoef= 0.23
RespirationRate= 0.2

MortalityRateFloat= 0.05
RootStartSeason = 100
RootEndSeason = 250
MortalityRateRootSeason = 0.005
MortalityRateRootWinter = 0.05
Q10MortalityRate= 0.05
DepthMortalityRate= 0.75

ConcNitrCritUpt= 0.00001
ConcNitrMonod= 7
ConcPhosCritUpt= 0.00001
ConcPhosMonod= 0.2
InflowCFB=1

*Parameters*

Latitude=52.27

MineralizationRate=0.25
Q10Mineralization=0.047
DenitrificationRate=0.07
Q10Denitrification=0.045

BulkDensity = 300000
LinSorptionNMin=0.00005
LinSorptionNMax=0.0002
LinSorptionNDayMax=240

LinSorptionPMin=0.001
LinSorptionPMax=0.001
LinSorptionPDayMax=90

SedimentSinkSpeed=0.1

# Appendix 6 NuswaLite parameters for the Ouse catchment

*Living Biomass Parameters*

NitrogenDMRatio= 0.08
PhosphorusDMRatio= 0.008 # 0.01
LightExtCoef= 0.23
RespirationRate= 0.10

MortalityRateFloat= 0.1
RootStartSeason = 100
RootEndSeason = 250
MortalityRateRootSeason = 0.05
MortalityRateRootWinter = 0.1
Q10MortalityRate= 0.05
DepthMortalityRate= 0.75

ConcNitrCritUpt=0.00001
ConcNitrMonod= 6
ConcPhosCritUpt=0.00001
ConcPhosMonod= 0.1
InflowCFB=1

*Parameters*

Latitude=53.
MineralizationRate=0.4
Q10Mineralization=0.047

DenitrificationRate=0.0015
Q10Denitrification=0.045

BulkDensity = 300000
LinSorptionNMax=0.0001
LinSorptionNMin=0.0001
LinSorptionNDayMax=240

LinSorptionPMin=0.005
LinSorptionPMax=0.01
LinSorptionPDayMax=360

SedimentSinkSpeed=0.02

# Appendix 7 NuswaLite parameters for the Vansjø-Hobøl catchment

*Living Biomass Parameters*

NitrogenDMRatio= 0.1
PhosphorusDMRatio= 0.005
LightExtCoef= 0.23
RespirationRate= 0.15

MortalityRate= 0.05
Q10MortalityRate= 0.0

RootStartSeason=100
RootEndSeason=250
MortalityRateRootSeason=0.05
MortalityRateRootWinter=0.05
MortalityRateFloat=0.05
DepthMortalityRate=9999999

ConcNitrCritUpt=0.00001
ConcNitrMonod= 1
ConcPhosCritUpt=0.00001
ConcPhosMonod= 0.0000001
InflowCFB=0.0

*Parameters*

Latitude=53.
MineralizationRate=0.25
Q10Mineralization=0.047

DenitrificationRate=0.002
Q10Denitrification=0.045

BulkDensity = 400000

LinSorptionNMax=0.0001
LinSorptionNMin=0.0001
LinSorptionNDayMax=240

LinSorptionPMin=0.00125
LinSorptionPMax=0.004
LinSorptionPDayMax=330

SedimentSinkSpeed=0.03

# Appendix 8 Model input for the Vansjø-Hobøl catchment

*Table 1 Definition of soil hydrological parameters*

| | | Top | Bottom | thetar | thetas | Ks | alpha | l | n |
|---|---|---|---|---|---|---|---|---|---|
| Upper | CC | 0 | 25 | 0.01 | 0.52 | 95.22 | 0.06 | -4.78 | 1.10 |
| | LC | 0 | 25 | 0.01 | 0.47 | 66.61 | 0.04 | -2.69 | 1.16 |
| | LL | 0 | 25 | 0.01 | 0.47 | 63.62 | 0.04 | -2.50 | 1.17 |
| | MO | 0 | 20 | 0.00 | 0.77 | 6.67 | 0.02 | -1.85 | 1.15 |
| | SS | 0 | 25 | 0.01 | 0.52 | 88.72 | 0.01 | -0.06 | 1.48 |
| | UD | 0 | 35 | 0.01 | 0.51 | 98.48 | 0.04 | -3.90 | 1.11 |
| | FO | 0 | 35 | 0.01 | 0.51 | 98.48 | 0.04 | -3.90 | 1.11 |
| | OT | 0 | 35 | 0.01 | 0.51 | 98.48 | 0.04 | -3.90 | 1.11 |
| Lower | CC | 25 | 300 | 0.01 | 0.48 | 38.27 | 0.05 | -5.47 | 1.11 |
| | LC | 25 | 300 | 0.01 | 0.48 | 40.15 | 0.05 | -5.43 | 1.11 |
| | LL | 25 | 300 | 0.01 | 0.45 | 45.77 | 0.05 | -3.98 | 1.15 |
| | MO | 20 | 300 | 0.01 | 0.86 | 2.93 | 0.01 | -1.59 | 1.28 |
| | SS | 25 | 300 | 0.01 | 0.44 | 76.98 | 0.02 | 0.04 | 1.70 |
| | UD | 35 | 300 | 0.01 | 0.10 | 0.50 | 0.01 | -4.30 | 1.16 |
| | FO | 35 | 300 | 0.01 | 0.10 | 0.50 | 0.01 | -4.30 | 1.16 |
| | OT | 35 | 300 | 0.01 | 0.10 | 0.50 | 0.01 | -4.30 | 1.16 |

*Table 2Definition of drainage parameters*

| Plot | Drainage tubes | | | Open drainage | | | Interflow | |
|---|---|---|---|---|---|---|---|---|
| ID | distance | Depth | resistance | dist | depth | resistance | coefficient | exponent |
| ANCC | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| ANLC | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| ANLL | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| ANMO | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| ANSS | - | - | - | 150 | -50 | 10 | 0.5 | 0.5 |
| ANUD | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| BNCC | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| BNLC | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| BNLL | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| BNMO | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| BNSS | - | - | - | 150 | -50 | 10 | 0.5 | 0.5 |
| BNUD | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| CNCC | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| CNLC | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| CNLL | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| CNMO | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| CNSS | - | - | - | 150 | -50 | 10 | 0.5 | 0.5 |
| CNUD | 8 | -80 | 500 | 10 | -20 | 30 | 0.01 | 0.1 |
| DNMO | - | - | - | 10 | -20 | 50 | 0.01 | 0.1 |
| ENFO | - | - | - | 10 | -20 | 30 | 0.5 | 0.5 |
| FNOT | - | - | - | 10 | -20 | 30 | 0.5 | 0.5 |

*Table 3 Definition of soil parameters*

| Soil | Horizon | | Density | AlFe | Org.Mat. | Sand | Silt | Clay | pHKCl | CNratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | Top | Bottom | kg/m3 | mmol/kg | % | % of mineral | | | - | - |
| CC | 0 | 25 | 1.24 | 250 | 4.52 | 0.1 | 62.4 | 37.5 | 5.8 | 10 |
| CC | 25 | 75 | 1.54 | 250 | 0.91 | 0.4 | 61.9 | 37.7 | 6.1 | 9 |
| CC | 75 | 300 | 1.54 | 250 | 0.91 | 0.4 | 61.9 | 37.7 | 6.4 | 30 |
| LC | 0 | 25 | 1.24 | 125 | 4.49 | 13.9 | 67.6 | 18.5 | 5.8 | 10 |
| LC | 25 | 75 | 1.57 | 250 | 0.98 | 0.6 | 62 | 37.4 | 6.1 | 9 |
| LC | 75 | 300 | 1.57 | 250 | 0.98 | 0.6 | 62 | 37.4 | 6.4 | 30 |
| LL | 0 | 25 | 1.22 | 125 | 4.59 | 16.4 | 66.3 | 17.3 | 6.4 | 9 |
| LL | 25 | 65 | 1.49 | 125 | 0.99 | 13.2 | 62.7 | 24.1 | 6.5 | 9 |
| LL | 65 | 300 | 1.49 | 125 | 0.99 | 13.2 | 62.7 | 24.1 | 6.7 | 30 |
| MO | 0 | 20 | 0.75 | 100 | 56.47 | 36 | 57.2 | 6.8 | 5 | 15 |
| MO | 20 | 65 | 0.75 | 100 | 56.47 | 36 | 57.2 | 6.8 | 5 | 15 |
| MO | 65 | 300 | 0.75 | 100 | 56.47 | 36 | 57.2 | 6.8 | 5 | 30 |
| SS | 0 | 25 | 1.26 | 50 | 4.53 | 54.4 | 38.8 | 6.8 | 4.6 | 14 |
| SS | 25 | 65 | 1.6 | 50 | 0.8 | 62.5 | 32.2 | 5.3 | 4.6 | 17 |
| SS | 65 | 300 | 1.6 | 50 | 0.8 | 62.5 | 32.2 | 5.3 | 4.8 | 30 |
| UD | 0 | 15 | 1.18 | 125 | 5.55 | 6.6 | 62.8 | 30.6 | 5.8 | 9 |
| UD | 15 | 35 | 1.18 | 125 | 5.55 | 6.6 | 62.8 | 30.6 | 5.8 | 9 |
| UD | 35 | 65 | 1.18 | 125 | 0.5 | 6.6 | 62.8 | 30.6 | 6.1 | 30 |
| UD | 65 | 300 | 1.18 | 125 | 0.5 | 6.6 | 62.8 | 30.6 | 6.4 | 30 |
| FO | 0 | 15 | 1.18 | 125 | 1 | 6.6 | 62.8 | 30.6 | 7.1 | 25 |
| FO | 15 | 35 | 1.18 | 125 | 1 | 6.6 | 62.8 | 30.6 | 7.1 | 25 |
| FO | 35 | 300 | 1.18 | 125 | 0.5 | 6.6 | 62.8 | 30.6 | 7 | 30 |

*Table 4 Initial condition P sorption*

| Parent material | Top | Bottom | PoxAlFe | COPOEB |
|---|---|---|---|---|
| peat | 0 | 10 | 0.04 | 0.0002 |
| | 10 | 35 | 0.02 | 0.0002 |
| | 35 | 65 | 0.02 | 0.0001 |
| | 65 | 100 | 0.02 | 0.0001 |
| | 100 | 1300 | 0.02 | 0.0001 |
| sand | 0 | 10 | 0.021 | 0.0002 |
| | 10 | 35 | 0.021 | 0.0002 |
| | 35 | 65 | 0.02 | 0.0001 |
| | 65 | 100 | 0.016 | 0.0001 |
| | 100 | 1300 | 0.016 | 0.0001 |
| clay | 0 | 10 | 0.05 | 0.0002 |
| | 10 | 35 | 0.04 | 0.0002 |
| | 35 | 65 | 0.02 | 0.0001 |
| | 65 | 100 | 0.03 | 0.0001 |
| | 100 | 1300 | 0.03 | 0.0001 |
| forest | 0 | 10 | 0.05 | 0.00005 |
| | 10 | 35 | 0.04 | 0.00005 |
| | 35 | 65 | 0.02 | 0.00005 |
| | 65 | 100 | 0.03 | 0.00005 |
| | 100 | 1300 | 0.03 | 0.00005 |

*Table 5 Oxygen diffusion parameters*

| | Coefficient | Exponent |
|---|---|---|
| CC | 1.5 | 2.5 |
| LC | 1.5 | 2.5 |
| LL | 1.5 | 2.5 |
| MO | 0.06 | 1.5 |
| SS | 0.4 | 2.5 |
| UD | 1.5 | 2.5 |
| FO | 1.5 | 2.5 |
| OT | 1.5 | 2.5 |

*Table 6 Material and general ANIMO parameters*

| Description | Value | Unit |
|---|---|---|
| Assimilation efficiency of dissolved organic matter | 0.1 | - |
| Assimilation efficiency of exudates | 0.1 | - |
| Assimilation efficiency of humus/biomass | 0.25 | - |
| Reduction factor for organic transformations under oxygen limited situations | 0.5 | - |
| Decomposition rate for organic dissolved matter | 30 | $a^{-1}$ |
| Denitrification rate (only active under nitrate limited conditions) | 0.005 | $a^{-1}$ |
| Decomposition rate for root exudates | 365 | $a^{-1}$ |
| Decomposition rate for humus biomass | 0.02 | $a^{-1}$ |
| Nitrification rate | 365 | $a^{-1}$ |
| Mass fraction transformed directly into humus | 0.75 | kg/kg |
| Nitrogen content of exudates | 0.025 | kg/kg |
| Nitrogen content of humus biomass | 0.048 | kg/kg |
| Phosphorus content of exudates | 0.0025 | kg/kg |
| Phosphorus content of humus biomass | 0.006 | kg/kg |
| Thickness of top of soil compartment | 0.02 | m |
| Thickness of soil compartment | 0.20 | m |
| Fraction of runoff passing the surface reservoir | 0.2 | |
| Fraction of runoff passing the first soil layer | 0.25 | |

*Table 7 Crop parameters*

| Description | Grain | Grass | Forest | unit |
|---|---|---|---|---|
| Length of crop cycle: 1 = fixed, 2 = variable | 1 | 1 | 1 | - |
| Emergence | 5-1 | 1-1 | 1-1 | date |
| Harvest | 9-1 | 12-30 | 12-30 | date |
| Length of the crop cycle | 124 | 366 | 366 | d |
| Extinction coefficient for diffuse visible light | 0.6 | 0.75 | 0.73 | - |
| Extinction coefficient for direct visible light | 1 | 0.75 | 0.73 | - |
| Choice between LAI [=1] or soil cover fraction [=2] | 1 | 1 | 2 | - |
| Choice between crop factor [=1] or crop height [=2] | 1 | 2 | 1 | - |
| No water extraction at higher pressure heads | 0 | 0 | -1 | cm |
| h below which optimum water extraction starts for top layer | -1 | -1 | -2 | cm |
| h below which optimum water extraction starts for sub layer | -1 | -1 | -2 | cm |
| h below which water uptake reduction starts at high Tpot | -500 | -200 | -60 | cm |
| h below which water uptake reduction starts at low Tpot | -900 | -800 | -60 | cm |
| No water extraction at lower pressure heads | -16000 | -8000 | -600 | cm |
| Minimum canopy resistance | 70 | 70 | 70 | s/m |
| Level of high atmospheric demand | 0.5 | 0.5 | 0.5 | cm/d |
| Level of low atmospheric demand | 0.1 | 0.1 | 0.1 | cm/d |
| Ecsat level at which salt stress starts | 6 | 5.6 | 5.6 | dS/m |
| Decline of rootwater uptake above ECMAX | 4 | 7.6 | 7.6 | %/dS.m |

| | | | | |
|---|---|---|---|---|
| Switch for rainfall interception method 0 = no interception, 1 = ag.crops (COFAB), 2 = Closed forest | 1 | 0 | 2 | - |
| Interception coefficient Von Hoyningen-Hune and Braden | 0.25 | 0.25 | 0.25 | cm |
| Switch for applicatoin irrigation scheduling [Y=1, N=0] | 0 | 0 | 0 | - |
| Aeric mass of tubers harvested | 0 | - | 0 | kg/ha |
| Expected cumulative N-uptake in period 1 | 78 | - | 250 | kg/ha |
| Expected cumulative N-uptake in period 2 | 33 | - | 250 | kg/ha |
| Cumulative transpiration in first period | 0.121 | - | 0.45 | m |
| Cumulative transpiration in second period | 0.072 | - | 0.45 | m |
| Julian daynumber when max. N-uptake rate alters | 197 | - | 366 | d |
| Maximum selectivity factor for N-uptake | 5 | - | 5 | - |
| Factor for actual transpiration in crop uptake | 1 | - | 1 | - |
| Expected cumulative P-uptake in period 1 | 13 | - | 50 | kg/ha |
| Expected cumulative P-uptake in period 2 | 6 | - | 50 | kg/ha |
| maximum root mass obtained at the end of the growing season | 1600 | - | 4500 | kg/ha |

*Table 8 Specific parameters for grass*

| Description | value | unit |
|---|---|---|
| Selectivity factor for NH4-N uptake by convective transpiration flow | 1 | - |
| Transpiration stream concentration factor for phosphate in grassland | 5 | - |
| Maximum shoot production | 0.35 | kg/m2 |
| Mass fraction of shoots lost by grazing | 0.2 | kg/kg |
| Mass fraction of shoots lost by harvesting | 0.05 | kg/kg |
| Relative duration of sunshine | 0.321 | - |
| Shoot production rate | 2.3 | - |
| Turnover rate for dying of roots | 0.0055 | 1/d |
| Management factor grasslands | 1 | - |
| Day number of first day of growing season | 121 | - |
| Day number of last day of growing season | 274 | - |
| Day number of start of grazing season when AMSHMIGRSTART has not been exceeded | 130 | - |
| Minimum quantity of grass shoots required for grazing within the period | 0.175 | kg/m2 |
| Amount of shoots to be exceeded when harvesting will occur in a combined system of cutting and grazing | 0.375 | kg/m2 |
| First order diffusion rate coefficient for NO3-N uptake | 0.0028 | 1/d |
| Amount of shoots to be exceeded when harvesting will occur in a system of cutting only | 0.375 | kg/m2 |
| Amount of remaining shoots after a cutting event in a combined system of cutting and grazing | 0.165 | kg/m2 |
| Amount of remaining shoots after a cutting event in a system of cutting only | 0.075 | kg/m2 |
| Efficiency factor for gross dry matter production in shoot system of grassland | 1 | - |
| Weight fraction of grass shoots dry matter | 0.6 | - |
| Day number where the maximum gross dry matter production is expected (related to light interception) | 182 | - |
| Reduction factor for grass production due to grazing by cattle | 1 | kg/kg |
| Minimum nitrogen content of grass shoots | 0.019 | kg/kg |
| Maximum nitrogen fraction in shoot | 0.05 | kg/kg |
| Minimum nitrogen content of grass roots | 0.0076 | kg/kg |
| Maximum nitrogen content of grass roots | 0.02 | kg/kg |
| Transpiration stream concentration factor for nitrate in grassland (convective uptake) | 1 | - |
| Transpiration stream concentration factor for nitrate in grassland (diffusive uptake) | 0.028 | 1/d |
| Minimum phosphorus content of grass shoots | 0.003068 | - |
| Maximum phosphorus content of grass shoots | 0.00543 | - |
| Minimum phosphorus content of grass roots | 0.001786 | - |
| Maximum phosphorus content of grass roots | 0.003163 | - |

*Table 9 Composition of slurry in Vansjø-Hobøl*

| Weight fraction | Cattle slurry | Pig slurry | Poultry slurry |
|---|---|---|---|
| Dry matter | 0.07000 | 0.06800 | 0.33000 |
| Organic matter | 0.03000 | 0.05417 | 0.19375 |
| Ammonium | 0.00180 | 0.00320 | 0.00550 |
| Organic nitrogen | 0.00150 | 0.00260 | 0.00930 |
| Total nitrogen | 0.00330 | 0.00580 | 0.01480 |
| Phosphate | 0.00045 | 0.00126 | 0.00547 |
| Organic phosphorus | 0.00015 | 0.00026 | 0.00093 |
| Total phosphorus | 0.00060 | 0.00152 | 0.00640 |

# Appendix 9 The Zelivka catchment – Scenario analysis

C. Siderius

## Contents

# 1 Introduction

This report describes the modelling of 6 different scenarios for the Zelivka Catchment in central Czechia by Alterra within the European Euroharp project.

The Zelivka catchment is situated some 50 km southeast of the Czechian capitol of Prague and measures 1189 $km^2$. It is a tributary of the Sazava River. Its elevation ranges from 318 m to 765 m with an average of 552 m. The Zelivka reservoir at the end of the catchment is the most important source of drinking water for the capitol. The periodically deteriorating water quality of the Zelivka River as a result of high nitrate and phosphorus loads is therefore an important concern.

The main land covers are arable land and forest. Interesting is the drop in fertilisation of arable land by about 35% in the early 90's after the political turnover. Despite this large decrease only a slight reduction in concentrations and loads for the period 1996-2000 can be observed. This scenario exercise of the Euroharp project looks further into this kind of land use and management changes. For testing the different models in their capability to deal with land use changes the modelling of the following changes in land management are proposed:

A 20 % increase in N and P applications by inorganic fertilisers
B 20 % decrease in N and P applications by inorganic fertilisers
C 20 % increase in livestock numbers
D 20 % decrease in livestock numbers
E Area of the predominant crop increases to cover the entire agricultural land
F 20 % of the agricultural areas are abandoned and replaced by forestry

Based on the provided input data water levels, crop development and nutrient uptake, discharges, concentrations and finally loads are modelled with the Alterra NL-Cat package. The set up and results of the various scenarios will be described in this report.

# 2 Reference situation

The study was carried out with the NL-Cat package which consists of the sub models:

- for soil hydrology: Swap version 3.0.3 (Kroes and Van Dam, 2003);
- for soil nutrients: Animo version 4.0.14 (Groenendijk *et al*, in prep, Renaud *et al*, 2004);
- for surface water quantity: SWQN version 1.0.7 (Smit *et al.*, 2008);
- for surface water quality: NuswaLite version 1.16 (Siderius *et al.*, 2008).

The measures defined for the scenarios mainly focus on changes in land use and fertilizer input. The reference input on land management and fertilizer use and its results will be explained briefly in this chapter. More detailed information can be found in the Euroharp Zelivka Catchment report.

## 2.1 Current land management

In the Zelivka catchment 5 land use classes (table 1 and figure 1) were defined. Urban area and water are not used for the soil water modelling discretisation. This leaves 3 land use units, arable, forest and natural grassland.

Table 1 Distribution of land use (km2 and as % of the total catchment area)

| land use | $km^2$ | % |
|---|---|---|
| Arable | 614.0 | 51.7 |
| Forest | 357.3 | 30.1 |
| Grassland | 148.0 | 12.5 |
| Urban area | 48.2 | 4.1 |
| Water | 20.0 | 1.7 |

The area of open water is integrated in the surface water modelling. The urban area is assumed to be reacting as well drained grassland and is added to the area of a drained grassland plots or a grassland plot with a deep groundwater table in each subcatchment.

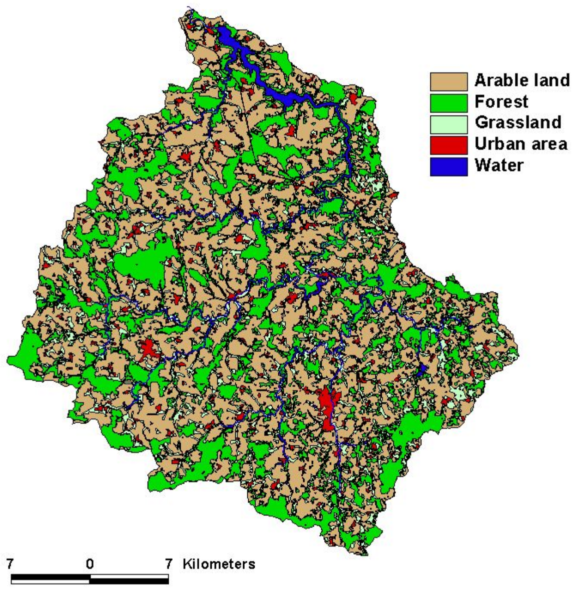



*Figure 1 land cover map*

The different land covers (table 2) were simulated using default parameter sets for arable land, grassland and forest. Only for rape, winter wheat, spring barley and clover the Leaf Area Index (LAI) was adjusted for the Zelivka climatic region with the Wofost crop growth simulator (Boogaard et al., 1998) using climatic data from southern Germany. All other parameters like rooting depth and water and salt stress for arable, forest and grassland were derived from standard SWAP crop parameters. Winter wheat is the most dominant crop and therefore present twice in this rotation (23% of arable area).

*Table 2 Parameter sets for the distinguished land cover types*

| Land cover nr | | Land cover type |
|---|---|---|
| 1 | Arable | Rotation winter wheat - rape - corn – w. wheat - potatoes – clover – s. barley |
| 9 | Grass | Natural grassland |
| 11 | Grass | Cultivated grassland |
| 17 | Forest | forest coniferous |
| 2 | Urban | not simulated by soil models |
| 5 | Water | not simulated by soil models |

Table 3 shows the emergence dates of the different crops.

*Table 3 Original and modelled emergence and harvesting dates for arable crops*

| | | Original dates | | Modelled dates | |
|---|---|---|---|---|---|
| year | cropID | emergence | harvest | emergence | harvest |
| 1 | potatoes | 05-01 | 09-10 | 05-01 | 09-10 |
| 2 | w.wheat | 09-20 | 07-05 | 01-01 | 08-01 |
| 3 | rape | 08-25 | 07-10 | 01-01 | 08-01 |
| 4 | corn | 03-20 | 09-10 | 03-20 | 10-01 |
| 5 | w.wheat | 09-20 | 07-05 | 01-01 | 08-01 |
| 6 | clover | 03-20 | 09-10 | 01-01 | 12-30 |
| 7 | s.barley | 04-01 | 09-01 | 04-01 | 09-01 |

## 2.2 Historical manure and fertilizer input

An analysis of historical fertilizer and manure applications with average data available for three periods (1988-1992, 1993-1996 and 1997-2000) resulted in values as given in table 4. Both manure and fertilizer use is decreasing in the last decade.

*Table 4 Historical yearly average fertilizer applications (kg/ha)*

| | Period | Manure | | Fertilizer | | N Fixation | |
|---|---|---|---|---|---|---|---|
| | | N | P | N | P | N | P |
| Arable | 1947-1987 | 75 | 18 | 85 | 28 | 34 | 4 |
| | 1988-1994 | 60 | 15 | 52 | 10 | 34 | 4 |
| | 1995-2001 | 55 | 13 | 52 | 8 | 34 | 4 |
| Cultivated grassland | 1947-2001 | 60 | 15 | | | 17 | 4 |
| Natural grassland | 1947-2001 | | | | | 37 | 4 |
| Forest | 1947-2001 | | | | | 37 | 4 |

On arable land manure is applied in three applications spread over October. Fertilizer N and P are applied in three applications in April. Manure on cultivated grassland was applied the first of each month from April till September. No information was available on the differences in fertilizer and manure input for different crops. N and P inputs were therefore the same for all crops.

The 34 kg N fixation on arable land comes totally from clover (80 kg N/yr on 14% of arable land) and rape (40 kg N/yr on 14% of arable land). On grassland and forest a constant N fixation of 17 – 34 kg N/yr was applied depending on the availability of additional manure N.

## 2.3 Current loads

In table 5 the average N balance over the last 14 years of the soil nutrient model for all agriculture (including cultivated grassland) plots is given. As can be seen a slight decrease in storage is modelled. Especially during the last 10 to 15 years fertilizer input is quite low. Crops like rape and clover do add some extra N and P by biological N fixation (in table 15 lumped with Fertilizer and Manure amounts).

*Table 5 Nitrogen balance for agriculture (kg ha$^{-1}$ yr$^{-1}$)*

| | Fertilizer | Manure | Deposition | Net crop uptake | discharge | seepage | volatilization | denitrification | Δ storage |
|---|---|---|---|---|---|---|---|---|---|
| In | 59 | 69 | 12 | | | | | | |
| Out | | | | 105 | 27 | 3 | 2 | 21 | |
| Δ stor. | | | | | | | | | -19 |

Total loads in the surface water midstream (4200) and near the outlet (1000) after the Zelivka reservoir are presented in figures 2 till 5 (for location see figure 5). Total retention in the surface water is on average 40% for Nitrogen and 92% for Phosphorus.

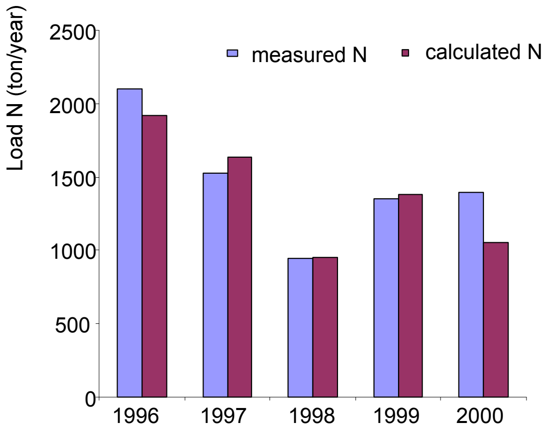



*Figure 2 Annual N loads for point 1000*

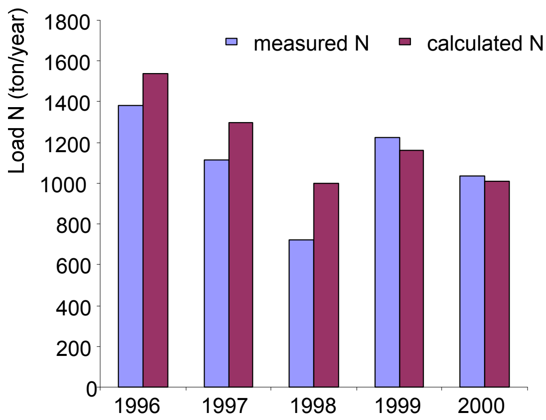



*Figure 3Annual N loads for point 4200*

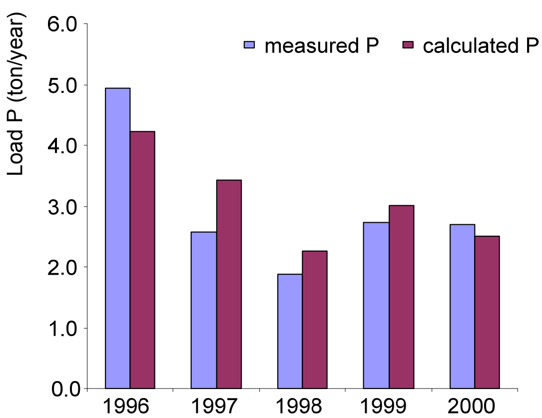



*Figure 4 Annual P loads for point 1000*

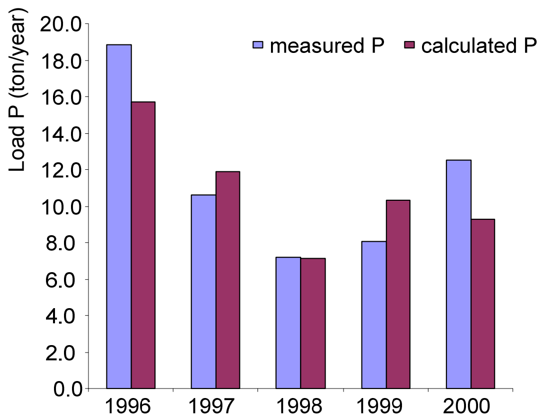



*Figure 5 Annual P loads for point 4200*

Measured and calculated total yearly loads do correspond quite well. Also modelled daily concentrations on which the loads are based did correspond well which confirms of the capability of the NL CAT model to simulate the reference situation.

# 3 Scenarios

## 3.1 Introduction

This report describes the modelling of 6 different scenarios for the Introduction

The following scenario measures were defined:

A 20 % increase in N and P applications by inorganic fertilizers
B 20 % decrease in N and P applications by inorganic fertilizers
C 20 % increase in livestock numbers
D 20 % decrease in livestock numbers
E Area of the predominant crop increases to cover the entire agricultural land
F 20 % of the agricultural areas are abandoned and replaced by forestry

The changes according to the scenarios are made year by year over the validation period, in the Zelivka case from 1995-2001. All other data and model settings are kept similar to the reference situation.

For the Zelivka catchment results are given for two stations no. 4200 and 1000, (i.e. upstream and down stream large lake) as some of the (other) distributed models are not developed to include lakes and can only calculate loads at station 4200. Figure 6 shows station 4200 and 1000.

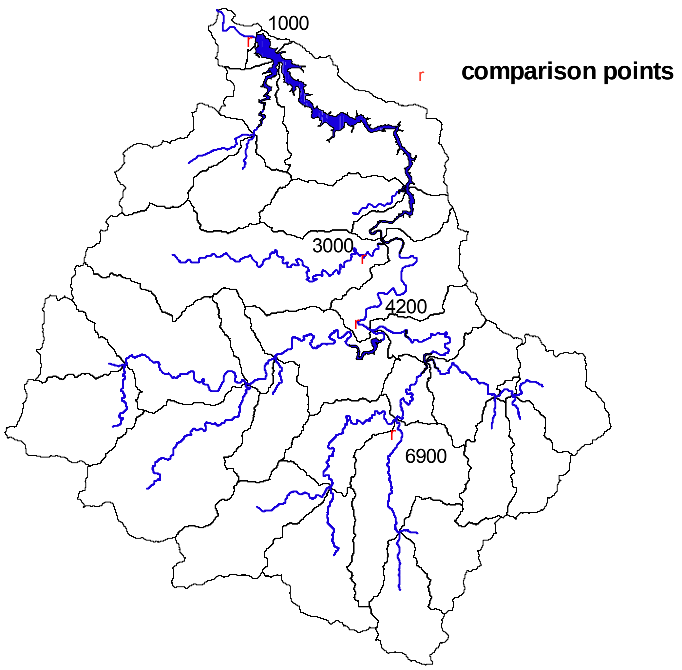



*Figure 6 comparison points*

## 3.2 Scenario A and B

### Setup

Table 6 shows how an increase (Scenario A) or a decrease (Scenario B) of 20% of N and P applications by inorganic fertilizers is modelled.

*Table 6 Manure and fertilizer applications for various land uses*

| | Period | | Manure | | Fertilizer | | N Fixation | |
|---|---|---|---|---|---|---|---|---|
| | | | N | P | N | P | N | P |
| Arable | 1947-1987 | | 75 | 18 | 85 | 28 | 34 | 4 |
| | 1988-1994 | | 60 | 15 | 52 | 10 | 34 | 4 |
| | 1995-2001 | Reference | 55 | 13 | 54 | 9 | 34 | 4 |
| | | Scenario A | | | 64.8 | 10.8 | | |
| | | Scenario B | | | 43.2 | 7.2 | | |

### Results

Although fertilizer application is increased or decreased by 20% the change in loads is only a few percent (figures 7 and 8, a and b). There are various reasons for this small difference.

First of all, fertilizer applications are already quite low after the political turnover at the end of the eighties – beginning of the nineties. So a 20% increase or decrease is relatively small in absolute terms. Moreover crops have the capacity to use, for a large part, the extra amount of fertilizer. The uptake increases first. Furthermore extra N and P input also reduce the depletion of the soil storage of N and P.

Finally also the surface water body can buffer an increase or decrease in nutrient discharge from the soil. This can be seen by the difference in % change between station 4200 and 1000, with the large Zelivka reservoir in between.
What is somewhat remarkable is that an increase in organic P application can cause a decrease in loads during a short period in winter and vice versa.

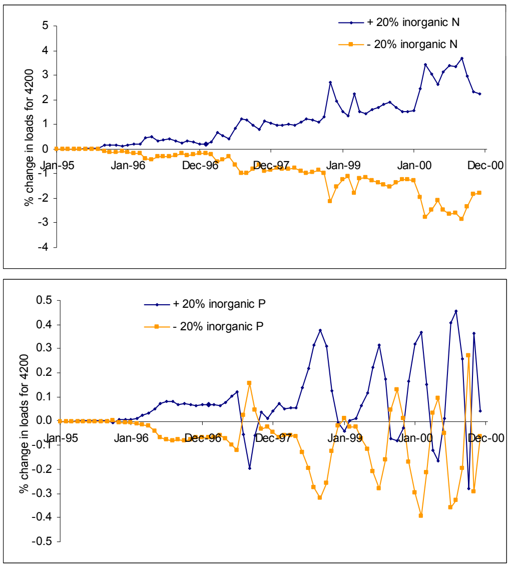



*Figure 7 a and b Changes in N and P loads for station 4200*

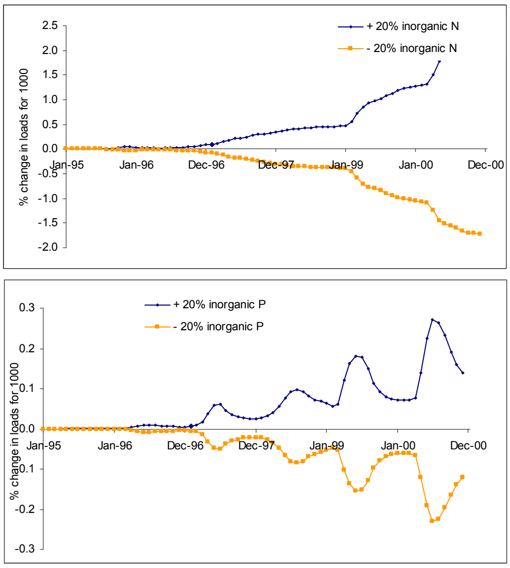



*Figure 8 a and b Changes in N and P loads for station 1000*

## 3.3 Scenario C and D

### Setup

Table 7 shows how an increase or decrease of 20% in livestock numbers affects N and P applications.

*Table 6 Manure and fertilizer applications for various land uses*

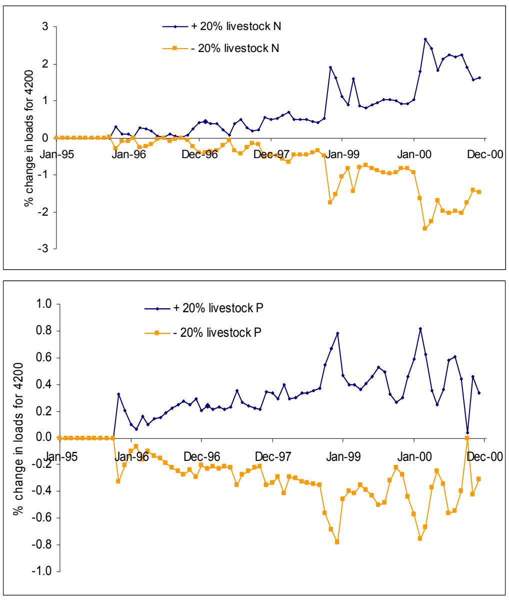
| | Period | | Manure | | Fertilizer | | N Fixation | |
|---|---|---|---|---|---|---|---|---|
| | | | N | P | N | P | N | P |
| Arable | 1947-1987 | | 75 | 18 | 85 | 28 | 34 | 4 |
| | 1988-1994 | | 60 | 15 | 52 | 10 | 34 | 4 |
| | 1995-2001 | Reference | 55 | 13 | 54 | 9 | 34 | 4 |
| | | Scenario C | 66 | 15.6 | | | | |
| | | Scenario D | 44 | 10.4 | | | | |

### Results

Similar to scenario A and B also a change in manure amounts gives only slight change in loads. The same effect of buffering in the surface water between station 4200 and 1000 can be seen.

There are some small differences. The change in organic P (scenarios C and D) is higher and does not give such fluctuating changes in loads as a change in inorganic P (compare figure 9b with 7b). This can be explained by the inorganic P absorbing capacity of the soil which buffers inorganic P leaching, while organic P is released more directly. Furthermore Manure/Inorganic P application is higher than organic P application so a 20% increase or decrease can have more effect.

For N the opposite can be seen. Here an increase in inorganic N gives the largest change in loads as mineral inorganic N is the largest contributor to N concentrations in soil and surface water and is released faster.



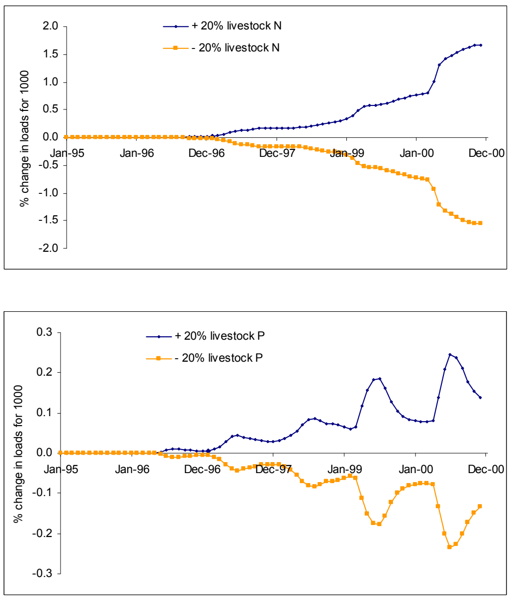




*Figure 9 a and b Changes in N and P loads for station 4200*

*Figure 10 a and b Changes in N and P loads for station 1000*

## 3.4 Scenario E and F

### Setup

In the Zelivka catchment winter wheat is the most dominant crop. In scenario E it is used over the entire agricultural land (defined as the cultivated land) from 1995 onwards with the exception of all cultivated grassland plots.

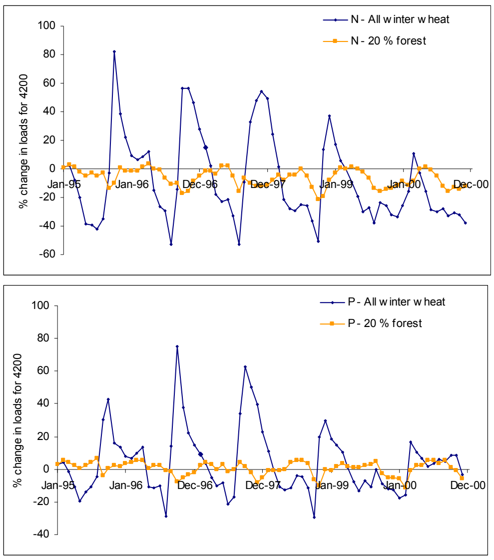
In scenario F 20 % of agricultural land is transformed into forest after 1995. To use the historically developed characteristics of each, previously arable, plot (in organic matter content, nutrient concentrations etc) a new calculation was made in which all arable plots become forested after 1995. 20 % of nutrient and water outputs of this calculation were combined with 80% of the original.

### Results

Large fluctuations can be seen in figure 11 and 12, going from positive to negative. This is the results of the difference in growing period in combination with manure and fertilizer application.
Winter wheat starts growing first of January (table 3) while some other crops in the reference situation like potatoes do no emerge before the first of May. The effect of this early growing period of winter wheat can be seen in figure 11[a] and 11[b] for scenario E, where nutrient loads are lower during spring as they are being "used" by the winter wheat.

In autumn the opposite occurs. Harvest of winter wheat takes place the first of August, so when manure is applied in October no crop is present. The increase in difference in loads compared to the reference situation is highest in this period.

The extra loads decreases over time in scenario E. When only winter wheat is cropped and added fertilizer amounts are kept the same the soil is being exhausted. Yields do not directly decline but storage in the soil decreases and so does the leaching of nutrients, resulting in lower loads.



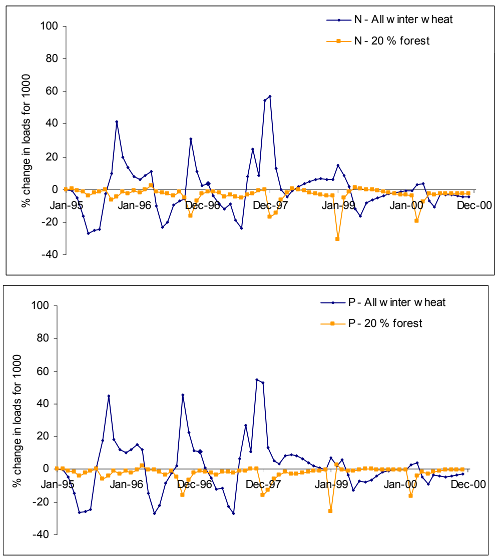




*Figure 11 a and b Changes in N and P loads for station 4200* *Figure 12 a and b Changes in N and P loads for station 1000*

# 4 Conclusions and discussion

- The NL Cat model is very well capable of simulation of the proposed scenarios.

- The NL Cat model can do more. The scenarios are now more or less isolated measures instead of real scenarios. It would be interesting to model various combinations of measures together in one scenario, like an increase in fertilizers, manure and a change in land use representing for example a more intensive agriculture.

- Especially the land use change scenarios seem not very realistic and too narrow defined. A total change to winter wheat is not very likely, especially not when fertilizer applications are not adjusted according to the new situation.

- Furthermore a 20% change to nature or forest can have a much larger effect on nutrient leaching and water discharge when it is concentrated on certain areas like the areas with higher groundwater tables along the river and streams which are now partly drained. Now only an overall percentage change irrespective of location and soil and hydrological characteristics is applied.

- The time span of the scenario modelling is too short. As can be seen the difference in loads is still increasing after 7 years of modelling. It takes a much longer period to see the full effect of changes and to reach a new equilibrium.

# Appendix 10 The Enza catchment – Scenario analysis

D. Walvoort & C. Siderius

## Contents

# 1 Introduction

This report describes the modelling of 6 different scenarios for the Enza Catchment in Italy by Alterra within the Euroharp project.

The scenario exercise of the Euroharp project tests the ability of the model to perform a scenario analysis for the Enza catchment. For testing the different models in their capability to deal with land use changes the modelling of the following changes in land management are proposed:

A 20 % increase in N and P applications by inorganic fertilisers
B 20 % decrease in N and P applications by inorganic fertilisers
C 20 % increase in livestock numbers
D 20 % decrease in livestock numbers
E Area of the predominant crop increases to cover the entire agricultural land
F 20 % of the agricultural areas are abandoned and replaced by forestry

Based on the provided input data water levels, crop development and nutrient uptake, discharges, concentrations and finally loads are modelled with the Alterra NL-Cat package. The set up and results of the various scenarios will be described in this report.

# 2 Scenarios

## 2.1 Introduction

This report describes the modelling of 6 different scenarios for the Introduction

The following scenario measures were defined:
A 20 % increase in N and P applications by inorganic fertilizers
B 20 % decrease in N and P applications by inorganic fertilizers
C 20 % increase in livestock numbers
D 20 % decrease in livestock numbers
E Area of the predominant crop increases to cover the entire agricultural land
F 20 % of the agricultural areas are abandoned and replaced by forestry

The changes according to the scenarios are made year by year over the calibration and validation period, in the Enza case from 1992-2001. All other data and model settings are kept similar to the reference situation.

For the Enza catchment results are given for the outlet (Coenzo)

## 2.2 Scenario A and B

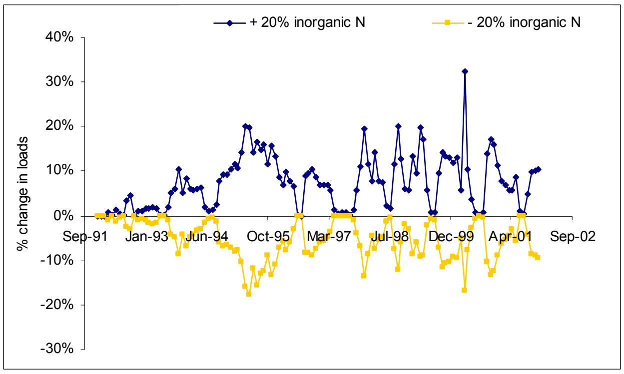
### Setup

An increase (Scenario A) or a decrease (Scenario B) of 20% of N and P applications by inorganic fertilizers is modelled by directly adding or subtracting 20% of inorganic fertilizer similar to the Zelivka scenario analysis.

### Results

Figures 1a and 1b show the differences in N and P load over the validation and calibration period. Especially for P loads it can be seen that changes increase over the years. 12 years might be too short to show the full effect of a scenario analysis.

The differences of the scenario analyses are much higher for the Enza catchment than for the Zelivka catchment where changes were in the order of magnitude of only a few percent for nitrogen and less than 1 percent for phosphorus. An important factor will probably be the lack of surface water retention the Enza catchment. Also the modelled soil column is shallower in the Enza catchment. Another factor might be the intensity of fertilisation which is much higher in the Enza catchment than in the Zelivka catchment. An increase or decrease has a larger effect. Further analysis could shed more light on the differences and the processes influencing the scenario outcome.



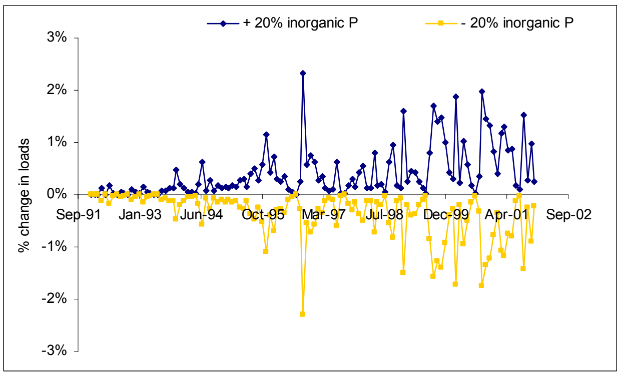




*Figure 1 a and b Changes in N and P loads*

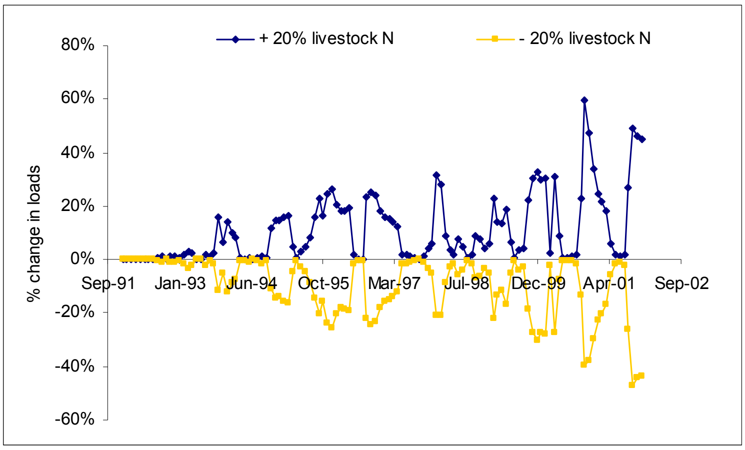
## 2.3 Scenario C and D

### Setup

An increase or decrease of 20% in livestock numbers is imposed by increasing or decreasing organic N and P applications. Alfalfa is the only crop that receives inorganic fertilizer so only part of the land under agriculture is affected by this scenario.

### Results

Figure 2a and 2b show large differences as a result of the increase and reduction of organic fertilizer. As can be seen in these pictures the differences are high. This can be explained by the already large application of organic N and P in the reference situation. Any extra application results in a direct loss as the soil has hardly any capacity to retain the extra addition.



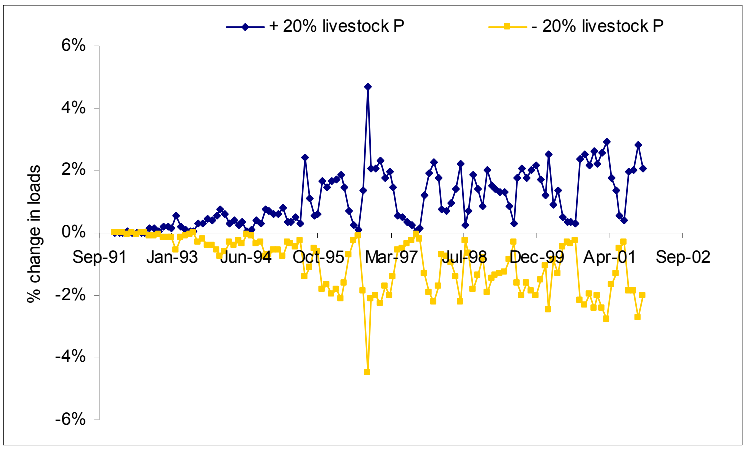




*Figure 2a and b Changes in N and P loads*

## 2.4 Scenario E and F

### Setup

In the Enza catchment alfalfa is the most dominant crop. In scenario E it is used over the entire agricultural land (defined as the cultivated land) from 1992 onwards.

In scenario F 20 % of agricultural land is transformed into forest after 1992. To use the historically developed characteristics of each, previously arable, plot (in organic matter content, nutrient concentrations etc) a new calculation was made in which all arable plots become forested after 1995. 20 % of nutrient and water outputs of this calculation were combined with 80% of the original.

### Results

In figure 3a and 3b the reduction in N and P loads as a result of conversion to forest can clearly be seen.
In the same graphs the change to a dominance of Alfalfa results in extreme extra discharges during some months as fertilizer application events differ from the other arable crops used in the reference situation. Furthermore Alfalfa receives a high amount of organic and inorganic fertilizer which also explains part of the difference.

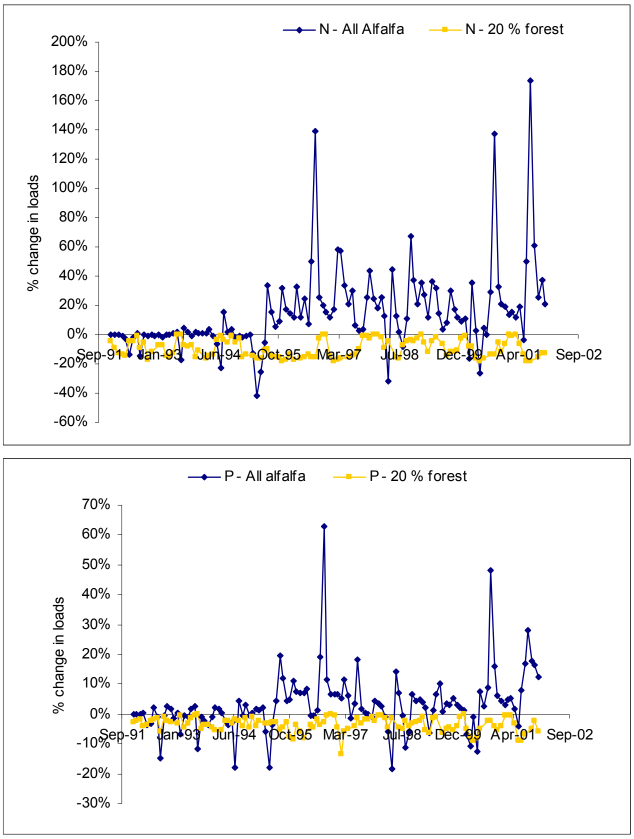



*Figure 3 a and b Changes in N and P loads*

# 3 Conclusions and discussion

- As was shown for the Zelivka catchment the NL Cat model is for the Enza catchment also very well capable of simulation of the he proposed scenarios.

- The changes in the Enza catchment are much higher than in the Zelivka catchment. Lack of surface water retention, a smaller soil column and a more intensive fertilisation are important factors which can explain this difference.

- Especially the land use change scenarios seem not very realistic and too narrow defined. A total change to Alfalfa is not very likely, especially not when fertilizer applications are not adjusted according to the new situation.

- As was shown for the Zelivka catchment the time span of the scenario simulation for the Enza catchment was also too short. As can be seen the difference in loads is still increasing after 12 years of modelling. It takes a much longer period to see the full effect of changes and to reach a new equilibrium.