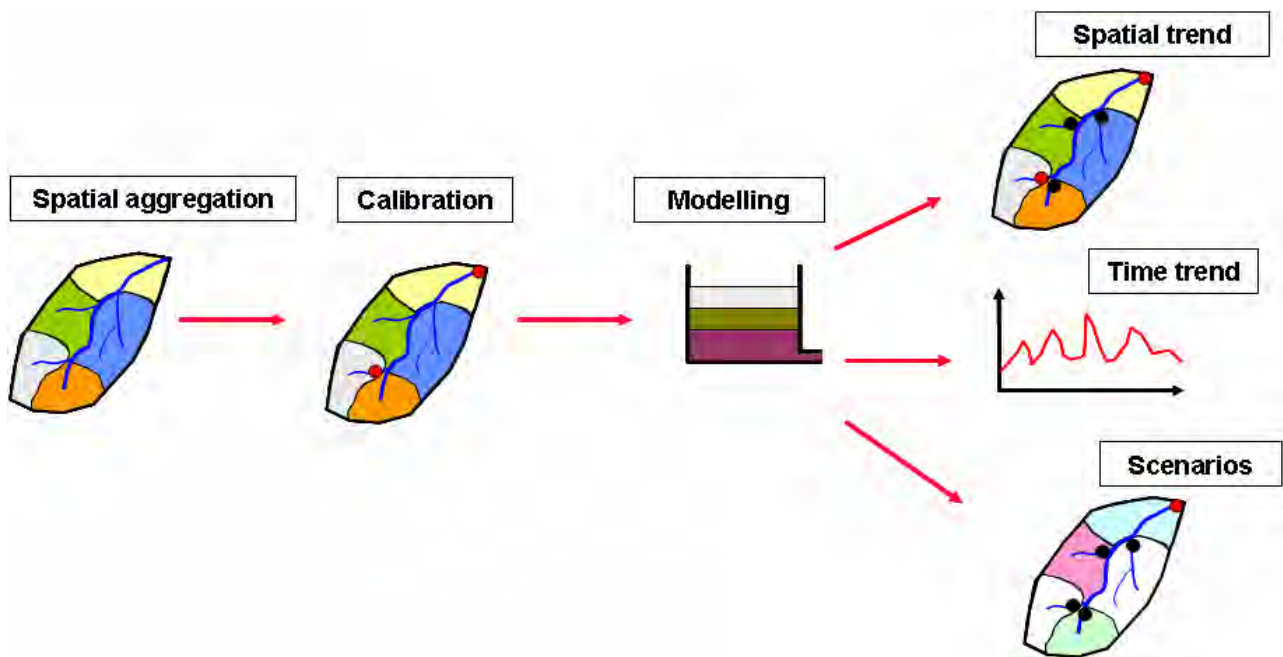




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AQUAPOL-project:

Model applications and comparison in the Kapos catchment, Hungary



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REPORT

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Abstract

AQUAPOL is a project funded by The Research Council of Norway (RCN) under the EU Candidate Countries Programme. The project has carried out a pilot study in the Kapos catchment in Hungary, with the overall aim to develop tools facilitating the implementation of the Water Framework Directive (WFD) in Hungary. This report describes the application and inter-comparison of tools for the quantification of nutrient fluxes in the Kapos catchment. 4 different approaches were tested in the Kapos catchment; Source Apportionment (SA), TEOTIL, INCA-P and SWAT, listed from simple to complex. The study showed that each approach has different strengths and weaknesses. The simpler approaches are quick and very useful for screening purposes. The more complex models provide deeper insight into the catchment processes, provide results on a finer time resolution and, at least to some extent, support scenario analysis for management purposes. The project has been carried out as a close co-operation between VITUKI CONSULT Rt and the Norwegian Institute for Water Research (NIVA).

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2. Modelling	2. Modelling
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The AQUAPOL-project

**Model applications and comparison in the Kapos
catchment, Hungary**

Report from the development, testing and comparison of
modelling tools

Preface

AQUAPOL was a three-year project funded by The Research Council of Norway (RCN) under the EU Candidate Countries Programme, ending in March 2006. The project has carried out a pilot study in the Kapos catchment in Hungary within the framework of a close-operation between VITUKI CONSULT Rt and the Norwegian Institute for Water Research (NIVA). The main objectives of the AQUAPOL project were to provide improved tools for integrated assessment of pollution load and ecological status and gain experience in the practical application of these tools. In addition, the exchange and transfer of knowledge in modelling nutrient discharges/losses and assessing ecological status by means of tight co-operation between experts from both Hungary and Norway should facilitate the implementation of the relevant parts of the EU Water Framework Directive.

To that end, the AQUAPOL project should:

1. develop a modelling tool, and use this tool to generate a pollution load model adapted to the Kapos catchment
2. apply three different approaches for the quantification of the pollution load in the Kapos river catchment (TEOTIL type of model, the SWAT model and the Source Apportionment) and compare the results of these models and the models currently used in Hungary in terms of strengths, weaknesses and applicability for the Kapos catchment
3. develop and test scientific tools for assessing the ecological status of the most important water bodies in the Kapos catchment, including assessment of the reference conditions for all the relevant types of water bodies, in accordance with the WFD criteria.

This current report provides the results from the model application and comparison activities of the AQUAPOL-project, c.f. points 1 and 2 above. The application of the INCA-P model has been added to the project to provide a more complete modelling concept. This has been made possible by close co-operation with other projects such as the EU funded BMW project. Furthermore, the AQUAPOL project has been closely linked to the EU funded EUROHARP project, both in terms of SWAT model application, Source Apportionment, and data gathering and compilation within the Kapos catchment.

The AQUAPOL-project was co-ordinated by Stig A. Borgvang, Head of Unit Integrated Resources Management at NIVA. The modelling part of the project, as reported in this report, was lead by Tor Haakon Bakken (NIVA), in co-operation with Attila Lázár, Mária Szomolányi and Ágnes Németh (Vituki Consult Rt), and Torulv Tjomsland and John Rune Selvik, NIVA with regard to the TEOTIL model application.

Oslo, April 2006

Tor Haakon Bakken

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Summary

AQUAPOL was a project funded by The Research Council of Norway (RCN) under the EU Candidate Countries Programme, carried out within the framework of a close co-operation between VITUKI CONSULT Rt and the Norwegian Institute for Water Research (NIVA). The project has carried out a pilot study in the Kapos catchment in Hungary, with the overall aim to develop and test tools facilitating the implementation of the Water Framework Directive (WFD) in Hungary. The main objectives of the AQUAPOL project were to provide improved tools for integrated assessment of pollution load and ecological status and gain experience in the practical application of these tools. In addition, the exchange and transfer of knowledge in modelling nutrient discharges/losses and assessing ecological status by means of tight co-operation between experts from both Hungary and Norway should facilitate the implementation of the relevant parts of the EU Water Framework Directive.

To that end, the AQUAPOL project should:

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3. develop and test scientific tools for assessing the ecological status of the most important water bodies in the Kapos catchment, including assessment of the reference conditions for all the relevant types of water bodies, in accordance with the WFD criteria.

This current report provides the results from the model application and comparison activities of the AQUAPOL-project, c.f. points 1 and 2 above. The application of the INCA-P model has been added to the project to provide a more complete modelling concept. This has been made possible by close co-operation with other projects such as the EU funded BMW project. Furthermore, the AQUAPOL project has been closely linked to the EU funded EUROHARP project, both in terms of SWAT model application, Source Apportionment, and data gathering and compilation within the Kapos catchment.

This report describes the application and inter-comparison of tools for the quantification of nutrient fluxes in the Kapos catchment. The catchment covers an area of 3170 km² and is located in the Danube River Basin, in the south-western part of Hungary. The dominant part of the catchment is hilly and the mean flow is 7.14 m³/s at the outlet. Five cities and 203 villages are located within the catchment, with a total population of approximately 280 000 persons. Arable land covers approximately 62 % of the catchment, grassland 4.1 %, and forest 24.2 %. Agricultural production in the area largely consists of grain.

Four different approaches were tested in the Kapos catchment namely the Source Apportionment (SA), TEOTIL, INCA-P and SWAT, listed from simple to complex approaches or tools. The tools were calibrated with use of mostly the same data and time period (1995-2002), with some differences due to different requirements in input and calibration data. As the main concern in the catchment is related to eutrophication due to phosphorus loads and concentrations, there has been less focus on nitrogen related issues. The models/tools were calibrated and compared primarily from data of the location Pincehely, which is close to the outlet of the Kapos catchment.

The study showed that each model/tool/approach has different strengths and weaknesses. The simpler approaches easy to use and little time consuming; prove useful for screening purposes. The more complex models provide deeper insight into the various nutrient related processes within the catchment, provide results on a finer time resolution and, at least to some extent, support scenario analysis for management purposes, but they are more costly and more time and resource consuming.

From the application of the **Source Apportionment (SA)** method in the Kapos catchment it can be concluded that in the case of phosphorus, this approach does not work properly, even though the results from one of the locations (Törökkoppány) seem possible. In the case of all other locations, the phosphorus load from agricultural areas is negative. In reality, it is more likely that agriculture is one of the main nutrient sources in the Kapos catchment. In the case of nitrogen, the results are acceptable when compared with the measured data. It is not clear why the SA fails for phosphorus, but seems to work fine for nitrogen. It is therefore necessary to further analyse the reasons for the non-applicability of the SA in the Kapos catchment before the SA can be reliably applied for management purpose in the Kapos catchment. SA can handle simple analysis of management scenarios, if the model is well calibrated.

The overall conclusion from the **TEOTIL** application is that the model was found to be a simple, but very useful tool for screening purposes. It uses easily available information and data. The model is easy to understand and use, it requires low PC resources to store data and run the model. It provides quick and acceptable results (trends, magnitudes). TEOTIL handles both TotN and TotP, as long as input data (point sources discharges and diffuse losses) are available on both parameters. The model operates, in principle, on the same temporal and spatial resolutions as the input data, but is typically configured to run temporally on annual data (possible monthly if load discharge/loss data are available on monthly basis) and spatially at sub-catchment level. TEOTIL is, however, limited in terms of handling scenarios. Only scenarios F and G (see section 4.4) could be simulated, because the input dataset of TEOTIL does not contain parameters that reflect the changes proposed in scenarios A-D (see section 4.4). Some technical improvements would make the tool more useful and user-friendly, such as simultaneous simulation of several years and parameters, improved routines for data preparation, and improved handling of building user-defined functions/equations. Despite these apparent shortcomings, TEOTIL can be recommended as a useful and efficient screening tool in river basin analysis in e.g. the framework of the implementation of the EU WFD in Hungary.

INCA-P can be characterised as a promising ‘newcomer’ on the arena of calculation tools of P-concentrations and loads at catchment scale, despite its limited success in estimating TotP-loads in the Kapos catchment. The main reason for this is that the land surface erosion is not properly handled within INCA-P, which then subsequently significantly underestimates the TotP-load. The simulation of SRP is much better, and the results are definitely within an acceptable range. The hydrological peaks are also underestimated, which adds to the deviation between observed and simulated load. The model is expected to be improved on these issues; a new version will probably be ready for testing later this year. INCA-P is a semi-complex model, which makes the model fairly easy to understand and use, and it matches the available data and information well. INCA-P handled the simulations of all scenarios adequately, except for scenario E, without any time-consuming restructuring of the model. This indicates that it can be a very interesting tool for management purposes. Updated versions of INCA-P would be a powerful, but still not very resources-demanding, tool during the implementation of the EU WFD in catchments that are strongly influenced by agricultural activities.

SWAT is a very comprehensive and sophisticated tool to study the runoff of nitrogen and phosphorus from agricultural land. The model can be used to simulate the effects on the water quality from changes in land use and cultivation practice. SWAT has a very good reputation and has a high credibility among researchers and managers in Europe. The main drawback of

SWAT is that it is very time- and resources consuming to be applied in a new catchment, because the data requirements are very extensive and the calibration process is complex. It can take several weeks and months to set up the model on a new catchment (the exact need of time resources will depend on e.g. the skills and experiences of the modellers), which can disqualify the model unless necessary resources are available for the modelling tasks. The model produces several N and P-fractions as output. This can be important and useful when abatement measures are proposed, whenever the user wants to analyse internal processes (P and N-transport and transformation). SWAT handled easily most of the defined scenarios in the AQUAPOL project, except for scenario F that would have needed a somewhat significant restructuring of the model setup.

The four tools applied in AQUAPOL-project can to some extent be considered complementary. **The simpler tools (SA, TEOTIL)** can work as 'screening tools' to provide an overview of the pollution situation in a catchment. In an initial phase of a study, the simpler tools can be used to identify (i) the main pollution sources, (ii) which parts of the catchments have the most important problems and (iii) those parts that can be left out for further investigations ('not at risk', according to the WFD-terminology'). For more detailed studies where a deeper insight in processes determining the origin and fate of the nutrients and analysis of mitigation measures are required, more **comprehensive tools (INCA-P, SWAT)** can be applied, either on the whole catchment or on smaller 'problem areas' or sub-catchments.

Based on project experience, the importance of quality checking of data prior to starting the modelling activities (calibration and scenario simulation) should be emphasised. The more complex model, the more extensive data requirements and the more resources must be invested in the data checking. Despite the effort of the initial screening of the quality of the data; inconsistencies, errors and gaps were found in the data series during the calibration exercises in the Kapos catchment. This impeded the modelling activities and caused time-consuming recalibration of some of the models. Based on this experience, a thorough checking of the data checking prior to the modelling is highly recommended.

1. Introduction

The EU Water Framework Directive-WFD (2000/60/EC) provides the setting for water resource management throughout Europe. The Directive aims at achieving good ecological status for all natural surface water bodies. This objective should be met in principle no later than 2015. Good ecological status is defined as slight deviations from reference conditions, water bodies not or very little affected by human activity, for the biological and chemical elements in rivers and lakes.

Identification of pressures and assessment of impacts in River Basins are the first tasks in the implementation of the EU Water Framework Directive (WFD) to be completed before 22 December 2004. Member States shall collect and maintain information on the type and magnitude of significant anthropogenic pressures on water bodies leading to ecological impacts. The River Basin District Authorities have to conduct an analysis for each catchment, based on existing data on catchment characteristics such as land use, pollution sources and monitoring data.

In the case of nitrogen and phosphorus, an analysis of existing monitoring data in water bodies for trends should be carried out, as well as of the main nutrient pressures by conducting a source inventory quantifying the importance of the main nutrient sources:

- Point sources, such as waste water discharges from waste water treatment plants, industrial plants, scattered dwellings and fish farms.
- Diffuse sources, such as background nutrient losses, nutrient losses from agricultural activities, atmospheric deposition of nutrients and nutrient losses from forestry.

The information gathered on pressures and their impacts on water bodies should be used in deciding environmental objectives for the water bodies and the development of river basin management plans. The quantitative aspect is important, especially to evaluate the precise needs for pollution control to make each water body meet its environmental objectives.

In waters where the ecological status is not achieved, pollution load reductions must be assessed based on the goal of 'good ecological status' and the most cost-efficient mitigation measures selected. In the work of identifying and quantifying pollution load reductions, computer models can be very efficient and powerful tools.

The AQUAPOL project is a three-year joint research project (2003-2005) between NIVA and VITUKI CONSULT Rt, funded by The Research Council of Norway (RCN) with the aim of supporting the implementation of Water Framework Directive (WFD) in Hungary. The main objectives are to:

- Develop a modelling tool, and use this tool to generate a pollution load model adapted to the Kapos catchment. The new tool is based on the Norwegian TEOTIL model, but further developed in order to:
 - Adopt the model to Hungarian River basin units, differing from the Norwegian statistical regions
 - Integrate the model with ArcGIS
- Apply and compare 4 different approaches for the quantification of pollution load in the Kapos catchment, in order to:
 - Highlight the strengths and weaknesses of the different tools, based on their performance

- Highlight the strengths and weaknesses of the different tools, based on their intrinsic characteristics.
- Assess the applicability of the tools during the implementation of the WFD, in the Kapos catchment, in specific, and in Hungary in general.
- Develop and test scientific tools for assessing the ecological status of the most important water bodies in the Kapos catchment, including assessment of the reference conditions for all the relevant types of water bodies, in accordance with the WFD criteria.

The development and testing of tools and methods have been carried out in the Kapos catchment, Hungary, as a pilot river basin. This report describes the work done related to the first two of the three main objectives referred to above (development, testing and comparing modelling tools). The work related to the development of tools for assessing the ecological status (the third solid bullet point above) is reported separately.

2. The Kapos catchment

2.1 General description

The Kapos River is located in the Danube River Basin, in the south-western part of Hungary, among the Mecsek and Balaton-hills. It enters the Sió-canal that flows directly to the Danube. The size of the entire catchment is 3170 km², and the length of the Kapos River is 112.7 km. The average, low flow is 0.74 m³/s, the mean flow 7.14 m³/s, the high flow 174 m³/s in the Kapos River. The dominant part of the catchment is hilly.

Five cities and 203 villages are located within the catchment, with a total population of approximately 280 000 persons. Agricultural production in the area largely consists of grain. The catchment is not sensitive to floods; therefore, no levees can be found in the region.

The climate of the region is moderately warm and wet. The annual number of sun hours is about 2000, with only 200 hours during the winter season. The annual mean temperature is approximately 10 °C. The snow cover lasts for 35 days on average, with an average maximum depth of 23-24 cm.

The catchment includes fishponds and reservoirs. Only one reservoir (supplying water to 7 fishing ponds) is located on one of the main tributaries (Koppány creek), while the others are on small tributaries.

The shallow groundwater table is between 2 and 4 m below ground in valleys, and between 4 and 6 m in slopes. Increased levels of nitrate content of groundwaters are significant on the southern part of the watershed, but are less pronounced north of the Kapos River. The exploited amount of deep groundwater is moderate: about 0.5-0.75 l/s/km². The depth of artesian wells is greater than 200 m. Several thermal baths are established in the region. Table 2.1 shows some basic physical and statistical data, while figure 2.1 shows topographical information on the Kapos catchment.

Table 2.1. Basic data on Kapos catchment.

Property	Value
Catchment area	3170 km ²
Elevation range	100 – 660 m above sea level
Rainfall	680 - 700 mm (380-400 mm in the growing season)
Run-off	4x10 ⁻⁶ mm/s/km ²
Runoff coefficient	18 %
Excess water	25-40 mm
Soils	Mainly brown earth (54 %), brown soil with clay alleviations (20 %) and forest soil (17 %).
Arable land	61.9 %
Grassland	4.1 %
Forest	24.2 %
Open water	0.8 %
Cities/towns with more than 5000 inhabitants	Kaposvár (66 411) Komló (27 372) Dombóvár (20 211) Tamási (9 356)

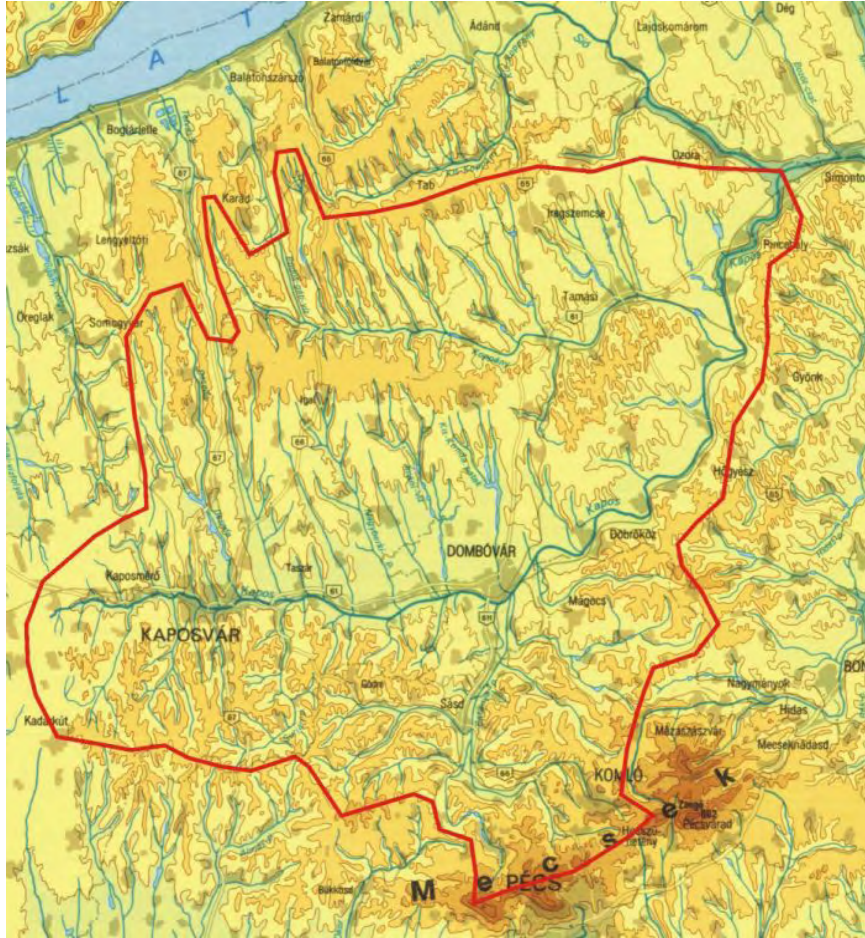


Figure 2.1. Topography of the Kapos catchment.



Figure 2.2. Landscape photo from the Kapos catchment.

3. Source apportionment – setup and application

3.1 Description of method

The source apportionment method (SA) is based on the assumption that the nutrient (total nitrogen or total phosphorus) transport at a selected river measurement site (L_{river}) represents the sum of the components of the nutrient discharges from point sources (D_P), the nutrient losses from anthropogenic diffuse sources (LO_D) and the natural background losses of nutrients (LO_B).

Furthermore, it is necessary to take into account the retention of nutrients in the catchment after the nutrients have been discharged to surface waters (R). This may be expressed as follows:

$$L_{river} = D_P + LO_D + LO_B - R \quad (1)$$

The aim of the source apportionment is to evaluate the contributions of specific point and diffuse sources of nutrients to the total riverine nutrient load, i.e. to quantify the nutrient losses from diffuse sources (LO_D) as follows:

$$LO_D = L_{river} - D_P - LO_B + R \quad (2)$$

The importance of the different sources may be expressed as:

$$\text{Proportion of } LO_B = (LO_B / L_{river} + R) \cdot 100\% \quad (3)$$

$$\text{Proportion of } D_P = (D_P / L_{river} + R) \cdot 100\% \quad (4)$$

$$\text{Proportion of } LO_D = (LO_D / L_{river} + R) \cdot 100\% \quad (5)$$

The method outlined above requires:

- Measurements at the selected river measurement site in order to determine L_{river} , which represents the riverine transport. The riverine transport is the quantity of a determinant carried by a watercourse per unit of time.
- Determinations of the nitrogen and phosphorus point source discharges (D_P) and natural background losses of nitrogen and phosphorus (LO_B) in the river catchment area concerned, as well as the quantification of the retention of nitrogen and phosphorus (R) in surface waters are needed. For this purpose, there are different methodologies available.

When there is more than one monitoring station in a catchment, the source apportionment can be performed for each sub-catchment with a monitoring station at the outlet.

The anthropogenic diffuse nutrient loss from agricultural areas in the catchment can be estimated following equation 6:

$$LO_{AG} = L_{river} - D_P - LO_B + R - LO_{AT} - LO_{SD} \quad (6)$$

Where:

- LO_{AG} Anthropogenic loss of nutrients from agricultural areas entering surface waters
- LO_{AT} Nutrient load from atmospheric deposition directly on surface waters in the catchment
- LO_{SD} Nutrient load to surface waters from scattered dwellings in the catchment as defined in HARP Guideline 5 (Borgvang and Selvik, 2000).

3.2 Calculation of input data and assumptions

Each of the parameters given in section 3.1 were calculated to yield the LO_D and LO_{Agri} . 4-5 different calculations were carried out. All of these used the same existing national datasets (discharge/water flow¹, water quality, point sources), but each version used different literature data for filling any gaps in information. This summary below presents the final version of the SA application.

A. Calculation of L_{river}

The calculation was carried out based on the bi-weekly surface water quality data and based on the daily discharge dataset.

After trying different calculation methods, the N and P yield of each surface water monitoring station was calculated for each year. The following equation was used:

$$L_{river} = \sum_{P1}^{Pi} (\bar{Q}_i * 86400 * c_i * 10^{-3} * n_i)$$

where

- L_{river} the amount of nutrient in the given year at the monitoring station (kg/year)
- $P_1, .. P_i$ time period 1, .. i
- \bar{Q}_i average discharge in the i^{th} time period (m^3/s)
- c_i measured concentration in the i^{th} time period (mg/l)
- n_i number of days in the i^{th} time period

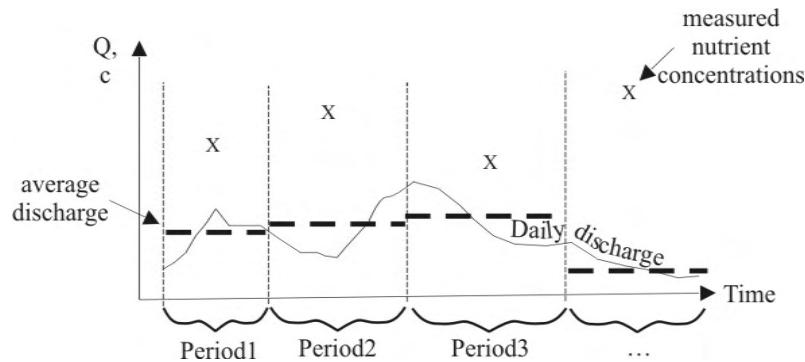


Figure 3.1. The figure shows graphically the interpolation of discharge data.

B. Calculation of D_p

The calculation used the discharge information of urban waste water treatment plants and industries (Source: National waste water cadastre database - szennyvízkataszteri adatbázis). Discharges from the point pollution sources were added together:

$$D_p = P_1 + P_2 + \dots + P_k$$

where $P_1 \dots P_k$ are the discharges of N or P of individual pollution sources (kg/year).

¹ The term 'discharge' is in this section used equivalent to water flow. In other contexts, especially related to point sources pollution, the term 'discharge' often means 'pollution load' (effluent load).

C. Calculation of LO_b

This calculation was mostly based on the Corine Land Cover data (1997) (forest, nature and wetland - [km²]), and a forest coefficient (0.0116 mg P/l; 0.0378 mg N/l). Beside these, the calculated regional, annual precipitation [mm] was used.

D. Calculation of R

Retention was calculated by the NutRet toolbox developed by the EUROHARP project (final version) (EUROHARP 9-2004).

E. Calculation of $LO_{Scattered}$

This calculation used the sum of untreated waste water for each sub-basin [m³], and the coefficients used in the TEOTIL model (Appendix A) (10 mg P/l (Novotny and Chesters, 1981), 40 mg N/l).

F. Calculation of LO_{Atm}

The atmospheric deposition was calculated based on the area of the sub-basin [km²], and the coefficients used in the TEOTIL model (3 kg P/km², 32 kg N/km²).

G. Calculation of LO_{urban}

The nutrient loads from urban areas were calculated from the annual precipitation [mm] of the sub-basin, the area of the settlements [km²], and the coefficients used in the TEOTIL model (0.6 mg P/l, 6.855 mg N/l).

Although Total phosphorus measurements were available for all monitoring station, the above calculations were carried out only for those stations that could be linked with meteorological stations that have daily precipitation data series (to ensure comparable results), see figure 3.2. In the case of Total Nitrogen, data were only available for Pincehely (the outlet station of the catchment); therefore, Source Apportionment application was only possible for the entire Kapos catchment.



Figure 3.2. The figure shows the division of sub-basins and the monitoring stations used in the source apportionment calculation.

3.3 Calibration

No specific calibration technique is available for the Source Apportionment calculation. The trial and error of applying different calculation methods and literature values is the only way to optimise the output results. During the first attempts of calibration, the following issues were taken into consideration:

- Numbers on background losses (natural areas) were taken from the literature.
- Since no atmospheric deposition station is located within the Kapos catchment, data were taken from a station outside the catchment, supplemented with literature values (using uniform deposition rates or precipitation dependent literature values).
- Literature values were applied for losses from scattered dwellings.
- Different calculation methods for retention.

After different trials, it was agreed that the results were not adequate and it was decided to use the applied TEOTIL coefficients. Unfortunately, this parameter set only gave slightly better results.

3.4 Results and discussion

Results of the Total Nitrogen (TN) and Total Phosphorus (TP) calculations are presented in the following tables.

Table 3.1. The table shows the results of the source apportionment (TN and TP) calculation at different locations in the catchment.

TN (tons) – Pincehely

Year	L _{river}	-	D _P	-	LO _B	+	R	=	LO _D	Year	LO _D	-	LO _{Scattered}	-	LO _{Atm}	-	LO _{Urban}	=	LO _{Agri}
1995	1188.5	-	187.6	-	23.3	+	1791.2	=	2768.8	1995	2768.8	-	119.8	-	104.1	-	735.2	=	1809.6
1996	2029.3	-	186.0	-	23.3	+	1791.2	=	3611.2	1996	3611.2	-	119.8	-	104.1	-	736.7	=	2650.5
1997	1280.1	-	173.8	-	16.8	+	1791.2	=	2880.7	1997	2880.7	-	119.8	-	104.1	-	530.0	=	2126.8
1998	1690.7	-	176.3	-	25.5	+	1791.2	=	3280.1	1998	3280.1	-	119.8	-	104.1	-	805.0	=	2251.1
1999	2536.2	-	153.8	-	28.4	+	1791.2	=	4145.1	1999	4145.1	-	119.8	-	104.1	-	898.9	=	3022.3
2000	1405.8	-	163.2	-	15.1	+	1791.2	=	3018.7	2000	3018.7	-	119.8	-	104.1	-	477.6	=	2317.1
2001	1239.7	-	140.3	-	18.9	+	1791.2	=	2871.7	2001	2871.7	-	119.8	-	104.1	-	595.9	=	2051.9

TP (tons) – Pincehely

Year	L _{river}	-	D _P	-	LO _B	+	R	=	LO _D	Year	LO _D	-	LO _{Scattered}	-	LO _{Atm}	-	LO _{Urban}	=	LO _{Agri}
1995	154.8	-	63.4	-	7.1	+	23.4	=	107.6	1995	107.6	-	30.0	-	9.8	-	64.3	=	3.6
1996	265.3	-	63.6	-	7.2	+	23.4	=	218.0	1996	218.0	-	30.0	-	9.8	-	64.5	=	113.8
1997	100.6	-	57.5	-	5.1	+	23.4	=	61.3	1997	61.3	-	30.0	-	9.8	-	46.4	=	-24.8
1998	221.6	-	58.7	-	7.8	+	23.4	=	178.4	1998	178.4	-	30.0	-	9.8	-	70.5	=	68.3
1999	376.7	-	48.2	-	8.7	+	23.4	=	343.1	1999	343.1	-	30.0	-	9.8	-	78.7	=	224.7
2000	115.3	-	55.5	-	4.6	+	23.4	=	78.5	2000	78.5	-	30.0	-	9.8	-	41.8	=	-3.0
2001	168.1	-	47.6	-	5.8	+	23.4	=	138.1	2001	138.1	-	30.0	-	9.8	-	52.2	=	46.2

TP (tons) – Tamási

Year	L _{river}	-	D _P	-	LO _B	+	R	=	LO _D	Year	LO _D	-	LO _{Scattered} d	-	LO _{Atm}	-	LO _{Urban}	=	LO _{Agri}
1995	21.0	-	0.2	-	1.3	+	3.1	=	22.6	1995	22.6	-	4.6	-	1.9	-	9.5	=	6.6
1996	25.0	-	0.2	-	1.1	+	3.1	=	26.7	1996	26.7	-	4.6	-	1.9	-	8.4	=	11.8
1997	10.2	-	0.2	-	0.7	+	3.1	=	12.3	1997	12.3	-	4.6	-	1.9	-	5.6	=	0.2
1998	24.1	-	0.2	-	1.2	+	3.1	=	25.8	1998	25.8	-	4.6	-	1.9	-	9.1	=	10.2
1999	47.0	-	0.2	-	1.4	+	3.1	=	48.6	1999	48.6	-	4.6	-	1.9	-	10.4	=	31.6
2000	14.0	-	0.1	-	0.7	+	3.1	=	16.1	2000	16.1	-	4.6	-	1.9	-	5.6	=	4.0
2001	19.8	-	0.1	-	0.8	+	3.1	=	21.9	2001	21.9	-	4.6	-	1.9	-	6.1	=	9.3

TP (tons) – Törökkoppány

Year	L _{river}	-	D _P	-	LO _B	+	R	=	LO _D	Year	LO _D	-	LO _{Scattered} d	-	LO _{Atm}	-	LO _{Urban}	=	LO _{Agri}
1995	12.4	-	0.0	-	0.7	+	0.4	=	12.1	1995	12.1	-	1.2	-	0.8	-	2.8	=	7.3
1996	12.2	-	0.0	-	0.6	+	0.4	=	12.0	1996	12.0	-	1.2	-	0.8	-	2.5	=	7.5
1997	11.1	-	0.0	-	0.4	+	0.4	=	11.1	1997	11.1	-	1.2	-	0.8	-	1.8	=	7.3
1998	11.8	-	0.0	-	0.6	+	0.4	=	11.5	1998	11.5	-	1.2	-	0.8	-	2.8	=	6.7
1999	21.2	-	0.0	-	0.7	+	0.4	=	21.0	1999	21.0	-	1.2	-	0.8	-	3.0	=	15.9
2000	12.3	-	0.0	-	0.4	+	0.4	=	12.3	2000	12.3	-	1.2	-	0.8	-	1.6	=	8.7
2001	9.6	-	0.0	-	0.4	+	0.4	=	9.6	2001	9.6	-	1.2	-	0.8	-	1.9	=	5.6

TP (tons) – Kurd

Year	L _{river}	-	D _P	-	LO _B	+	R	=	LO _D	Year	LO _D	-	LO _{Scattered} d	-	LO _{Atm}	-	LO _{Urban}	=	LO _{Agri}
1995	120.3	-	11.8	-	5.3	+	1.5	=	104.8	1995	104.8	-	21.7	-	6.5	-	50.3	=	26.3
1996	177.5	-	11.9	-	5.1	+	1.5	=	162.0	1996	162.0	-	21.7	-	6.5	-	48.8	=	85.1
1997	83.6	-	12.2	-	4.0	+	1.5	=	68.8	1997	68.8	-	21.7	-	6.5	-	38.7	=	1.9
1998	207.7	-	12.9	-	5.9	+	1.5	=	190.4	1998	190.4	-	21.7	-	6.5	-	56.8	=	105.5
1999	345.3	-	11.8	-	6.3	+	1.5	=	328.7	1999	328.7	-	21.7	-	6.5	-	60.6	=	240.0
2000	85.8	-	12.5	-	3.2	+	1.5	=	71.7	2000	71.7	-	21.7	-	6.5	-	30.9	=	12.6
2001		-	7.1	-	4.1	+	1.5	=		2001		-	21.7	-	6.5	-	39.5	=	

TP (tons) - Kaposvár-Fészerlak

Year	L _{river}	-	D _p	-	LO _B	+	R	=	LO _D	Year	LO _D	-	LO _{Scattered}	-	LO _{Atm}	-	LO _{Urban}	=	LO _{Agri}
1995		-	17.5	-	1.5	+	3.7	=		1995		-	5.4	-	2.1	-	18.5	=	
1996	31.0	-	16.3	-	1.6	+	3.7	=	16.9	1996	16.9	-	5.4	-	2.1	-	18.8	=	-9.4
1997	13.4	-	16.2	-	1.1	+	3.7	=	-0.2	1997	-0.2	-	5.4	-	2.1	-	13.6	=	-21.2
1998	27.1	-	15.2	-	1.8	+	3.7	=	13.8	1998	13.8	-	5.4	-	2.1	-	21.4	=	-15.0
1999	37.1	-	15.0	-	1.7	+	3.7	=	24.1	1999	24.1	-	5.4	-	2.1	-	20.0	=	-3.3
2000	9.0	-	13.6	-	0.9	+	3.7	=	-1.8	2000	-1.8	-	5.4	-	2.1	-	10.7	=	-20.0
2001	10.7	-	13.6	-	1.3	+	3.7	=	-0.5	2001	-0.5	-	5.4	-	2.1	-	15.3	=	-23.2

The above tables highlight with peach colour the results of the estimations of nutrient losses from diffuse sources. The results clearly show that this simplified calculation method works adequately for total nitrogen. For total phosphorus, the results are only realistic for the location of Törökkoppány. In case of all other calculations, results cannot be accepted, because the pollution load from the agricultural fields cannot be negative. This would mean that the agricultural field absorb nutrients from the surface waters. In reality, it is more likely that the agricultural sector is one of the main pollution sources in the Kapos catchment. The inadequate results are highlighted with yellow colour.

It can be concluded that in case of nitrogen, the results are acceptable, but in case of phosphorus, this calculation method does not provide realistic results.

3.5 Scenario modelling

Due to its highly simplified approach and the fact that the calibration of TotP failed, the source apportionment can not be used to analyse the effects on the water quality from different management scenarios.

4. TEOTIL – setup and application

4.1 Description of the model

The Norwegian TEOTIL model has been developed to quantify the nutrient loads to the sea in Norway, based on available regional statistical information (Selvik et al., 2005, Tjomsland and Bratli, 1996). During the AQUAPOL project, this quantification tool was further developed for Hungarian conditions. The development activities included both the development of built-in functions, and development of the ESRI ArcMap interface of the model. The user of TEOTIL can apply a selection of pre-programmed functions to set up a model based on the available data and the desired calculation routines. TEOTIL appears as a model maker tool. The input data for the model are point source data and export coefficients for nutrient losses, both organised in input files.

The main principles on the use of the software is available in Appendix A. Details of the TEOTIL run-file, Result files and Input files for the Kapos catchment are presented in Appendix B.

4.2 Input data and assumptions

The TEOTIL model in the Kapos calculates annual total phosphorus and total nitrogen loads at each sub-basin outlet. Beside the general catchment (sub-basin) characteristics, the model uses annual precipitation, point sources (waste water treatment plant and industrial loads), information on amounts of waste water not-collected by the sewerage system, and coefficients for nutrient losses from different land use categories. Coefficient information was collected from national survey reports and from literature. With the exception of the coefficients, all data are geo-referenced in order to use GIS facilities to prepare the input data and to present the results. All used data are publicly available. The modelling period was 1993-2003.

The developed TEOTIL model can be summarised as follows for the i^{th} sub-basin outlet point and a given year:

$$M_{\text{sum}, i} [\text{kg}] = M_{\text{agriculture}, i} [\text{kg}] + M_{\text{background}, i} [\text{kg}] + M_{\text{population}, i} [\text{kg}] \quad (1)$$

where

M_{sum}	calculated nutrient load (sum)
$M_{\text{agriculture}}$	diffuse losses from agricultural areas
$M_{\text{background}}$	loss from natural areas with little or no human activities and via atmospheric deposition
$M_{\text{population}}$	loss from urban areas (WWTPs, industries scattered dwellings and paved surfaces)

Equation (1) could be further detailed as follows:

$$M_{\text{sum}, i} [\text{kg}] = M_{\text{agriculture}, i} [\text{kg}] + [M_{\text{forest}, i} [\text{kg}] + M_{\text{nature}, i} [\text{kg}] + M_{\text{wetland}, i} [\text{kg}] + M_{\text{atm. dep.}, i} [\text{kg}]] + [M_{\text{scatt}, i} [\text{kg}] + M_{\text{urban}, i} [\text{kg}] + M_{\text{wwtp}, i} [\text{kg}] + M_{\text{industry}, i} [\text{kg}]] \quad (2)$$

where

$M_{forest}, M_{nature},$ and $M_{wetland}$	losses from natural areas
$M_{atm. dep.}$	deposition via precipitation
M_{scatt}	diffuse loss from scattered dwellings
M_{urban}	pollution from paved surfaces
$M_{wwtp}, M_{industry}$	discharges from point sources (industry and waste water treatment plants).

The further disaggregation of the equation would be:

$$M_{sum, i} [kg] = A_{agriculture, i} [km^2] * C_{agriculture, i} [mg/l] * P_i [mm] + [A_{forest, i} [km^2] * C_{forest, i} [mg/l] * P_i [mm] + A_{nature, i} [km^2] * C_{nature, i} [mg/l] * P_i [mm] + A_{wetland, i} [km^2] * C_{wetland, i} [mg/l] * P_i [mm] + A_{water, i} [km^2] * C_{atm. dep., i} [kg/km^2]] + [Q_{not collected ww, i} * C_{scattered, i} + A_{urban, i} [km^2] * C_{urban, i} [mg/l] * P_i [mm] + \sum L_{wwtp, i, k} * C_{wwtp, i} + \sum L_{industry, i, k} * C_{industry, i}] \quad (3)$$

where

A-s	areas
C-s	coefficients identified for each sub-basin, based on literature values
P_i	hydrological effective rainfall
$Q_{not collected ww}$	waste water not collected by sewerage system in each sub-basin
L-s	loads from point sources

Since the model does not consider the sub-surface processes, the precipitation data had to be modified to get the proper amount of water in the tributaries (hydrological effective rainfall). For this reason, based on hydrological (discharge) and precipitation data, the following equation was identified for each sub-basin:

$$P_i [mm] = a_i * e^{b_i * P_{total, i} [mm]} \quad (4)$$

where

P_i	corrected precipitation data for the i^{th} sub-basin for the given year
P_{total}	measured precipitation for the i^{th} sub-basin for the given year
a_i and b_i	constants for the i^{th} sub-basin.

When equations (3) and (4) are combined, the following summarised equation is valid:

$$M_{sum, i} [kg] = a_i * e^{b_i * P_{total, i} [mm]} \{ A_{agriculture, i} [km^2] * C_{agriculture, i} [mg/l] * + C_{forest, i} [mg/l] * (A_{forest, i} [km^2] * + A_{nature, i} [km^2] + A_{wetland, i} [km^2]) + A_{urban, i} [km^2] * C_{urban, i} [mg/l] \} + A * C_{atm. dep., i} [kg/km^2] + Q_{not collected ww, i} * C_{scattered, i} + \sum L_{wwtp, i, k} * C_{wwtp, i} + \sum L_{industry, i, k} * C_{industry, i} \quad (5)$$

Note that in the above equation (5), $C_{nature, i} [mg/l]$ and $C_{wetland, i} [mg/l]$ were substituted with $C_{forest, i} [mg/l]$, because these areas were considered as land categories with little or no human activities, and only one forest coefficient was found in the literature.

4.3 Calibration

The most important in-field and in-stream processes, such as transformation, sedimentation and denitrification, are not considered in most TEOTIL applications. It follows that the coefficients need to be thoroughly calibrated to the catchment condition, unless actual estimates of these coefficients have been made for the catchment. In the Kapos case, the Monte Carlo method was selected for adjusting coefficients. For each coefficient, the possible minimum and maximum values were identified from the literature and from existing datasets. Then 3 000 000 random values were generated for each coefficient, for each year and for

regions of the Kapos catchment (monitoring data were not available for each sub-basin). The minimum of the following equation was accepted as the best set of coefficients for the i^{th} region:

$$K = \min \left| \sum_{j=1}^n (M_{j,i} - \overline{M}_i)^2 \right. \quad (6)$$

where

K	optimised vector set of coefficients for all years
M_j	calculated nutrient load for the given year
\overline{M}_i	observed nutrient load for the given year
J	actual year

Originally, a retention tag was used to consider some of the nutrient retention processes. However, by using the EUROHARP NutRet software (EUROHARP 9-2004), this value would stay constant for all years, and in case of nitrogen, the retention tag was sometimes higher than the sum of all pollution sources. Therefore, a random variable was developed to consider sedimentation, decomposition and water outtake (irrigation), but this approach was at a later stage considered as theoretically incorrect. The final optimised calibration to the observed load (Monte Carlo method - Fedra, 1983) did not consider retention, irrigation, sedimentation or decomposition in the load calculation. The area specific coefficients established for the catchment were calibrated to provide a good match with measured values. It follows that effects of retention processes indirectly are included in these coefficients.

4.3.1 Calibration results

The Kapos catchment was divided into sub-catchments in two different ways. The first sub-catchment delineation was based on the actual river monitoring sites that resulted in 12 sub-catchments. With this approach the aim was to use the monitoring points as control points for the calculation, and keep the number of sub-catchments as low as possible. The second delineation aimed at having as many sub-catchments as possible to match the spatial resolution of the detailed ecological detailed assessment (carried out within the framework of the ecological status activities of the AQUAPOL-project) and by this be able to detect spatial differences within the catchment. The last approach resulted in 73 sub-catchments.



Figure 4.1. The delineation of the Kapos catchment into 12 (black lines) and 73 sub-catchments (brown lines).

12 Sub-catchments

TEOTIL calculates the load for each sub-catchment. They are accumulated downstream by using the pre-defined drainage system of the catchment. The total phosphorus (TP) load, before calibration, is illustrated in Figure 4.2a for the basin outlet monitoring station (Pincehely). Figures 4.2b and 4.3 present the calibrated TP model results for Pincehely station, and for all calibration stations, respectively.

Figure 4.2a shows that calculated loads without calibration resulted in considerable errors. However, the calibrated model works in a more satisfying way. Although the deviation is high between the measured and calculated loads in 1995 and 1997, the results are still acceptable. The Nash-Sutcliffe coefficient (efficiency factor) is 0.78 for the basin outlet point (Pincehely), indicating a fairly good agreement between measured and model predictions (Nash and Sutcliffe, 1970). The Nash and Sutcliffe coefficient varies between 1 and $-\infty$, with 1 indicating a perfect agreement. The average deviation from observed values is 87 % for TP. Furthermore, Figure 4.3 shows that only 3 sub-basin outlet points (Kaposvár-Fészerlak, Tamási, Pincehely) are outside a deviation of ± 30 %. These have outliers for 2-3 years.

Figures 4.4a and 4.4b present the results for total nitrogen (TN). Unfortunately, this parameter is only measured at the outlet station (Pincehely). For this reason, the calibration and efficiency calculations could only be done for the entire catchment. With the exception of the years 1995 and 1998, there is a reasonable agreement between observed and calculated TN loads (Nash-Sutcliffe coefficient = 0.51, average deviation = 96 %). The deviation is caused by the annual precipitation. Since figures on annual precipitation is the only driving force for the diffuse pollution in the model, the calculated load more-or-less follows the precipitation pattern. In 1995, the precipitation was close to the annual average, whereas the observed load was the lowest in the modelling period.

Figure 4.5 illustrates, according to TEOTIL results, that the agriculture sector is the most important category of pollution source in the catchment. This was expected based on the fact that 60-70 % of the catchment is used for agricultural purposes.

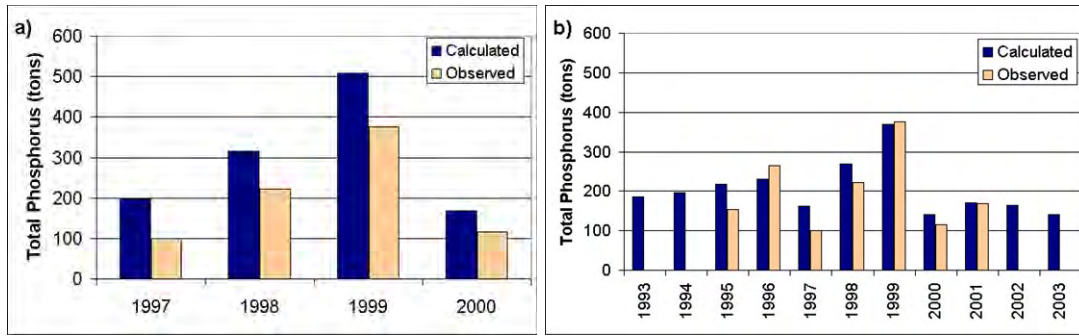


Figure 4.2. The calculated and observed TP-load at the basin outlet monitoring station without (a) and with calibration (b).

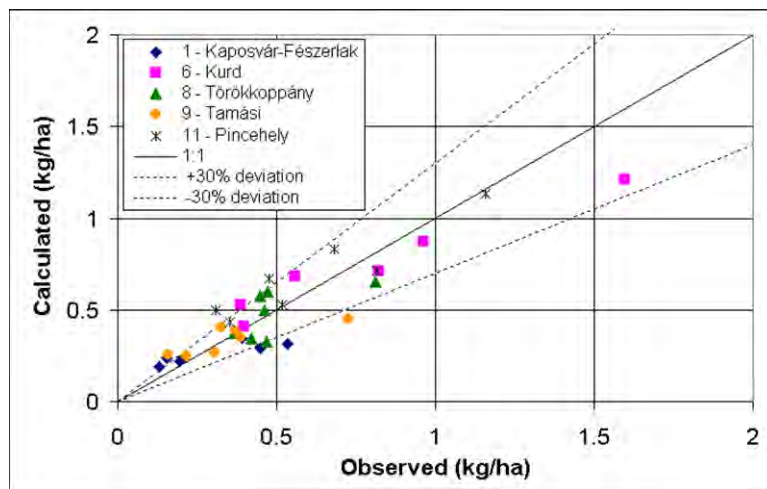


Figure 4.3. The deviation between calculated and observed specific TP loads for 5 monitoring stations within the Kapos catchment for individual years (1995- 2001).

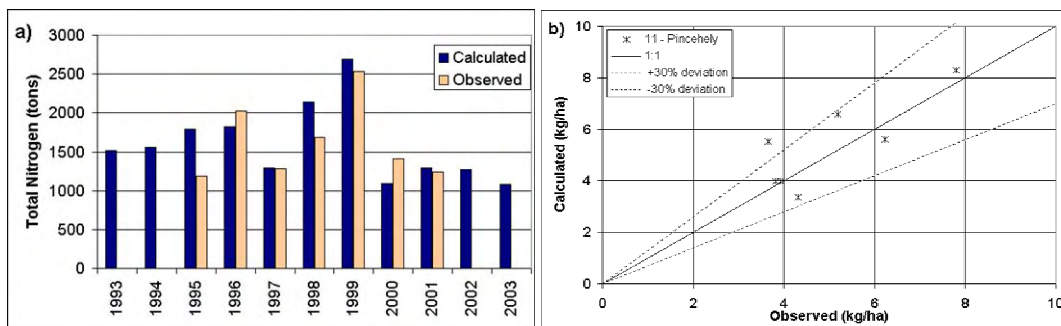


Figure 4.4. The observed and calculated TN load (a) and the corresponding deviation between calculated and observed loads for individual years (1995- 2001) (b) at the basin outlet monitoring station.

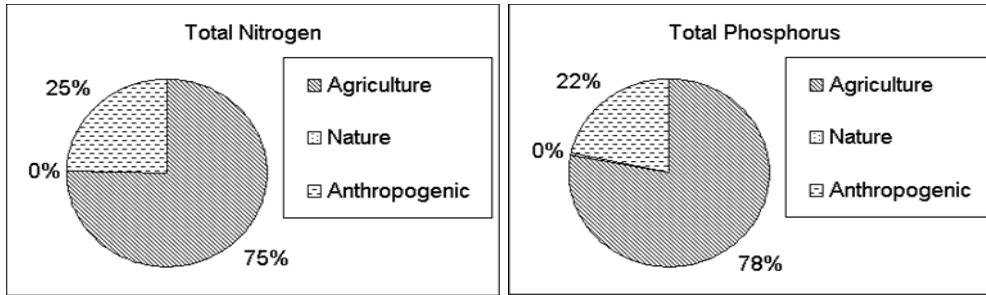


Figure 4.5. The calculated proportion of N and P sources of discharges/losses in the Kapos catchment as an average for the period 1993-2003. 'Nature' means runoff from areas without significant human activities. 'Anthropogenic' means point sources discharges.

73 sub-catchments

Figures 4.6, 4.7 compare the 12 and the 73 sub-catchment results for those overlapping control points where both approaches produced output. The time series for the specific load comparison graph shows more outliers for the 73 sub-catchment approach.

On the other hand, figures 4.8 and 4.9 indicate the importance of the more detailed spatial simulation in order to present a more differentiated result. Beside the fact that the 73 sub-catchments simulation show higher uncertainty in the results than for 12 sub-catchments simulation, these maps indicate, with more details, the areas of the catchments where the main problems are located. To achieve the WFD environmental targets, the areas with high nutrient loads should be focused upon in the mitigation plans.

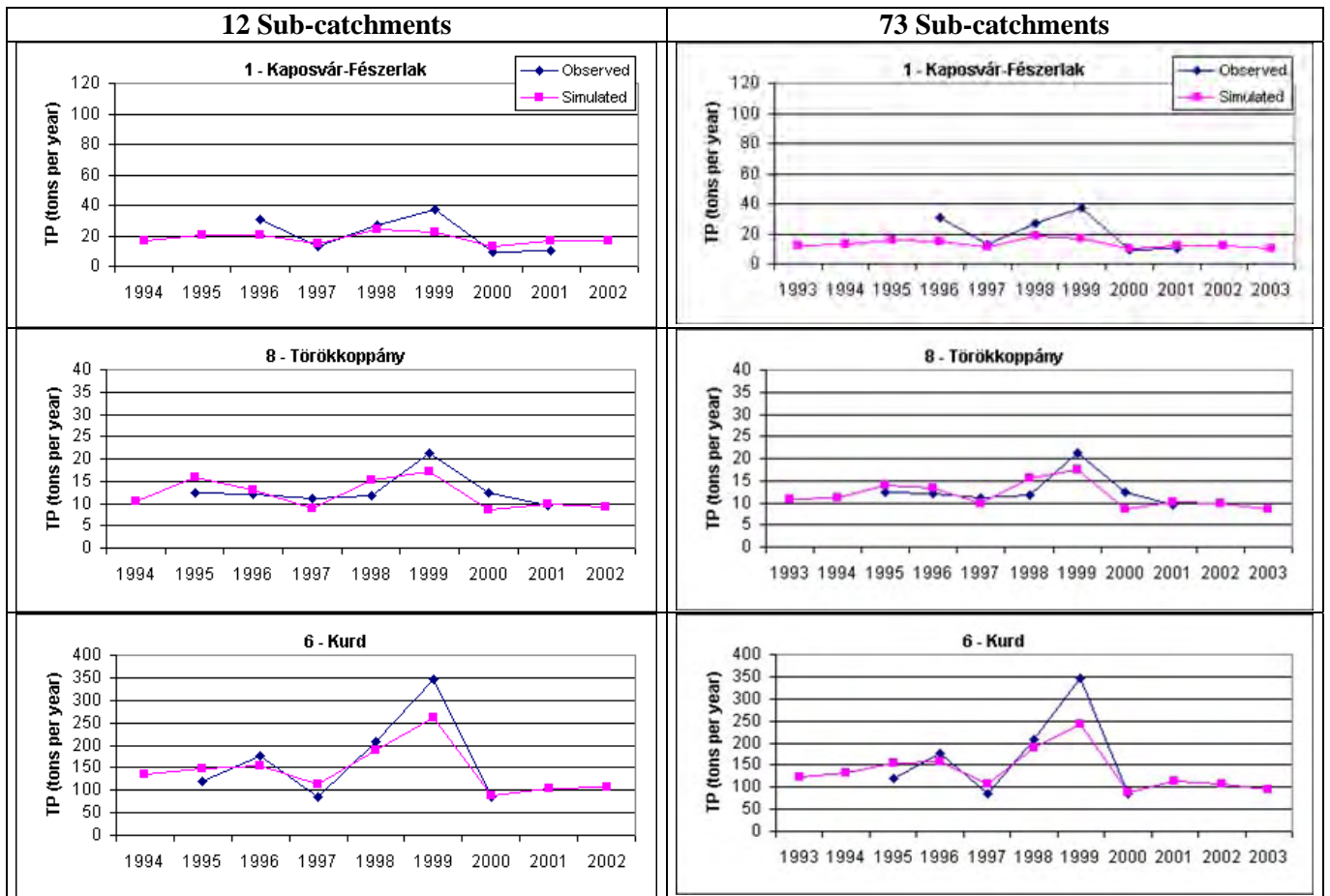


Figure 4.6. Comparison of the observed and simulated (calibrated) annual results for phosphorus at three different locations in the catchment. The results are produced based on the division of the catchment into 12 (left) and 73 sub-catchments (right).

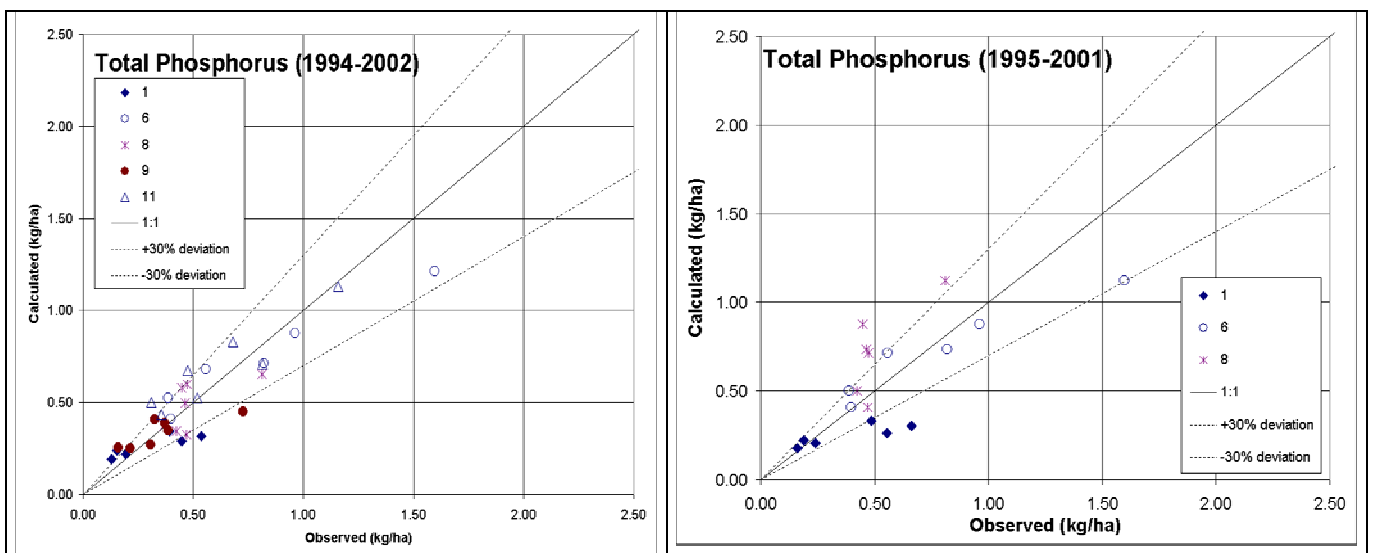


Figure 4.7. The deviation between the observed and simulated (calibrated) annual results at three different locations in the catchment. The results are produced based on the division of the catchment into 12 (left) and 73 sub-catchments (right).

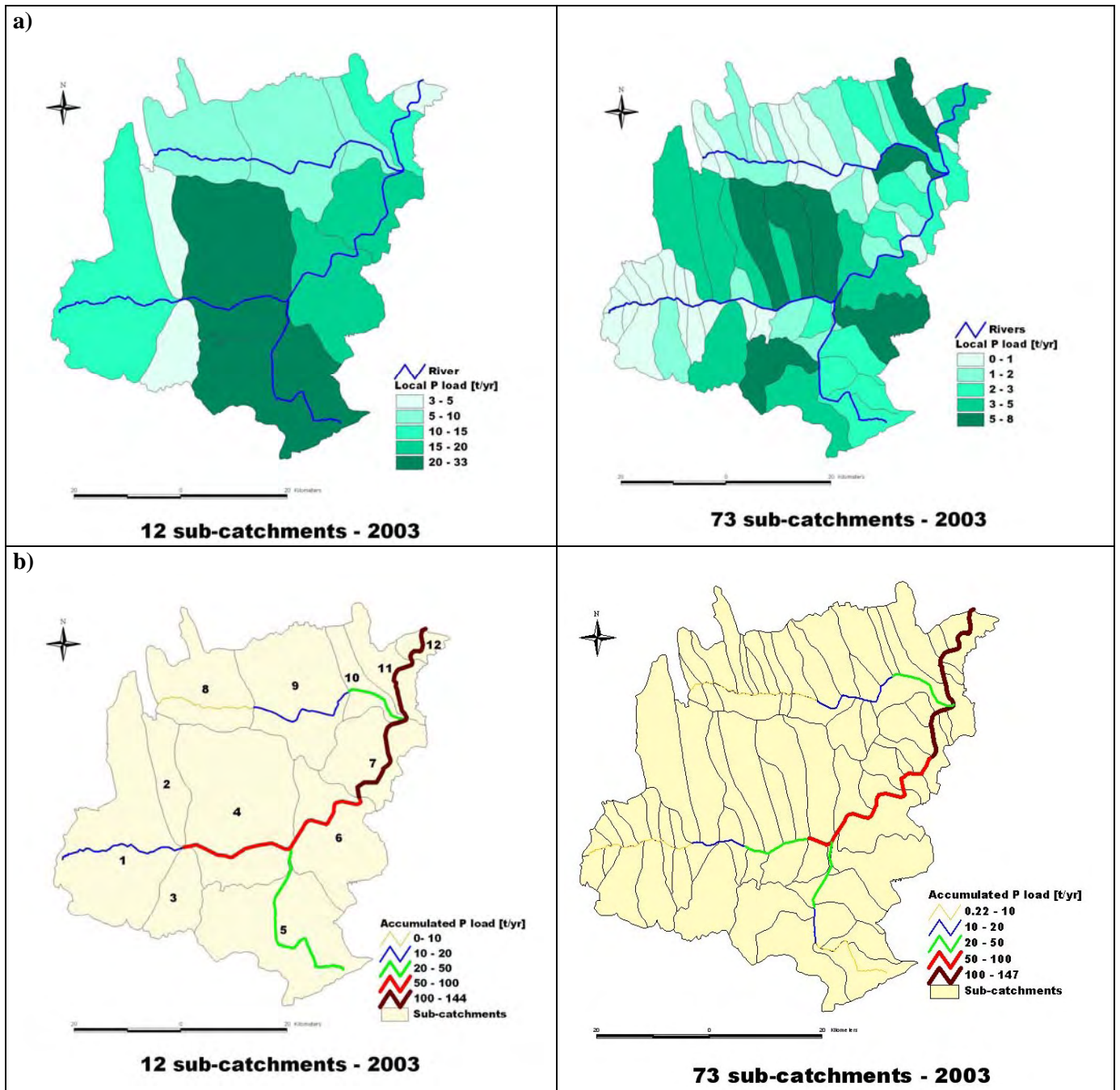


Figure 4.8. Maps presenting the calculated phosphorus load based on the division of the catchment into 12 and 73 sub-catchments respectively. The upper two maps (a) show the load of each sub-catchment [t/yr], while the lower two maps (b) show the accumulated load in the main streams in [t/yr]. The maps present the results from the year 2003-simulation.

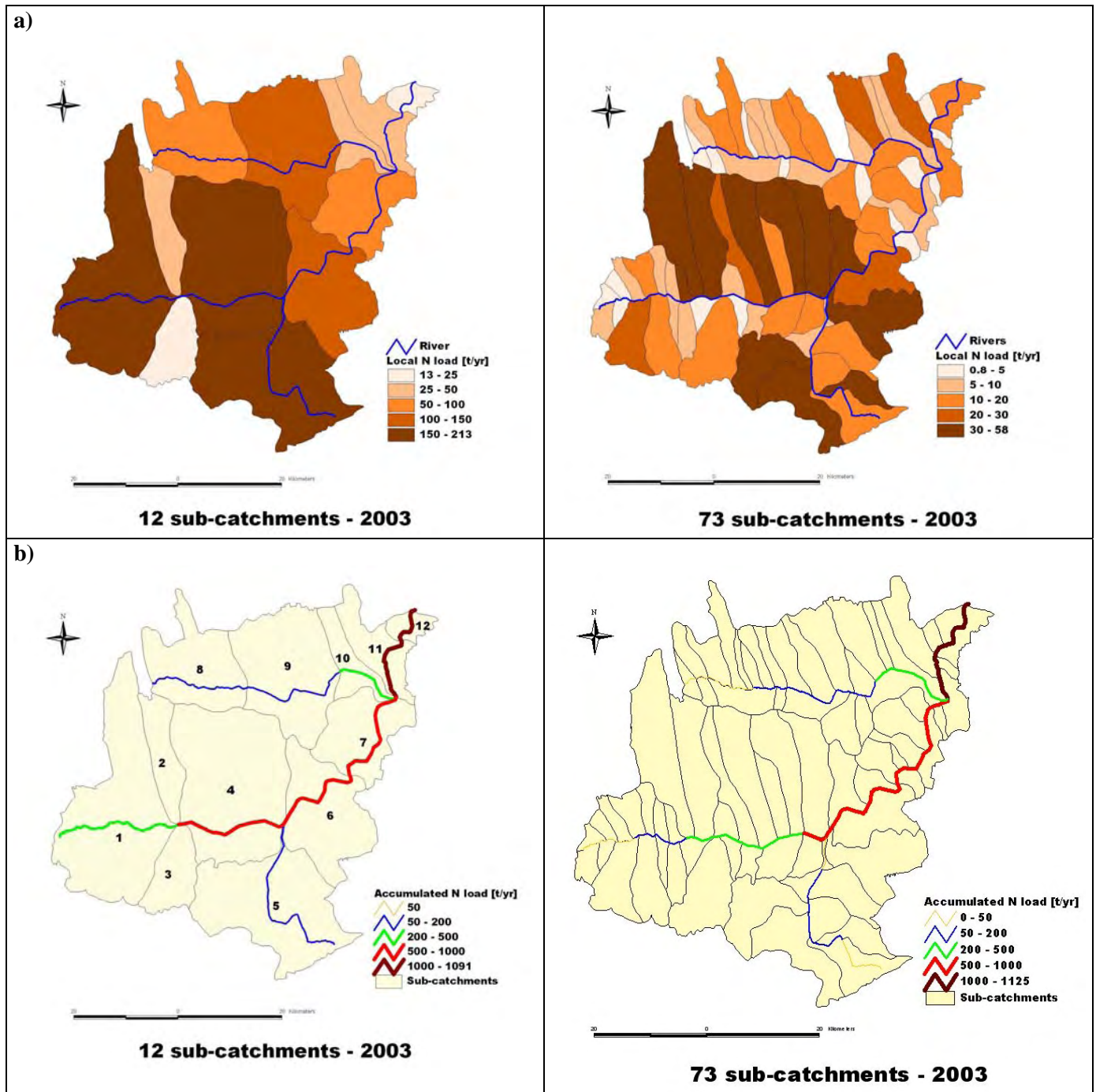


Figure 4.9. Maps presenting the calculated nitrogen load based on the division of the catchment into 12 and 73 sub-catchments respectively. The upper two maps (a) show the load of each sub-catchment [t/yr], while the lower two maps (b) show the accumulated load in the main streams in [t/yr]. The maps present the results from the year 2003-simulation.

4.4 Scenario modelling - TEOTIL

The AQUAPOL partners agreed on a set of scenarios to analyse the models' capability of simulating realistic management options. These scenarios are to a large extent based on scenarios that have been defined in the EUROHARP project (Vagstad and French, 2005).

The scenarios are the same as in EUROHARP, except that scenario G is added from the EUROHARP protocol. The scenarios are as follows:

- 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
- G 20 % decrease of point source loads (added from EUROHARP-protocol)

TEOTIL can only run Scenarios F and G due to its simplified modelling approach, which does not use fertiliser or livestock information as input parameters.

The TEOTIL model was set up with the modified dataset, and run for all years (the calibration period). The results are summarised in figures 4.10 – 4.17. The graphs in figures 4.10 and 4.11 present the simulated loads at Pincehely station (outlet sub-basin no. 11) compared to the measured load. The figures indicate that the model follows the observed (no measures) magnitude and trend. The 20 % change in agricultural areas (scenario F) caused significant decrease in the in-stream nutrient loads for both Total Nitrogen and for Total Phosphorus.

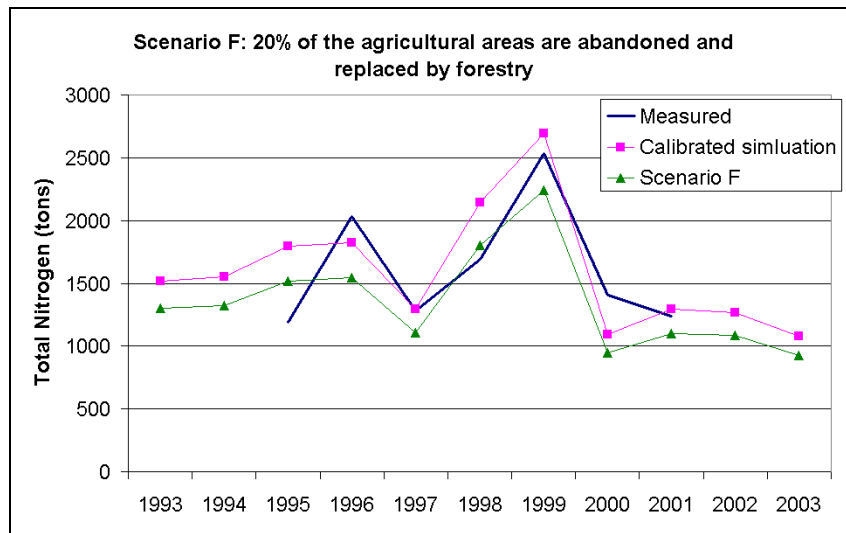


Figure 4.10. The simulation results of total nitrogen (TN) based on scenario F (details given in title and in the text in the beginning of this section), presented together with the measured/observed values and the results of the calibrated model. The figure gives the results at the outlet of sub-basin no 11 (Pincehely station).

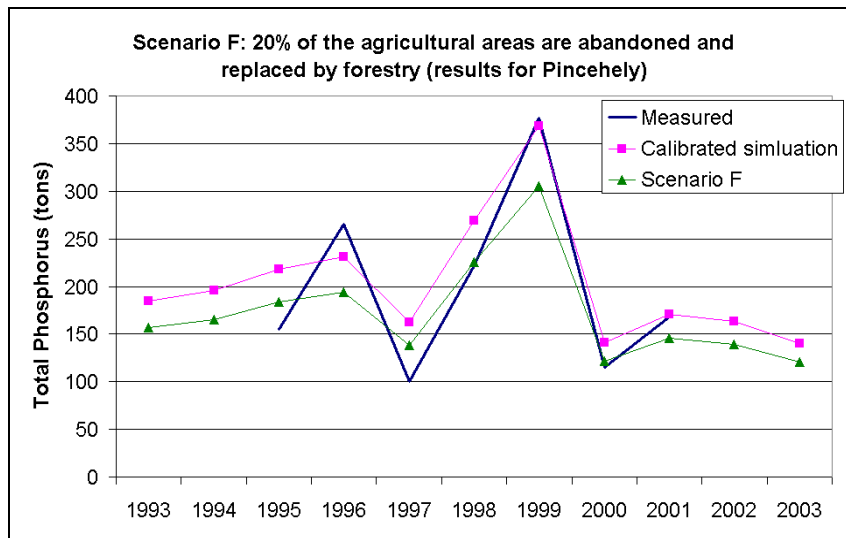


Figure 4.11. The simulation results of total phosphorus (TP) based on scenario F (details given in title and in the text in the beginning of this section), presented together with the measured/observed values and the results of the calibrated model. The figure gives the results at the outlet of sub-basin no 11 (Pincehely station).

Figures 4.12 and 4.13 present the scenario simulation results compared to the calibrated model results (reference). Each scenario result is compared to the related model results. The figures show the scenario results for Pincehely station (outlet sub-basin no. 11), but present also the minimum and the maximum change in nutrient loss in all 12 sub-catchments. They clearly show that the model reacts almost with a 1 to 1 ratio to the change in agriculture activities. The 20 % decrease in agricultural areas caused 12-19 % decrease in nutrient losses (about 15 % reduction near the basin outlet station – Pincehely).

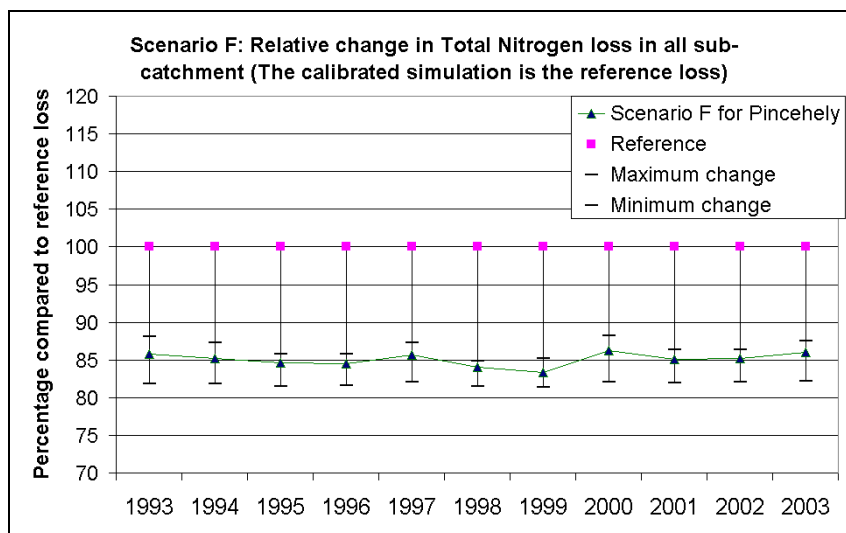


Figure 4.12. The relative change in TN-loss, based on the simulation of scenario F (details given in title and in the text in the beginning of this section). The solid green line shows the relative decrease in load at the outlet of sub-basin no 11 (Pincehely station) compared to the reference-situation, defined as the calibration results for the same period. The maximum and minimum refer to the maximum and minimum relative changes in load in the catchment, comparing the scenario results with all the reference simulations for all 12 sub-catchments.

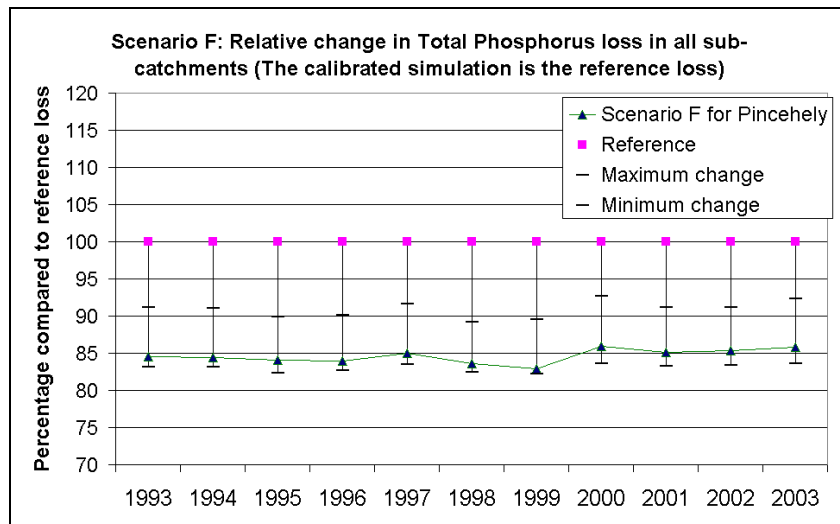


Figure 4.13. The relative change in TP-loss based on the simulation of scenario F (details given in title and in the text in the beginning of this section). The solid green line shows the relative decrease in load at the outlet of sub-basin no 11 (Pincehely station) compared to the reference-situation, defined as the calibration results for the same period. The maximum and minimum refers to the maximum and minimum relatively change in load in the catchment, comparing the scenario results with all the reference simulations for all 12 sub-catchments.

Figures 4.14 and 4.15 present the average change in nutrient loss compared to the calibration results. They clearly indicate where mitigating measures should be taken to effectively reduce the nutrient pressure from agricultural activities. The results show that a 20-25 % total nitrogen reduction, and a 15-19 % total phosphorus reduction could be achieved locally, if the agricultural areas were decreased by 20 % and replaced by forests.

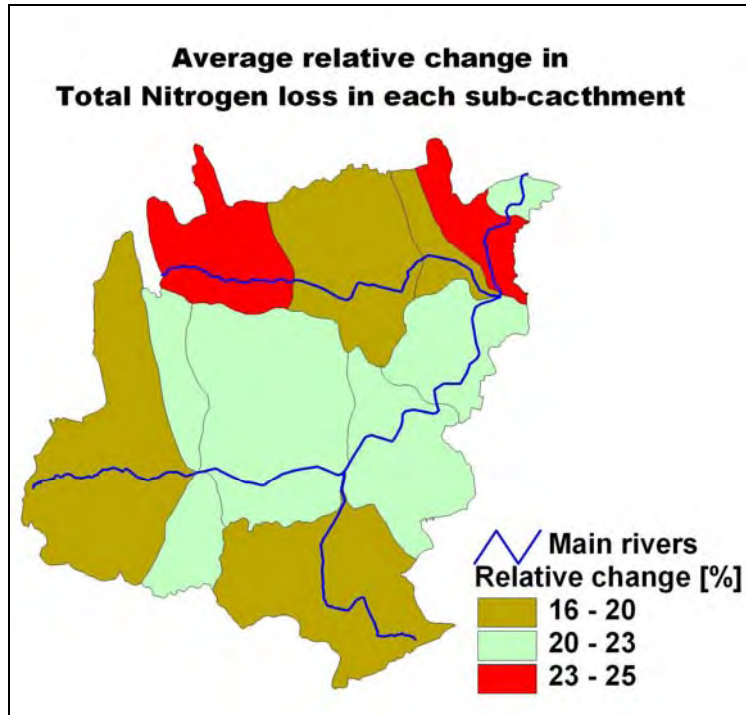


Figure 4.14. The map shows average (1993-2003, averaged for the whole period) relative change in TN-loss based on the simulation of scenario F (details given in the text in the beginning of this section) compared to the reference situation (defined as the calibration results) for each of the 12 sub-catchments.

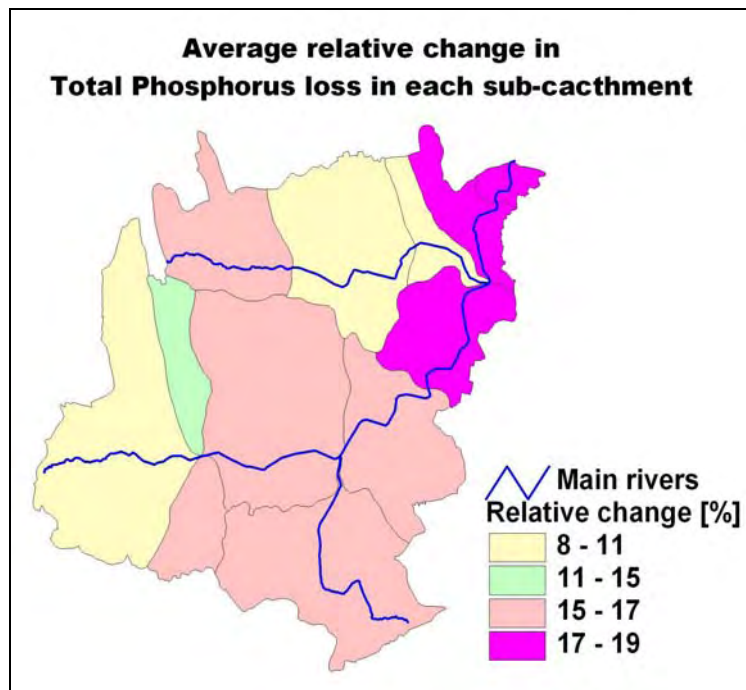


Figure 4.15. The map shows average (1993-2003, averaged for the whole period) relative change in TP-loss based on the simulation of scenario F (details given in the text in the beginning of this section) compared to the reference situation (defined as the calibration results) for each of the 12 sub-catchments.

Results of Scenario G (details given in the beginning of this section) are presented in the figures 4.16 and 4.17. The 20 % reduction in nutrient load from point sources caused only a 1-4 % change in nutrient loading. This is at an expected level since point sources only account for about 25 % and about 22 % of the total nitrogen and phosphorus total loads respectively.

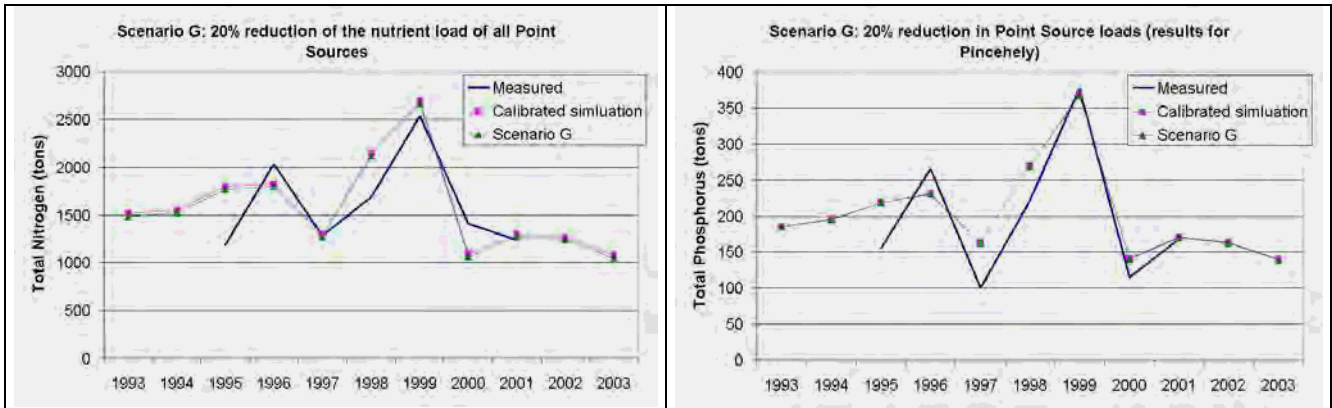


Figure 4.16. The simulation results of total nitrogen (TN) and phosphorus (TP) based on scenario G (details given in title and in the text in the beginning of this section), presented together with the measured/observed values and the results of the calibrated model. The figure gives the results at the outlet of sub-basin no 11 (Pincehely station).

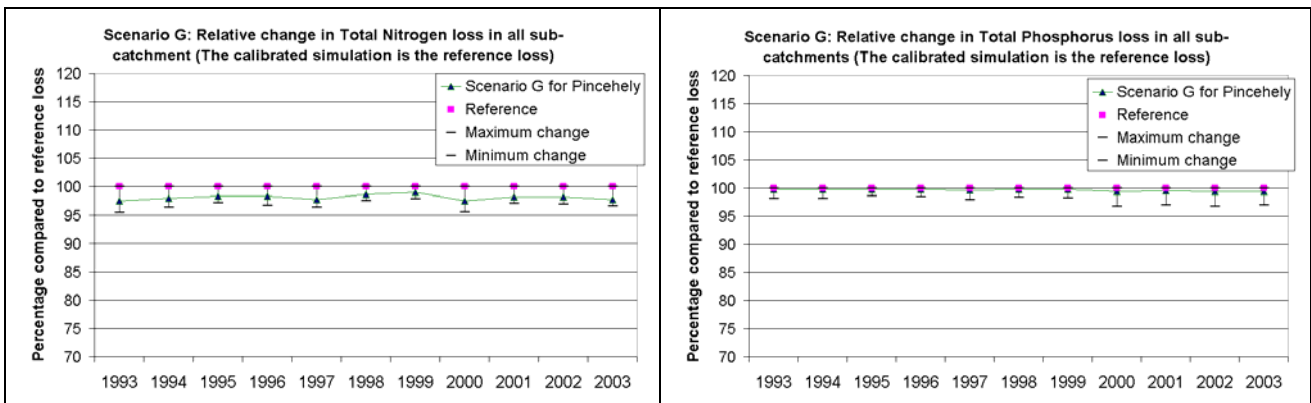


Figure 4.17. The relative change in TN- and TP-loss based on the simulation of scenario G (details given in title and in the text in the beginning of this section). The solid green line shows the relative decrease in load at the outlet of sub-basin no 11 (Pincehely station) compared to the reference-situation, defined as the calibration results for the same period. The maximum and minimum values refer to the maximum and minimum relative change in load in the catchment, comparing the scenario results with all the reference simulations for all 12 sub-catchments.

4.5 Discussion and conclusions on the TEOTIL modelling

4.5.1 The tool

The overall conclusion is that the TEOTIL model is a useful tool in water management at catchment scale and provides results quickly, i.e. low cost and little time-consuming (trends, magnitudes) for screening purposes. The model uses easily available information and data.

The main functions of the software are easy to understand and use. It does not require huge PC resources to store data and run the model.

The model appears as a model builder tool that allows the user to define which calculation routines to use in a specific model set-up, and many useful built-in functions are available. The set-up used in the Kapos catchment did not include any in-field or in-stream processes, which was a disadvantage with regard to investigating scenarios.

TEOTIL is not developed as commercial product, a complete user manual is not yet available in English and some of the functions are relatively difficult to use and understand without assistance from the developer. It follows that written information on how to handle error messages that will appear during modelling is insufficiently documented.

For the future development of the system, some emphasis should be given to the preparation of input datafiles. The finalisation of data preparation is somewhat time-consuming, especially during calibration, when basic data in text-format need to be changed between each simulation.

The calibration process could be supported by built-in functionality to explore results instead of performing time-consuming operations in copying data to other software for visualisation. This because the results are provided in a text file and the data have to be exported to MS Excel to be able to be seen as a graphs. Furthermore, the present version of the model handles each year and parameter separately. It is, however, a great advantage that the years and parameters can be changed easily in any text editor (Find/Replace) and the modeller does not need to programme the same over and over again.

The built-in functionality to establish equations could advantageously be further developed in order to encompass more sophisticated equations.

Model simulations can in general be done very quickly. In contrast, the extraction of and the study of the results might become a very time-consuming job unless the user specifies the set-up of the resulting text-files in a way that enables easy connection to other presentation tools. The GIS connection is useful new feature of TEOTIL, but it requires the ArcMap 9.x version.

4.5.2 Modelling results

The first run of TEOTIL before any calibration showed considerable deviations from the monitoring data. This was not unexpected due to the fact that agriculture was a major source for losses of nutrients to the aquatic environment in Kapos and that we had very uncertain coefficients for estimating these losses. The retention processes in these slow flowing rivers were also expected to be considerable, but no actual measurements were available. The fit of coefficients by means of a Monte-Carlo procedure enabled reasonable good correspondance with monitoring data after calibration. All available monitoring data from all years and stations were used in the calibration exercise; no validation was performed for other years.

Modelling results showed the clear dominance of nutrient losses from agriculture as the major nutrient source. However, in some sub-catchments with high population densities (cities) the discharge from population was higher than from agriculture. It appeared also that the agricultural nutrient losses from certain sub-catchments was higher than from others. These findings need to be considered when entering the planning of mitigation measures in the Kapos catchment, e.g. when implementing the WFD in Hungary.

TEOTIL does not include description of in-field and in-stream processes. This limits the model's ability to make scenario-calculations where the input factors to be adjusted are

embedded in these (missing) processes. The model responded reasonable to the two scenarios that could be simulated (land use transformation from arable land to forest and point source discharge changes/ construction of treatment facilities).

The objective of the project was also to develop and refine the TEOTIL model in Kapos under Hungarian conditions, which are quite different from Norwegian conditions. The model has produced acceptable results with regard to the screening of the most important sources of nutrient pollution in Kapos and produced realistic figures of the total nutrient load. The model has proven its ability to determine which sub-catchments have specifically high loads, which is an important input to future abatement studies.

5. INCA-P – setup and application

5.1 INCA-P described

The Integrated Catchment model for Phosphorus (INCA-P) (Wade et al., 2002) is a process-based, mass balance model that simulates the phosphorus dynamics in both the plant/soil system and the stream. The model simulates the spatial variation in phosphorus export from different land use categories within a river system, using a semi-distributed representation, thereby accounting for the impacts of different land management practices, such as inorganic and organic fertiliser and wastewater applications. The land-phase of INCA-P includes a simplified representation of direct runoff, soilwater and groundwater flows, and the soil processes that involve phosphorus. In addition, the model includes a multi-reach in-stream component that routes water down the main river channel. It simulates organic and inorganic phosphorus in the land phase, and total phosphorus (dissolved plus particulate phosphorus) TotP) concentrations in the in-stream phase. In-stream soluble reactive phosphorus (SRP) concentrations are determined from the TotP concentrations.

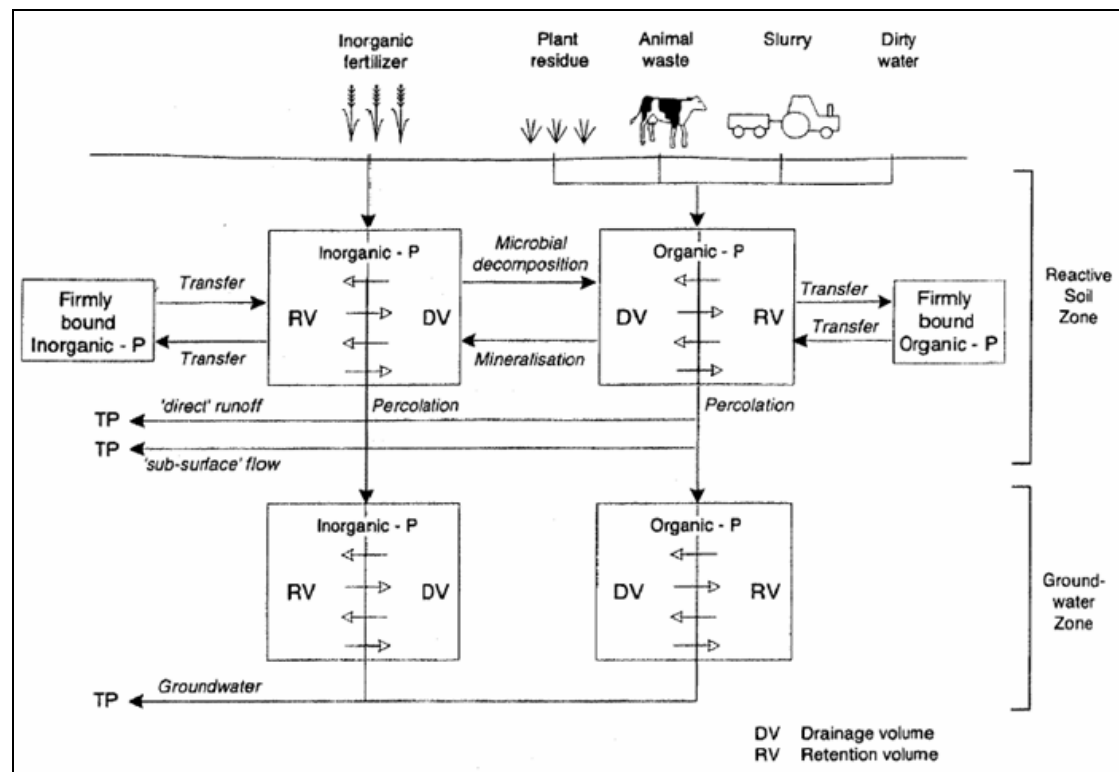


Figure 5.1. Phosphorus inputs, processes and outputs in the direct runoff, soil and groundwaters in the cell model of the land-phase component. TP = Total phosphorus. From Wade et al., 2002.

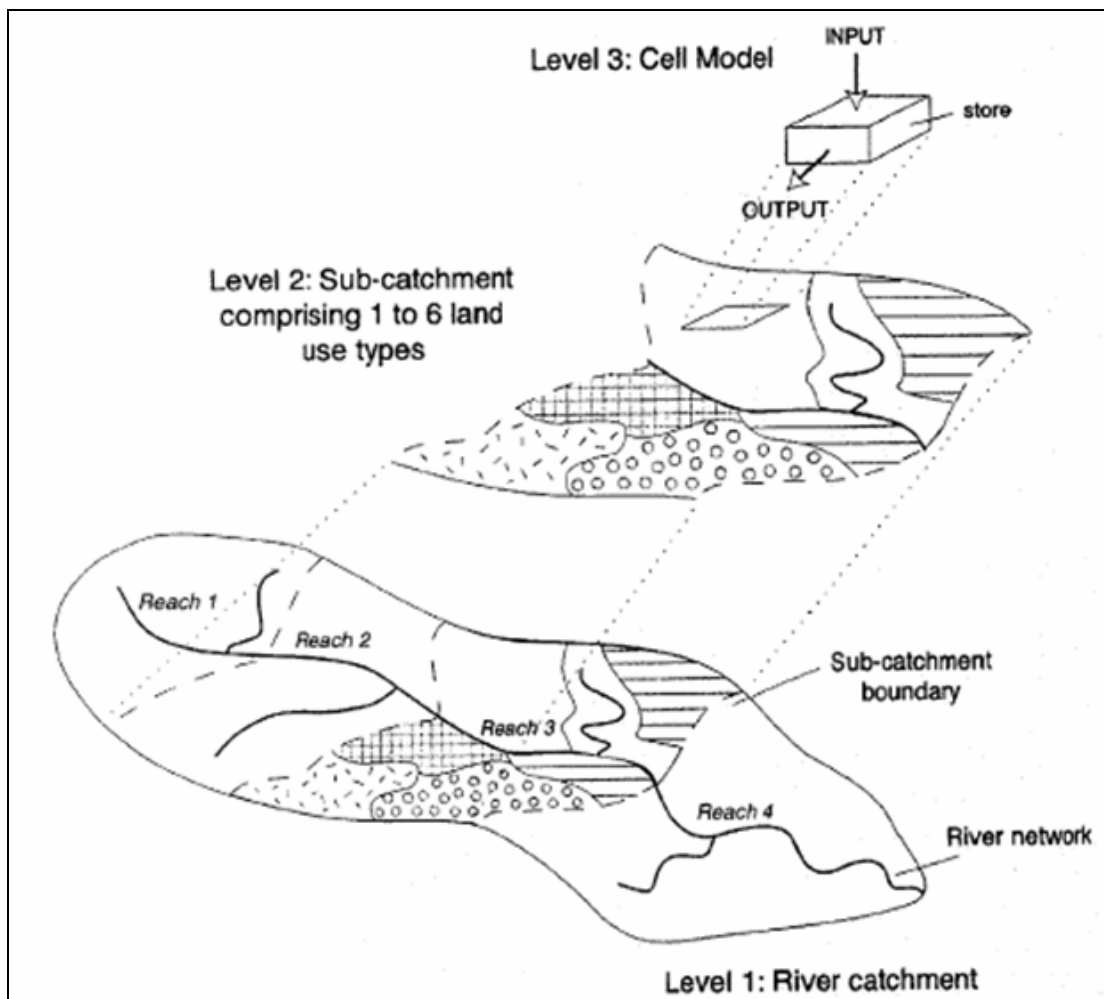


Figure 5.2. The land phase component model structure. At level 1 the catchment is decomposed into sub-catchments. At level 2, the sub-catchments are sub-divided into a maximum of 6 different land-use types. At level 3, the soil P transformations and stores are simulated using the cell model, from Wade et al. 2002.

5.2 Modifications of the hydrological module

During the application of INCA-P, and especially the preceding calculations of water balance (evapotranspiration, SMD (soil moisture deficit), and to some extent snow melt model), it was discovered that the hydrological response was not appropriately handled by the existing tools². It was concluded that these problems (deviations between observations and modelled water flow) could not be solved by simply adjusting model parameters, and structural changes were needed.

1. Due to the fact the evapotranspiration in Kapos is very high, approximately 85 % of the precipitation, the PET-factor (potential evapotranspiration) had to be set very high compared to other countries the routine has been applied in (e.g Norway, UK). As a result of this, the soil moisture deficit (SMD) is most of the year close to the defined maximum. This means that almost all of the 'small rainfalls' are absorbed by the SMD and no runoff produced. In reality, also 'small and medium size rainfalls'

² The calculation was initially based on 2 Excel-files (Not published, pers. comm. Øyvind Kaste, NIVA) and version 1.4.6 of INCA-P. All the described modifications have been done to the "SMD"-Excel-file.

produce some increase in the water flow in the rivers due to quick surface runoff and/or increased groundwater runoff. To compensate for this problem, a certain proportion of the precipitation is 'brought forward' to the HER (hydrological effective rainfall) in the SMD-file (a calculation prior to snow melt module). This was first implemented as a 'global quick runoff-fraction', valid for all time steps in the calculation.

2. Based on the new structure described above, new simulations were made. A new general pattern was discovered, i.e. that the modelled flow during the winter period was lower than the observed, and opposite during the summer (modelled higher than observed). For this reason, the runoff-fraction in the SMD was split into two, the Quick_Q_Summer and Quick_Q_Winter. The first covers the period April, May, June, July, August and September, and the Winter-parameter covers the period October, November, December, January, February and March. In Kapos, the Quick_Q_Winter-parameter was calibrated to a higher value than the Quick_Q_Summer, which can be explained physically, because the soil can be more or less frozen during the winter period and hence give a higher direct runoff.

The problem with the winter under- and summer overestimations have not been solved completely by implementing the new coefficient, but the improvements in the fit of the simulation were remarkable.

No systematic sensitivity analysis has been performed on the new parameters. However, based on the manual calibration process performed in Kapos, it is highly recommended that these parameters should be addressed carefully during the calibration since they seem to affect the modelled flow significantly. It should also be noted that it is most likely that selected hydrological routines from the HBV-model (Bergström, 1992) will be implemented in INCA-P before the summer 2006.

5.3 Input data and assumption

5.3.1 Sub-catchment division and terminology

The delineation of the Kapos catchment for INCA-P was identical to the delineation for the SWAT model (see section 6). The sub-catchment boundaries are based on the division produced by the SWAT model. However, while SWAT distinguished 34 sub-catchments, a division with only 10, but larger (aggregated) sub-catchments were applied for INCA-P modelling purposes.

The main stream was divided into 10 reaches in series (see comments on terms later in this section). The most upstream reach is sub-catchment 1 and the most downstream is sub-catchment 10. Four reach boundaries coincide with the locations of the gauging stations and hydrochemical sampling sites (see figure 5.5). The difference from the 12 sub-catchment delineation made as part of the TEOTIL-modelling (figure 4.1), is that the northern main tributary (Koppány) is aggregated into one unit. The reason for doing this aggregation in INCA-P is that the model is not capable of simulating a branched river system.



Figure 5.3. Sub-catchment boundaries of the Kapos catchment used in INCA-P.

There are two main tributaries in the catchment: River Kapos and River Koppány. The instream part of the INCA-P model uses an “in-series continuously-stirred tank reactor concept”, where the river system has to be defined as a single set of linked units of reaches. Based on this requirement, the whole watershed of River Koppány had to be defined as one of the 10 sub-catchments, which resulted in considerable differences in the sizes of the sub-catchments (table 5.1). Besides this, some of the monitoring stations in the area (Törökkopány, Tamási) could not be applied for calibration in INCA-P as they were situated on the River Koppány, and they were therefore not directly in series with the main reach structure.

Terminology

The term ‘reach’ is used in the paper of the developers of INCA-P (Wade et al., 2002) to describe the schematisation of a catchment and how the sub-catchments are linked into a chain of calculation units (see also figure 5.2). The downstream end of a reach coincides with the outlet of a sub-catchment. The term ‘section’, used in several figures in chapter 5 of this report (e.g. from figure 5.7 and onwards), refers to the outlet of a specific sub-catchment

(= downstream end of a reach) where results are extracted from the model. Section 9 means the outlet of sub-catchment 9, which is Pinchehely. The sections selected for results presentation usually coincide with locations where monitoring data are available.

5.3.2 Land cover categories

Six land cover classes were used in the application of INCA-P; non-fertilised agricultural area, fertilised agricultural area, water, wetland, forest and artificial area (see table 5.1 and figure 5.4). These land cover classes were defined on the basis of CORINE Land Cover (1:100 000) layer (1997). Seven agricultural land use categories were assigned to the “Fertilised agricultural area”, and three to the “Non-fertilised agricultural area” land cover category in INCA-P (see table 5.2).

Table 5.1. Area of the sub-catchments and the proportion of different land covers. The categories are based on the CORINE classification.

Sub-catchment ID	Area (km ²)	Land cover categories (% of the area)					
		Non-fertilised agricultural	Fertilised agricultural	Water	Wetland	Forest	Artificial
1	574	13	53	1	0	27	6
2	117	7	78	0	5	7	3
3	121	17	26	0	0	55	2
4	576	10	73	2	0	9	6
5	466	13	37	0	0	46	4
6	307	6	65	2	0	23	4
7	214	15	53	0	0	29	3
8	741	11	66	1	0	19	3
9	136	13	69	1	1	13	3
10	42	13	64	0	1	16	6

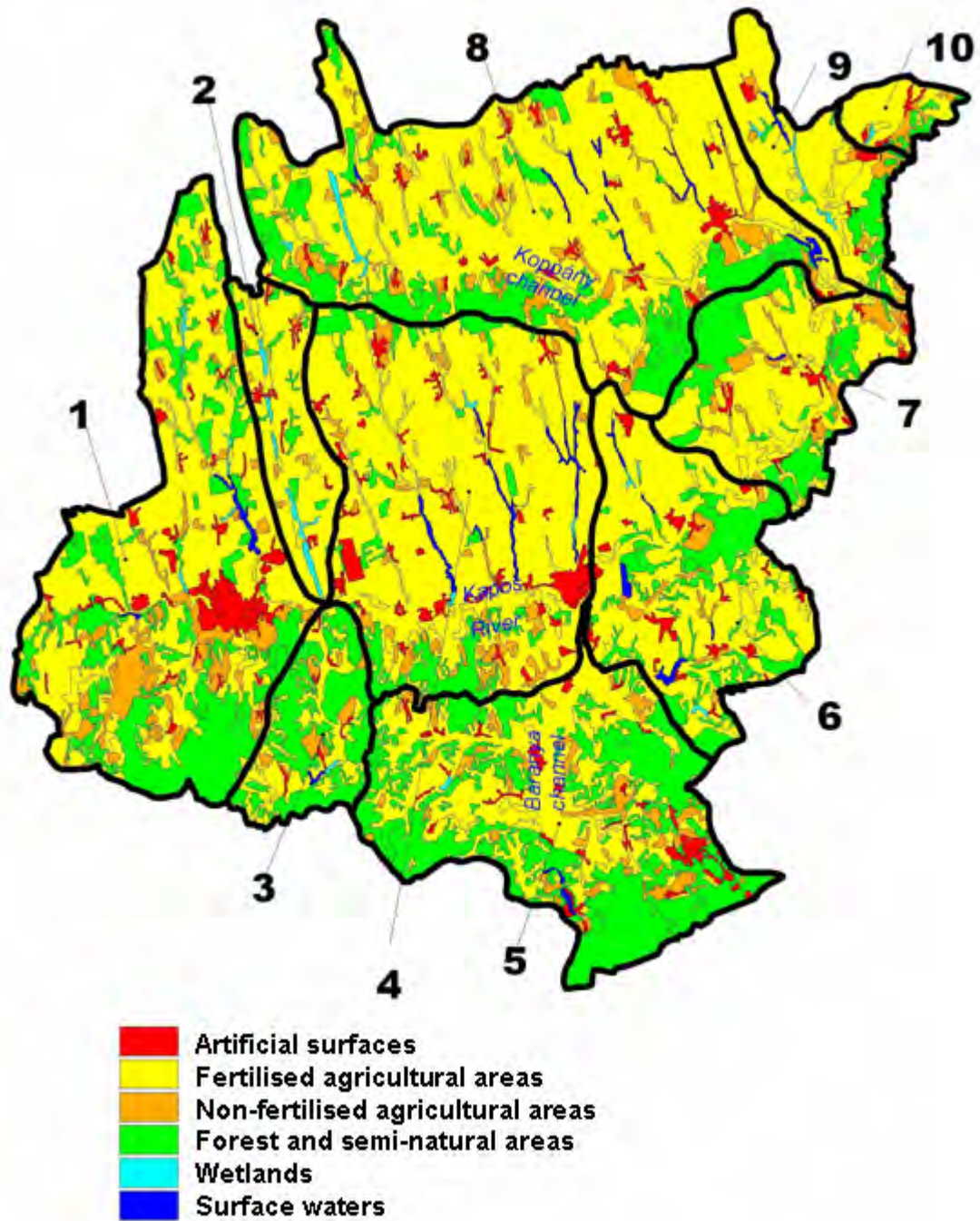


Figure 5.4. Land cover categories used for INCA-P modelling purposes in the Kapos catchment.

Table 5.2. CORINE land cover categories assigned to Agricultural land use types in INCA-P.

Fertilised agricultural areas	Non-fertilised agricultural areas
2.1.1 Irrigated Arable Land 2.1.2 Non-irrigated Arable Land 2.2.1 Vineyards 2.2.2 Fruit Trees and Berry Plantations 2.3.1 Pastures 2.4.1 Annual Crops Associated with Permanent Crops 2.4.2 Complex Cultivation Patterns	2.3 Pastures 2.4.3 Agricultural Land, with significant Areas of Natural Vegetation 2.4.4 Agro-Forestry Areas

5.3.3 Meteorological data

Four meteorological stations with observed daily precipitation and temperature data were used (see figure 5.5). Daily data were collected from the Institute of Hungarian Meteorological Service (OMSZ). Based on proximity and relief, the time series of these four weather stations were applied for the whole area of the catchment. As daily temperature data were available only for two stations (Kaposvár-Fészerlak and Iregszemcse), these were extended to the other two stations (table 5.3).

Table 5.3. Observations of the meteorological stations assigned to the sub-catchments.

Location of weather stations	Sub-catchment ID (= section)	Available data (daily resolution)
Kaposvár-Fészerlak	1, 2, 3, 5	temperature and precipitation
Kurd	4, 6	precipitation (temperature from Kaposvár)
Iregszemcse	8	temperature and precipitation
Tamási	7, 9, 10	precipitation (temperature from Iregszemcse)

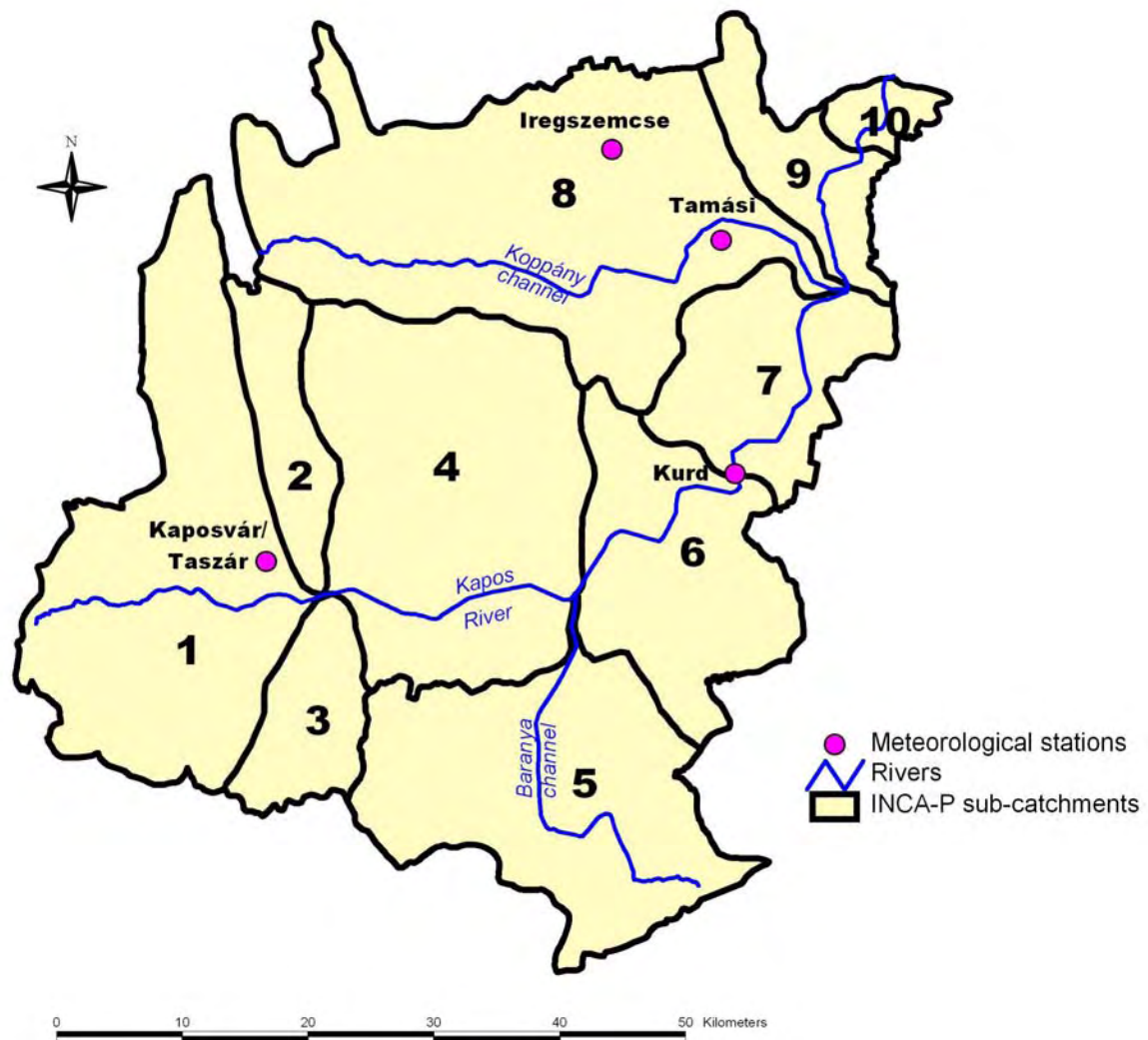


Figure 5.5. Location of meteorological stations with daily temperature and precipitation time series in the Kapos Catchment.

Comments

The available time series of daily mean air temperature were continuous and complete. However, in daily time series of precipitation, a considerable number of days were without observations. As INCA-P can only handle continuous daily time series for hydrological input, precipitation data had to be estimated for the missing periods.

1. For short periods with no observations (1 day to 1 week), the SWAT model's weather generator was used which, based on a 24 years long daily precipitation time series, generated precipitation data for the missing days.
2. For longer periods (one week to one year) with no observations, data from one of the three neighbouring stations were used. As an example, data from 1999 were missing at the weather station Iregszemcse and observations from Tamási (about 10 km from Iregszemcse) were used to fill in gaps.

Based on the observations of the weather stations above, daily SMD and HER were calculated by a given (and later modified) routine and a snow melt model.

5.3.4 Observed water quality data

Origin of data

Data on Total Phosphorus (TotP) and Soluble Reactive Phosphorus (SRP) concentrations were collected from the National Water Quality Database. Four monitoring stations were used in the area for observed TotP and SRP calibration. Each of them are located at the downstream boundary of one of the sub-catchments (figure 5.6).



Figure 5.6. Location of water quality and flow monitoring stations in the Kapos catchment.

Comments

Water quality is basically monitored twice a month, and covers to a large extent the period 1993-2002, which means that concentration time series of TotP and SRP cover more or less the whole calibration period, except the last 1-2 years. More details about the situation at the different monitoring stations are given in table 5.4.

Table 5.4. Periods with observed water quality and flow data.

Monitoring station	Sub-catchment ID ³	Periods with TotP data	Periods with SRP data	Periods with water flow data
Kaposvár	3	1994-2001	1993-2001	1993-2003
Dombóvár	5	1994-2002	1994-2002	1997-2002 ⁴
Kurd	6	1994-2002	1993-2002	1993-2003
Pincehely	9	1994-2002	1993-2002	1993, 1995-2003

5.3.5 Observed water flow data

Origin of data

Daily water flow data were obtained from the National Hydrological Forecasting Service. The same four monitoring stations (Kaposvár, Dombóvár, Kurd, Pincehely) were used as for the calibration of TotP and SRP (figure 5.6)

Comments

For section 3 (outlet of sub-catchment 3), some observations are missing in 1999 and in 2003, which leads to an underestimation of the observed annual flow these years.

Similarly, section 9 lacks some observations in 1997, as there are data only until the end of September. This leads to an underestimation of the observed annual flow that particular year. Being the most downstream monitoring station and located near the river's confluence with Sió-channel, the water flow values of Pincehely (section 9) have been handled with special attention. Sió-channel is a canalised waterway connecting Lake Balaton and River Danube through which the excess water of the lake is discharged. If the lock gate is open at Siófok and water is being released from Lake Balaton, backwater effects at Pincehely have to be considered. This might imply that the given observations are too high compared to the 'true' values during some periods.

The location Dombóvár (location 5) was more or less neglected, it was only used for support during the calibration, since data for the three other locations were more complete.

5.3.6 Fertiliser application

Origin of data

The fertiliser application on the agricultural areas of the Kapos catchment was split into organic and inorganic phosphorous (table 5.5) Data were based on the annual statistics of the two counties in the watershed (Somogy, Tolna) on the amount of P (P/ha/year) from chemical fertiliser and manure, which was obtained from the Regional Statistical Yearbooks published by the Hungarian Central Statistical Office (Hungarian Central Statistical Office). Data on fertiliser application were available for the whole modelling period 1993-2003.

³ The monitoring stations are located at the outlet of the given sub-catchments. The terms 'location' and 'section' used in the report refer to the outlet of the given sub-catchment no (i.e. location 9 = outlet of sub-catchment 9 = Pincehely).

⁴ No daily, continuous time series available.

Table 5.5. Applied P loads per year from organic and inorganic fertilisation in the Kapos catchment.

	Inorganic P (kg/ha/year)		Organic P (kg/ha/year)
	chemical fertiliser	manure	manure
1993	8.0	3.8	6.7
1994	7.2	3.8	6.7
1995	8.7	2.7	4.7
1996	9.1	3.1	5.4
1997	11.1	3.0	5.2
1998	15.0	4.2	7.4
1999	13.8	5.5	9.7
2000	18.1	6.8	11.9
2001	9.6	2.1	3.7
2002	9.2	3.7	6.4
2003	9.7	2.5	4.4

Comments

Yearly loads were converted to a daily application rate (kg/ha/day) for the period of fertiliser application since INCA-P requires for input data on daily resolution if the fertiliser application is split into more than one period, or the period of application changes from one year to the next. The chemical fertiliser is assumed to be evenly distributed on the fields in the period 1st March – 15th April, while the manure is assumed to be distributed evenly from 1st August – 30th November. It is assumed that the manure consists of mostly organic P and some inorganic P. These loads were then applied on the land use types given as “fertilised agricultural” (see table 5.2, all aggregated into one and the same land use type) in each sub-catchment.

5.3.7 Point sources/effluent discharge

Point source time series were estimated for wastewater treatment plants (municipal and industrial) and for raw wastewater from “scattered dwellings”. This is wastewater from settlements that have no sewage system and are therefore not connected to any of the wastewater treatment plants in the catchment.

Wastewater treatment plants and industrial discharges*Origin of data*

Data on Total Phosphorus concentration (mg/l) and wastewater discharge (m³/sec) of wastewater treatment plants were obtained from the Regional Environment and water Management Inspectorate, Pécs and from the National Wastewater Inventory (National waste water cadastre database). Industrial point sources are located only in five of the ten sub-catchments (table 5.6).

Table 5.6. Point sources in sub-catchments.

Subcatchment ID	Location (<i>name of the company</i>) of point source	Type
1	Juta	wwtp
	Kaposvár	wwtp
	Kaposvár (Kaposcukor Rt.)	industrial
	Kaposvár (<i>Kaposplaszt</i>)	industrial
	Kaposvár (<i>Kaposfil</i>)	industrial
	Kaposvár (<i>Kaposvolán Rt.</i>)	industrial
4	Mosdós (<i>Hospital</i>)	industrial
	Igal	wwtp
5	Komló	wwtp
	Sikonda	wwtp
	Orf	wwtp
	Sásd	wwtp
6	Dombóvár	wwtp
	Mágocs	wwtp
8	Balatonlelle	wwtp
	Tamási	wwtp

Comments

Both TotP and water flow data were average values based on seasonal observations, extended for the whole year. Due to the fact that INCA-P requires daily resolution input data, as year-to-year variation should be represented, the load from WWTPs and industries were distributed evenly for all days throughout the years. The spatial resolution of INCA-P required that the point sources were aggregated to sub-catchments.

Municipal wastewater from scattered dwellings*Origin of data*

As only larger towns are connected to wastewater treatment plants in the catchment, phosphorus losses from municipal wastewater at “scattered dwellings” had to be introduced as an additional time series input file for effluent waste water. Information and data were collected from the Statistical Yearbook of Hungary - 1998 (Hungarian Central Statistical Office), and were extended to the whole modelling period 1997-2003.

Comments

Statistics were available on the annual volume of wastewater not treated in Kapos catchment in 1998. Based on literature (Novotny-Chesters, 1981), the total phosphorus concentration was set to 10 mg/l and TotP load was calculated for each sub-catchment. Similarly, to the effluent from WWTP and industries, the load from scattered dwellings was distributed daily at sub-catchment level.

5.4 Calibration

For calibration purpose, the sections 3, 6 and 9 (outlet of sub-catchments Kaposvár, Kurd and Pincehely) were selected (see table 5.4), since the measurements mostly were from these locations. The selected calibration period was 1997-2003 since data from only this period were available when the data preparation and calibration work started.

5.4.1 Calibration with respect to water flow

The first step was to calibrate the hydrological module. This was done partly inside and partly outside the main shell of INCA-P. During this calibration some of the simplifications in the existing routines were considered unacceptable and modifications/improvements were made (see section 5.2). The optimisation of the hydrological model parameters resulted in parameter values as given in table 5.7.

Table 5.7. The most important parameters during the calibration of the hydrology of INCA-P and their calibrated value. The parameters are presented as a range, indicating that they have a spatial variation throughout the catchment.

Parameter	Function	Calibrated value
SMDMAX(mm)	Determines the maximum soil moisture deficit (SMD)	80 - 120
SMDTHR(mm)	Determines the threshold where the SMD starts increasing at a slower rate	40 - 60
Quick_Q_Summer (fraction, dimensionless)	Direct runoff (into HER and then INCA-P) in the summer period	0.055 - 0.1
Quick_Q_Winther (fraction, dimensionless)	Direct runoff (into HER and then INCA-P) in the winter period	0.19 - 0.22
FMELT (mm/k/day)	Factor determining the rate of the snow melt	3.5
Base flow index (fraction, dimensionless)	The proportion of the river runoff that derives from groundwater	0.62 - 0.7
Maximum soil retention volume (m)	Maximum volume of water stored in the soil	0.2
Direct runoff residence time (days)	Mean time taken for water to move through this compartment	0.001
Soil water residence time (days)	Mean time taken for water to move through this compartment	2
Groundwater residence time (days)	Mean time taken for water to move through this compartment	50

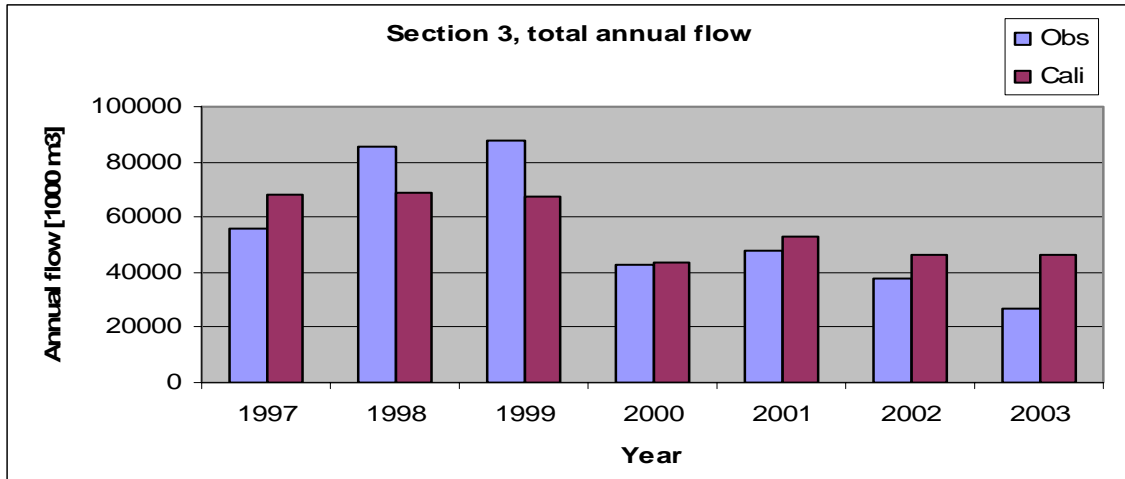


Figure 5.7. The observed and calculated (cali=calculated=calibrated) annual water flow at section 3 for the period 1997-2003. Please note that some observations are missing in 1999 and in 2003, leading to an underestimation of the observed annual flow these years. Note also comments given in 5.3.5.

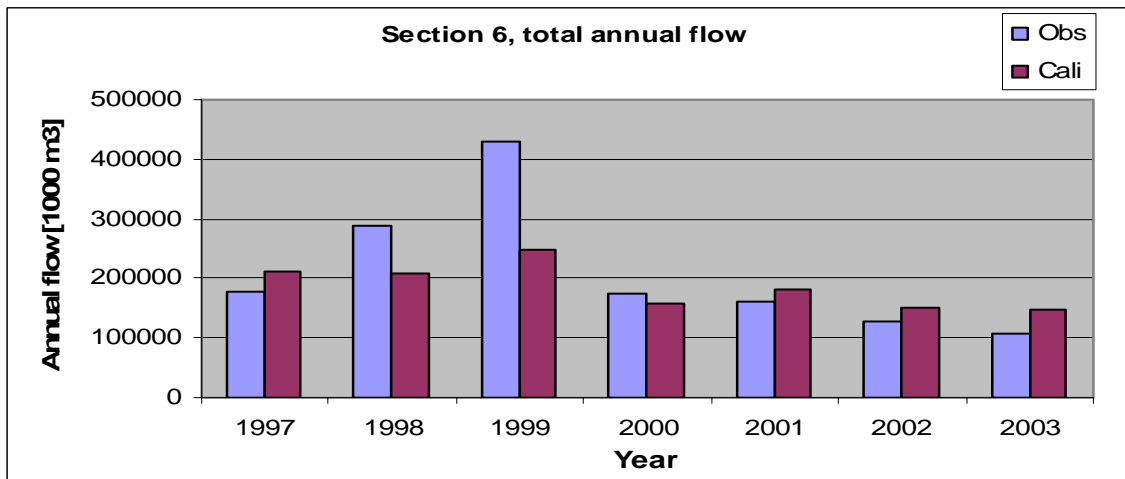


Figure 5.8. The observed and calculated (cali=calculated=calibrated) annual water flow at section 6 for the period 1997-2003.

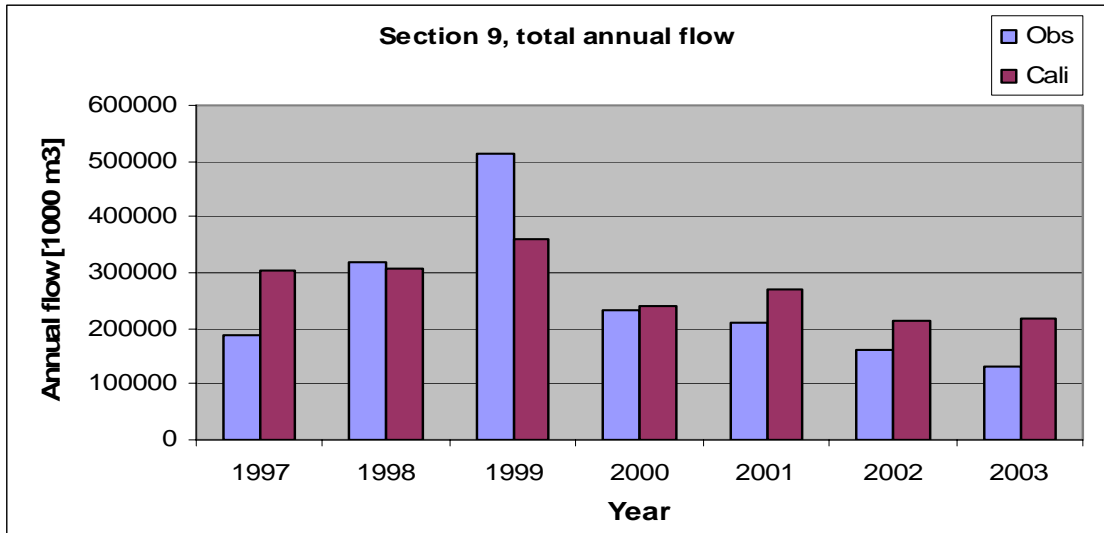


Figure 5.9. The observed and calculated (cali=calculated=calibrated) annual water flow at section 9 for the period 1997-2003. Please note that some observations are missing in 1997 (data only to the end of September), leading to an underestimation of the observed annual flow this year. Note also the comments given about this station in section 5.3.5.

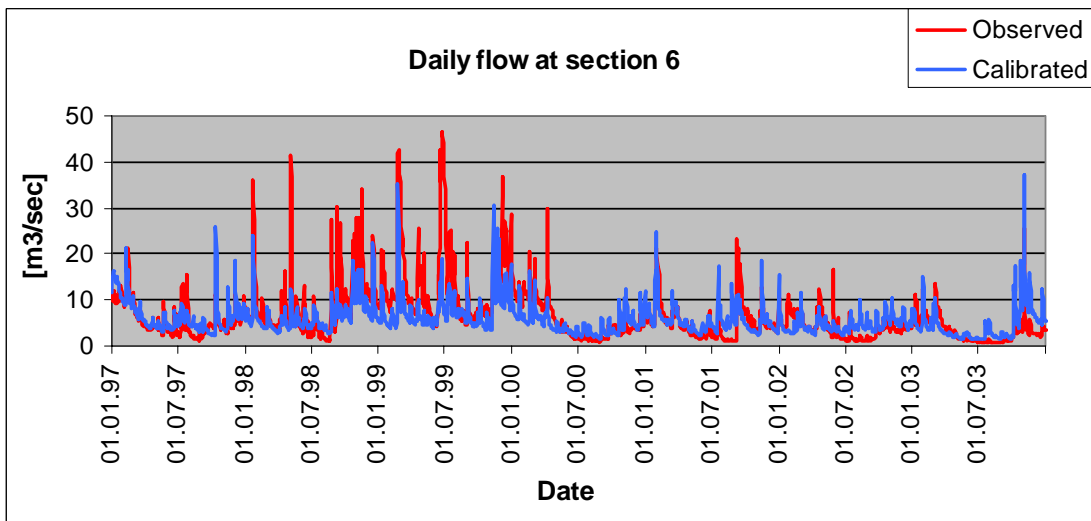


Figure 5.10. The observed and calculated (calibrated) daily water flow at section 6 for the period 1997-2003.

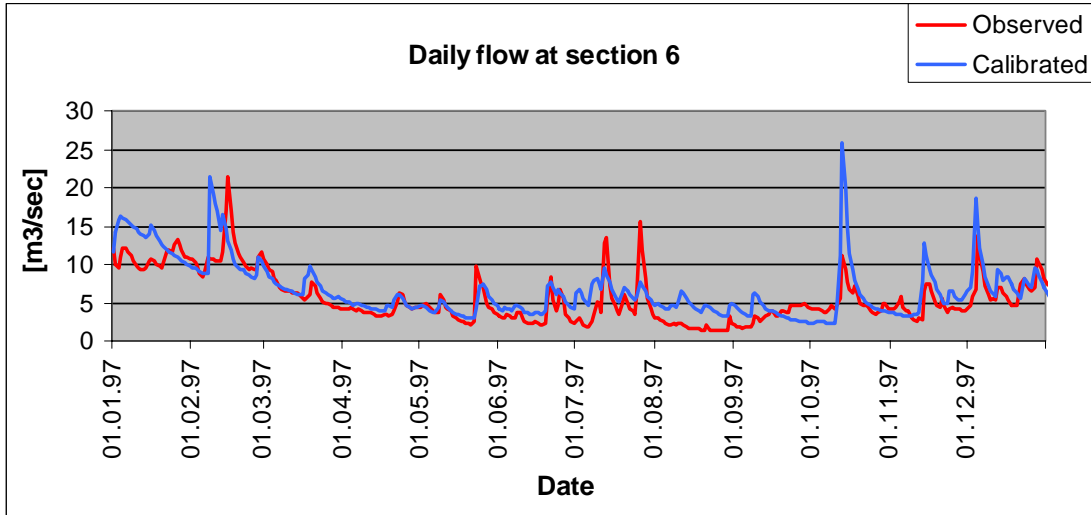


Figure 5.11. The observed and calculated (=calibrated) daily water flow at section 6 for the period January 1997 – December 1997.

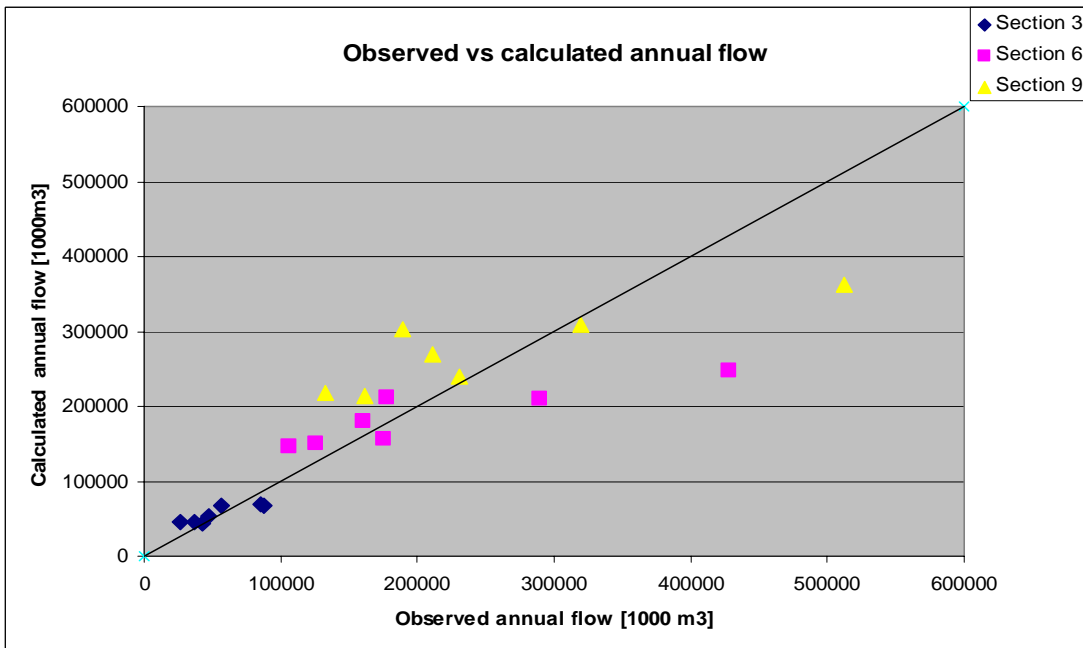


Figure 5.12. The deviation between the observed and calculated annual water flow for the period 1997-2003.

Comments:

Figure 5.12 shows that INCA-P underestimates, on annual basis, the water flow those years with high annual flow. This is the case for all three sections. Furthermore, the model overestimates the annual water flow those years, except for one year, with average or low flow, but to a lesser extent than the underestimation of high flows. However, there are also possible errors in the observations, and especially in the monitored values during extreme events, like in the flooding event in the summer of 1999. This event was extraordinary since it happened during the summer and lasted for a long period (according to the observed values),

which again adds significantly to the volume of water transported through the catchment that year. Based on information given by VITUKI CONSULT Rt, the data for this year should be handled with special care since they may be erroneous, which again might explain some of the deviation between the calculated values and the observations.

It should also be noted that INCA-P does not handle human manipulation of the natural hydrological regime. There are approximately 175 fish ponds in the catchment, with a small dam construction regulating the water level. Generally, these ponds are regulated in such a way that the water level is kept as high as possible during the summer period. This means that water is stored during spring/summer, which reduces the natural runoff in these periods. This might lead to an increased evaporation during the same period, and possibly higher flow in the rivers when a rain event occurs and the ponds are filled with water (late summer/autumn).

Water is in some parts of the catchment withdrawn for irrigation purposes. This causes also an increase in the evapotranspiration and a delay in the hydrological response. Most of the water is probably abstracted in the lower part of the catchment which may also explain some of the gaps between the calculated and observed water flows.

See further statistical data on the calibration of the hydrology in tables 5.10 and 5.11.

5.4.2 Calibration with respect to TotP and SRP

The second step was to calibrate the model with respect to TotP and SRP-observations made in the instream water. All of this calibration was done on parameters to be tuned within the INCA-P shell. Table 5.8 lists the most important parameters tuned as part the calibration of INCA-P in Kapos.

Table 5.8. The most important parameters during the calibration of the P-module. Those parameters presented as a range indicate that they have a spatial variation throughout the 10 sub-catchments.

Parameter	Function	Calibrated value
Organic-P uptake rate (m/day)	Rates at which organic-P is taken up by plants	0 - 6
Inorganic-P uptake rate (m/day)	Rates at which inorganic-P is taken up by plants	0 - 6
Immobilisation	Rate at which inorganic P is immobilised in the soil	0.1
Mineralisation	Rate at which organic P is converted into inorganic P	0.2
Firmly bound organic-P input (m/day)	Rate at which organic P is locked away in the soil	0 – 0.22
Firmly bound organic-P output (m/day)	Rate at which organic P is released to the soil	0 – 0.1
Firmly bound inorganic-P input (m/day)	Rate at which inorganic P is locked away in the soil	0 – 0.22
Firmly bound inorganic-P output (m/day)	Rate at which inorganic P is released to the soil	0 – 0.1
SUP proportion	The proportion of TotP as soluble non-reactive P	0.25 – 0.5

The goals of the water quality modelling in Kapos were to simulate TotP and SRP-concentrations in the water bodies and the loads of TotP and SRP in Kapos adequately.

Simultaneously, the calibration made should be based on both TotP/SRP observations at three different sections (and to some extent also section 5), which then gives a multi-objective goal of the calibration. Based on the fact that the primary use of the modelling results are for ecological considerations, and that calculation of ‘observed load’ introduces a new aspect of uncertainty during the time-interpolation, the observations of TotP- and then SRP-concentrations were selected to be the most important output variables during the calibration. Since no automatic calibration routine is present, the calibration was done by manually changing the model parameters, running the model, comparing the output with the observation, refining the model parameters, running the model again, as an iterative process.

Table 5.9. The table shows the average observed and calculated (cali=calculated=calibrated) concentrations of TotP [mg/l] and SRP [mg/l] during the whole calibration period (1997-2003). Dev = Deviation.

Section	TotP [mg/l]				SRP [mg/l]			
	Obs	Cali	Dev	Dev %	Obs	Cali	Dev	Dev %
3	0.296	0.452	-0.156	-52.7	0.092	0.222	-0.130	-141.7
5	0.610	0.417	0.193	31.7	0.294	0.306	-0.013	-4.4
6	0.726	0.423	0.303	41.8	0.309	0.310	-0.001	-0.3
9	0.659	0.486	0.173	26.3	0.257	0.286	-0.029	-11.1

Table 5.9 shows a clear deviation between the observations and calibrated values of TotP at all sections. Results from sections 5 and 9 can be considered acceptable, while the deviation at especially section 3 is too big. The situation for SRP is much better and gives a good correlation between the observations and the model output, except for section 3, where the deviation is very high. The same negative deviation can be seen for TotP. During the calibration procedure, the negative deviation at section 3 was compensated by the parameter values with the result that a positive deviation was introduced at the more downstream sections. Since the same high overestimation (by the model) is observed at the most upstream parts of the catchment (section 3) for SRP, a possible reason for this might also be error in the input data, or an inaccurate spatial representation of input data.

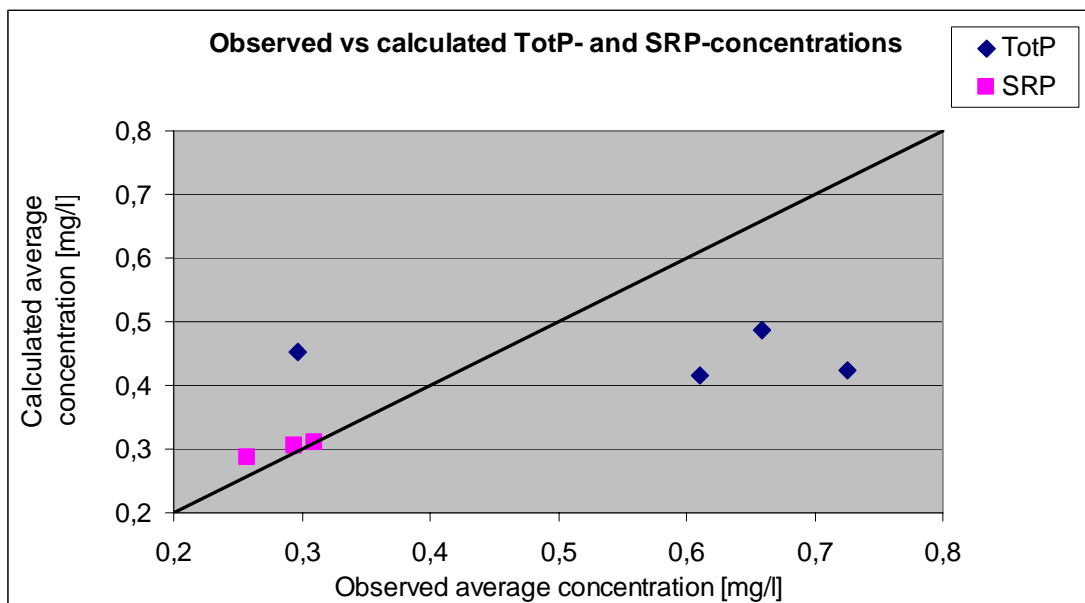


Figure 5.13. The average observed and calculated concentrations of TotP [mg/l] and SRP [mg/l] during the whole calibration period (1997-2003). The figure is based on the data in table 5.9

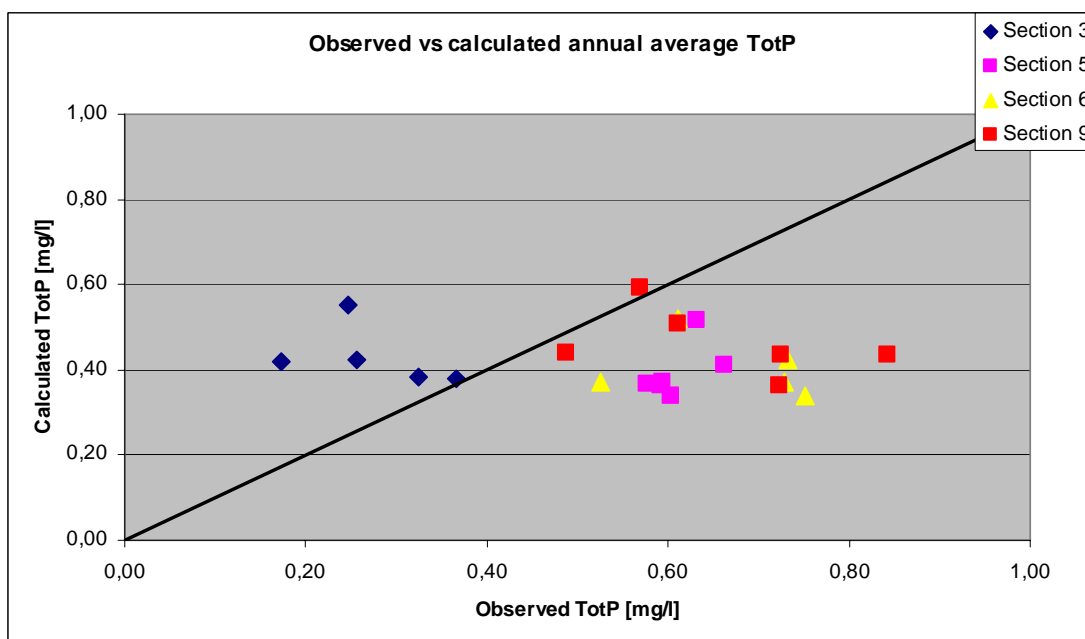


Figure 5.14. The average observed and calculated concentrations of TotP [mg/l] each year in the period 1997-2003, at all sections utilised in the calibration.

Based on figure 5.14 it is clear that the model underestimates the concentrations of TotP at the sections in the downstream parts of the catchment. These are the sections with the higher concentrations of TotP. In general, it also seems that the model does not represent the variations in concentration along the catchment appropriately. The calculated values of TotP fit better to the line $y = \text{constant}$ than to a 1:1-line ($y = \sim 0.45$). The fit is better for SRP,

except for section 3. Figure 5.14 shows more or less the same picture as figure 5.13, but with a higher variability since annual average values of TotP are plotted.

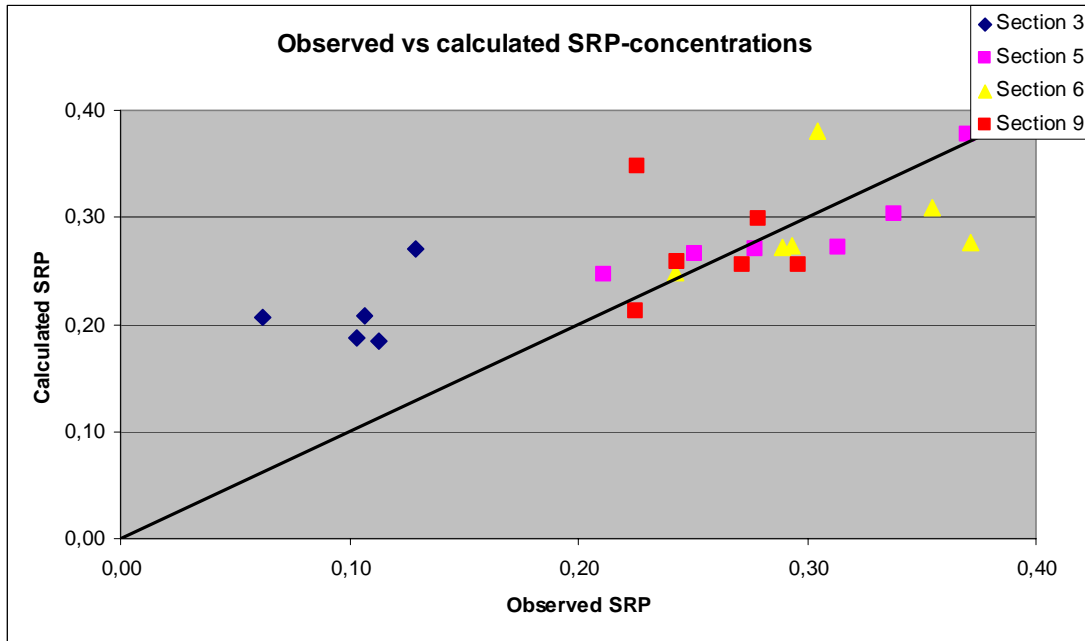


Figure 5.15. The average observed and calculated concentrations of SRP [mg/l] each year in the period 1997-2003.

Figure 5.15 underlines the findings presented above (table 5.9 and figure 5.13) and the data fit quite well to the 1:1-line, except for the calculated values at section 3. The annual results at section 3 is fairly consistent and do not show a higher variability than the data from the other sections. The large deviation can by this not be explained from an extreme year, but a systematic error seems to be present, which might stem from errors in the input data (e.g. load of P).

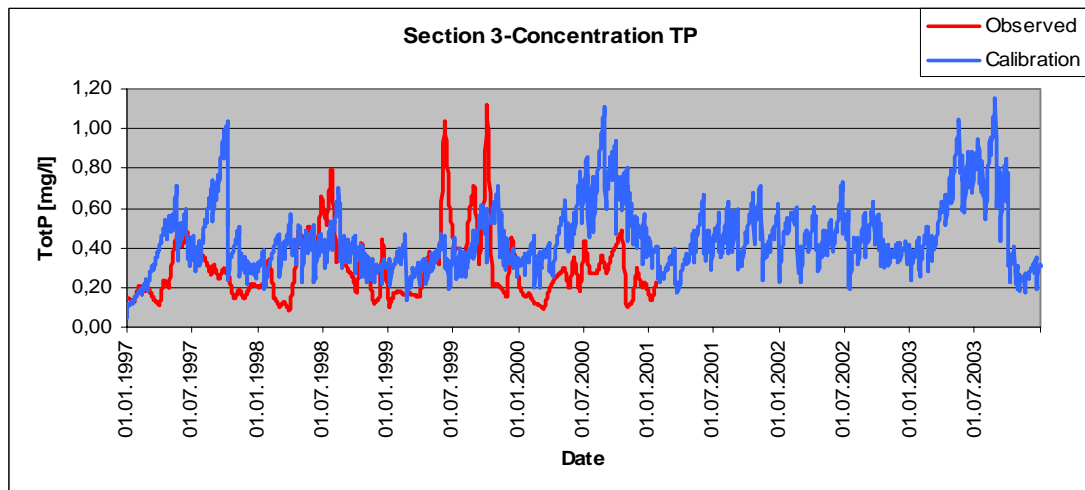


Figure 5.16. The observed versus the calculated (=calibrated) concentration (daily) of TotP in mg/l at section 3.

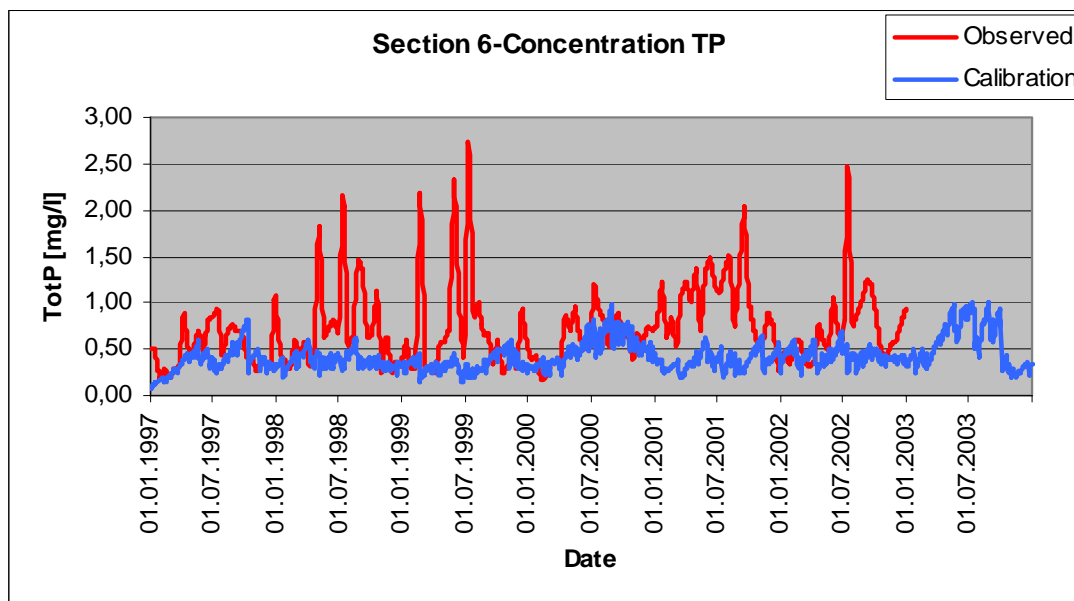


Figure 5.17. The observed versus the calculated (=calibrated) concentration (daily) of TotP in mg/l at section 6.

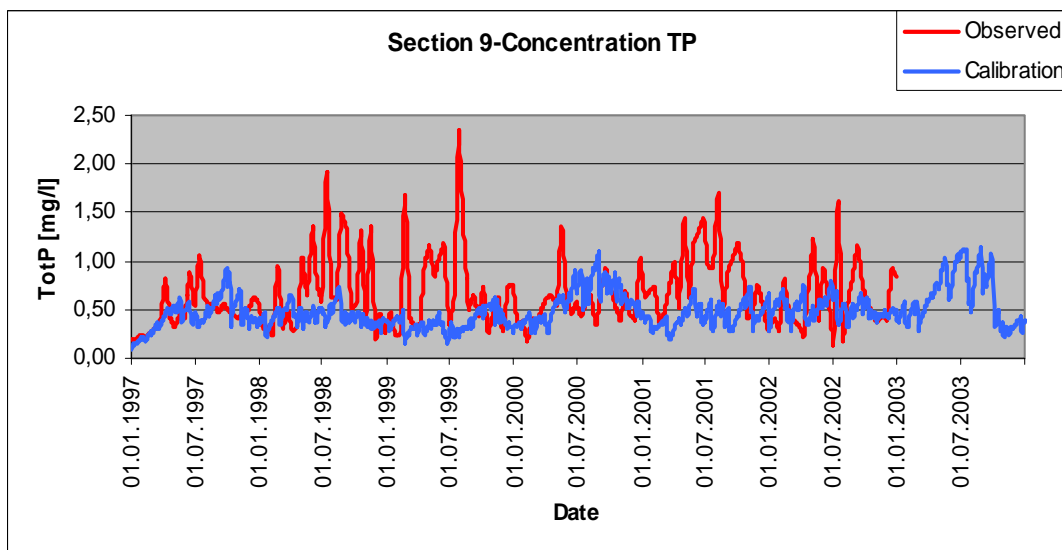


Figure 5.18. The observed versus the calculated (=calibrated) concentration (daily) of TotP in mg/l at section 9.

Figures 5.17-5.18 (sections 6 and 9) show that the low concentrations of TotP are simulated well, but the higher concentrations/peaks are inappropriately modelled. The high peaks in the observations are not matched by similar high concentration values in the model output. The same pattern can not be seen at section 3 (figure 5.16), which might be due to a systematic error.

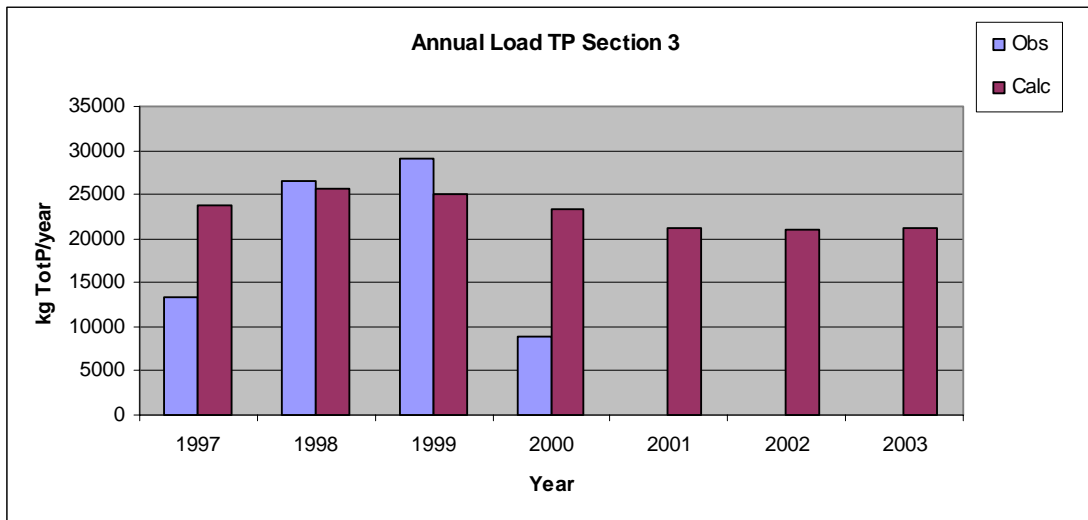


Figure 5.19. The “observed” and modelled (calc=calculated=calibrated) annual load of TotP [kg/year] out of sub-catchment 3 in the period 1997-2003. Please note there is missing flow data for a few days in 1999, leading to an underestimation of the load for this year.

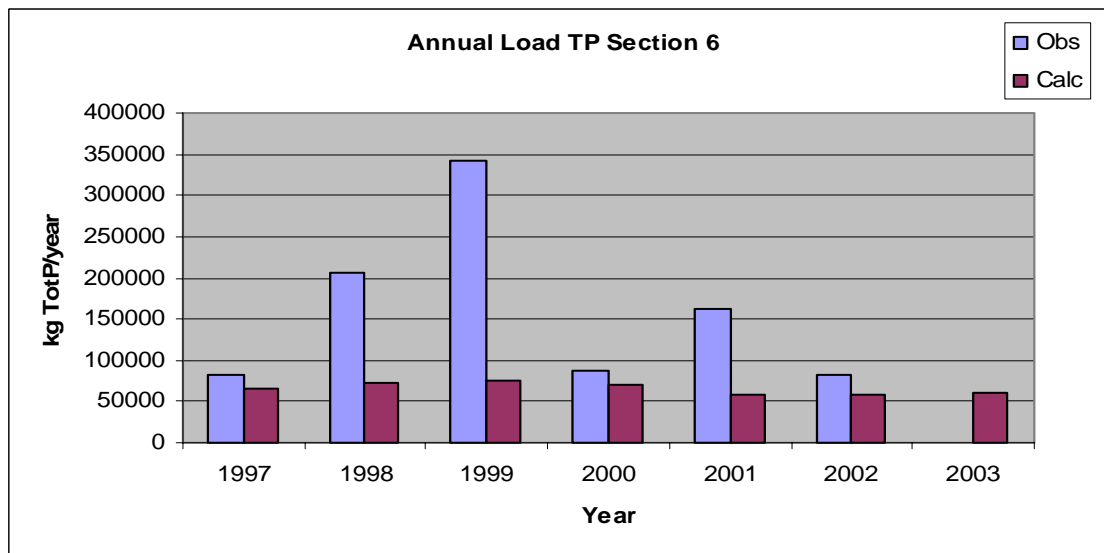


Figure 5.20. The “observed” and modelled (calc=calculated=calibrated) annual load of TotP [kg/year] out of sub-catchment 6 in the period 1997-2003.

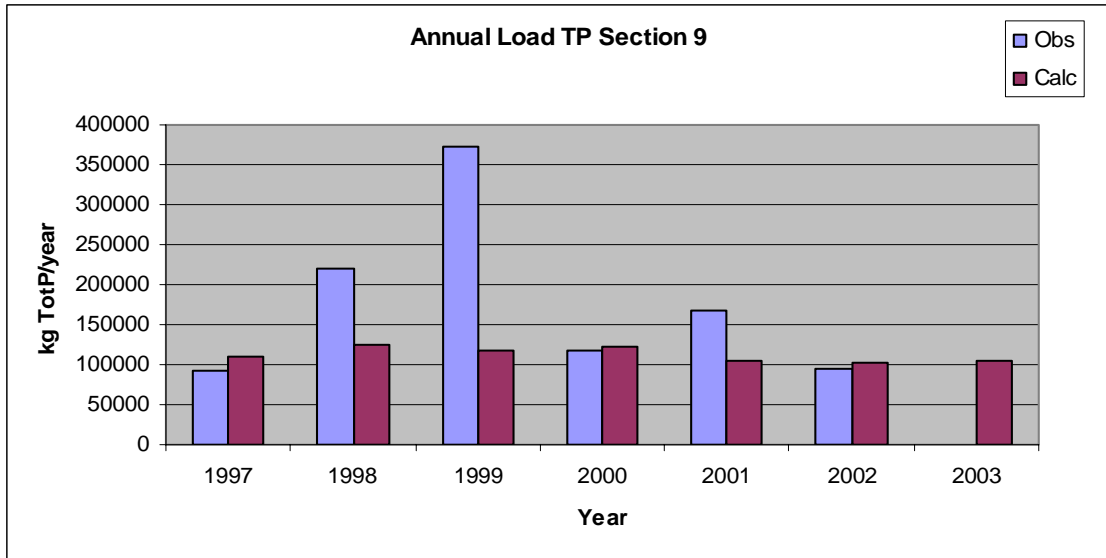


Figure 5.21. The “observed” and modelled (cali=calculated=calibrated) annual load of TotP [kg/year] out of sub-catchment 9 in the period 1997-2003. Please note there is missing flow data for the period October – December 1997, leading to an underestimation of the observed load for this year.

The results presented in the figures 5.20 and 5.21 show that the model underestimates the TotP load, and the deviation is largest those years with high annual load, which further coincide with those years of high annual flow (1998 and especially 1999). The results from section 3, presented in figure 5.19 (section 3) do not show the same pattern, which might be explained by the fact that they are probably biased by a systematic error.

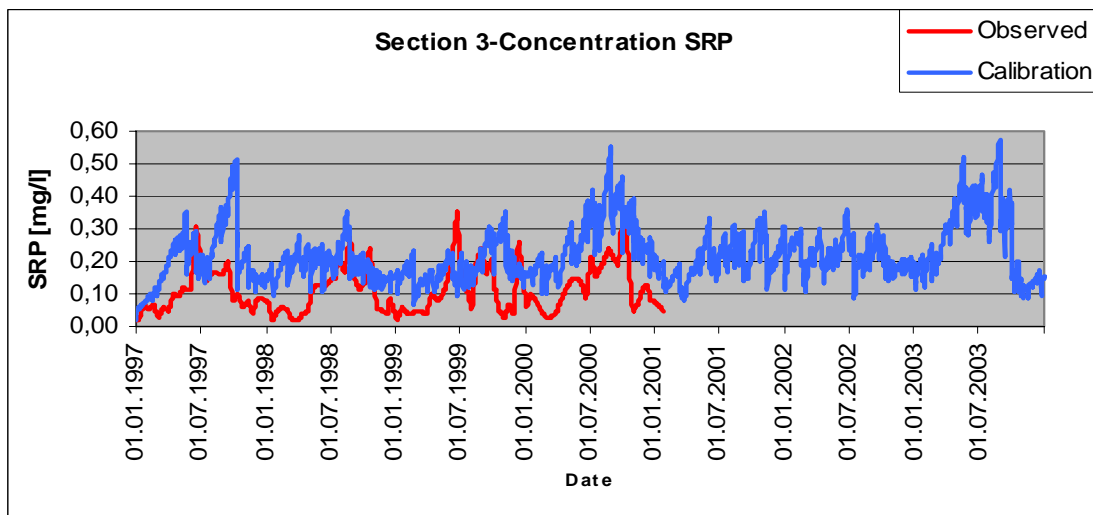


Figure 5.22. The observed versus the calculated (=calibrated) concentration (daily) of SRP in mg/l at section 3.

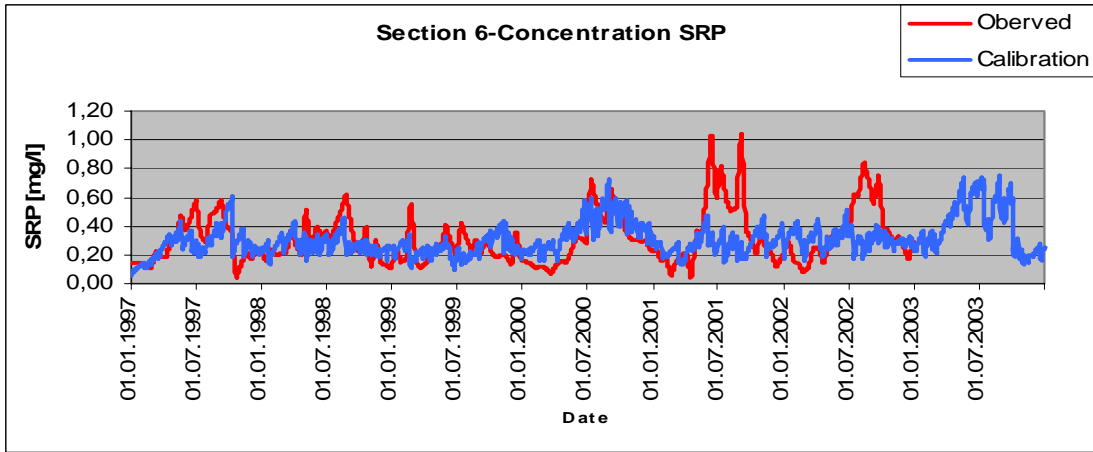


Figure 5.23. The observed versus calculated (cali=calculated=calibrated) concentration (daily) of SRP in mg/l at section 6.

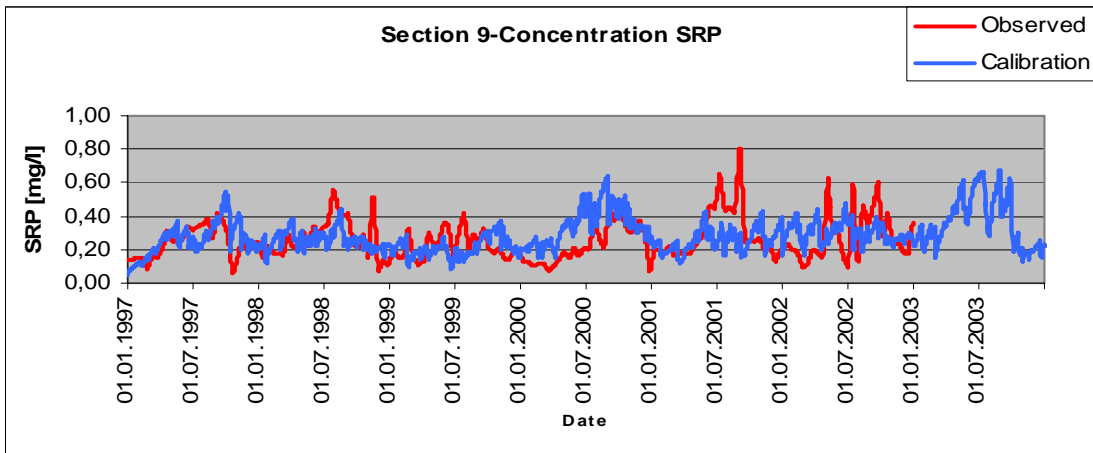


Figure 5.24. The observed versus calculated (=calibrated) concentration (daily) of SRP in mg/l at section 9.

The daily values of SRP give in most cases a better correlation between the observed and calculated values than TotP, and the dynamic variation is better represented by the model. Again, the calculated level at section 3 is too high.

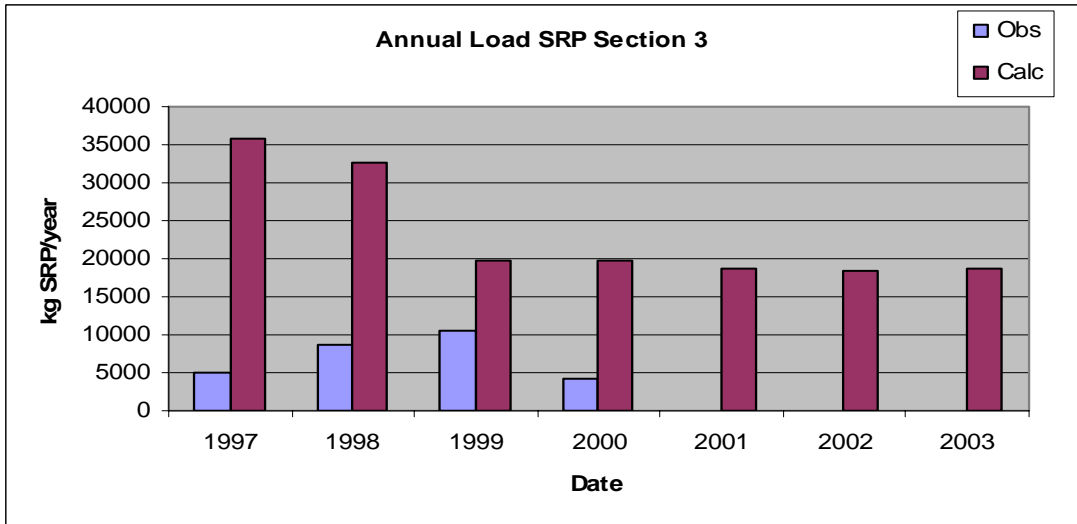


Figure 5.25. The “observed” and modelled (cali=calculated=calibrated) annual load of SRP [kg/year] out of sub-catchment 3 in the period 1997-2003. Please note there are missing flow data for a few days in 1999, leading to an underestimation of the observed load for this year. Obs = observed values, cali = calibration values.

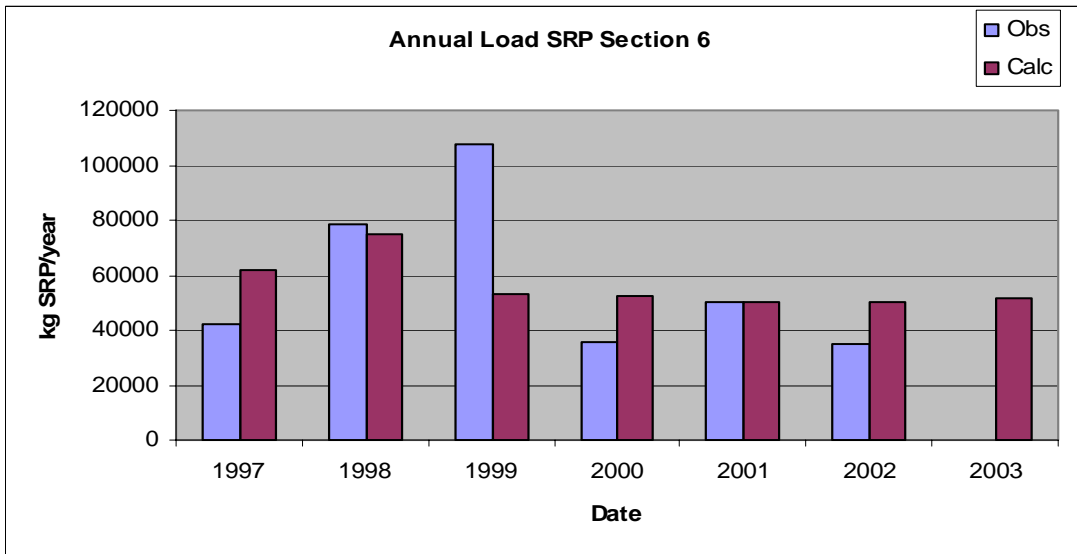


Figure 5.26. The “observed” and modelled (cali=calculated=calibrated) annual load of SRP [kg/year] out of sub-catchment 6 in the period 1997-2003. Obs = observed values, cali = calibration values.

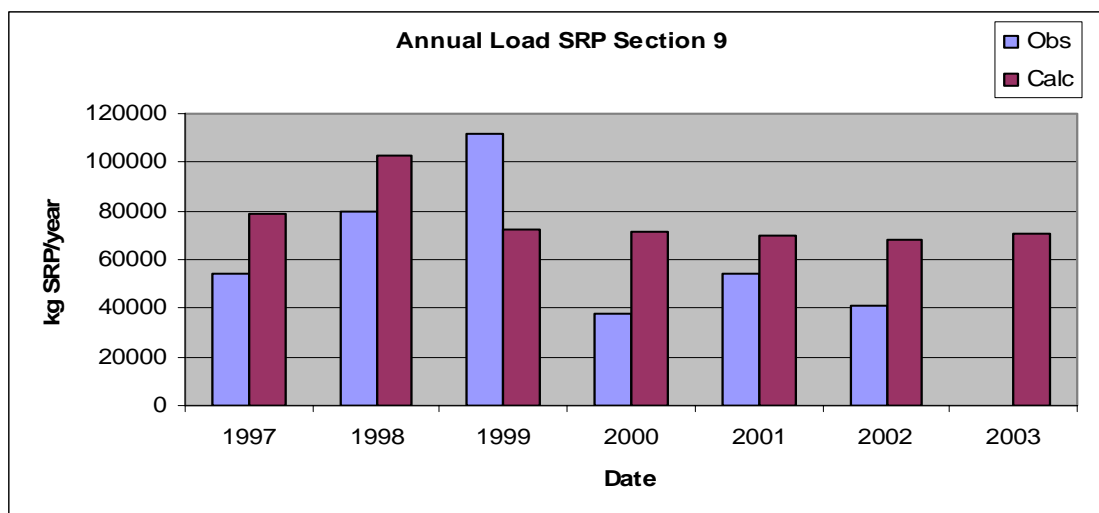


Figure 5.27. The “observed” and modelled annual load (cali=calculated=calibrated) of SRP [kg/year] out of sub-catchment 9 in the period 1997-2003. Please note there are missing flow data for the period October – December 1997, leading to an underestimation of the load for this year.

The observed and calculated loads of SRP match better than the load of TotP. Similar to TotP, the load in 1999 is underestimated by the model compared to the observations. 1999 was an extreme hydrological year and the observations from the flooding period should also be handled carefully, since the measurement of high water flows can be biased. The load is directly based on the water flow and it can be expected that the load values show a large deviation in those years with extreme flooding events than in years with normal hydrological conditions.

Comments to the calibration

The general picture of the calculation of TotP-concentrations is that TotP is overestimated at the most upstream section (3) and underestimated at the 3 downstream sections, except for 2-3 years at section 9 which present a fairly good fit (figure 5.14). The same figure indicates that the calculations at section 5 give a fairly consistent underestimation. At this section all years, except one, is underestimated with approximately 40 %, while the underestimation at section 6 varies between ~15-60 %. The same figure also indicates that the deviation between the modelled TotP-concentrations and the observations gets larger as the concentrations increase. Analysing the modelled annual average TotP-concentration, it is not possible to see any significant trend with increasing observed TotP.

The figures 5.16-5.18 show the daily calculated TotP-concentrations together with the observations. At all sections the basic level, when the peaks in the observations are dismissed, is fairly well calculated. However, it seems that the model does not capture the peaks in the observations. The reason for this can be that INCA-P does not include any specific routines for handling runoff/erosion from land area. Inclusion of such a routine would probably improve the handling of peak events considerable, which also would reduce the deviations in the annual numbers.

The calculation of average SRP-concentration (annual values, figure 5.15), indicates a better fit than for TotP, except at section 3 that is overestimated by the model. It also seems that the dynamic variation in SRP-concentrations is better handled than TotP (figures 5.22-5-24). This might also be explained from the fact that SRP is not linked to erosion of particles to the same extent as TotP.

The load is calculated by multiplying daily concentration figures with daily water flow figures. Over- or underestimation of both concentration and flow will increase any error when comparing observed and calculated loads. To be able to calculate daily load, the observations of TotP/SRP-concentrations were interpolated in time, since observations of TotP/SRP are scattered. A linear interpolation routine was used to generate regular time series with one day time step. The calibration results indicate that the TotP-load is overestimated in section 3 (outlet of sub-catchment 3). 1998, and especially 1999, were 'wet' years and an underestimation of calculated load was expected for these years (figure 5.19). The model results show a significant underestimation in section 6 (outlet of sub-catchment 6, see figure 5.20), and the results are particularly poor in the 'wet' years (1998 and even more extreme in 1999). The modelled results are more in accordance with the observations at section 9 (figure 5.21), again except for the 'wet' years.

The SRP-load (figures 5.24-5.26) is considerably overestimated at section 3, but the results are reasonable at section 6 and slightly too high at section 9.

A question to be raised is if too much phosphorus as TotP (from fertiliser, wastewater treatment plants and scattered dwellings) are entered as input into the most upstream sub-catchments, and especially in sub-catchment 1. A reduction in the input load to this part of the catchment will improve the general picture, i.e. that the model overestimates the load and concentrations of TotP and SRP at section 3, and gives better correspondence with the observations at sections 6 and 9. If this is the case, the SUP-factor (soluble unreactive phosphorus) must be adjusted to reduce the proportion of SRP. This adjustment of the input should, of course, only be done if the proposed changes can be justified by a thoroughly evaluation of the situation with regard to real phosphorus losses and discharges in the Kapos catchment.

Statistical results based on the EUROHARP-protocol

A protocol for assessing model performance and support comparison between models was defined in the EUROHARP-project (EUROHARP 8-2004). The main reason to include these types of statistical results in this report is to be able to compare the results of the model testing in Kapos with other quantification tools and catchments utilised in the EUROHARP-project. These results are available from the EUROHARP Toolbox at :

www.EUROHARP.org/toolbox.

Table 5.10 shows the results for 3 sections according to the said protocol. The notation followed in the expressions below is according to the given reference. In all expressions, there are n observations and n corresponding predictions (*i.e.* model results). Observations are denoted by O_i and predictions by P_i , for $i \in \{1, 2, \dots, n\}$.

Mean Error (ME)

The mean error is a measure of systematic error or bias. In the definition below, $ME < 0$ denotes overestimation, and $ME > 0$ underestimation. The range of ME is from $-\infty$ to $+\infty$. It's optimum value is $ME = 0$ (no systematic error).

$$ME = \frac{1}{n} \sum_{i=1}^n (O_i - P_i)$$

Mean Absolute Error (MAE)

The mean absolute error is given by:

$$MAE = \frac{1}{n} \sum_{i=1}^n |O_i - P_i|$$

where $|\cdot|$ denotes the absolute value. The ideal is 0.

Root Mean Squared Error (RMSE)

The root mean squared error is a measure of accuracy. It's range is $0, \infty$. Lower values indicate greater accuracy. It is calculated according to the equation below.

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (O_i - P_i)^2}$$

Nash-Sutcliffe's Model Efficiency (EF)

Nash-Sutcliffe's Model Efficiency (EF) varies from $-\infty$ to 1, with 1 as the optimum value. A value of 0 means that substituting P_i by the average value of all observations, gives an equally efficient model. It is calculated according to the equation below.

$$EF = \frac{\sum_{i=1}^n (O_i - \bar{O})^2 - \sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} = 1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2}$$

Table 5.10. Statistical results, based on model results and observations, according to EUROHARP 8-2004. All the concentration and load data refer to TotP.

Statistical test	Variable	Section		
		3	6	9
Mean error	Flow [m ³ /s]	-0.10	1.21	-0.09
	Concentration [mg/l]	-0.23	0.33	0.20
	Load [kg]/day	-28.1	256.4	174.4
	Load [kg]/year	-10258	93614	63688
	Load [kg]/ha*day	-0.00035	0.00119	0.00054
	Load [kg]/ha*year	-0.126	0.433	0.196
Mean absolute error	Flow [m ³ /s]	0.79	3.11	4.06
	Concentration	0.28	0.37	0.30
	Load [kg]/day	46.1	284.9	297.7
	Load [kg]/year	16837	104019	108705
	Load [kg]/ha*day	0.00057	0.00132	0.00092
	Load [kg]/ha*year	0.207	0.481	0.334
Root mean square error	Flow [m ³ /s]	1.39	5.27	6.03
	Concentration [mg/l]	0.33	0.54	0.42
	Load [kg]/day	67.6	672.9	566.0
	Load [kg]/year	528	5250	4416
Nash-Sutcliffe's ME	Flow [m ³ /s]	0.26	0.32	0.31
	Concentration [mg/l]	-5.14	-0.83	-0.63
	Load [kg]/day	-0.411	-0.135	-0.076

Table 5.11. Long-term average flow, concentration and load (TotP) at sections 3, 6 and 9 for the period 1997-2003. The observed datasets are not complete these years.

Variable	Section		
	3	6	9
Flow [m ³ /s]	1.80	6.62	8.14
Concentration [mg/l]	0.30	0.73	0.66
Load [kg]/day	53	438	487
Load [kg]/year	19460	160088	177870
Load [kg]/ha*day	0.00065	0.00203	0.00150
Load [kg]/ha*year	0.24	0.74	0.55

The mean errors of table 5.10 show that the annual flow values are overestimated at sections 3 and 9, and underestimated at section 6, taking the whole period of data into consideration (water balance for the whole period). By comparing these values with table 5.11, it can be concluded that the errors are small at sections 3 and 9 (approximately 5 % and 1 %), but larger at section 6. The reason for the larger deviation at this section is the underestimation of the flow in 1998 and 1999, the 'wet years'.

The mean absolute error indicates that the fit on the flow values seen in the mean error (good water balance for the whole period) to some extent is caused by the fact that the underestimation of flow some periods (days/weeks) is compensated by an overestimation in other periods. This because the mean absolute errors are significantly higher than the mean error values. The typical situation is that INCA-P underestimates the flow in high-flow periods and overestimates in low-flow periods.

The statistical results derived from the concentration data are slightly different compared to the flow results, since the difference between mean error values and mean absolute errors are much smaller. This can be explained by a more or less systematic error, since the model underestimates the error at sections 6 and 9, and to some extent systematically overestimates the TotP-concentrations at section 3. This picture is only biased by the fact that also the peaks in the concentrations are underestimated at section 3.

Since the nutrient load is calculated based on flow and concentrations, these results can be explained by the rationale given for flow and concentration.

The Nash-Suttcliffe's Model Efficiency-criteria applied on the simulated flow data gives values around 0.3. According to Killingtveit and Sælthun (1995) 'normal values' of a calibrated HBV-model (Bergström, 1992) for Norwegian condition is between 0.6 and 0.9. The poorer calibration results of INCA-P in Kapos can be explained by the fact that the hydrological module is fairly simple and that the evapotranspiration in the catchment is very high compared to the conditions the model is developed for.

5.5 Definition and simulation of management scenarios

As part of the EUROHARP-project (www.EUROHARP.org), the following management scenarios were suggested for model testing (Vagstad and French, 2005), see also similar testing of TEOTIL (section 4.4), SWAT (section 6.4) and the comparison in section 7.2.2:

- 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 (= 20 % increase in organic P⁵)
- D 20 % decrease in livestock numbers (= 20 % decrease in organic P)
- 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
- G 20 % decrease of Point Source loads (added scenario which is not part of the EUROHARP-project)

Scenarios A, B, C, D, F and G were modelled with use of INCA-P in Kapos. Scenario E was discarded since INCA-P is not capable of differentiating between different crops within the fertilised areas. Scenarios A, B, C and D were interpreted by increasing/decreasing the input time series of inorganic/organic with 20 %, all other factors were left unchanged. Scenario F was implemented by reducing the fertilised agricultural area for each sub-catchment by 20 % and replacing this with forest. Scenario G was simulated by reducing the time series of load (effluent flow values) from point sources and scattered dwellings with 20 %.

⁵ It is assumed that all of the phosphorus from livestock manure is organic (no inorganic), which is a simplification compared to the 'true' situation. See also the division of manure into organic P and inorganic P in table 5.5 (ordinary input data).

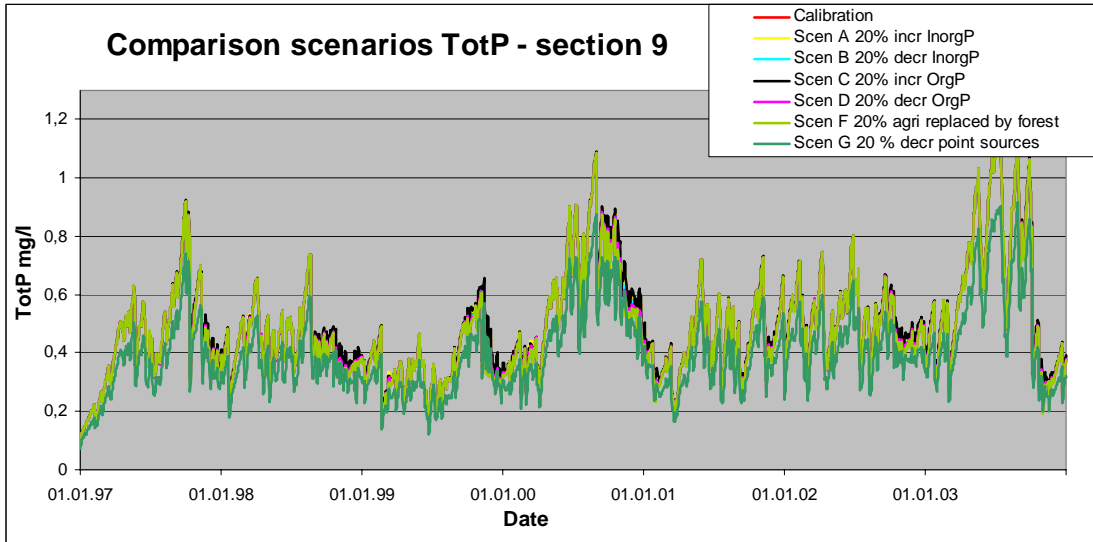


Figure 5.28. TotP-concentrations from the calibration and all the simulated scenarios for the period 1997-2003.

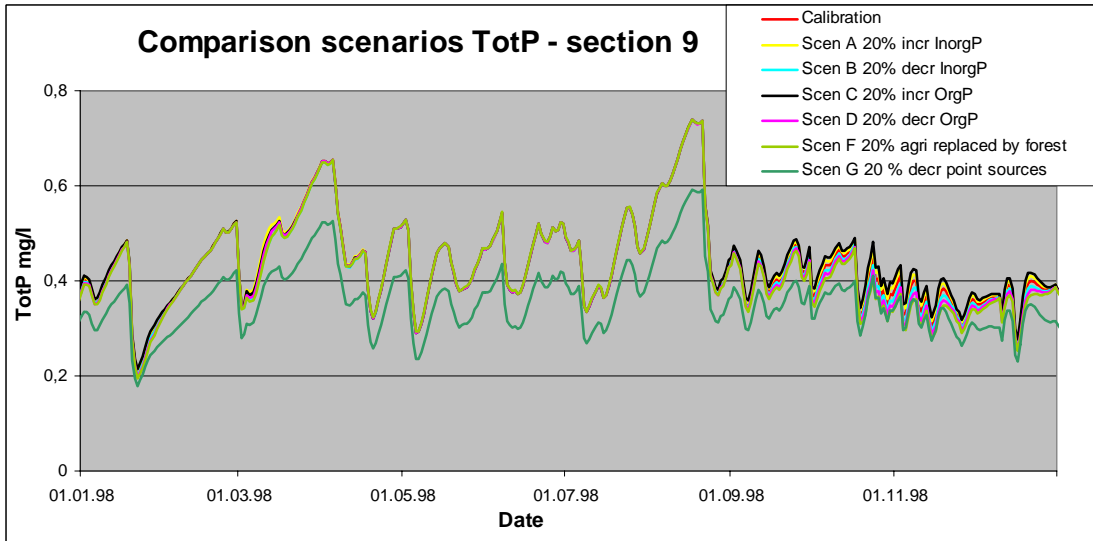


Figure 5.29. TotP-concentrations from the calibration and all the simulated scenarios for 1998. All the scenarios, except scenario G, and the calibration are more or less identical until September, which means that some of the lines are shaded in this period.

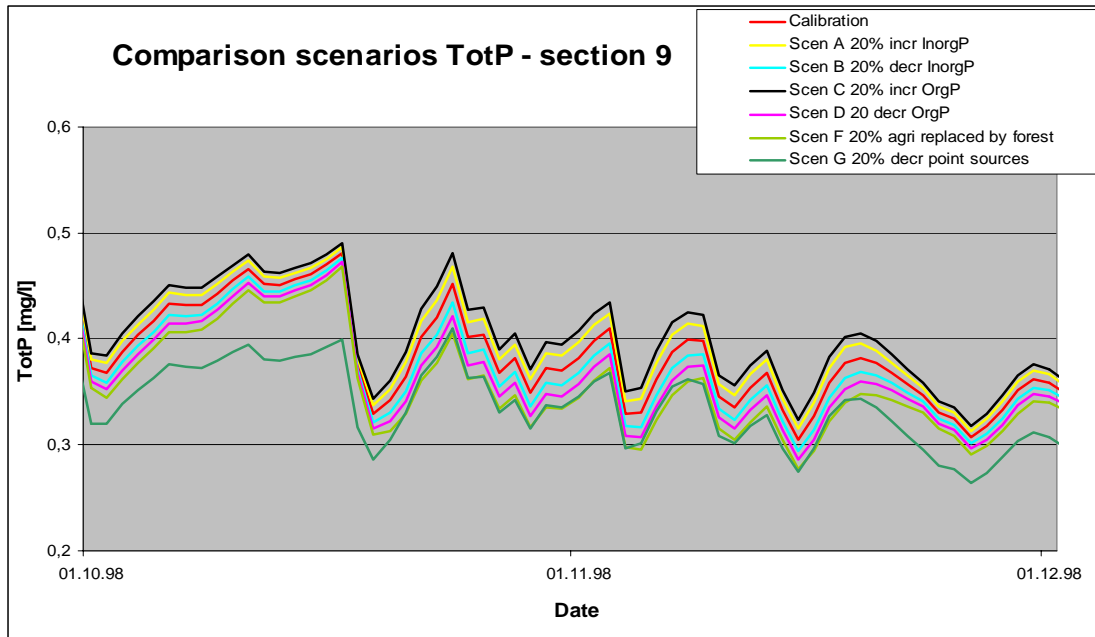


Figure 5.30. TotP-concentrations from all the simulated scenarios and the calibration run from October 1998 to the end of November the same year. This period is after harvest with no plant uptake of of P from fertilised areas.

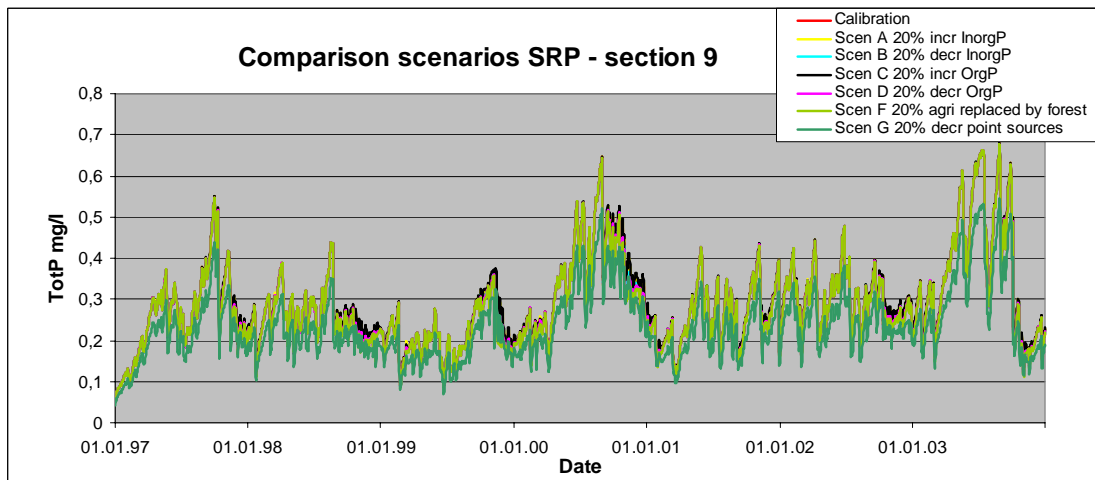


Figure 5.31. SRP-concentrations from all the simulated scenarios and the calibration run for the period 1997-2003.

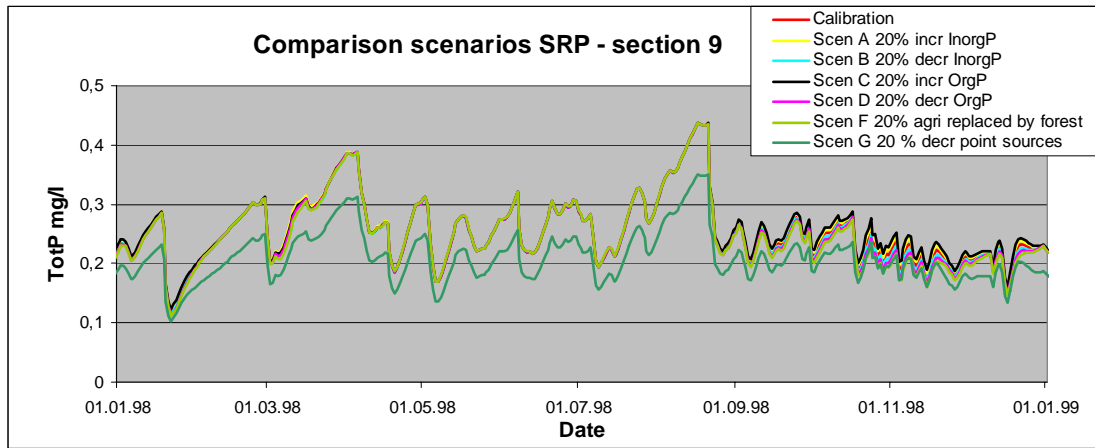


Figure 5.32. SRP-concentrations from all the simulated scenarios and the calibration run for the 1998. All the scenarios, except scenario G, and the calibration are more or less identical until September, which means that some of the lines are shaded in this period.

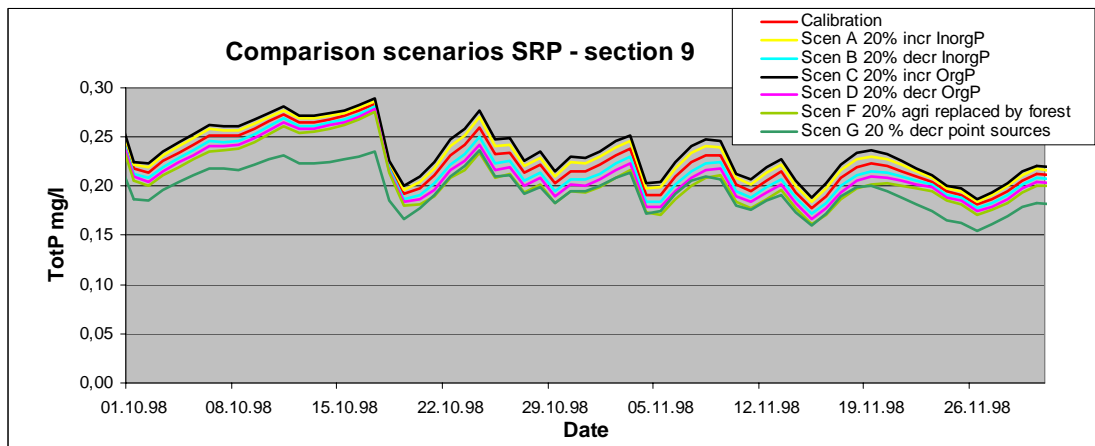


Figure 5.33. SRP-concentrations from all the simulated scenarios and the calibration run from October 1998 to the end of November the same year. This period is after harvest with no plant uptake of phosphorus from fertilised areas.

Comment:

The general picture from all sections (also those not shown), where modelling results are compared, is that an increase/decrease in inorganic/organic P-fertiliser application does not affect the concentrations of TotP and SRP significantly, except for the period after harvest. The plant growth period (fertilised) is in the model set to be from day 70 and 160 days onwards (March 11th – August 18th), while the fertiliser, converted into a daily application rate (kg/ha/day), is applied during the period of 1st March to 15th April (inorganic P) and 1st August to 30th November (mostly organic P, some inorganic P). Due to the changes in the political system of Hungary, subsidies in the agricultural sector have been reduced and the level of application is now generally low (Feher, pers. comm., 2005). This means that the available P is taken up by the plants until harvest and the plants removed, even though the fertiliser application is increased (ref. scenarios A and C). A change in the concentrations can only be seen in the periods where there are no plants to absorb the phosphorus (a few days in early March and after harvest, medio August). Similarly, a decrease in the P-application does not affect the P-concentrations in the rivers significantly, as the plants capacity to absorb P is never exceeded during these scenarios.

It is also interesting to see that the increase/decrease in the phosphorus losses from manure application will, according to the model simulations, affect the P-concentrations in the rivers more than a reduction in the same relative amount of inorganic fertiliser. The reason for this is first of all due to the timing of the spreading of the manure as it also occurs in periods when the plants do not act as P-sinks (after harvest).

Scenario F (change in land use categories) results in a larger difference in water quality than changes in fertiliser application. In this scenario, 20 % of the fertilised areas in each sub-catchment are abandoned and replaced by forest. However, the difference is only significant during periods with no plant growth and concurrent application of fertilisers. This also indicates that the timing of the fertiliser application with the growing season is a very important.

Reducing the point sources discharges, including the scattered dwellings (scenario G), by 20 % entails the largest reductions in the P-concentrations. This means, that if the costs and social/political acceptance of such a measure is at the same level as reducing the fertiliser application, reducing the point sources discharges should be implemented first.

It should be noted that INCA-P adds the effluent time series (point sources/scattered dwellings) directly to the river system without any local retention. This probably overestimates the load entering the main water bodies since retention in the soil and minor tributaries is neglected in the model.

The conclusion from the INCA-P scenario modelling is that a 20 % reduction in the point source discharges will positively affect the water quality significantly. A similar reduction in the fertiliser application (20 %) will to a very little extent improve the water quality. These findings are basically not supported by the TEOTIL results (see section 4.4), but are to a large extent supported by the SWAT results (see section 6.4). A further comparison of scenario results are given in sections 7.2 and 7.3.

5.6 Conclusions from the INCA-P modelling in Kapos

The calibration of INCA-P is a two-step procedure. The first step is to calibrate the hydrological part of the model and the second to do the same with the routines determining the P-losses and the water quality in the receiving waters. The calibration of the hydrological module is a very time-consuming procedure, which is partly done outside INCA-P, partly inside. After the first trials of calibration it also became clear that the initial model structure could not reproduce the observations with an acceptable accuracy, and modifications were necessary (see section 5.2). This improved the calibration results substantially. However, the years with the highest flood events (especially in 1999, but also in 1998) are still insufficiently handled since the model tends to underestimate the runoff these years. Consequently, the deviations in the loads are also largest these years. An improvement of the hydrological routine of the model, which is planned to be done in the close future, will then improve also the results of the nutrient load calculations

Figures 5.16-5.18 show the daily calculated TotP-concentrations together with the observations. At all sections the basic level, when the peaks in the observations are discarded, appears to be fairly well calculated. In contrast to this, the model does not seem to capture the peaks in the observations. The reason might be that INCA-P does not include any specific routines for handling runoff/erosion from land areas. Inclusion of such a routine would probably improve the handling of peak events considerably, which would also reduce the deviations in the annual figures. Model development work related to erosion from the land areas of catchment has started, and is expected to give improved accuracy in the simulation of

total phosphorus. This development work is carried out in projects independently of the AQUAPOL-project.

The daily and annual values of SRP give basically a better correlation between the observed and calculated values than TotP, and the dynamic variation is better represented by the model. Again, the calculated level at section 3 is too high.

The observed and calculated concentration loads of SRP match better than the load of TotP. Similarly to TotP, 1999 is underestimated by the model compared to the observations. 1999 was an extreme hydrological year and the observations from the flooding period need to be handled carefully, since the measurement of high water flows can be biased. The load is directly based on the water flow and it can be expected that the load values show a larger deviation those years with extreme flooding events than years with normal hydrological conditions. Similar to the calculation of TotP, the calculated SRP level at section 3 is basically too high.

It can be questioned if the input data values on TotP discharges (wwtp + scattered dwellings) and fertiliser applications, entered into the most upstream sub-catchments of Kapos River (especially sub-catchment 1) are too high. A reduction in the nutrient input load to this part of the catchment will improve the general picture, i.e. that the model overestimates the load and concentration of TotP and SRP at section 3. Furthermore, it would also give better correspondence with the observations at sections 6 and 9. The calibrated parameter values would also probably be more consistent throughout the catchment. Follow-up discussions with local experts/data providers have confirmed that there is probably some systematic error (too high load from point sources) in the input data in this part of the catchment.

INCA-P does not use soil types explicitly as input data as some other diffuse runoff models do, like for instance SWAT (ref. section 6). Soil type affects both the runoff pattern of the water (hydrology), and hence also phosphorus transported by the water. The P-transformation is also affected by the composition and concentration of ions in the soil, to a large extent given by the soil type. INCA-P uses mineralisation, immobilisation and the rates for firmly bound organic and inorganic phosphorus to represent P-processes in the soil, together with the hydrological determined soil moisture. It should be considered if soil type should be used as direct input to the model, since this is in many cases information/data that are readily available.

In the calibration, the plant uptake is considered purely a calibration parameter. However, plant growth and uptake rates can be estimated for the different types of plants from literature values. It should also be noted that the fertilised areas in Kapos catchment are in INCA-P aggregated into one area type, consisting of all crop types receiving fertilisers. This means that all plant types (crops) grown on fertilised areas are handled with the same growth rate, date of harvest etc, and an averaged type of parameter had to be defined for these processes.

This simplified parameterisation also leads to the problem of handling scenario E (“Area of the predominant crop increases to cover the entire agricultural land”) in INCA-P. The processes related to plant growth, harvest, etc are hence handled more or less as a ‘black box’, by setting the parameter values purely based on calibration of P-concentrations without any direct relation to a bio-physical understanding of the given processes, Scenario E can therefore not be simulated.

Technically, INCA-P handles most of the defined scenarios well. It is fairly easy and fast to manipulate the input data to reflect the given scenarios. All the scenarios A-F are area-based scenarios, which a catchment model like INCA-P is able to handle. However, a problem might appear as more local measures, such as buffer strips and sedimentation ponds, are to be simulated. Representing changes in a ‘small scale’ (more correct, small extent/areas) in a model that operates on a large area (large extent) is problematic for all models, even in

models with a fairly fine spatial resolution. Furthermore, increasing the spatial resolution introduces challenges related to parameterisation of the model and, possibly also, computing time.

The general picture during the scenario testing is that increase/decrease in inorganic/organic P-fertiliser application does not affect the concentrations of TotP and SRP in the waters significantly, except for the period after harvest. This means that the available P is taken up by the plants, when present, even though the fertiliser application is increased. Similarly, a decrease in the P-application does not affect the P-concentrations in the rivers significantly, as the plants' capacity to absorb P is not exceeded.

It is also interesting to see that the increase/decrease in the phosphorus from manure will, according to the model simulations, affect the P-concentrations in the rivers more than the reduction in the amount of inorganic fertiliser. This because of the timing of the spreading of the manure, as it occurs in periods when the plants do not act as sinks (after harvest).

Finally, it should be underlined that the results of the scenarios are not verified by any observations. This means that none of the simulated scenarios (increase/decrease of fertiliser, change of land use and the effect on the concentrations of phosphorus) can be compared to observations. We must therefore base our conclusions from the scenario results on the assumption that the calibrated model represents the processes in the catchment in such a way that the results are reliable. If we do not believe in the model, the scenario results can only be considered as a sensitivity analysis of the model.

6. SWAT – setup and application

6.1 Description of the model

6.1.1 Model concept

The modelling of the Kapos catchment was also undertaken with SWAT2000 software (Neitsch et al., 2002), developed by Blackland Research & Extension Center (USA) and Grassland, Soil and Water Research Laboratory (USA), applying AVSWAT2000 ArcView extension and graphical interface. SWAT (Soil and Water Assessment Tool) is a complex river basin scale model, developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large watersheds with varying soils, land use and management conditions over long periods of time. The details provided in section 6.1 are based on Neitsch et al. (2002).

SWAT is:

- Process oriented - The physical processes associated with water movement, crop growth, nutrient cycling, etc. are directly modelled by built-up equations.
- Multi-parametered - SWAT requires specific information about weather, soil properties, topography, vegetation and land management practices occurring in the watershed.
- Spatial distributed - A variety of management strategies can be performed in large basins.
- Dynamic - Non-steady run-off processes can be simulated from the precipitation time series.

SWAT is a continuous time model, i.e. a long-term yield model, consequently it is not designed to simulate detailed, single-event flood routing.

SWAT allows a number of different physical processes to be simulated in a watershed. For modelling purposes, a watershed may be partitioned into a number of sub-watersheds or sub-basins. The use of sub-basins in a simulation is particularly beneficial when different areas of the watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology. By partitioning the watershed into sub-basins, the user is able to reference different areas of the watershed to one another spatially.

Input information for each sub-basin is grouped or organized into the following categories: climate; hydrologic response units (HRU); ponds/wetlands; groundwater; and the main channel, or reach, draining the sub-basin. Hydrologic response units are lumped land areas within the sub-basin that are comprised of unique land cover, soil, and management combinations.

Simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin.

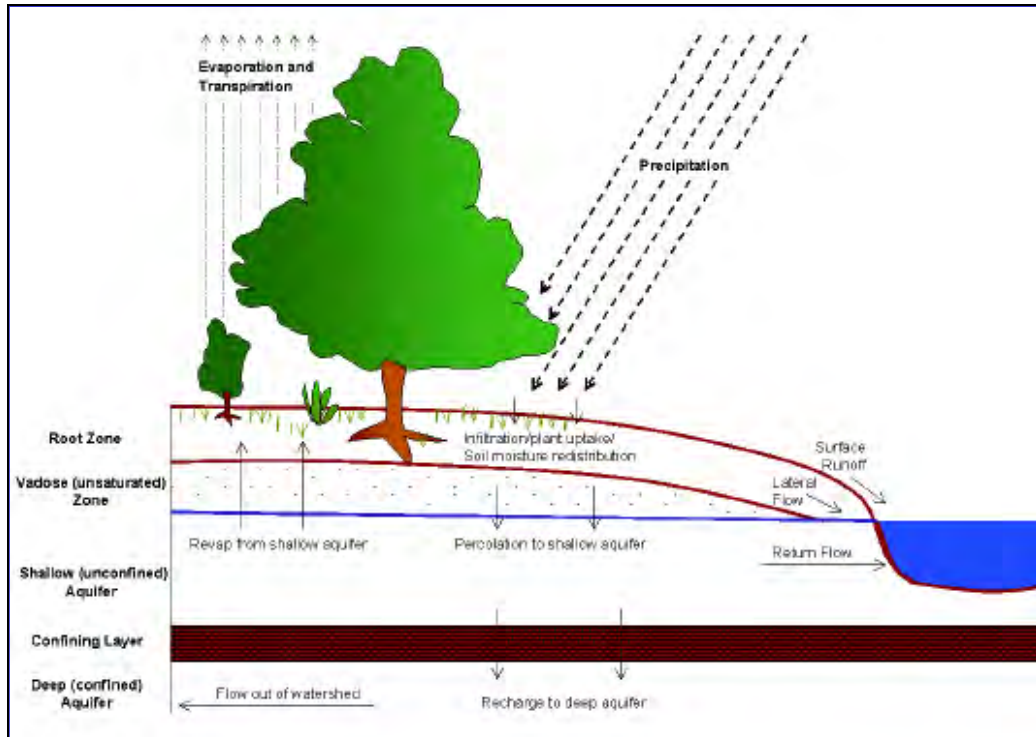


Figure 6.1. Land phase of the hydrologic cycle (Neitsch et al., 2002).

The second division is the water or routing phase of the hydrologic cycle, which can be defined as the movement of water, sediments and nutrients through the channel network of the watershed to the outlet.

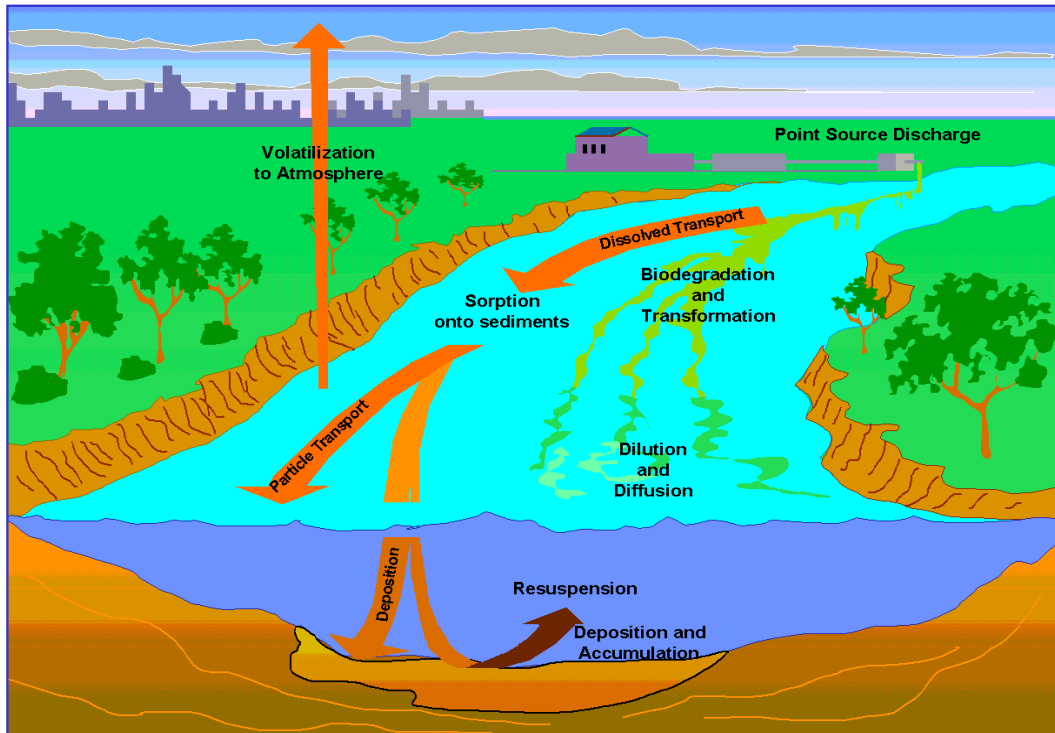


Figure 6.2. The routing phase of the hydrologic cycle (Soil and Water Assessment Tool Theoretical Documentation, 2002).

6.1.2 Land phase of the hydrologic cycle

The hydrologic cycle, as simulated by SWAT, is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

where

SW_t	-	final soil water content (mm H ₂ O),
SW_0	-	initial soil water content on day i (mm H ₂ O),
t	-	time (days),
R_{day}	-	is the amount of precipitation on day i (mm H ₂ O),
Q_{surf}	-	the amount of surface runoff on day i (mm H ₂ O),
E_a	-	the amount of evapotranspiration on day i (mm H ₂ O),
w_{seep}	-	amount of water entering the vadose zone from the soil profile on day i (mm),
Q_{gw}	-	the amount of return flow on day i (mm H ₂ O)

Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. The different inputs and processes involved in this phase of the hydrologic cycle are:

- Climate - The climatic variables required by SWAT consist of daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity. The model allows values for daily precipitation, maximum/minimum air temperatures, solar radiation, wind speed and relative humidity to be input from records of observed data or generated during the simulation.
- Hydrology - Precipitation may be intercepted and held in the vegetation canopy (canopy storage) or fall to the soil surface. Water on the soil surface will infiltrate into the soil profile (infiltration) or flow overland as runoff. Runoff moves relatively quickly toward a stream channel (surface runoff) and contributes to short-term stream response. Infiltrated water may be held in the soil and later evapotranspired (evapotranspiration) or it may slowly make its way to the surface-water system via underground paths (lateral subsurface flow, return flow/base flow).
- Land cover/Plant growth - SWAT utilises a single plant growth model to simulate all types of land covers. The plant growth model is used to assess removal of water and nutrients from the root zone, transpiration, and biomass/yield production.
- Erosion - Erosion and sediment yield are estimated by the model for each HRU with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1995) using the amount of runoff.
- Nutrients - SWAT tracks the movement and transformation of several forms of nitrogen and phosphorus in the watershed. Nutrients may be introduced to the main channel and transported downstream through surface runoff and lateral subsurface flow.

Plant use of nitrogen and phosphorus is estimated using the supply and demand approach.

In addition to plant use, nitrate and organic N may be removed from the soil via mass flow of water. Amounts of $\text{NO}_3\text{-N}$ contained in runoff, lateral flow and percolation are estimated as products of the volume of water and the average concentration of nitrate in the layer. Organic N transport with sediment is calculated with a loading function developed by McElroy et al. (McElroy et al., 1976) and modified by Williams and Hann (Williams and Hann, 1978) for application to individual runoff events. The loading function estimates the daily organic N runoff loss based on the concentration of organic N in the top soil layer, the sediment yield, and the enrichment ratio. The enrichment ratio is the concentration of organic N in the sediment divided by that in the soil.

In addition to plant use, soluble phosphorus and organic P may be removed from the soil via mass flow of water. Phosphorus is not a mobile nutrient and interaction between surface runoff with solution P in the top 10 mm of soil will not be complete. The amount of soluble P removed in runoff is predicted using solution P concentration in the top 10 mm of soil, the runoff volume and a partitioning factor. Sediment transport of P is simulated with a loading function as described in organic N transport.

- Management - SWAT allows the user to define management practices taking place in every HRU. The user may define the beginning and the ending of the growing season, specify timing and amounts of fertiliser, pesticide and irrigation applications as well as timing of tillage operations. At the end of the growing season, the biomass may be removed from the HRU as yield or placed on the surface as residue. In addition to these basic management practices, operations such as grazing, automated fertiliser

and water applications, and incorporation of every conceivable management option for water use are available.

6.1.3 Routing phase of the hydrologic cycle

Once SWAT determines the loadings of water, sediment, nutrients and pesticides to the main channel, the loadings are routed through the stream network of the watershed. In addition to keeping track of mass flow in the channel, SWAT models the transformation of chemicals in the stream and streambed.

Routing in the main channel or reach

Routing in the main channel can be divided into four components: water, sediment, nutrients and organic chemicals. Flow is routed through the channel using a variable storage coefficient method developed by Williams (Williams, 1969) or the Muskingum routing method.

The transport of sediment in the channel is controlled by the simultaneous operation of two processes, deposition and degradation. In this version of SWAT, the equations have been simplified (in comparison with previous versions where stream power was defined as the product of water density, flow rate and water surface slope), and the maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity.

Nutrient transformations in the stream are controlled by the in-stream water quality component of the model. The in-stream kinetics used in SWAT for nutrient routing are adapted from QUAL2E (Brown and Barnwell, 1987).

Routing in the reservoir

The water balance for reservoirs includes inflow, outflow, rainfall on the surface, evaporation, seepage from the reservoir bottom and diversions. The model offers three alternatives for estimating outflow from the reservoir: to input measured outflow, to specify a water release rate and to input the user specify monthly target volumes.

Sediment routing is defined by three main components: sediment inflow, settling of sediment in the reservoir and sediment outflow. The amount of sediment in the reservoir outflow is the product of the volume of water flowing out of the reservoir and the suspended sediment concentration in the reservoir at the time of release.

For nutrient routing a simple model for nitrogen and phosphorus mass balance was taken from Chapra (Chapra, 1997) with three assumptions: 1) the lake is completely mixed; 2) phosphorus is the limiting nutrient; and, 3) total phosphorus is a measure of the lake trophic status.

6.2 Input data and assumptions

6.2.1 Watershed delineation

The delineation of the Kapos catchment for SWAT model was based on the following map-based input data:

- Digital Elevation Model (100x100 m) of the catchment area (1:100 000)
- Digitised version of 'Atlas of Hungary', and refined boundaries of the catchment boundary, refined by the regional Water Authorities to the focused area
- Digitised stream network based on the 1: 50 000 scale map, substituting the lakes for polylines to make the network continuous

In addition, outlets of sub-catchments are formed where the monitoring stations and point pollution sources are located.

The whole catchment area was divided into 34 sub-catchments by the automatic delineation tool of SWAT. An area of 5000 hectares was defined as threshold drainage area (see figure 6.3), which defined the minimum drainage (critical source area) area required to form the origin of a stream during digitalisation of the stream network. Consequently the smaller the specified number of hectares, the more detailed the delineated drainage network. Sub-catchment borders were generated at confluent points of the stream network and at outlet points, hence the delineation of the watershed was an iterative process.

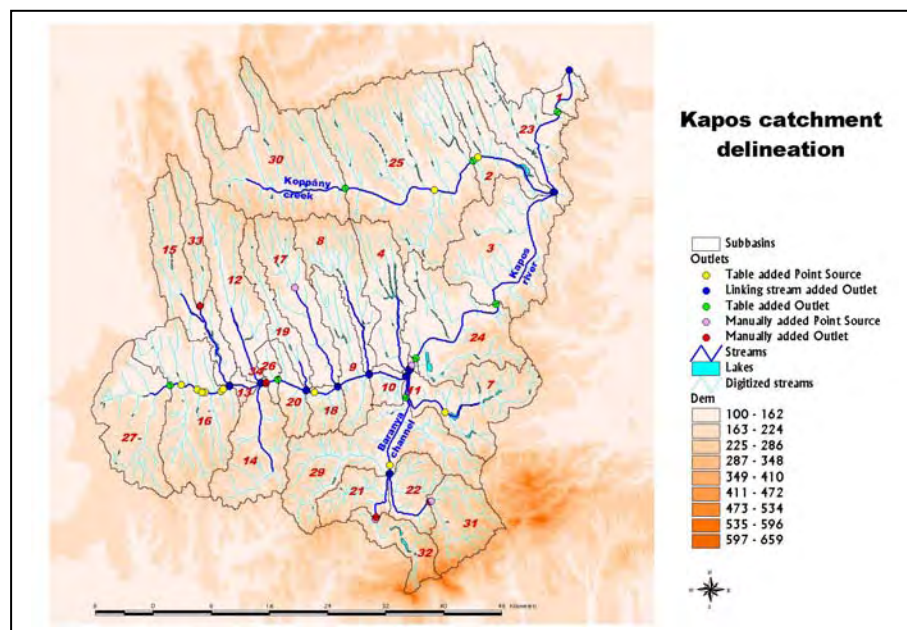


Figure 6.3. The division of the whole river basin into 34 sub-catchment division.

6.2.2 Hydrologic response unit (HRU) distribution

Land use and soil characterisation for the Kapos catchment was performed by loading land use and soil themes into the ArcView project. In case of land uses, the CORINE Land Cover (1: 100 000) layer was used as the basis. Since agriculture is the dominant land use category

of the Kapos catchment, the cultivation methods were further sub-divided during the later phase of the modelling. The reclassification of the land uses was elaborated according to the SWAT built in database categories, which resulted in seven land use classes: agricultural area, forest, pasture, three urban land use classes and wetland (see figure 6.4).

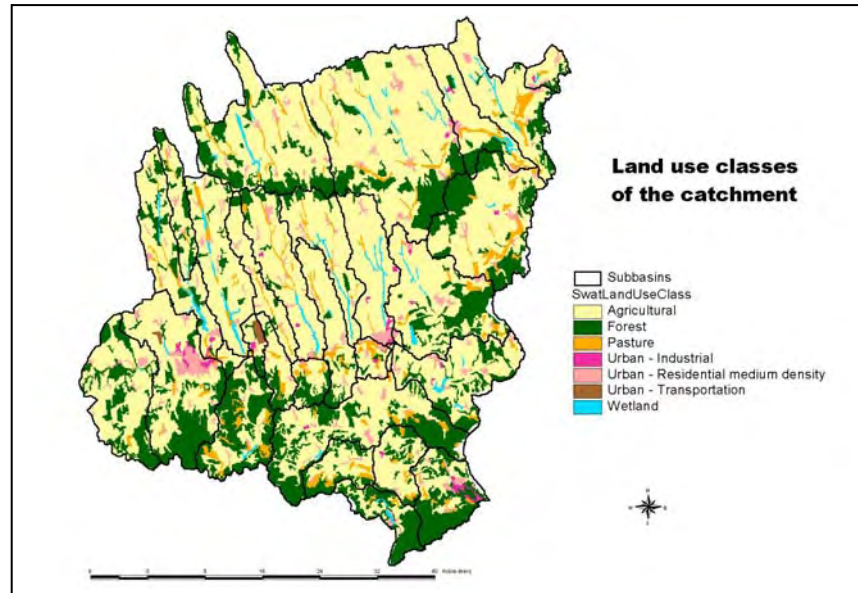


Figure 6.4. The land use classes of the catchment.

The base of the soil definitions was the Hungarian AGROTOPO layer (1:100 000). The further refinement of the physical soil parameters was carried out by consulting local experts. The available information (physical parameters) was imported into the SWAT User Soil database. The reclassification was done by using this database.

Following the overlay process of the land use and soil category layers and choosing the “multiple HRUs” option (with 15 % threshold value in case of the land use, 20 % threshold value in case of the soil type) in HRU calculation process, 90 HRUs were distributed in the whole catchment. Using threshold levels for land use and soil types, the model discarded minor categories under the limit, and the remaining was reapportioned according to the categories’ upper limit. Thereafter, the model generated detailed descriptions at catchment and sub-catchment levels (the number of HRUs with the land use and soil classes and their spatial extent for each HRU, see table 6.1).

Table 6.1. Land use and soil distribution after the threshold application

Land use categories	ID	Area [ha]	% of area
Pasture	PAST	524.3	0.2
Forest-Deciduous	FRSD	78369.4	24.6
Transportation	UTRN	395.7	0.1
Agricultural	AGRR	238883.4	75.1
Residential - med. dens.	URMD	109.2	0.03

Soil types	ID	Area [ha]	% of area
Brown forest soils with clay illuviations with different genetic and hydrologic properties	SST0712	4026.5	1.3
	SST0724	66294.8	20.8
	SST0734	3447.2	1.1
	SST0735	10405.8	3.3
Brown earth (Ramann brown forest soils) illuviations with diff. genetic and hydrologic properties	SST0922	628.0	0.2
	SST0923	55353.7	17.4
	SST0924	23085.5	7.3
Peaty meadow soils	SST2713	3268.8	1.0
Chernozem brown forest soils	SST1123	42876.2	13.5
Pseudomyceliar (calcareous) chernozems	SST1323	107578.7	33.8
Rendzinas	SST0459	1316.7	0.4

Sub-dividing the catchment into areas having unique land use and soil combinations enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers/crops and soils. Furthermore, during the simulation, runoff has been predicted separately for each HRU and routed to obtain the total runoff for the watershed, increasing the accuracy of load predictions and providing an improved physical description of the water balance.

After definition of the HRUs, the model created all input files from originally built-in databases (User Soils, User Weather Stations, Land Cover/Plant Growth, Fertiliser, Pesticide, Tillage, Urban).

6.2.3 Meteorological data

Weather data used in the simulation consist of six main components:

- Weather generator data - The weather generator module was developed to calculate missing daily weather data. It uses real station data (the more stations the better approximation), and the software extrapolates these data spatially and temporarily. This module requires long time series for at least 1 station. The weather generator was populated with 24 years of data for two stations during the Kapos model set-up (Kaposvár and Iregszemcse); missing data for other stations were calculated based on these stations.
- Rainfall data – Data from five meteorological stations with daily precipitation time series were imported into the model (Kaposvár, Iregszemcse, Tamási, Kurd, Cece, see figure 6.5). The latter (Cece), located outside of the watershed, had no great impact on the simulated runoff.
- Temperature data – data from two meteorological stations with daily minimum and maximum air temperature time series were used (Kaposvár and Iregszemcse).

- Solar radiation data – The model simulated daily time series as no observed series of solar radiation were available.
- Wind speed data - The model simulated daily time series as no observed series of wind speed were available.
- Relative humidity data - The model simulated daily time series as no observed series of relative humidity were available.

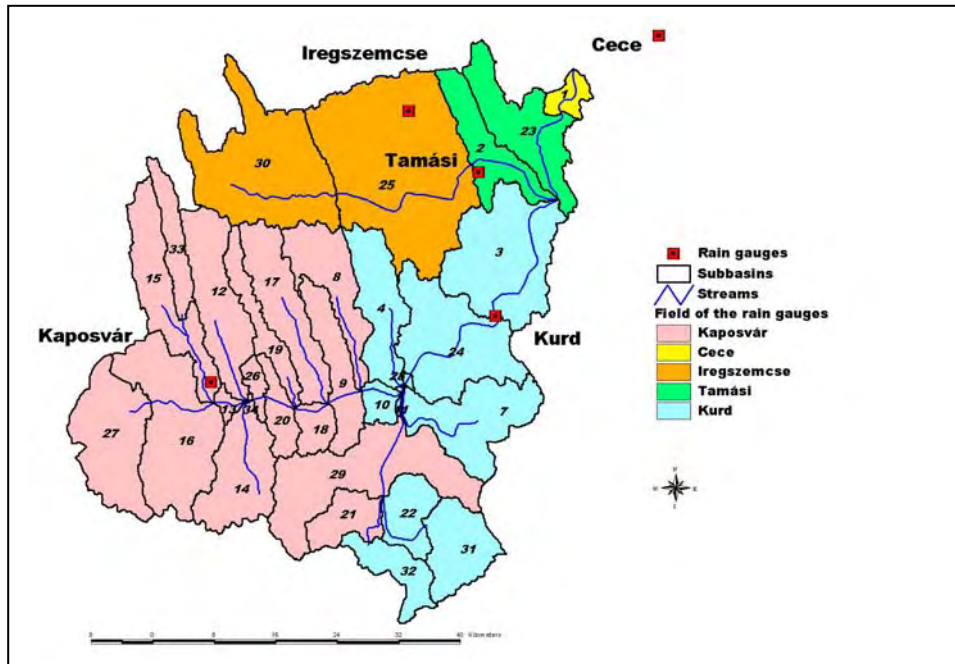


Figure 6.5. The distribution of rainfall stations and their linkages to sub-catchments in the Kapos catchment.

The model extended the rainfall data series to the nearest sub-catchment areas. As figure 6.5 indicates, at least one meteorological station with daily precipitation data series would have been needed on the southern part of the catchment (sub-catchments 21, 22, 29, 31 and 32) to improve the simulations, because this area has a more hilly/mountainous character than the other parts of the catchment. The lack of such a station generated a number of problems in the hydrological calibration and in the further modelling activities. It is clear that a proper spatial distribution of the precipitation is essential in such a complex catchment since it ranges from a plain to a hilly and mountainous character.

6.2.4 Point sources/effluent discharges

SWAT model allows the user to input point pollution loads into the model as a constant value for the all modelling time period, as annual, monthly or daily loads.

SWAT required very detailed input about point pollution sources (Organic-N, NO₃-N, NO₂-N, NH₄-N, Organic-P, Mineral-P) in the Kapos catchment, but only annual discharges of these components were available. Discharges data from 11 communal wastewater treatment plants and 5 industrial plants were finally taking into account as significant point pollution sources and relevant data entered into the model.

As the Hungarian national waste water cadastre (National waste water database) contains discharges data only as annual loads of total-N and total-P, more detailed information on loads was collected at the competent Regional Authorities.

6.2.5 Fertiliser application

As seen earlier in this report, agriculture is the main diffuse pollution source in the Kapos catchment. Information about yearly amounts of N and P fertiliser and manure applied within the catchment during the simulation period was based on the annual statistic of two counties (Somogy and Tolna), published in the official annual Regional Statistical Yearbooks by the Hungarian Central Statistical Office (Regional Statistical Yearbook). Annual fertiliser and manure loads were then calculated by means of application rates [kg/ha] for the fertilised agricultural land uses of the catchment (see table 6.2). Data input of these annual rates to the model was carried out by scheduling by date. SWAT requires the modeller to set a specific date for fertiliser application in each sub-catchment, which then might cause a timing-uncertainty during the simulation. Inorganic fertilisers (N, P) were scheduled in March, and manure in October. Fertiliser quantities were input into the “Management input file” of the model. The timing of the fertiliser application was slightly different from what was done in the setup of INCA-P, where the fertiliser was applied in the periods 1st March – 15th April and 1st August – 15th November.

The fertiliser database of SWAT contains a number of types of fertiliser and manure applied in agricultural practices of the United States. This was considered very useful when the organic fertiliser data were imported to the model for the application in Kapos catchment.

Table 6.2. Specific inorganic and organic N and P fertiliser application in the Kapos catchment in the modelling period.

	1998	1999	2000	2001	2002	2003
Inorganic N (kg/ha/year)	95.646	93.225	103.563	45.601	44.722	42.594
Inorganic P (kg/ha/year)	15.041	13.824	18.063	9.618	9.151	9.736
Manure (kg/ha/year)	1062	1384	1500	529	9215	633

6.2.6 Observed water flow data

Daily average water flow data series were received from the Hungarian National Hydrological Forecasting Service.

Six monitoring stations were selected in the area for calibrating the daily discharge values of the model, three of them on the Kapos river (Fészerlak, Kurd, Pincehely), two on Koppány creek as the main tributary (Törökkoppány, Tamási) and one monitoring station at the outlet of Baranya channel (Csikóstöttös) (see figure 6.6). These monitoring points divided the catchment into six main drainage areas. Hydrological calibration of the model was carried out for these main drainage areas with quite different hydrological and hydrogeological properties (see section 6.3).

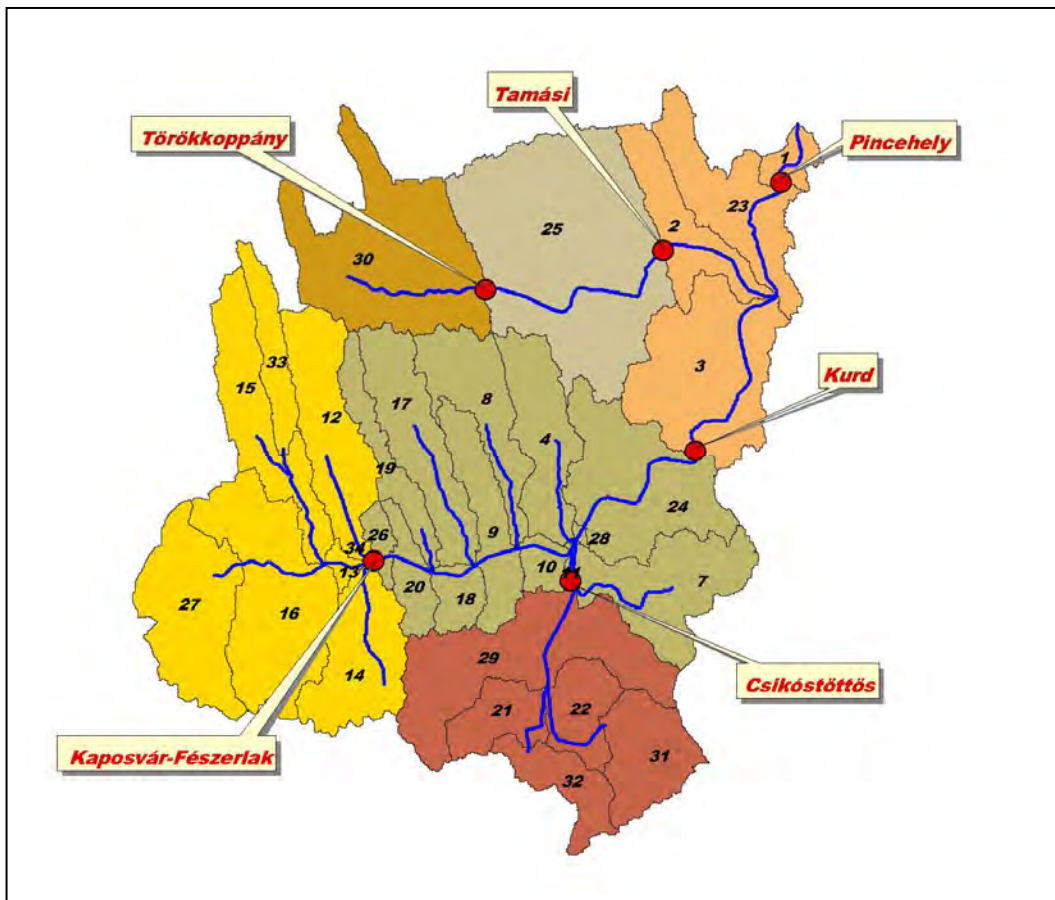


Figure 6.6. Monitoring stations used and the related drainage areas in the Kapos catchment.

6.2.7 Observed water quality data

Concentration data on different inorganic and organic N and P were collected from the Hungarian National Water Quality Database (National Water Quality Database). The same six (national level) monitoring stations were used as for the hydrological calibration and validation.

Since the water quality measurement frequency is generally twice a month at these monitoring stations, regression analysis were needed to fill the missing gaps of the concentration data series. Regression analysis were carried out by dividing long-time discharge data series measured at different monitoring stations into sections with rising stage, recession stage and low-water periods.

Power functions were generally applied to calculate the missing concentration values for the sediment and different nutrient forms ($\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, $\text{NO}_2\text{-N}$, N_{org} , $\text{PO}_4\text{-P}$, P_{org}). The monthly sediment and nutrient pressures were then calculated based on these completed concentration and water discharge data series.

6.3 Calibration

6.3.1 Hydrological calibration

Hydrological calibration of the model was carried out based on (i) the User Manual (SWAT2000 User Manual, Neitsch et al., 2002) and (ii) a “Sensitivity analysis” paper (Lenhart et al., 2002). The calibration was done on both yearly and daily simulation time steps.

The primary goal of the calibration was to adjust the yearly water balance, and secondly to calibrate with respect to the seasonal fluctuation of the flow and the high flow events in the different drainage areas.

The calibration period was from 1st January 1998 to 31st December 2002, as the measured stream flow data series were complete for this period.

When applying the “Baseflow filter program” (developed by USGS) suggested by the SWAT User Manual and downloaded from the official SWAT website (http://www.brc.tamus.edu/swat/soft_baseflow.html), it became possible to divide the measured daily stream flow data series into baseflow and surface runoff components. Furthermore by using this software, some other parameters of the “groundwater input file” could be generated (e.g.: “baseflow alpha factors” and “baseflow days” for river segments of drainage areas).

The TURC equations (Turc, 1961 and Turc, 1963), which enable the calculation of yearly evapotranspiration with limited data, were used in the Kapos catchment:

$$E_{tp}^T = \frac{P}{\sqrt{0,9 + \frac{P^2}{K^2}}}$$

where:

$$E_{tp}^T \quad - \quad \text{evaporation of the bare soil (mm)}$$

$$K = 300 + 25 \cdot T + 0,05 \cdot T^3$$

$$P \quad - \quad \text{yearly precipitation amount (mm)}$$

$$T \quad - \quad \text{yearly mean air temperature (°C)}$$

$$E_{tp}^e = a \cdot E_{tp}^T$$

where:

$$E_{tp}^e \quad - \quad \text{evapotranspiration (mm)}$$

$$E_{tp}^T \quad - \quad \text{evaporation of the bare soil (mm)}$$

$$a \quad - \quad \text{vegetation coefficient}$$

Based on earlier applications of SWAT and proposed by Neitsch et al. (2002), the vegetation coefficient were defined as follows:

$a = 1.13$ for areas without forests, with pasture or poor vegetation and
 $a = 1.62$ for areas with forests.

With the data series of the meteorological station of Iregszemcse the long-term evapotranspiration rates of Kapos catchment were calculated (see table 6.3), which was further entered into SWAT.

Table 6.3. Calculated yearly evapotranspiration (ET) values for the Kapos catchment.

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
P [mm]	674	583	620	434	743	643	503	729	444	605	485	605
T [°C]	9.5	10.8	10.5	11.0	9.6	9.4	10.4	11.1	10.7	10.8	11.1	10.0
ET [mm]	559	549	560	464	584	547	500	616	467	559	499	543

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
P [mm]	527	646	592	839	741	466	780	949	510	573	495	436
T [°C]	11.3	10.7	12.4	10.4	10.0	11.2	11.4	10.6	10.2	10.9	11.8	11.2
ET [mm]	528	575	582	629	593	488	641	660	502	547	515	467

The potential evapotranspiration (PET) was calculated by the model. The Priestly-Taylor method was applied as simulation option and selected between the four options allowed by the model (Penman-Monteith method, Hargreaves method and input of daily measured time series).

The hydrological calibration process represented a much more complex task in the case of the Kapos catchment than the User Manual demonstrated, due to the diverse hydrology, geology, hydrogeology and morphology conditions. The sensitivity analysis – which was the other basis of the work - was carried out on a simplified, small, artificial watershed. This means that due to the artificial conditions, the model sensitivity to the investigated parameters was occasionally different from what was experienced in the real situation of the Kapos catchment. The parameters gave sometimes quite opposite results of what was indicated in the paper of Lenhart et al. (2002).

At the beginning of the calibration, the surface runoff was generally at a high rate, but the baseflow components and the evapotranspiration of the watershed were at quite low levels according to the measured/calculated values. The greatest challenge of the calibration was to approximate the peak flows of flood events close enough to real values in those cases where several drainage areas contributed to the flow. This because the simulated peak water flows were in most cases 2-3 times higher than observed. This phenomenon was especially problematic for the year 1999, when the precipitation was extremely high.

Calibration was done for the model was found to be sensitive for the following parameters:

- SOL_AWC: available water capacity in the soil layers
- SOL_K: saturated hydraulic conductivity of soil layers
- SOL_Z: maximum soil depth
- SOL_ZMX: maximum root depth
- ESCO: soil evaporation compensation factor
- EPCO: plant uptake compensation factor
- CN2: SCS runoff curve number
- CNOP: SCS runoff curve number for management operation
- HEATUNITS: total HU for cover/plant to reach maturity
- CANMX: maximum canopy storage
- OV_N: Manning's "n" value for overland flow
- REVAPMN: threshold depth of water in shallow aquifer for „revap” to occur

GWQMN:	threshold depth of water in shallow aquifer required for return flow to occur
GWREVAP:	groundwater „revap” coefficient
GW_DELAY:	groundwater delay
ALPHA_BF:	baseflow alpha factor
RCHG_DP:	deep aquifer percolation factor
CH_N2:	Manning’s “n” value for main channel
CHK2:	effective hydraulic conductivity in main channel
SMFMN:	minimum melt rate for snow during the year
SMTMP:	snow melt base temperature
SFTMP:	snowfall temperature
TIMP:	snowpack temperature lag factor
SURLAG:	surface runoff lag time
SNO50COV:	snow water equivalent (corresponds to 50 % snow cover)
SNOCVMX:	minimum snow water content (corresponds to 100 % snow cover)

Scarce information was available about the “real” crop pattern of the agricultural area of the sub-catchments (spatial and temporal distribution). Therefore, the most commonly grown crops of the catchment area were distributed for the entire Kapos catchment. According to the data of the statistical yearbooks, and as a result of field visits during the project, this was: 40 % corn, 30 % wheat and 30 % sunflower.

The annual simulation results are presented in figures 6.7-6.12. The simulated values of the first year are presented with red circles in the next figures. These values should be handled with care, because the SWAT model needs a certain time to properly simulate the hydrology of the catchment (filling up the water system). Therefore, the simulation results for the first 10-11 months of the first year do not usually reflect the real situation. The ‘X’ axis of the diagrams presents the observed values, whereas the ‘Y’ axis shows the simulated results. The red line indicates the optimum value (perfect simulation).

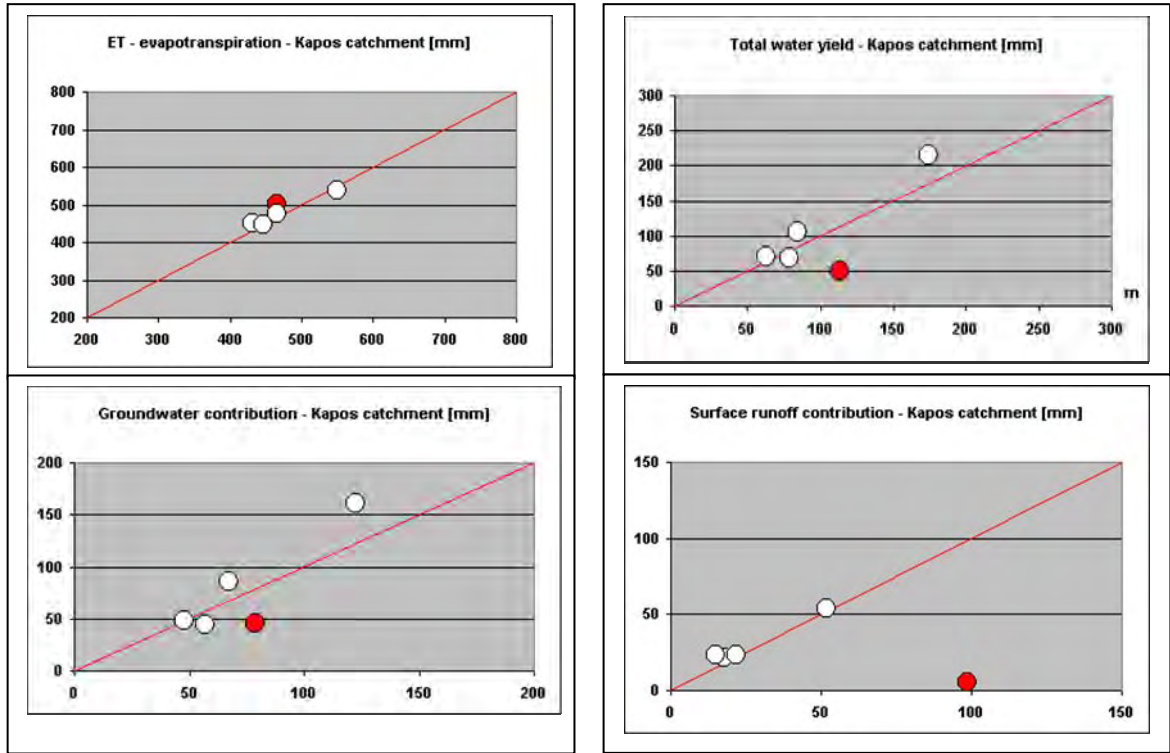


Figure 6.7. Observed (x-axis) annual data plotted against the calculated values (y-axis) from the location Pincehely, close to the outlet of the catchment. The red circles indicate results from the first year of simulation that are biased by inaccuracies in the initial state of the model.

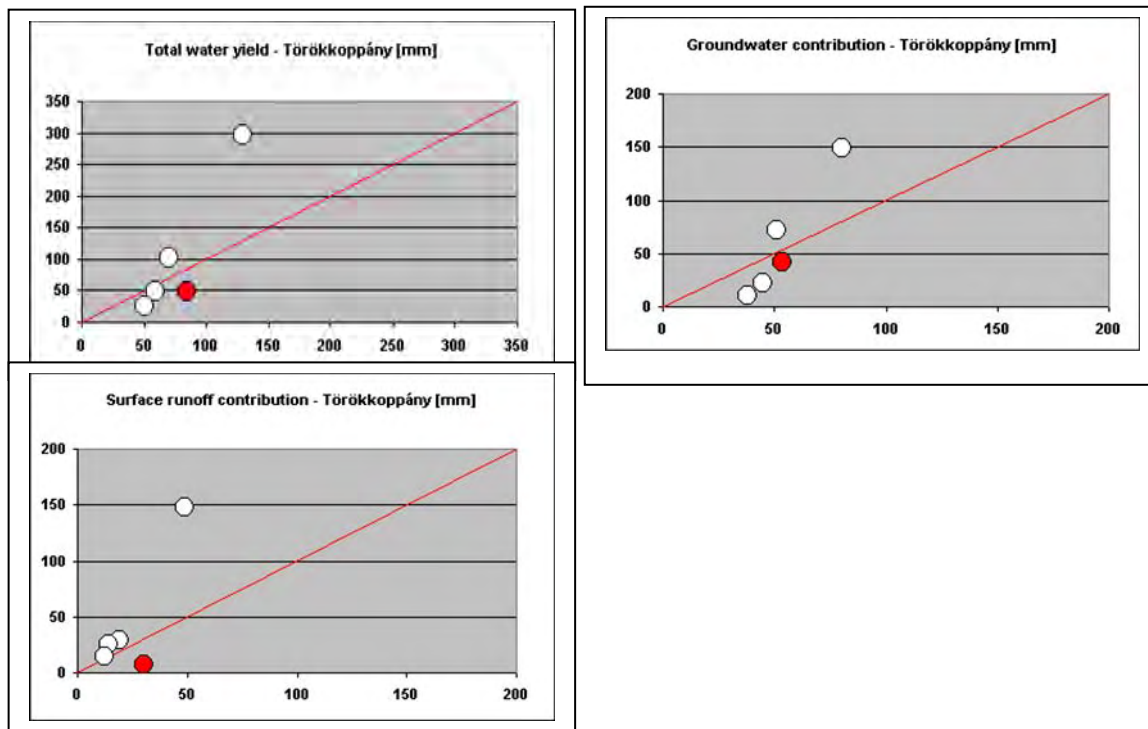


Figure 6.8. Observed (x-axis) annual data plotted against the calculated values (y-axis) from the location Törökkoppány (Koppány creek). The red circles indicate results from the first year of simulation that are biased by inaccuracies in the initial state of the model.

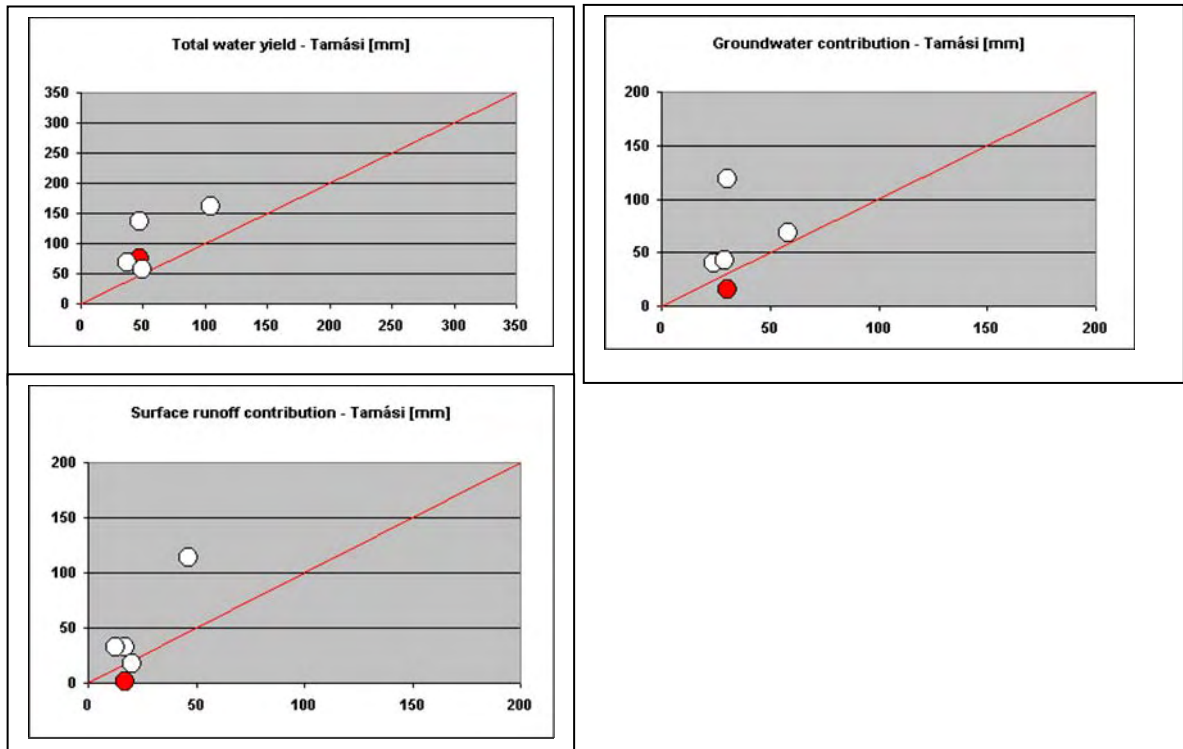


Figure 6.9. Observed (x-axis) annual data plotted against the calculated values (y-axis) from the location Tamási (Koppány creek). The red circles indicate results from the first year of simulation that are biased by inaccuracies in the initial state of the model.

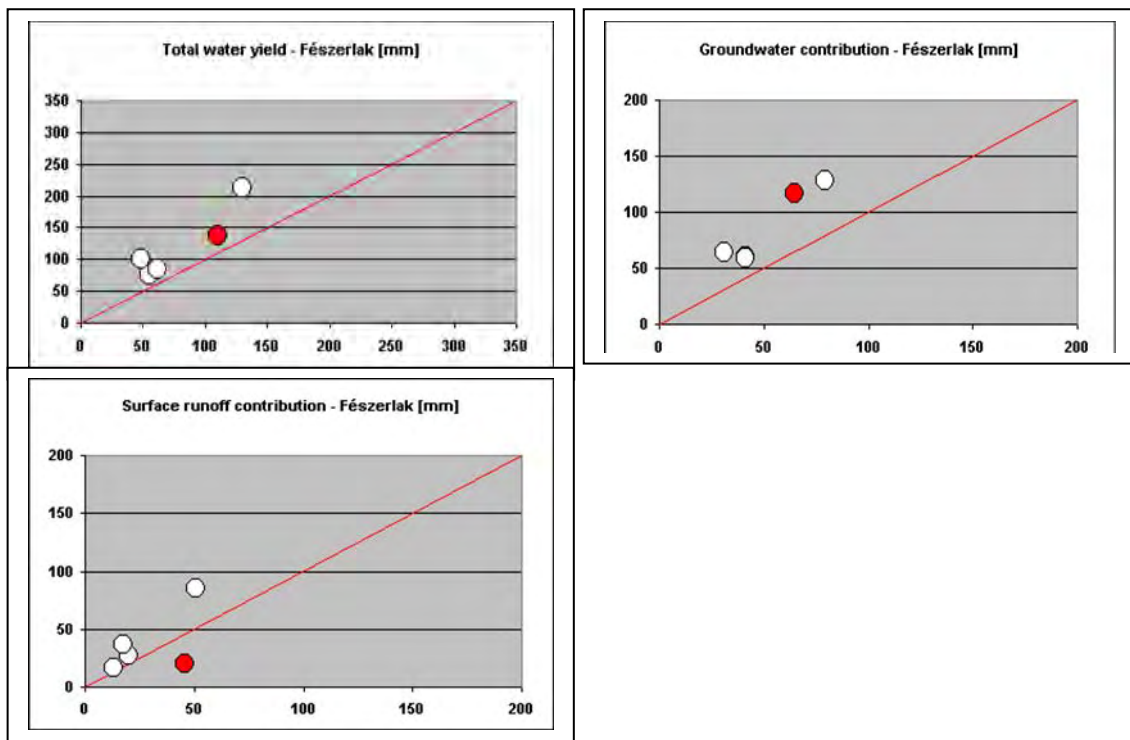


Figure 6.10. Observed (x-axis) annual data plotted against the calculated values (y-axis) from the location Kaposvár-Fészerlak (Kapos river). The red circles indicate results from the first year of simulation that are biased by inaccuracies in the initial state of the model.

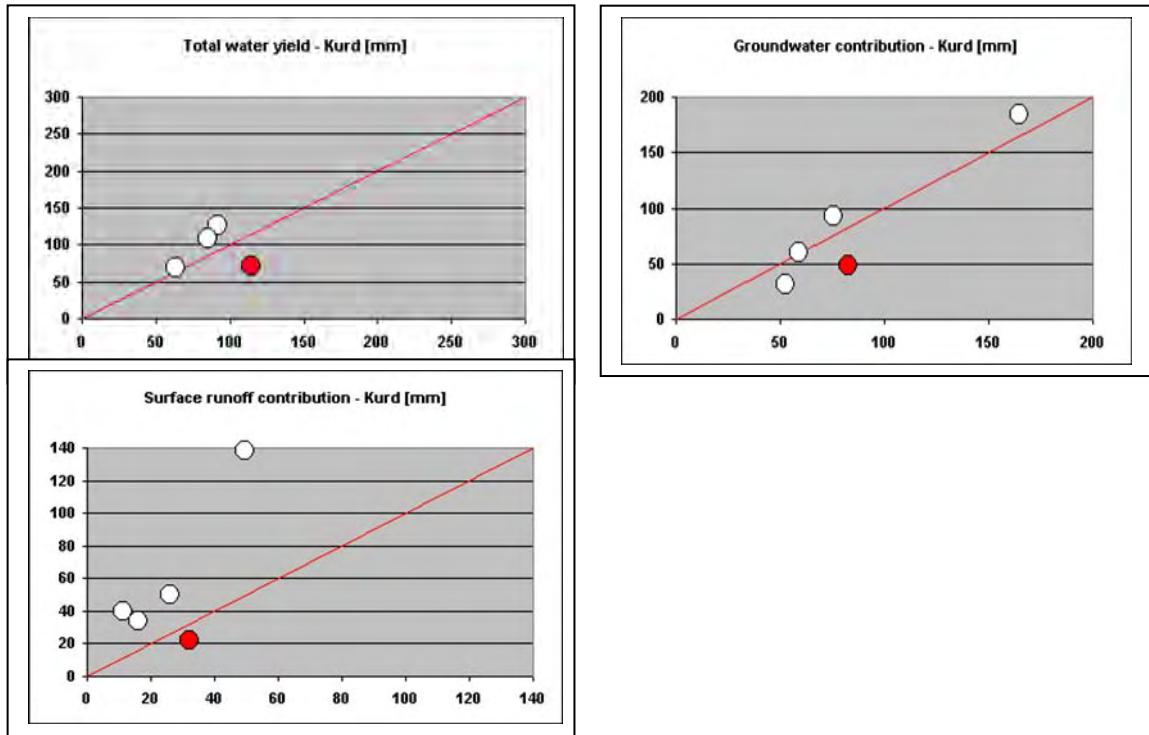


Figure 6.11. Observed (x-axis) annual data plotted against the calculated values (y-axis) from the location Kurd (Kapos river). The red circles indicate results from the first year of simulation that are biased by inaccuracies in the initial state of the model.

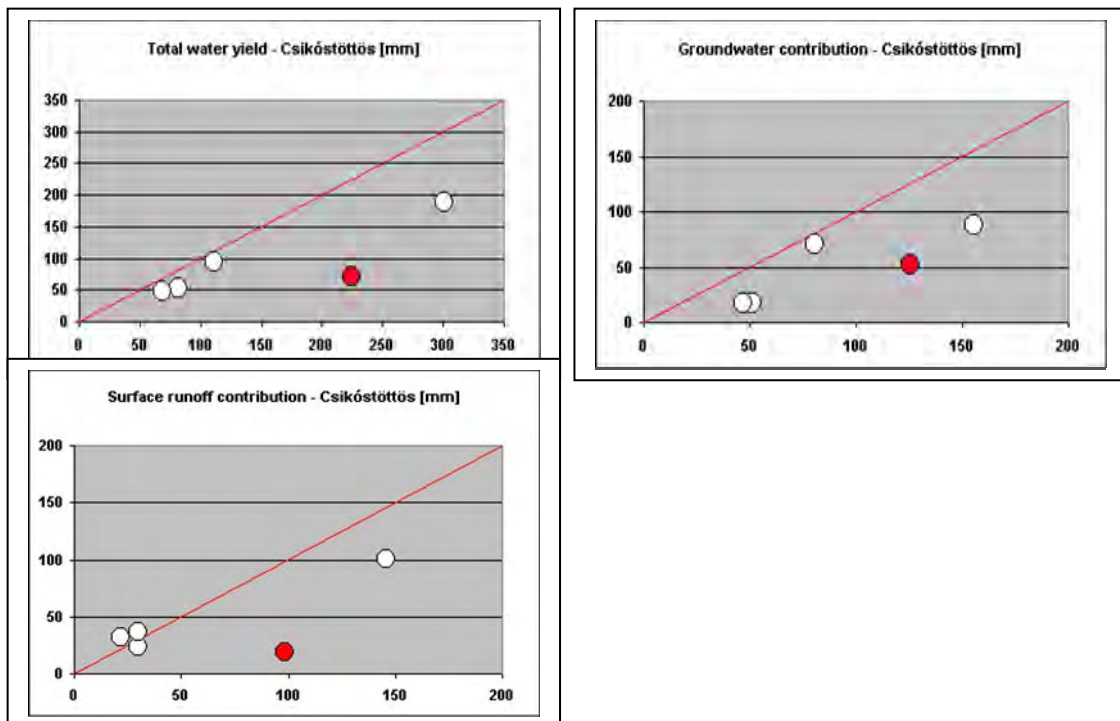


Figure 6.12. Observed (x-axis) annual data plotted against the calculated values (y-axis) from the location Csikóstötös (Baranya channel). The red circles indicate results from the first year of simulation that are biased by inaccuracies in the initial state of the model.

The figures 6.7 – 6.12 also show deviations for other years than the first year (red circles) of the calibration. The largest deviation from the observed surface runoff occurred in 1999. This year had significantly higher precipitation than any other year. During the hydrological calibration it was not possible to take into account this specific year. If the model was calibrated with respect to the 1999 flow data, the model would not work properly for all other years, and vice versa.

Figures 6.13 – 6.18 present the simulated and observed discharges in daily time step. They also show the related precipitation (PCP) data series. The calibration problem of the year 1999 can also be seen on these figures.

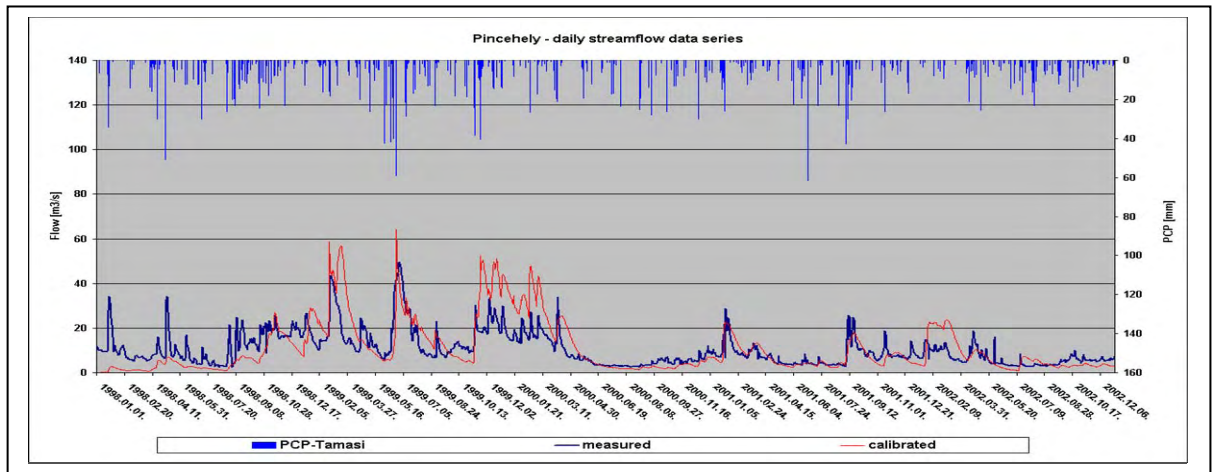


Figure 6.13. Simulated and observed daily discharge/water flow [m^3/sec], and the related precipitation [mm] at Pincehely (Kapos river).

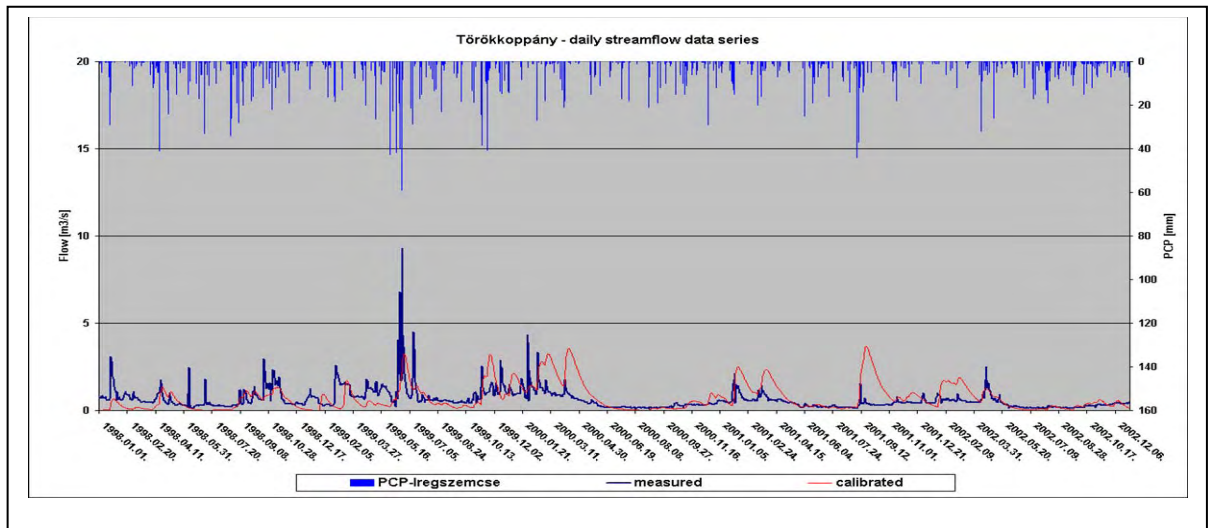


Figure 6.14. Simulated and observed daily discharge/water flow [m^3/sec], and the related precipitation [mm] at Törökkoppány (Koppány creek).

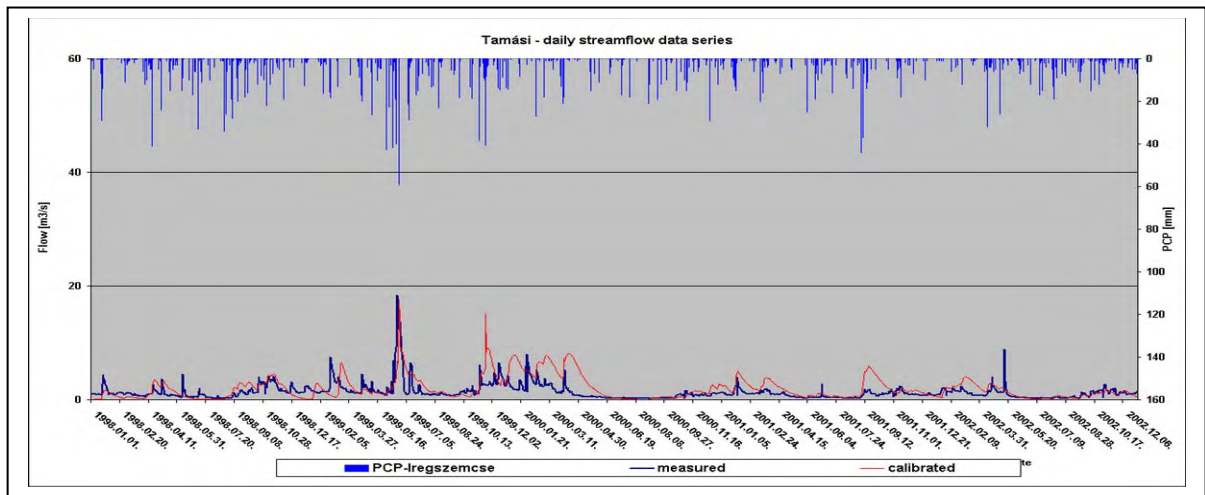


Figure 6.15. Simulated and observed daily discharge/water flow [m^3/sec], and the related precipitation [mm] at Tamási (Koppány creek).

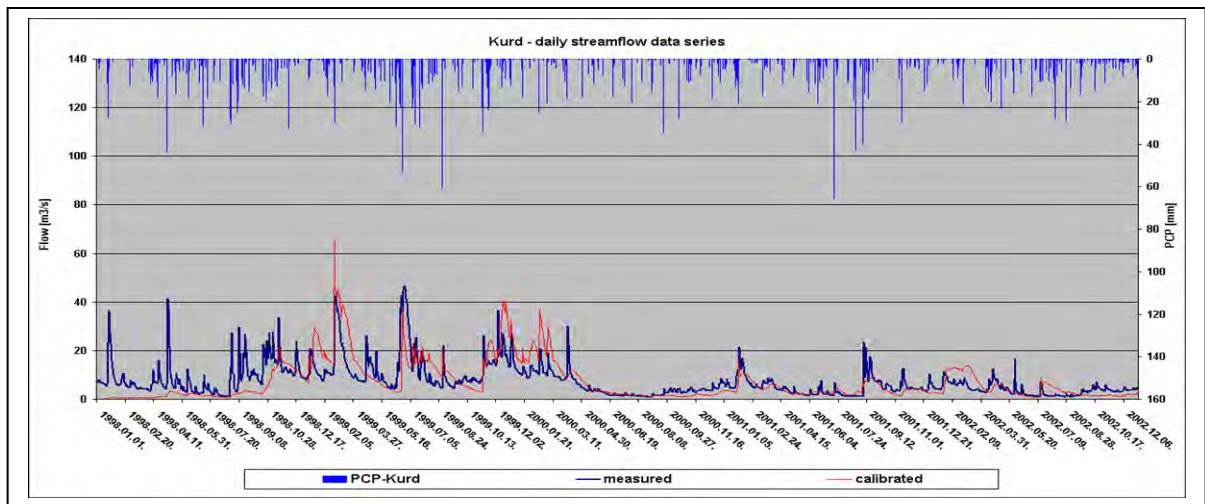


Figure 6.16. Simulated and observed daily discharge/water flow [m^3/sec], and the related precipitation [mm] at Kurd (Kapos river).

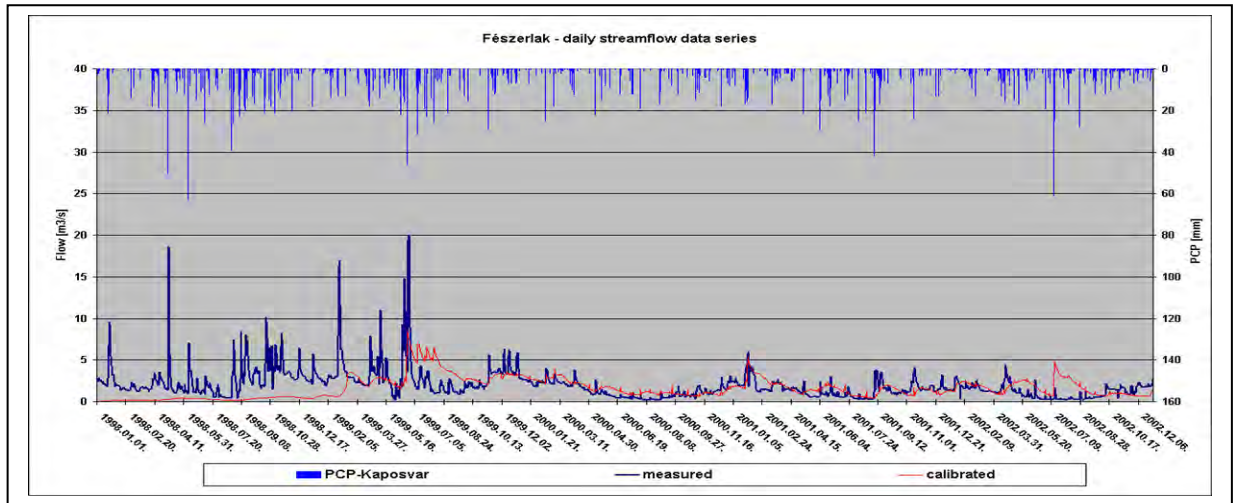


Figure 6.17. Simulated and observed daily discharge/water flow [m^3/sec], and the related precipitation [mm] at Kaposvár–Fészerlak (Kapos river).

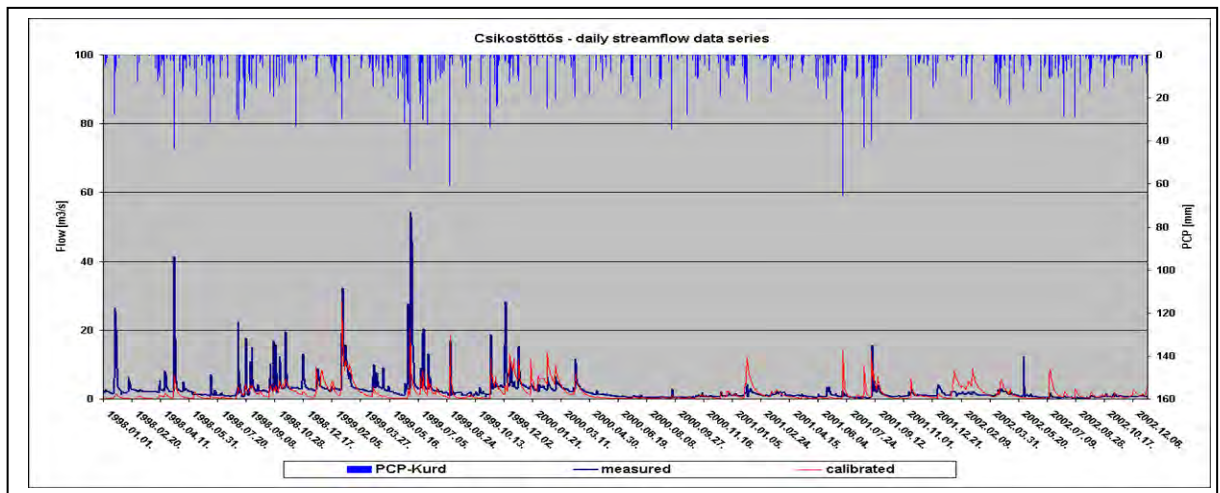


Figure 6.18. Simulated and observed daily discharge/water flow [m^3/sec], and the related precipitation [mm] at Csikóstötös (Baranya canal).

After completing the calibration, the model was tested on the validation year (2003) with the final parameter set. Results of the extended simulation period (1998-2003) are presented in figures 6.19 – 6.21 for Pinchehely, Tamási and Csikóstöttös monitoring stations respectively.

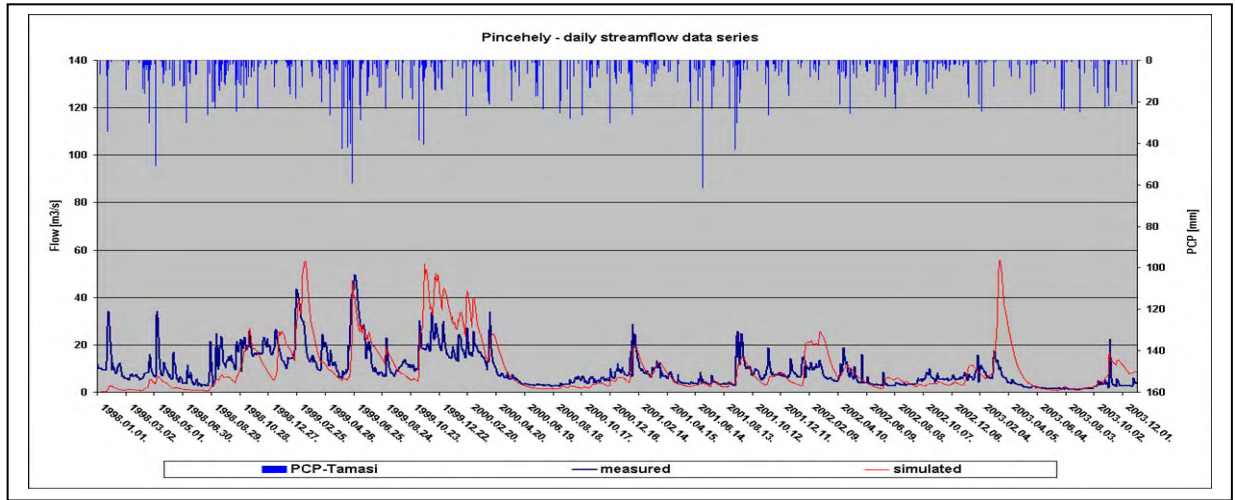


Figure 6.19. Simulated (calibrated and validated) and observed daily discharge/water flow [m³/sec], and the related precipitation [mm] at Tamási.

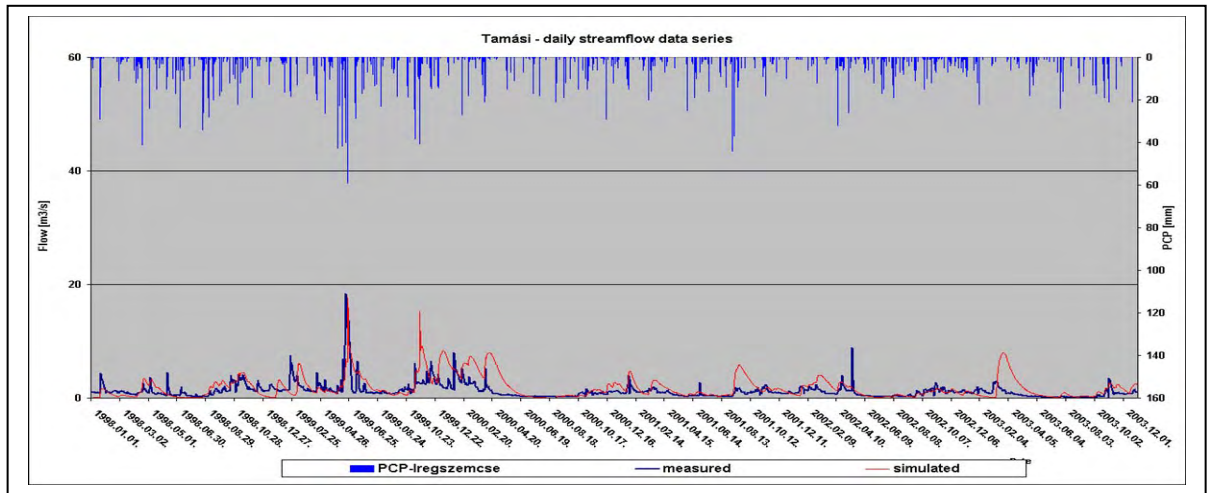


Figure 6.20. Simulated (calibrated and validated) and observed daily discharge/water flow [m³/sec], and the related precipitation [mm] at Pinchehely (Kapos river).

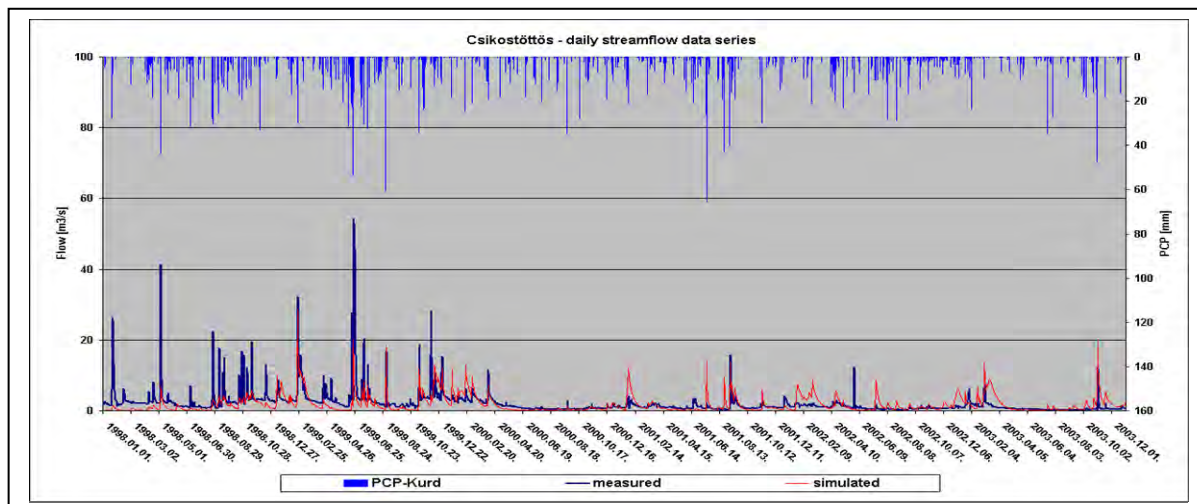


Figure 6.21. Simulated (calibrated and validated) and observed daily discharge/water flow [m^3/sec], and the related precipitation [mm] at Csikóstöttös.

The simulated water flow/discharge values in 2003 provided a good correlation with the observed data. The only exception was a peak value in March 2003, which was much higher than the measured values. All streams of the Kapos catchment have generally an extreme discharge fluctuation character.

The calibrated model simulates well the catchment processes in both low and mean flow periods. However, in order to properly simulate periods with significant precipitation and surface runoff, there is a need for better data series for both discharges and precipitation, preferably with higher spatial resolution (i.e. increased number of stations).

6.3.2 Sediment and nutrient calibrations

The sediment and nutrient calibrations were carried out at the same monitor stations as for the hydrological processes, and for the same time period (1998-2002), but in monthly time step as suggested by EC – JRC (EC - JRC, pers. comm., 2005).

There are two sources of sediments in the SWAT simulation: loadings from HRUs/sub-basins and channel degradation/deposition. Because the simulated quantities were much higher than the observed ones, the calibration was focused on the parameters listed below:

For HRU/sub-basin loadings:

USLE_P:	USLE crop management factor
SLSUBBSN:	USLE slope length factor
SLOPE:	slope of HRUs
BIOMIX:	bio-mixing efficiency
CNOP:	SCS runoff curve number for management operation
USLE_C:	crop management factor

For channel degradation/deposition:

SPCON:	linear parameter used for channel sediment routing
SPEXP:	exponential parameter used for channel sediment routing

The results of the sediment calibration are presented in figure 6.22 for the monitoring stations at Pincehely, Csikóstöttös, Kurd and Tamási.

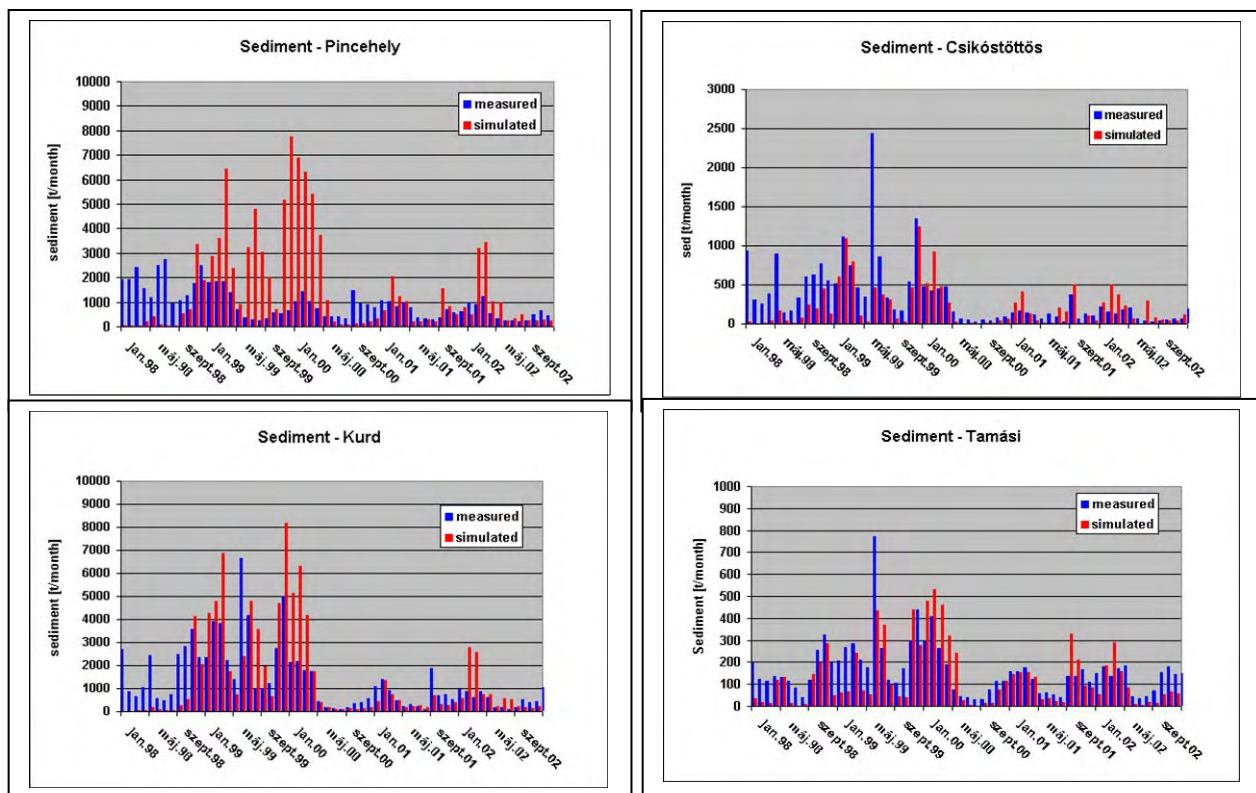


Figure 6.22. Observed and calibrated monthly sediment loads from different drainage areas.

The simulated monthly amounts were much higher than the measured in seasons with high precipitation rate, because the surface runoff peaks had a great impact on the soil erosion from the catchment.

Another aspect that possibly affects the nutrient transport/retention in the Kapos catchment is the large number of fish ponds. 175 small fishponds with 21.9 km² water surface are not represented by the model, because there was no information available about their characteristic and water quality, except their location and size (see figure 6.23). 51 of the fish ponds, with 5.1 km² water surface, are located on the drainage area of the Koppány creek (the branch in the northern part of the catchment).

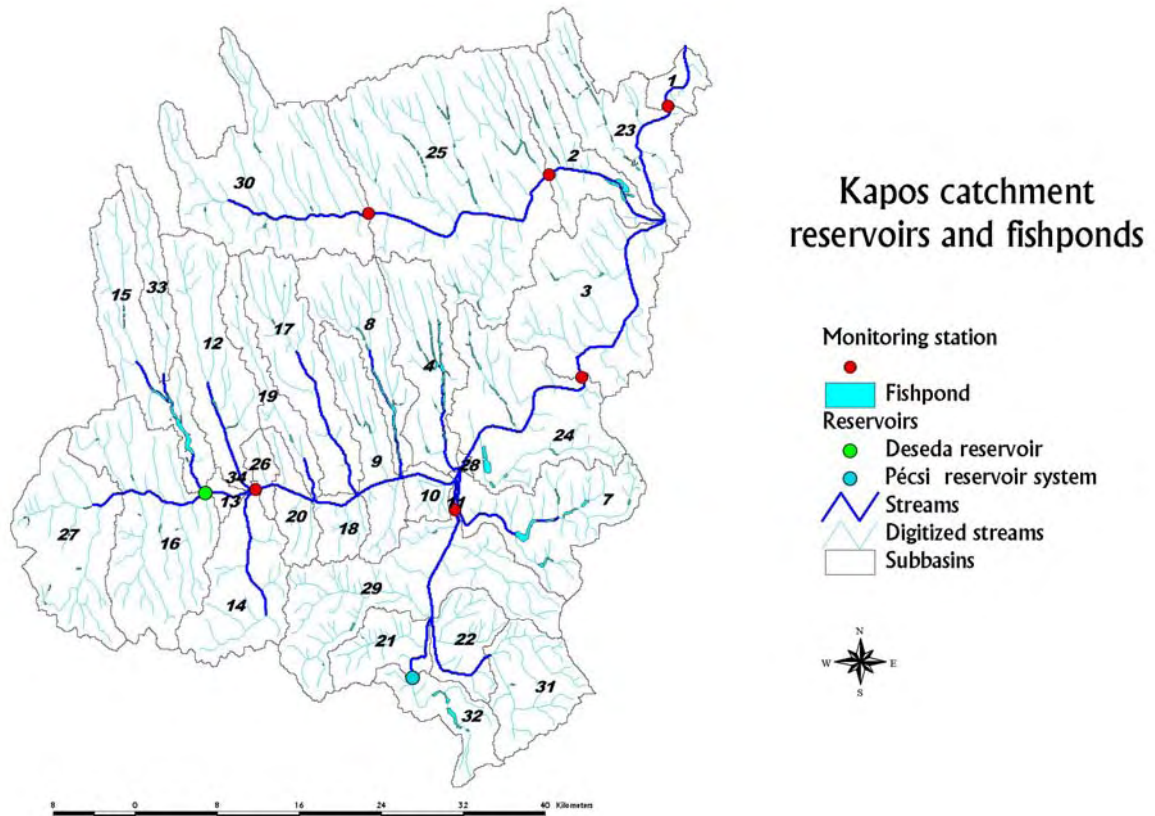


Figure 6.23. Location of the fish ponds and the reservoirs within the Kapos catchment.

SWAT simulates nitrite, ammonia, nitrate, soluble phosphorus, organic nitrogen and organic phosphorus loads. Nutrient calibration could be divided into two steps: calibration of nutrient loadings and calibration of in-stream water quality processes.

The land phase of the nutrient calibration was elaborated according to the seven steps suggested by the User Manual (Neitsch et al., 2002):

1. Checking the correct initial concentration of the nutrients in the soil.
 SOL_NO₃: initial concentration of the nitrate in the soil
 SOL_MINP: initial concentration of the soluble P in the soil
 SOL_ORGN: initial concentration of the organic N in the soil
 SOL_ORGP: initial concentration of the organic P in the soil
 These values were input to the model by soil types and based on expert judgement.
2. Verifying that fertiliser applications are correct.
 FERT_LY: fraction of fertiliser applied to the top 10 mm soil
 The model needed different values of this parameter for all drainage areas.
3. Verification that tillage operations are correct, because tillage redistributes nutrients in the soil and alters the amount available for interaction or transport by surface runoff. These operations (scheduled by date in March and in November) were input to the model by crop types and based on local expert judgment.
4. Alteration of biological mixing efficiency by HRU that controls mixing due to biological activity in the entire watershed.
 BIOMIX: biological mixing efficiency

The model was found not being sensitive to this parameter.

5. Modification of the nitrogen percolation coefficient for the whole catchment, which controls the amount of nitrate removed from the surface layer in runoff relative to the amount removed via percolation.

NPERCO: nitrate percolation coefficient

This parameter was adjusted during the calibration.

6. Modification of the phosphorus percolation coefficient for the whole catchment, which is the ratio of the phosphorus concentration in the surface (10 mm upper layer of the soil) to the concentration of phosphorus in percolated water.

PPERCO: phosphorus percolation coefficient.

This parameter was adjusted during the calibration.

7. Modification of the phosphorus soil partitioning coefficient for the whole catchment, which is the ratio of the soluble phosphorus concentration in the surface 10 mm of soil to the concentration of phosphorus in surface runoff.

PHOSKD: phosphorus soil partitioning coefficient

This parameter was adjusted during the calibration.

SWAT includes in-stream nutrient cycling processes by the QUAL2E module. These processes were controlled by the input parameters of the general water quality (.wwq input file at catchment level) and the stream water quality (.swq input file at sub-catchment level) files. Some of these parameters have been adjusted (mainly the initial water quality values, and oxidation, hydrolysis and mineralisation rates) during the calibration, whereas for the other parameters the default values were used, because there was not sufficient information about in-stream microbiotic processes.

There were only two *in-situ* measurements with chlorophyll-a concentration and the corresponding biomass at the monitoring points. To adjust in-stream biological and chemical processes, the model would need a number of specific values according to the biological and biochemical parameters (e.g. algal settling rate, organic nutrient settling rates, benthic inorganic nutrient source rates).

Calibrated monthly amounts of nutrients in the period 1998-2002 at Pincehely, Csikóstöttös, Kurd and Kaposvár-Fészerlak are shown in the figures 6.24-6.31. There are no measured nutrient loads at Kaposvár-Fészerlak after February 2001, because concentration data series from the National Water Quality Database were available only until this date.

The quantities of **P_{min}** in the figures (6.24-6.31) include the mineral (including soluble) phosphorus loads only transported with water out of the reach during the time step, because the model does not calculate the mineral phosphorus fraction attached to sediment/particles and transported with water (only the amounts transported by surface runoff into the reach). Consequently the total P was calculated by summing the above mentioned mineral (including soluble) fraction and the organic phosphorus loads.

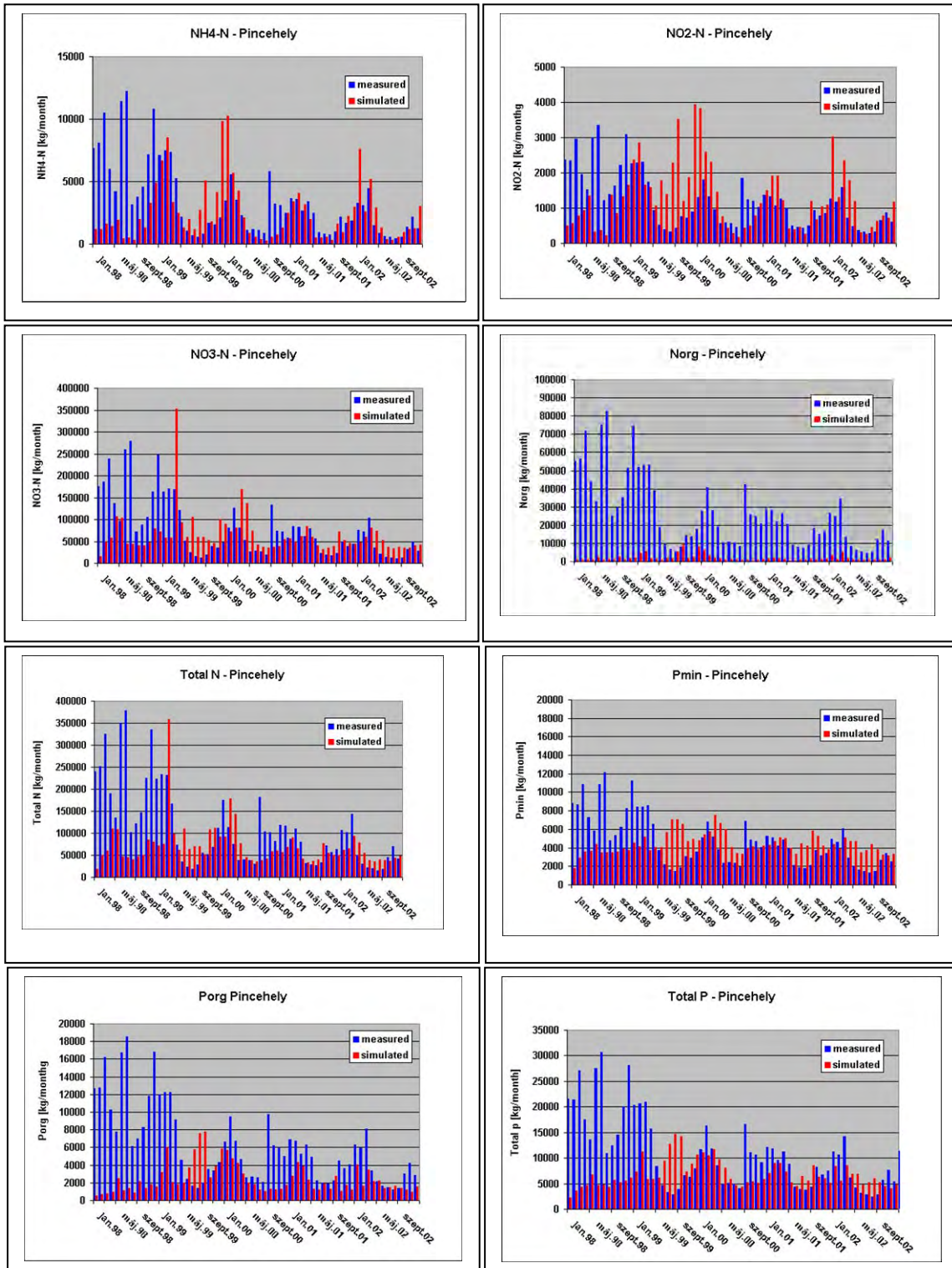


Figure 6.24. Monthly observed and calculated (calibrated) load at location Pincehely (Kapos river).

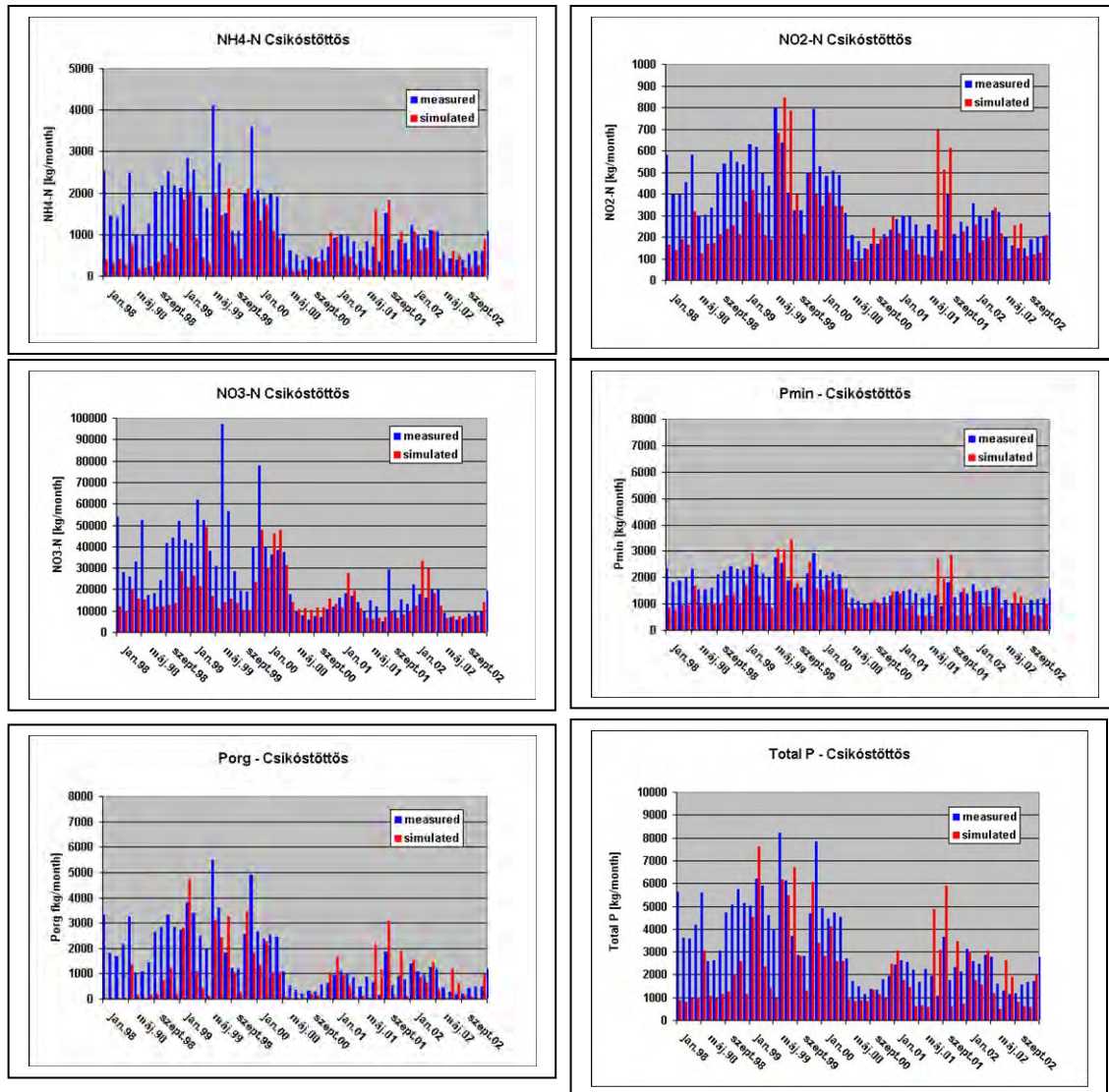


Figure 6.25. Monthly observed and calculated (calibrated) load at location Csikóstöttös (Baranya channel).

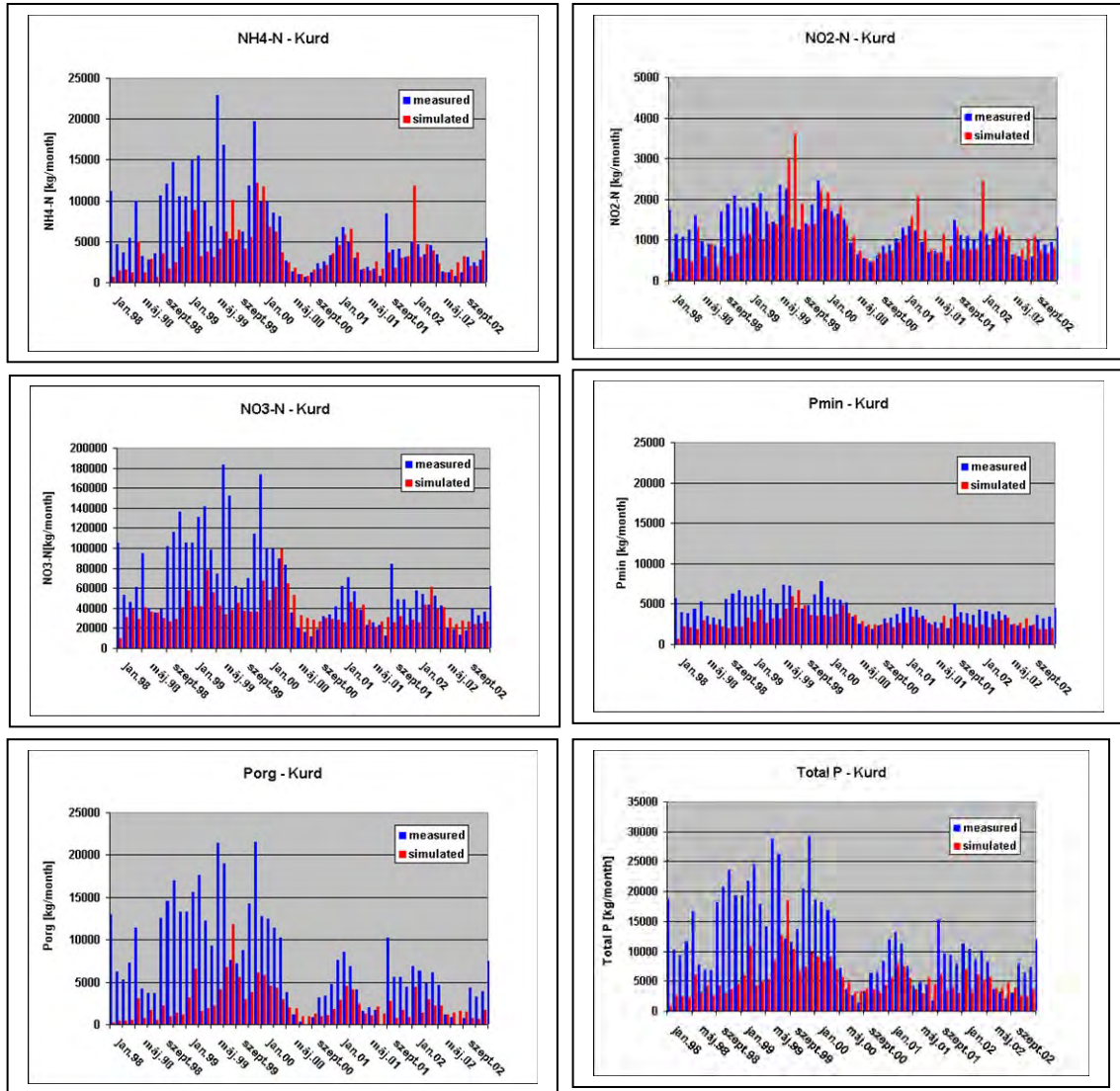


Figure 6.26. Monthly observed and calculated (calibrated) load at location Kurd (Kapos river).

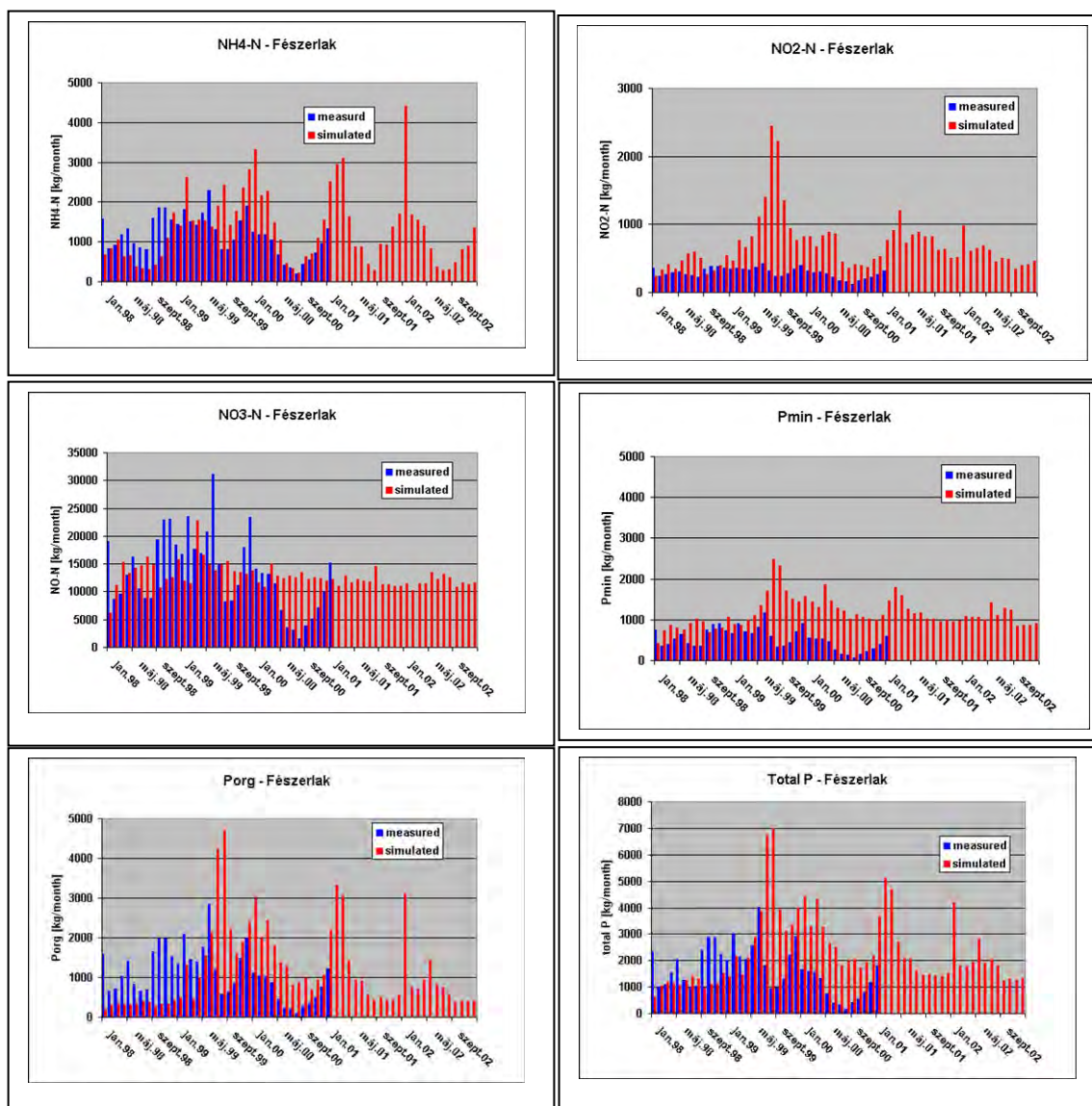


Figure 6.27. Monthly observed and calculated (calibrated) load at location Kaposvár–Fészerlak (Kapos river).

As the figures 6.24 – 6.27 show, the model generally underestimates the monthly nutrient loads, except at the Kaposvár–Fészerlak monitoring station. Significant point pollution sources are located up-stream from this monitoring station and the results indicate that annual pollution loads might be reported wrongly. In other words, the given point sources fed into the model in the upper parts of Kapos river are most probably too high, which also concurs with the findings in the INCA-P application (see section 5.4.2).

The simulation period was then extended to the year 2003 to validate the model with calibrated parameters. Results in monthly time step are presented in figures 6.28-6.31.

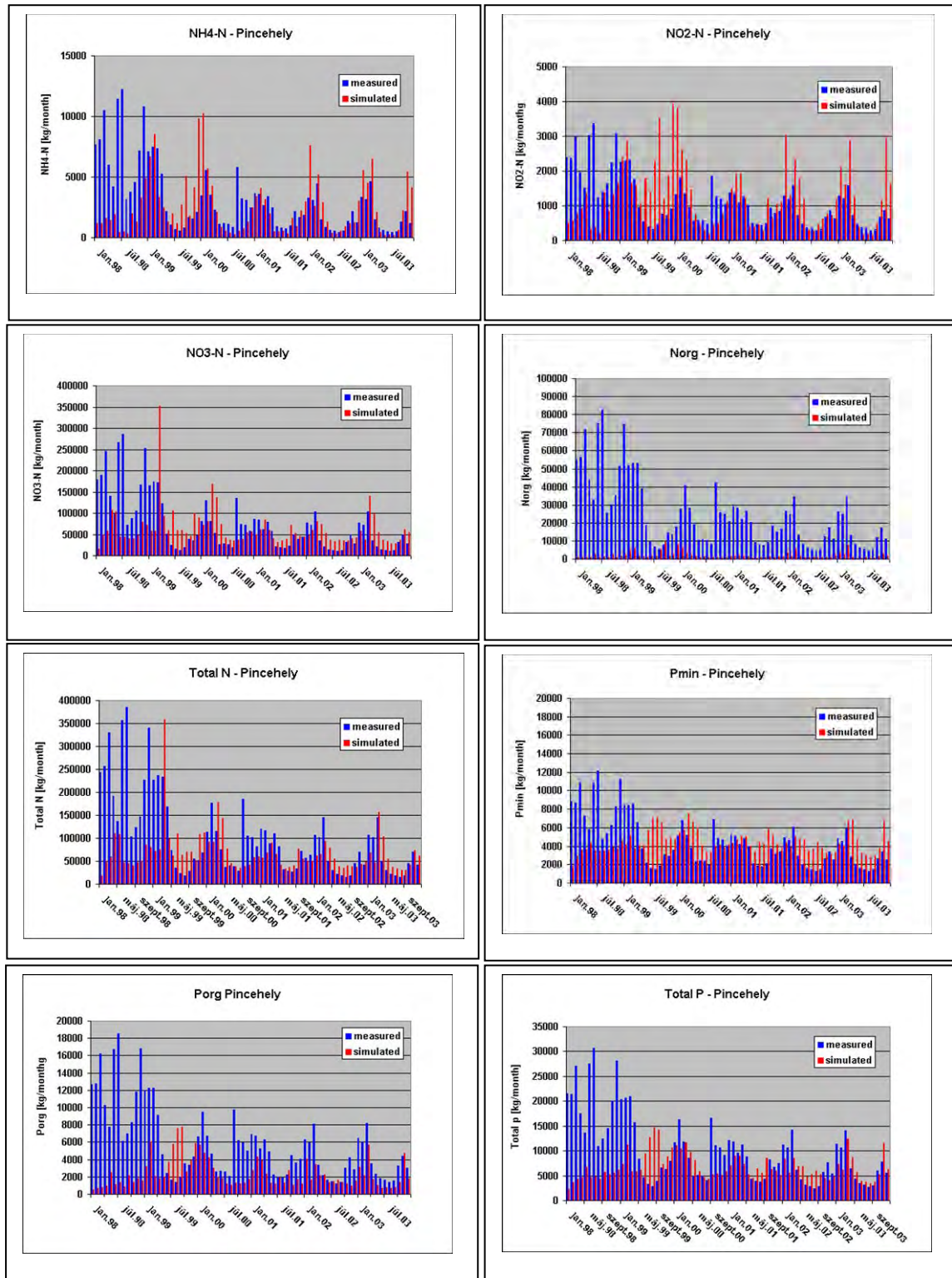


Figure 6.28. Monthly observed and calculated (calibrated and validated) load at location Pincehely (Kapos river).

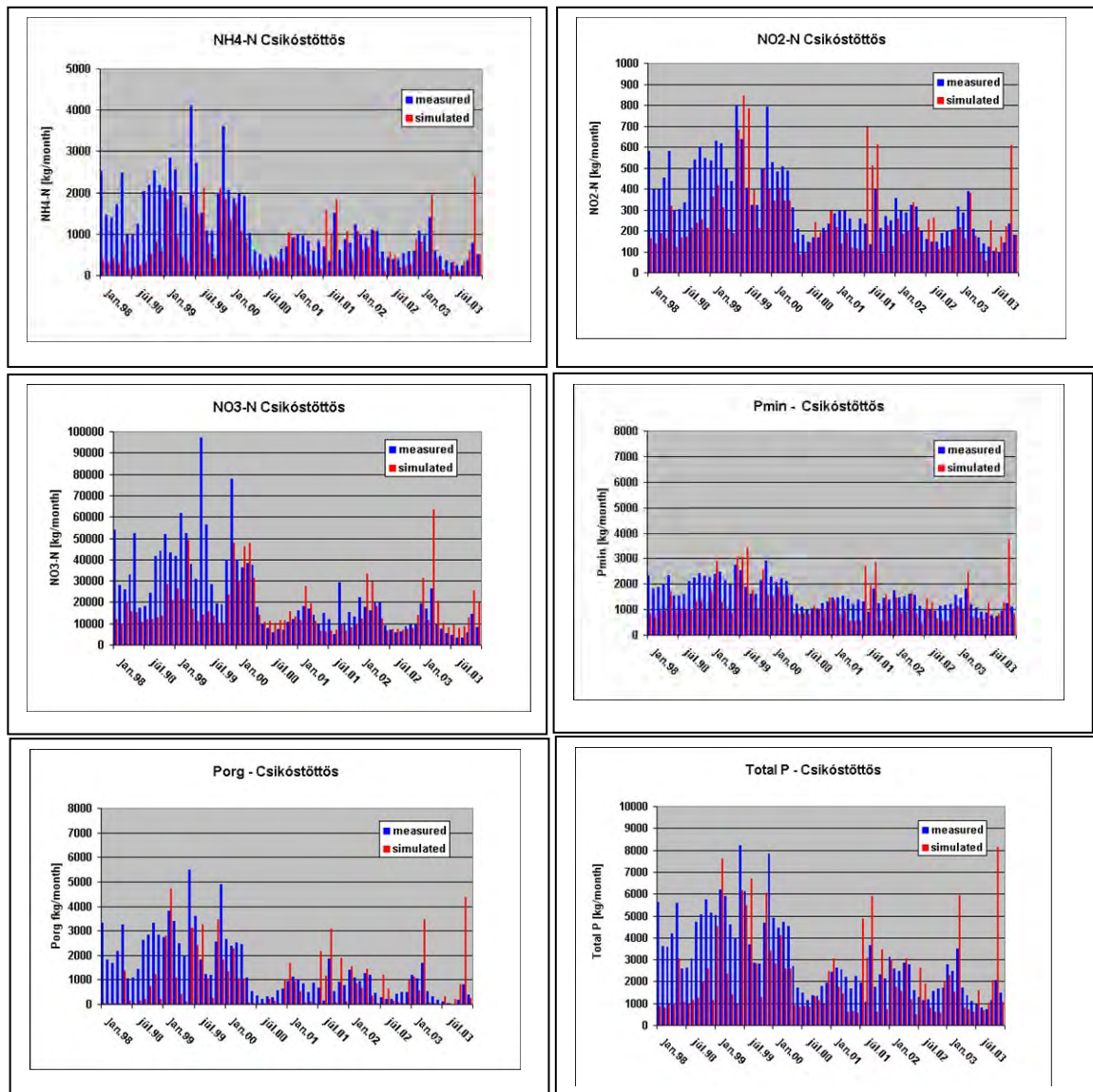


Figure 6.29. Monthly observed and calculated (calibrated and validated) load at location Csikóstöttös (Baranya channel).

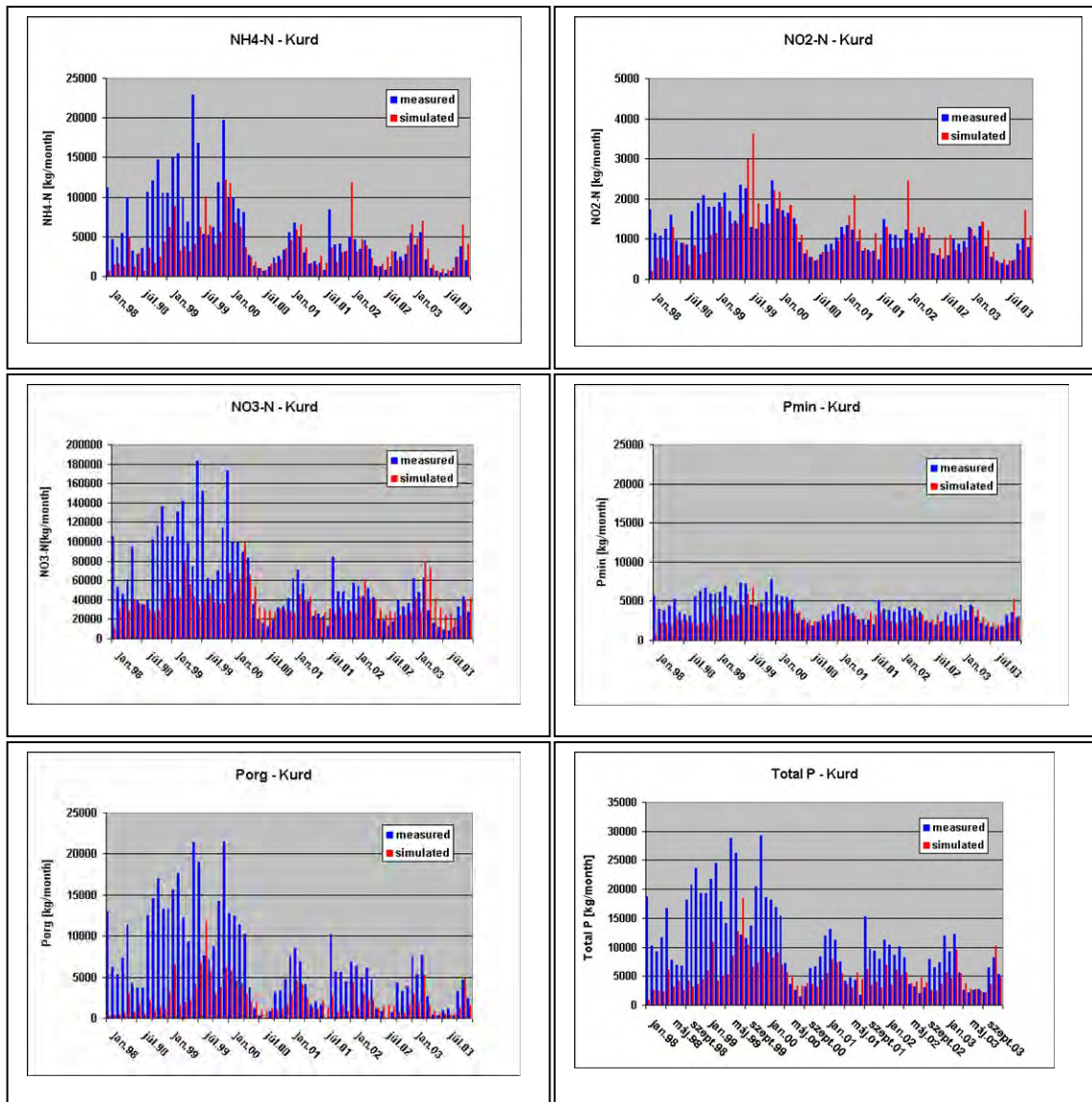


Figure 6.30. Monthly observed and calculated (calibrated and validated) load at location Kurd (Kapos river).

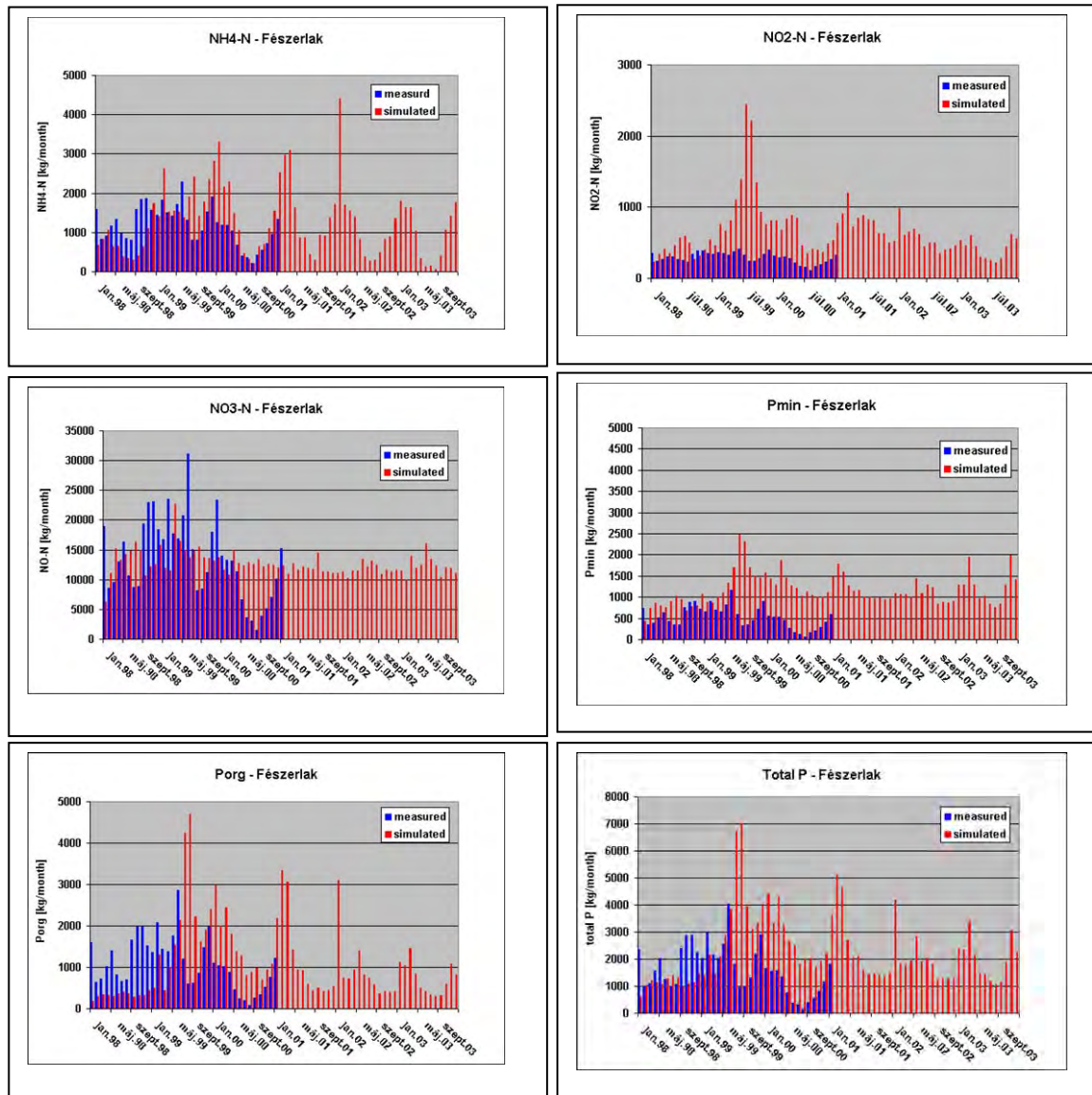


Figure 6.31. Monthly observed and calculated (calibrated and validated) load at location Kaposvár–Fészerlak (Kapos river).

Based on the calibrated results, the simulated monthly amounts of inorganic N and P correspond well with the seasonal variation of the observations. In general, the organic nutrient forms are underestimated. This is the case, especially for organic nitrogen, which is measured only at Pinchely (basin outlet station), another complicating aspect for the calibration.

The maximum values of simulated nutrient values (organic and inorganic) were linked to significant precipitation events. In general, the nutrient loads were overestimated during these events. The results of the first 10-11 months of simulation, show very low nutrient loads due to the ‘filling-up phenomena’ (the water/nutrient reservoir of the model is filled before appropriate amount of water/nutrient load is released) of the model.

As a conclusion, SWAT simulates the nutrients well in low-flow and mean-flow periods, but during high-flow periods the loads were overestimated. The peak runoff rates of the hydrological part of the model have a great impact on calculated nutrient fluxes.

Figures 6.32-6.34 present the annual nutrient amounts at related monitoring stations (Pincehely, Kurd, Fészerlak) to ease the comparison of the SWAT results with the INCA-P and TEOTIL results.

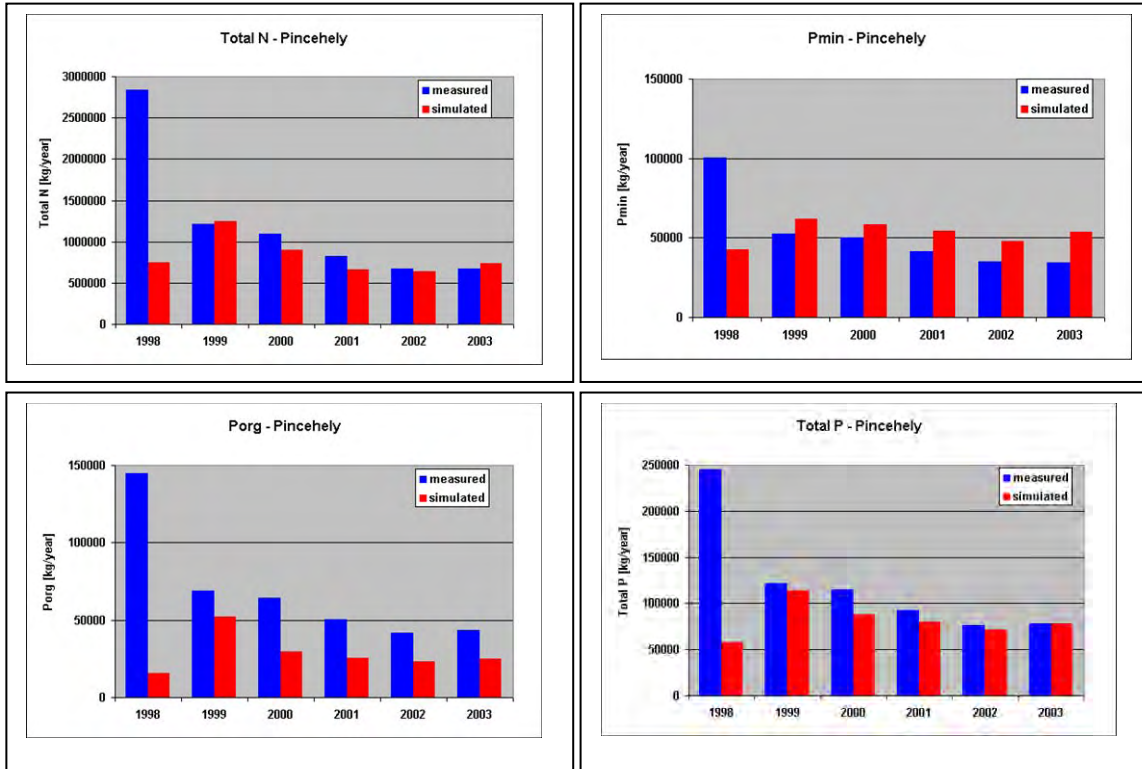


Figure 6.32. Observed and simulated annual load of nutrients [kg/year] at location Pincehely (Kapos river).

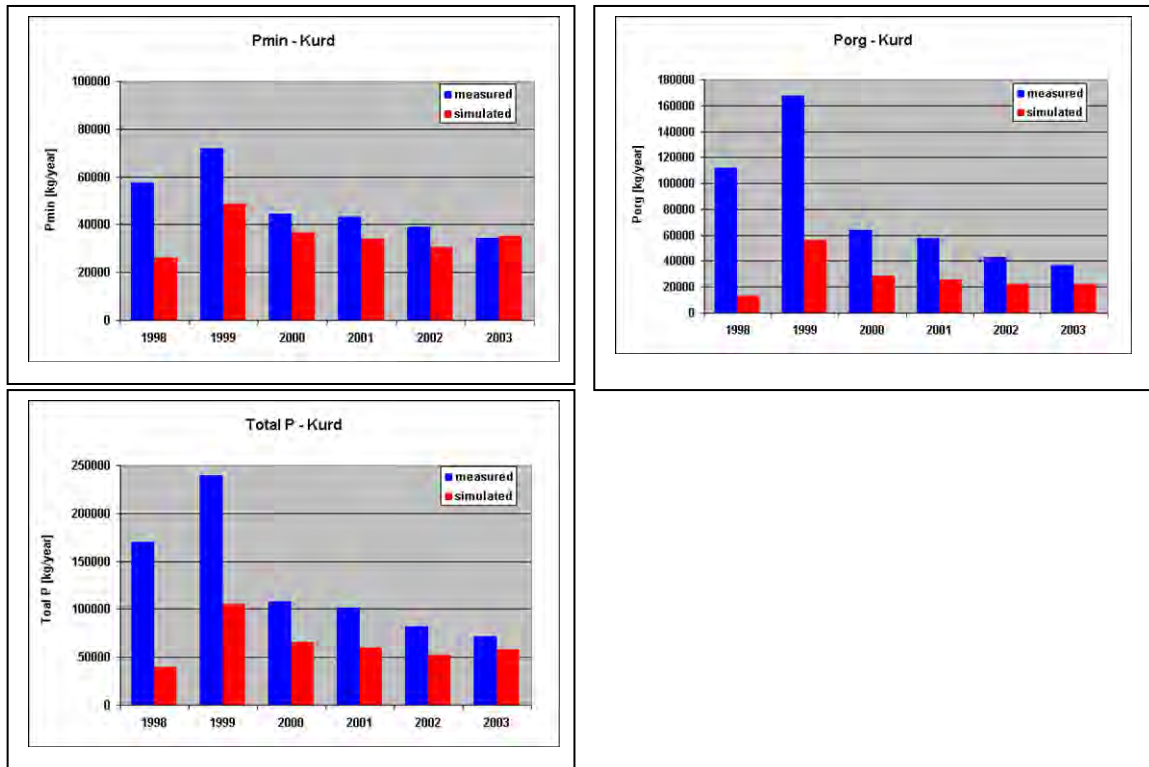


Figure 6.33. Observed and simulated annual load of nutrients [kg/year] at location Kurd (Kapos river).

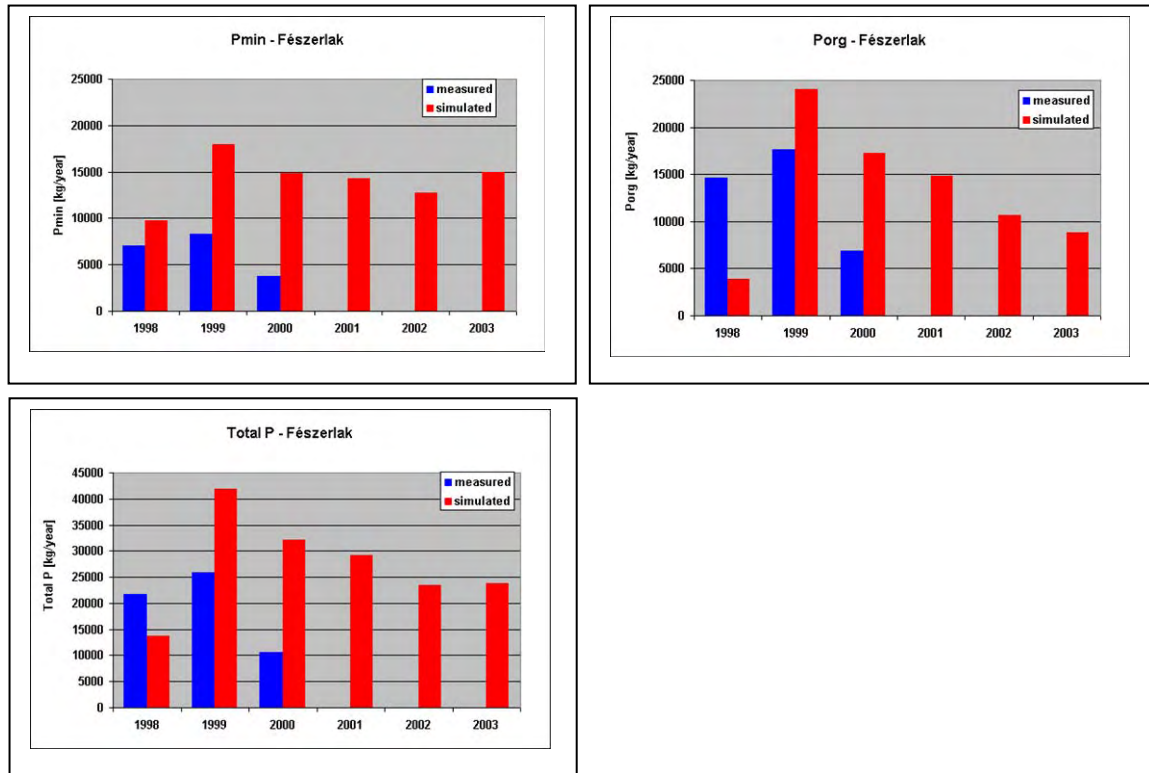


Figure 6.34. Observed and simulated annual load of nutrients [kg/year] at location Kaposvár-Fészerlak (Kapos river).

6.4 Definition and simulation of management scenarios

The AQUAPOL partners agreed on a set of scenarios to analyse the models' capability of simulating realistic management options. These scenarios are to a large extent based on scenarios that have been defined in the EUROHARP project (Vagstad and French, 2005). The scenarios are the same as in EUROHARP, except that scenario G is added from the EUROHARP protocol. The scenarios are as follows:

- 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
- G 20 % decrease of point source loads (added from EUROHARP-protocol)

The SWAT scenario analysis considered the scenarios A, B, C, D and G. The other scenarios (E and F) were not simulated, because changing of land use categories would have needed extensive restructuring of the model setup by introducing a new division of HRUs of the watershed. The scenarios were conducted for the whole simulated period.

The results show that the size of the loads are only to a small extent affected in the case of scenarios A, B, C and D. In the case of scenario G, simulated loads were significantly decreased in the entire watershed. Due to the limited changes in load for the scenarios A-D, and in order to make these changes visible in the figures, only a small part of the simulation period (one year, where both mean-flow and high-flow periods took place) is presented in figures 6.35-6.37.

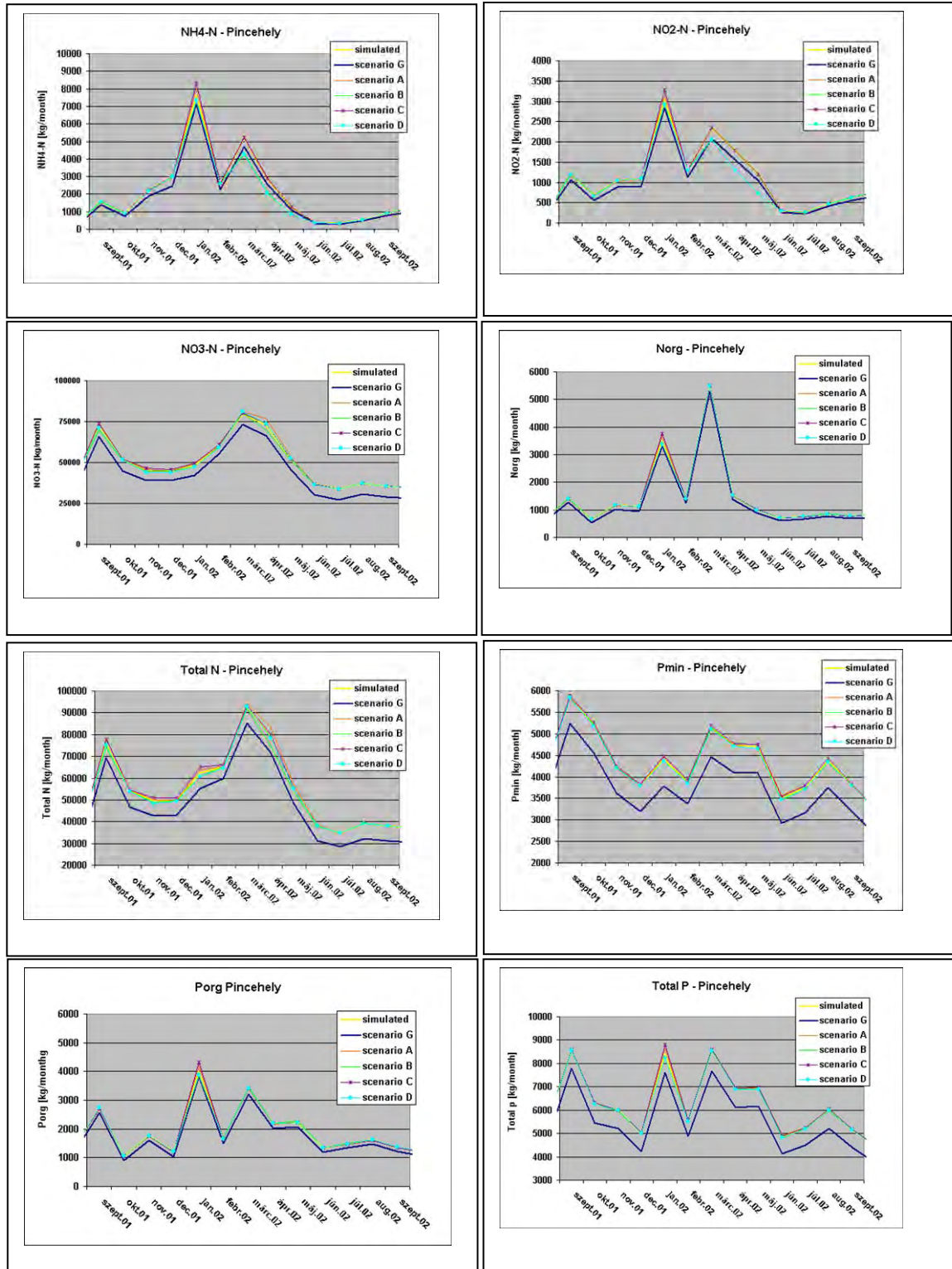


Figure 6.35. Scenario results (monthly load) at location Pincehely (Kapos river) along with the calibration results.

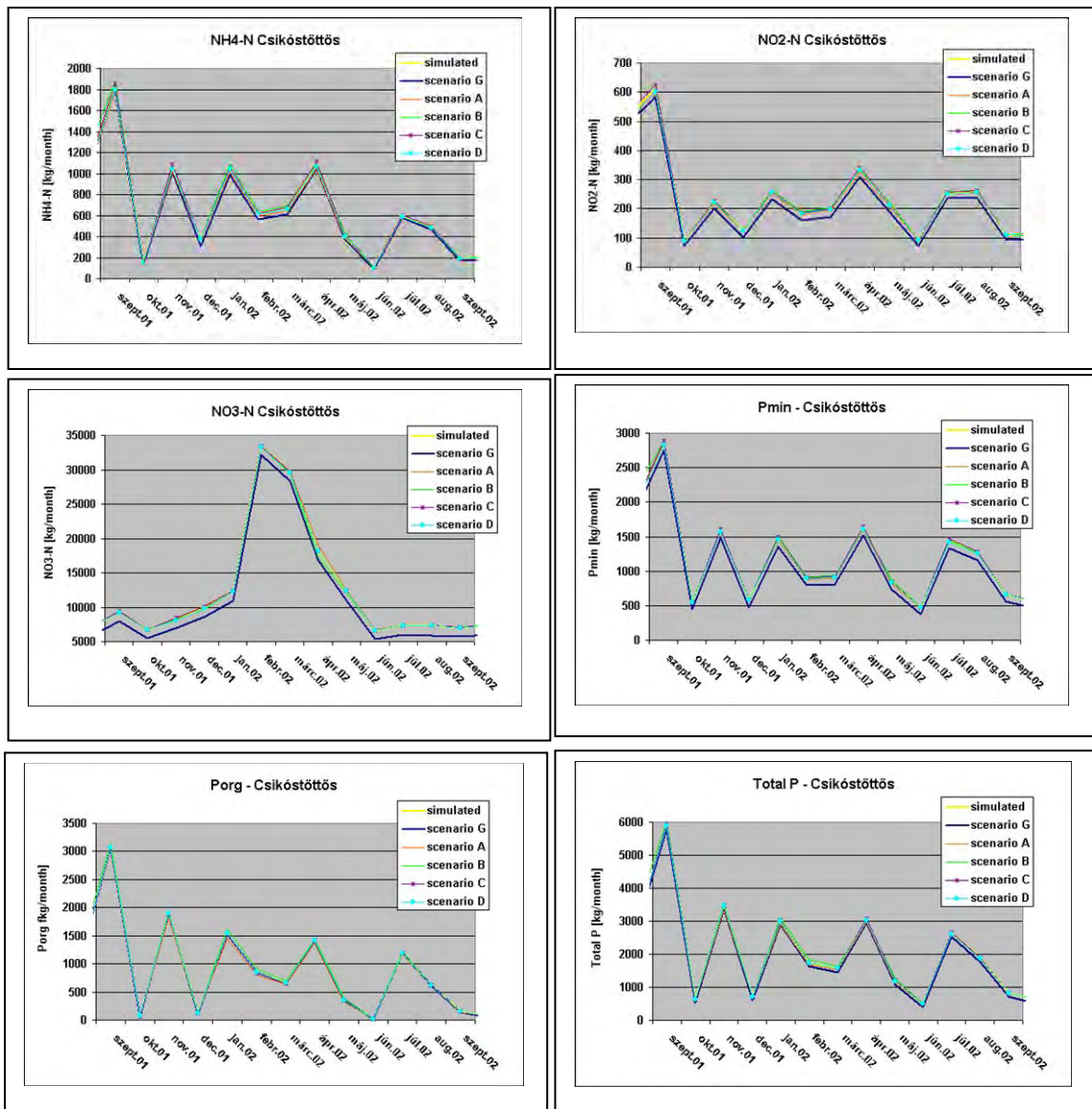


Figure 6.36. Scenario results (monthly load) at location Csikóstöttös (Baranya canal) along with the calibration results.

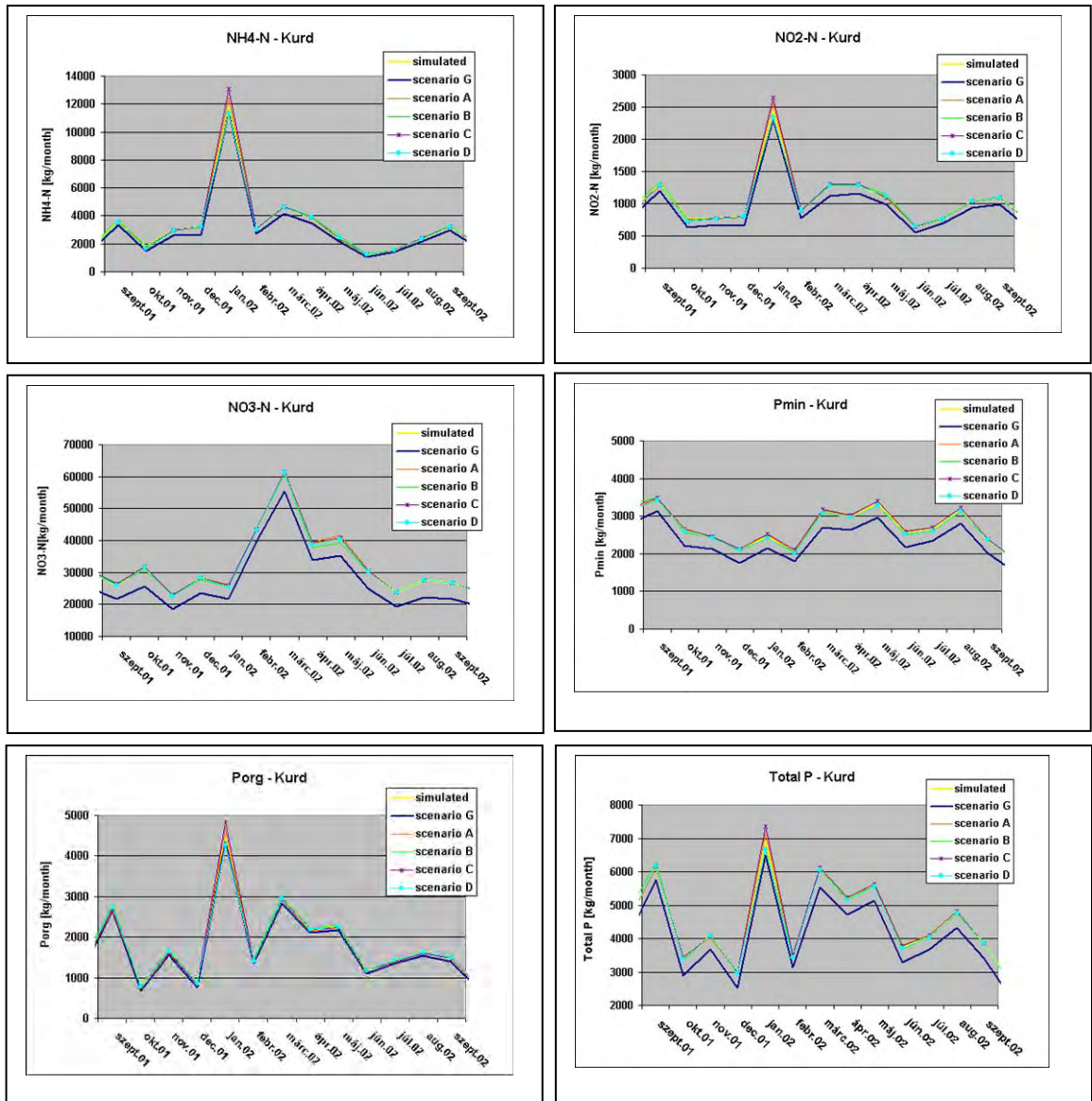


Figure 6.37. Scenario results (monthly load) at location Kurd (Kapos river) along with the calibration results.

Figures 6.38 and 6.39 present the simulated annual loads of total nitrogen and total phosphorus from the different scenarios at Pincehely monitoring station (near the outlet of the Kapos catchment).

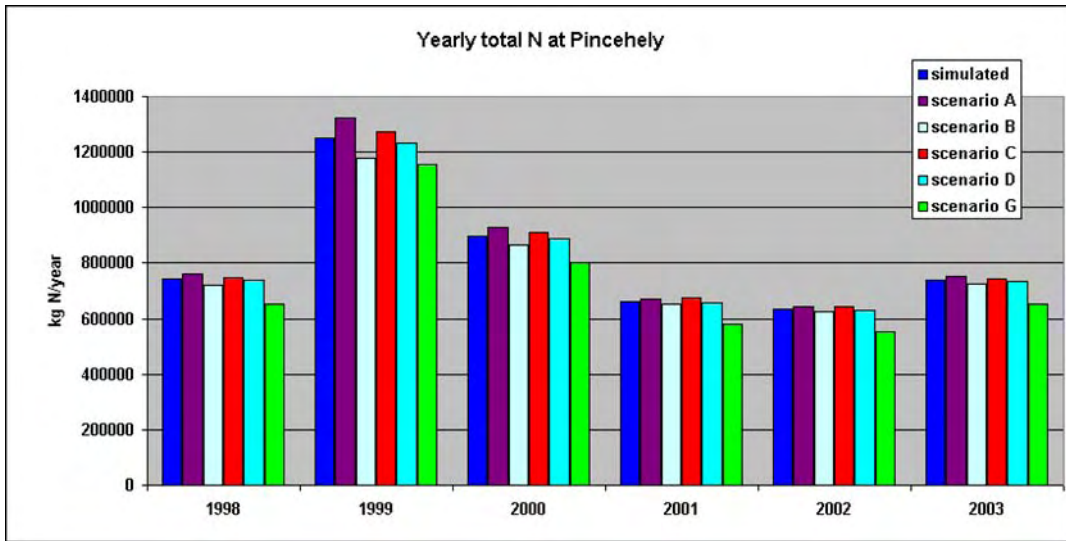


Figure 6.38. Yearly loads of total N at the location Pincehely (Kapos river), as a function of different scenarios. Note that ‘Simulated’ means the data series generated by the calibrated SWAT model.

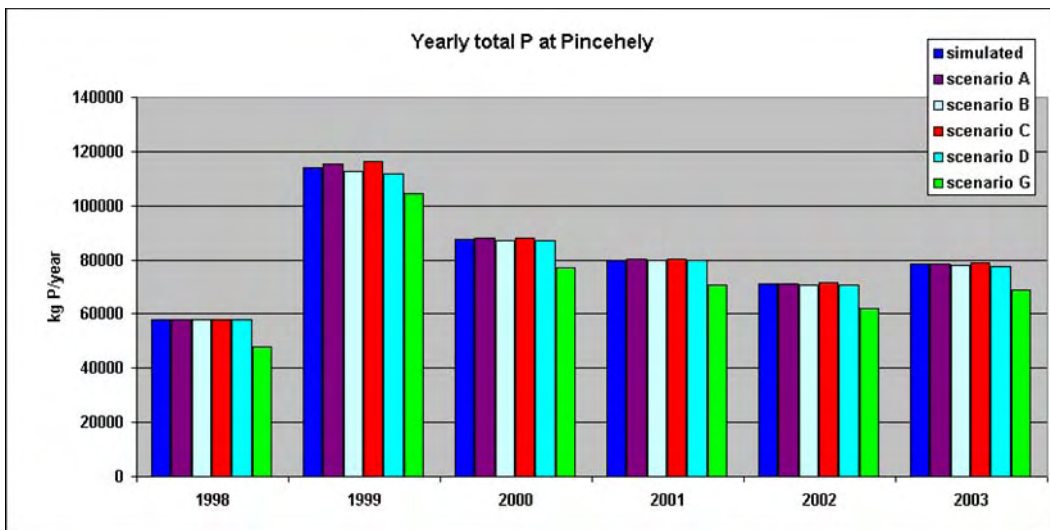


Figure 6.39. Yearly loads of total P at the location Pincehely (Kapos river), as a function of different scenarios. Note that ‘Simulated’ means the data series generated by the calibrated SWAT model.

The results of the scenario analysis show that the effect of the inorganic fertiliser application (scenarios A and B) on in-stream Nitrogen loads is greater than the effect caused by changing the organic fertiliser applications (scenarios C and D). The situation is opposite for Phosphorus, where scenarios C and D (change is organic fertiliser) have a greater effect on the Phosphorus loads at Pincehely than scenarios A and B (change in inorganic fertiliser). In a

management context, the decrease of the inorganic fertiliser application should therefore be preferred to decrease the nitrogen load to surface waters. To achieve lower P concentrations and loads, the application of organic fertilisers should be reduced.

Finally, the SWAT simulations show that scenario G (reduced discharges from point sources) gives a significantly greater effect on the in-stream load, both with respect to Nitrogen and Phosphorus. The year-to-year variation is also greater, varying from a decrease in N load by 7-13 % and a decrease in P load by 8-18 % at Pincehely in the modelling period (see also sections 7.2.2 and 7.3.3).

Table 6.4. The relative changes in surface water load of total N and total P at the location Pincehely (Kapos river), for the different scenarios. The change is relative to the calibration runs.

Scenario/component	Total N (%)	Total P (%)
A	2.8	0.4
B	-2.8	-0.4
C	1.3	0.9
D	-1.0	-0.8
G⁶	– (7-13)	– (8-18)

6.5 Conclusions on the application of SWAT

The calibration of the SWAT model involves the calibration of three main parts of the model. The first is the calibration of the hydrological part of the model, which is based on the calculation and adjustment of the relevant parameters governing the water balance. This process was carried out on yearly and daily time steps in collaboration with the SWAT experts of EC – JRC. The calibrated model simulated well the catchment processes in both low and mean flow periods. However, there were deviations in the water flow in periods with significant precipitation and high surface runoff, which supported the fact that the model would have needed more detailed information about the spatial variation in meteorology (better spatial coverage), see also section 6.3.1.

Precipitation data are probably the most important input data to SWAT. Without sufficient quality, quantity and spatial distribution/coverage of these data, the model does not simulate the water flow/discharge values appropriately. This issue has an important further effect on sediment and nutrient simulations.

The second and third parts of the calibration process are the calibration of the sediment and nutrient (N, P) loads coming from land areas and transported in the streams. These simulations and adjustments were carried out in monthly time steps. Based on the calibrated results, the simulated monthly amounts of inorganic N and P basically showed a good correlation with the observations, even though the organic nutrient forms were underestimated. The maximum values of simulated nutrient values (organic and inorganic) were linked to major precipitation events. The nutrient loads were overestimated during these events, which is explained by the insufficient coverage of meteorological stations.

Fishponds and reservoirs are important in the calculation of sediment and nutrient retention within the catchment. In the setup of SWAT in Kapos, only two of the largest reservoirs

⁶ The range indicates a year-to-year variation in the decrease of Nitrogen and Phosphorus for this scenario.

(Deseda and Pécsi reservoir systems) were taken into account, due to missing information about the other ponds (175 fishponds, see figure 6.23) and reservoirs.

SWAT requires extremely detailed and accurate information on agricultural management practices, and types of management operations in order to function appropriately. Due to lack of observed or measured data/information, expert judgements were to a large extent applied. Therefore, with improved information about plant types, timing of planting, irrigation, fertiliser application, harvest, tillage, grazing, etc. the model would probably simulate the hydrology, sediment and nutrient loads closer in accordance with the observations.

Following the privatisation of agricultural areas in Hungary (1990s), the official registration of the fertiliser application was stopped. Fertiliser input data was based on official statistical data on fertiliser sales. The model results indicate that these application rates are most probably underestimated. This theory was supported by the results from the scenarios A and B, which gave almost no change in in-stream loads.

In Hungary, only bi-weekly surface water measurements are available for nutrients and sediments (quality parameters). The SWAT simulations produce output with a daily time step. In order to calibrate daily variations in nutrients, much more frequent monitoring data are necessary. The daily results of the modelling should for this reason be handled with great care, and should preferably be aggregated into at least average monthly values.

The built-in aggregated automatic calibration tool was not applicable in the Kapos catchment, and the calibration had to be done manually in each drainage area. Since this manual adjustment is extremely time consuming, it is recommended to keep the number of sub-catchments and HRUs (hydrological response units) at a reasonable number, matching the spatial resolution of the available data.

The model requires very detailed chemical and microbiological coefficients that were not available for the Kapos. No sensitivity analysis has been performed to estimate the effects of these parameters on the simulated water quality. These parameters were set to their default values during the simulations.

Although SWAT is a very complex model, producing extensive amounts of output, its' capabilities to present the results are weak. Manual extraction of relevant subsets of output data (results), was found to be very labor-intensive. Therefore, specific tools to extract the necessary values from this huge amount of output was developed within the project. The development of these "support tools" needed quite significant resources to programme, but they were very useful during the calibration process. These dedicated tools are not part of the SWAT model package, but were developed within the project.

In general, the SWAT model is an extremely detailed (temporarily and spatially) and complex (large number of processes embedded) tool to simulate watershed processes, requiring a huge amount of input data/information. The data required to properly set up the model are often not available, and the lack of some key parameters cannot be fully compensated with calibration techniques. Despite the fact that the model is very data demanding and requires significant man-power to run, SWAT was found to be a highly adequate model to simulate nutrient processes in the Kapos catchment.

7. Comparison of methods/models

7.1 Comparison by characteristics

This is an overview of model characteristics used for model comparison in the AQUAPOL-project. The term “quantification tool” is used interchangeably with “model”, and the approaches considered range from the very simple methods to the highly complex. It includes Source Apportionment, TEOTIL, INCA-P and SWAT, listed from simple to complex.

Table 7.1. This table compares different characteristics of the four different quantification approaches/models tested in the Kapos catchment.

Characteristics/ aspects considered	Description	Source apportionment (SA)	TEOTIL	INCA-P	SWAT
Data requirements versus data availability.	Does the available data match the data needs of the model? Is more data than easily available required? Is essential data, which is available, not used by the model? What about the spatial and temporal resolution/coverage of data, like flow, water quality parameters, data on pollution sources/loads?	This approach uses point source and diffuse source data/coefficients to calculate total loads, alternatively point source data and riverine loads to calculate diffuse losses - no processes involved. Sufficient data was available for performing a SA calculation.	The model needs yearly or monthly discharge figures of point sources, i.e. industrial plants not connected to municipal treatment plants, municipal treatment plants and scattered dwellings not connected. With regard to the quantification of diffuse losses, information such as area of the different type of land use, coefficients (kg/km ² or mg/l) for calculating the nutrient losses, both anthropogenic and natural. Data from characteristic water discharge stations and /or	Precipitation/temperature-data was available on daily basis, as well as water flow for calibration. Similarly, sufficient water quality data was available for calibrating the model. The fertiliser data was to some extent based on qualified guess (timing, distribution, amount, etc). Type of crop (by defining uptake rates) was considered free parameters for calibration. Sowing/harvest data was also based on qualified guess. See details about this issue in section 5.3. However, the data	SWAT has very strict and extensive data requirements. In case of Kapos data availability, expert judgement was necessary to a large extent to define many of the model parameters required (the case for 30 – 40 % of the parameters), such as hydrology, soil properties, meteorology, agricultural practices, biological and chemical parameters. Availability of meteorological data series was limited, and the model has a great sensitivity for climate data. The higher the resolution, the better

Characteristics/ aspects considered	Description	Source apportionment (SA)	TEOTIL	INCA-P	SWAT
			<p>precipitation stations. In the case of the Kapos catchment, all data was obtained from official sources and digital maps. Discharge coefficients from industry were taken from literature and adjusted by calibrations.</p>	<p>requirements seem to match the available data well.</p>	<p>the results.</p>
<p>Temporal resolution and span</p>	<p>Which time resolution is the model producing results/simulating output? Daily, monthly, annual time step? Is the model handling multi-year simulations?</p>	<p>This is a very simplified calculation approach. It is not recommended to use on a daily or monthly basis (only annual).</p>	<p>The model runs for a characteristic period, for example one year. The time step of model depends on the input data. It can be daily as well, if the data and the equations are set accordingly.</p>	<p>The model basically requires daily time steps in the input data, produces output on daily resolution and it can run several years. Within INCA-P, the calculation time is approximately 1 sec/year.</p> <p>The external hydrological routine is very time-consuming to use as the number of years (and number of met-stations) increase. For this reason, the calibration of this module can take several days as it takes some hours to run a new calibration for 4 met-stations and seven years of calibration period.</p>	<p>Input data has different time resolution: daily, monthly, annual, static. In case of some parameters, time resolution can be selected by the user, but for others, it is fixed in the model.</p> <p>The output can be selected as being daily, monthly or annual amounts depending on the application, and it can run several years of simulation.</p>
<p>Spatial resolution and span</p>	<p>Is the selected model a catchment-based model?</p>	<p>The calculation can be done separately for sub-</p>	<p>The main catchment may be divided in sub-</p>	<p>The number of sub-catchments to be defined</p>	<p>Spatial resolution depends on the user setup of the</p>

Characteristics/ aspects considered	Description	Source apportionment (SA)	TEOTIL	INCA-P	SWAT
	Does the model lump the catchment into one homogenous unit? Does it split the catchment area into sub-catchments, uniform grid cells or equivalent?	basins, or for the whole river basin.	catchments with known interior drainage. The user is free to choose the resolution, but the connection (flow-direction) between sub-catchments have to be priori defined.	is technically unlimited, but for practical purposes limited by how detailed the available data is, and the limitation given by the “in-series continuously-stirred tank reactor concept” (see section 5.1 and 5.3.1). This latter aspect imposes a constraint that the model does not handle branched networks, but aggregates all branches into separate and homogenous units.	model. The model requires geo-referenced datasets. Spatial data input (maps in e.g. shape file format) is helped by ArcView interface (<i>with Spatial Analyst extension</i>). Spatial resolution of the model is based on the DEM resolution, consequently the smallest unit of land use and soil categories can be DEM grid sized.
Process description	Which processes in the catchment/water bodies are embedded in the model/method?	No processes are embedded.	<p>The model is general and may be set up for almost any chemical component and any processes that may be described with mean values for the simulated period.</p> <p>The model was prepared for total phosphorus and total nitrogen. The area loss coefficients represent mean yearly surface- and subsurface run off. The transport downward the water courses may include retention processes when coefficients are available.</p>	INCA-P simulates the water flow in three different compartments, as direct runoff, soil water and groundwater, based on HER (hydrological effective runoff) as the main input data. In the river a linear-reservoir routing method, modified by lateral inflow, calculates the water flow. The land-phase P-model simulates the P-transformations and stores in the soil and groundwater based on a bio-geo-chemical	<p>Non-steady run-off processes can be simulated from the precipitation time series.</p> <p>The physical processes associated with water movement, crop growth, nutrient cycling, etc. are directly modelled by built-up equations.</p> <p>The simulation process can be divided for two main components: (i) land-phase, (ii) routing phase (in-stream).</p> <p>Both parts have complex hydrological, sediment and nutrient/pesticide</p>

Characteristics/ aspects considered	Description	Source apportionment (SA)	TEOTIL	INCA-P	SWAT
				<p>description. The in-stream P-model calculates the dilution and P-transformation, and if applied, the corresponding algal, epiphyte and macrophyte growth response.</p> <p>For further details, see Wade et al., 2002.</p>	<p>processes. Some options can be further selected in simulation setup:</p> <ul style="list-style-type: none"> - rainfall/runoff/routing method; - rainfall distribution (<i>skewed normal or mixed exponential</i>); - potential ET method (<i>Priestly-Taylor, Penman-Monteith, Hargreaves or read-in</i>); - channel water routing (<i>variable storage or Muskingum</i>) method. <p>Detailed description about processes is available in Neitsch et al., 2002.</p>
<p>How well can the output variables be related to the specific management issues?</p>	<p>Are the results produced by the model directly comparable with the environmental goals given by the managers/authorities?</p>	<p>Annual sum of diffuse losses in water and annual agricultural losses are calculated based on riverine monitoring data which then determines the output variables.</p>	<p>The model was developed for total phosphorus and total nitrogen. The results were yearly water discharges, loads and concentrations. The results were calculated for each of the source types (industry, municipal waste water, diffuse agricultural sources).</p>	<p>Concentrations of TotP and SRP are, together with flow, the most important outputs. Based on these outputs, also the load can be calculated.</p> <p>The model also calculates the fluxes of water out of the direct runoff, soil water and groundwater compartments. INCA-P calculates the</p>	<p>A number of output files are generated in every SWAT simulation:</p> <ul style="list-style-type: none"> - summary output file; - HRU output file; - sub-basin output file; - main channel or reach output file; - reservoir output file. <p>Depending on the print code selected (<i>in the input control code file</i>), the</p>

Characteristics/ aspects considered	Description	Source apportionment (SA)	TEOTIL	INCA-P	SWAT
				<p>concentration of P in the land phase and in the sediments in the river reaches, the grain size of the sediments, and some biomass variables, if the these processes are “switched on” during the calculation.</p>	<p>output files may include all daily values, daily amounts averaged over the month, daily values averaged over the year, or daily amounts averaged over the entire simulation period. The output files contain amounts of the water balance components, sediment, chemical and biological components and the different nutrient forms. Detailed description about processes and putput is available in the Users’ Manual (Neitsch et al., 2002).</p>
<p>Handling of relevant management scenarios</p>	<p>What type of management scenarios/measures (mitigative measures like changed agricultural practise, buffer strips, climate changes, etc) can be simulated directly or indirectly?</p> <p>See also sections 3.5, 4.4, 5.5, 6.4, 7.2.2 and 7.3.3.</p>	<p>None. See also section 3.5.</p>	<p>Scenarios can be modelled by changing the sources, such as one specific source, all sources of a specific type, the sources in particular regions and changed water discharge.</p> <p>See also sections 4.4, 7.2.2 and 7.3.3.</p>	<p>INCA-P seems to handle area-type of measurer (changes in fertiliser application, land use within sub-catchments, some management practises like sowing/harvest time, etc) appropriately. Reduction in point sources can also be simulated, but measures that needs to be defined with a very precise</p>	<p>Handling of management scenarios depends on the required data input. Some is easy by using a built-in text editor (e.g. fertiliser loads), but others are much more difficult, because the user might have to go back to an earlier model-building phase (e.g. forest and agricultural area changing requires to go back to</p>

Characteristics/ aspects considered	Description	Source apportionment (SA)	TEOTIL	INCA-P	SWAT
				<p>location or a very limited area extent (such as change of the outlet of a point source within the same sub-catchment, establishment of border vegetation, sedimentation, ponds) cannot be handled directly.</p> <p>See also sections 5.5, 7.2.2 and 7.3.3.</p>	<p>watershed delineation process).</p> <p>See also sections 6.4, 7.2.2 and 7.3.3.</p>
Model documentation	Is the available documentation sufficient for setting up the model? Is other type of user support available?	Only a concept equation is available.	No manual exist. The model builder software is rather self explanatory. It should be sufficient to study an example before starting on your own.	<p>The model structure and equations are published in Wade et al. 2002. A dedicated user manual of the system is also available. The version used during the modelling in Kapos, dated August 2004, is still missing some information and is not completely synchronised with the version 1.4.6 used as the modelling tool.</p> <p>The developers have been available for questions via e-mail.</p>	<p>The model is well documented by developers and the Manuals about AVSWAT2000 (<i>Theoretical Documentation, User's Manual and User's Guide, Neitsch et al., 2002</i>) are downloadable from the official web site of the SWAT Team.</p> <p>Users can visit the official public web site of SWAT Forum to help each other (http://www.brc.tamus.edu/swat/userforums.html).</p> <p>The developers have also been available for urgent questions via e-mail.</p>

Characteristics/ aspects considered	Description	Source apportionment (SA)	TEOTIL	INCA-P	SWAT
Connection to other tools for model linking, presentation, analysis	Can the results easily be exported to other tools (MS Excel, GIS, statistical tools, etc) for further analysis? Does the model produce output to ascii-files? Can the model be linked to calculation models? Similarly, does the model accept input provided by MS Excel, ArcView?	No ready-made connections.	<p>The data files and result files are text files. The files are easy to export into Excel</p> <p>The model is linked to ArcView. Special scripts in ArcView are written for preparation of the input data and for presentation of the results on digital maps.</p>	<p>INCA-P produces the output as timeseries dumped to text files, which are easy to open and further processing in MS Excel. However, some manual reformatting is sometimes necessary due to problems with the tab-formatting of the text files.</p> <p>There is no easy way of linking input or output data to/from INCA-P to external GIS-tools like ArcView/ArcGIS.</p>	<p>SWAT produces the output primarily in .txt (<i>ASCII</i>) files or can be loaded into dBASE tables in case of yearly/monthly print out frequency. AVSWAT2000 has an ArcView interface, consequently it is possible to display results on maps and graphs (<i>with Map-Chart built-in tool</i>).</p> <p>It was difficult to extract required time series from output files during calibration for years based on daily print out frequency, therefore it was necessary to develop some special 'data-mining' scripts (<i>Excel and Delphi macros</i>).</p>
Costs of setting up the model (for a similar catchment as Kapos).	Quantify the costs and resources utilised in setting up the model, in terms of person-time, purchase of software.	A simple model can be built in a few days.	Most of the time is usually needed to prepare the data. The actual setup of the model with the prepared data can be done during a couple of days.	2-3 weeks for a trained person as soon as all the data (quality-checked) is available. No costs of purchasing software.	If data is prepared in the right format, the data input requires 4-5 weeks. The most time consuming operation is the watershed delineation, because it is an iterative process based on DEM, where the optimum number of sub-basins and HRU

Characteristics/ aspects considered	Description	Source apportionment (SA)	TEOTIL	INCA-P	SWAT
					distribution has to be set by the user. The software can be free of charge downloaded from the official web site of the SWAT Team: http://www.brc.tamus.edu/swat/soft_model.html
Uncertainty/sensitivity	Are there any built-in capabilities to support these types of analysis?	Uncertainty/sensitivity analysis are not supported.	There are no built-in tools to automatically run uncertainty/sensitivity analysis, and each model parameters must be changed manually one by one.	There are no built-in tools to automatically run uncertainty/sensitivity analysis, and each model parameter must be changed manually one by one. Adjusting model parameters, running a new simulation, inspecting and storing the new results are extremely time-consuming activities if performed for a large set of parameter values and in applications with limited resources.	There is built-in calibration tool in SWAT to analyse uncertainty/sensitivity of the model. However, it can work only using the same changes for the entire watershed. Therefore the different parameter adjusting in case of each drainage area (or smaller hydrologic unit) needs to be done manually. In case of such a large watershed as the Kapos catchment, it is quite time consuming.

7.2 Comparison by performance

7.2.1 Calibration results

The four different tools applied for the quantification of the nutrient losses have produced a vast amount of output. The results presented in the previous sections (especially for INCA-P and SWAT) are only sub-sets of the output the models have generated. To make a comparison of the different models/approaches a selection of ‘what’ and ‘in which way’ to compare and present must be made. The rationale behind this selection is presented in the following.

Selection of component/nutrient fraction: Some of the models produce a large number of output variables. The most common output variables are flow and concentrations of NO_3N , NH_4N , TotN, SRP/ PO_4P and TotP (see details in each section). Loads of the different nutrient fractions can be calculated, either internally by the model or externally in for example MS Excel, based on flow and concentration figures. The most interesting component when analysing ecological conditions in freshwaters is the load of TotP, beside the directly biological available phosphorus (SRP/ PO_4P). To include as many tools as possible and to avoid potential errors due to wrong interpretation of P-fractions, the load of TotP is selected for model comparison purposes.

Selection of time resolution and period: INCA-P and SWAT both produced outputs on daily basis, while the Source Apportionment (SA) and TEOTIL produced results on annual basis. When eutrophication is the problem to be studied, seasonal and monthly data, if available, are required. Since a disaggregation of the results of SA and TEOTIL should be avoided, as this does not provide additional insight to the dynamics of the catchment, annual results are compared. The results are analysed and compared primarily for those years covered by all quantification approaches.

Selection of location: The most downstream location with observations, Pincehely, is selected as the location of comparison since it integrates the very most of the catchment (given as location 9 in the INCA-P setup).

Statistical method: The results are simply compared by the deviation from the observed load in tonnes TotP/year, see table 7.2 and figure 7.1. Note that ‘observed’ does not necessarily need to be correct. There may be errors in the measurements and the extrapolation/interpolation of TotP-concentrations in time introduces uncertainty. Also note that the observed loads and the presented Source Apportionment loads are equal. This is due to the fact that the Source Apportionment method calculates the diffuse losses directly from the observed loads as a difference between total load and point source load.

Table 7.2. Comparison of annual load of TotP [tonnes/year] at the location Pincehely, close to the outlet of the Kapos catchment. Empty cells indicate that the model is not calibrated for these years, i.e. the models are calibrated for different time periods.

Year/ quantification method	Observed	Source Apportion- ment	TEOTIL	INCA-P	SWAT
1993			185.1		
1994			195.6		
1995	154.8	154.8	218.4		
1996	265.3	265.3	230.9		
1997	100.6	100.6	162.6	110.1	
1998	221.6	221.6	269.4	125.2	58.0
1999	376.7	376.7	368.4	118.3	114.0
2000	115.3	115.3	141.5	123.7	87.6
2001	168.1	168.1	170.9	104.2	79.9
2002	96.1		163.7	103.5	71.0
2003			140.4	106.2	78.3

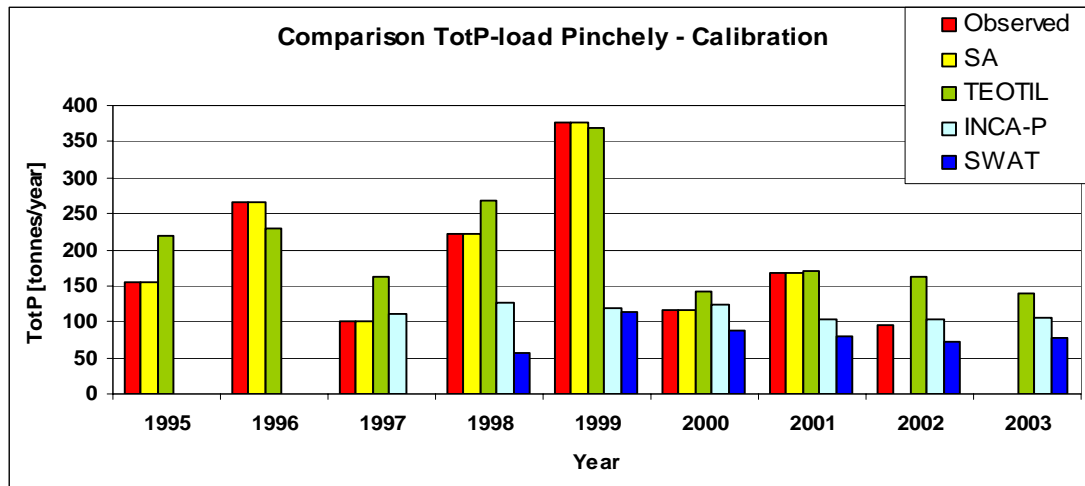


Figure 7.1. Comparison of the annual load of TotP calculated by the four different quantification methods and ‘observed/measured’ load at Pincehely (close to the outlet of Kapos).

7.2.2 Scenario results

The AQUAPOL partners agreed on a set of scenarios to analyse the models’ capability of simulating realistic management options. These scenarios are to a large extent based on scenarios that have been defined in the EUROHARP project (Vagstad and French, 2005). The scenarios are the same as in EUROHARP, except that scenario G is added from the EUROHARP protocol. The scenarios are as follows:

- 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
- G 20 % decrease of point source loads (added from EUROHARP-protocol)

None of the four models were capable of running all scenarios, due to limitation in the concept of the model/quantification tool, inappropriate model structure or simplifications in process descriptions. However, the scenarios and models marked with a ‘X’ in table 7.3 were run. Based on the arguments stated above, the scenario results are compared with the use of TotP-load on annual basis for the whole simulation period, see Figures 7.2-7.7. The outlet of the catchment (Pincehely) is again selected as the location for comparison.

Table 7.3. Overview of which scenarios for run by which models. The Xs indicate that this combination of quantification tool and scenario was run. Empty cells mean that these scenarios could not be handled by the given model.

Quantification method/ Scenario	Source Apportionment (SA)	TEOTIL	INCA-P	SWAT
A			X	X
B			X	X
C			X	X
D			X	X
E				
F		X	X	
G		X	X	X

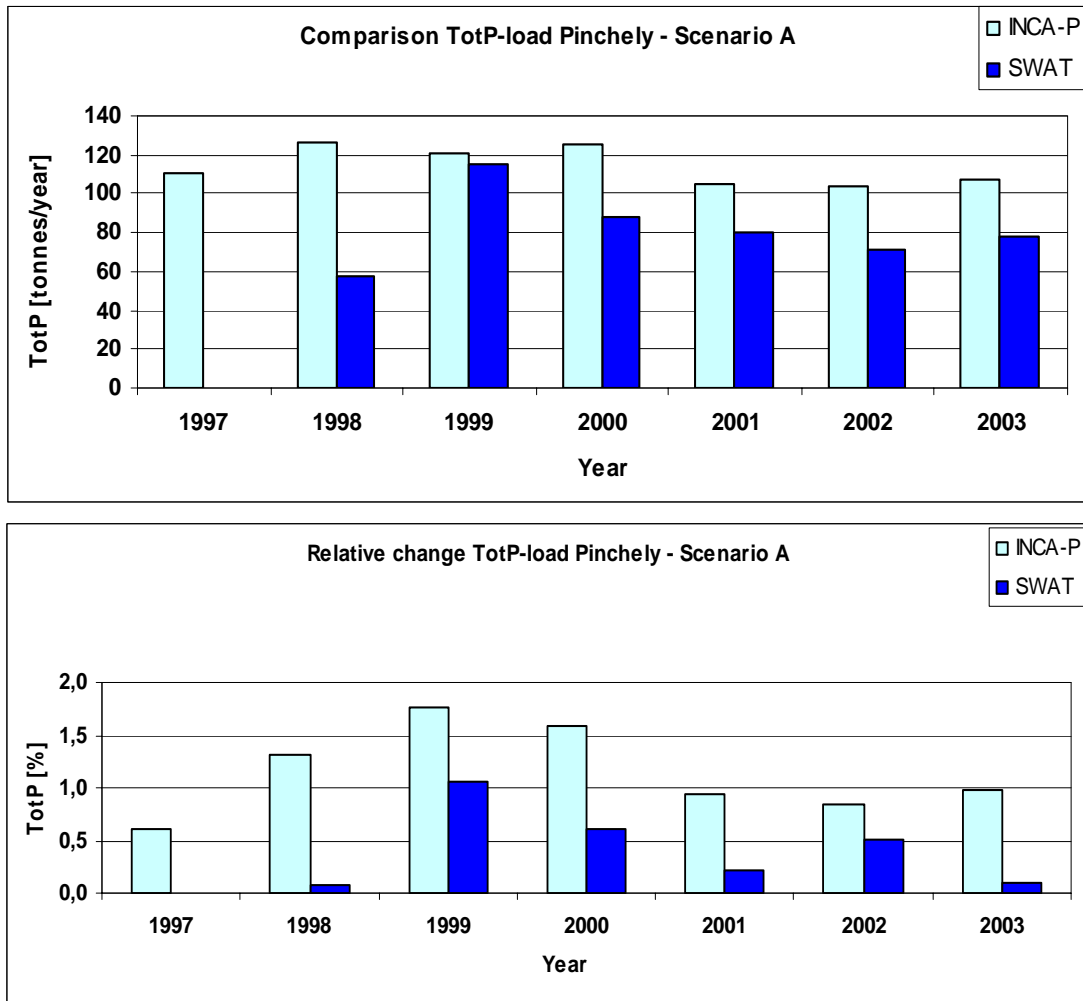


Figure 7.2. Comparison of the annual load of TotP at Pinchely (close to the outlet of Kapos), given scenario A, calculated by two different quantification methods. The upper part shows absolute values, while the lower part shows the relative change from the calibration.

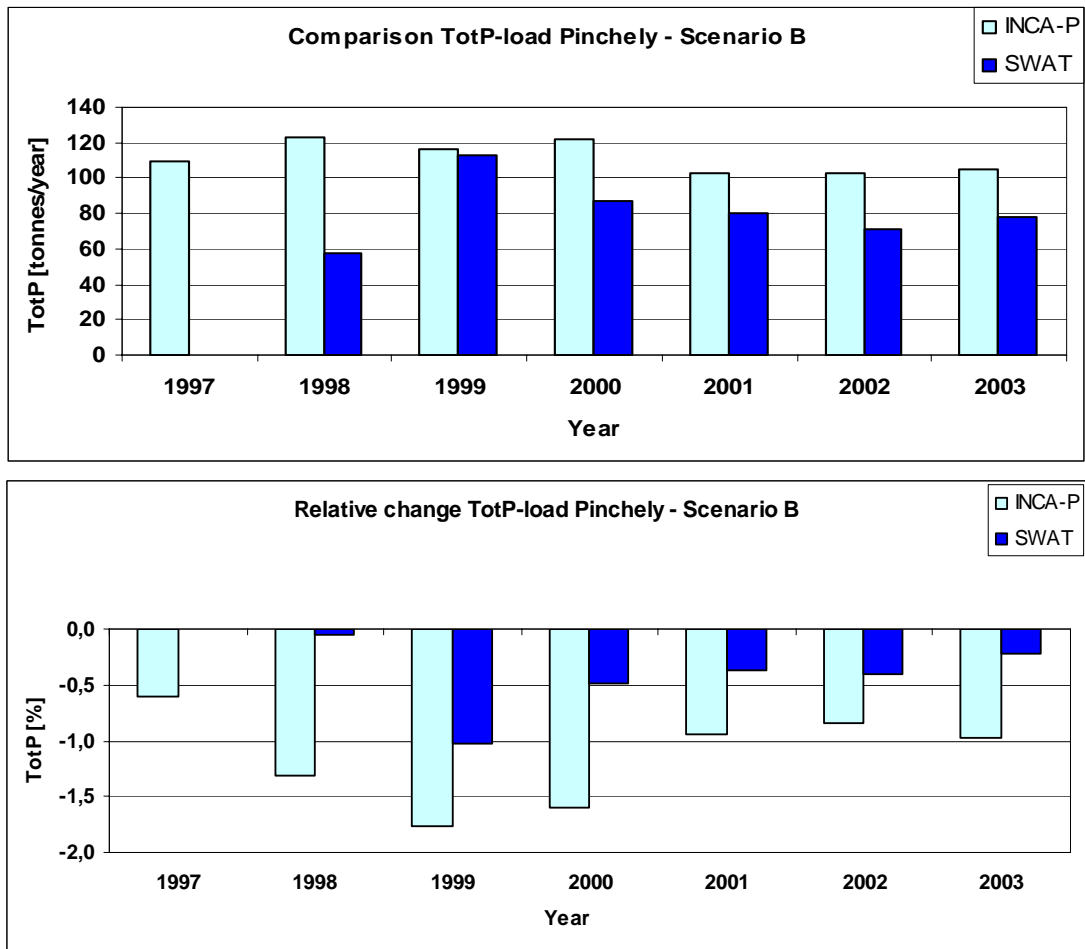


Figure 7.3. Comparison of the annual load of TotP at Pinchely (close to the outlet of Kapos), given scenario B, calculated by two different quantification methods. The upper part shows absolute values, while the lower part shows the relative change from the calibration.

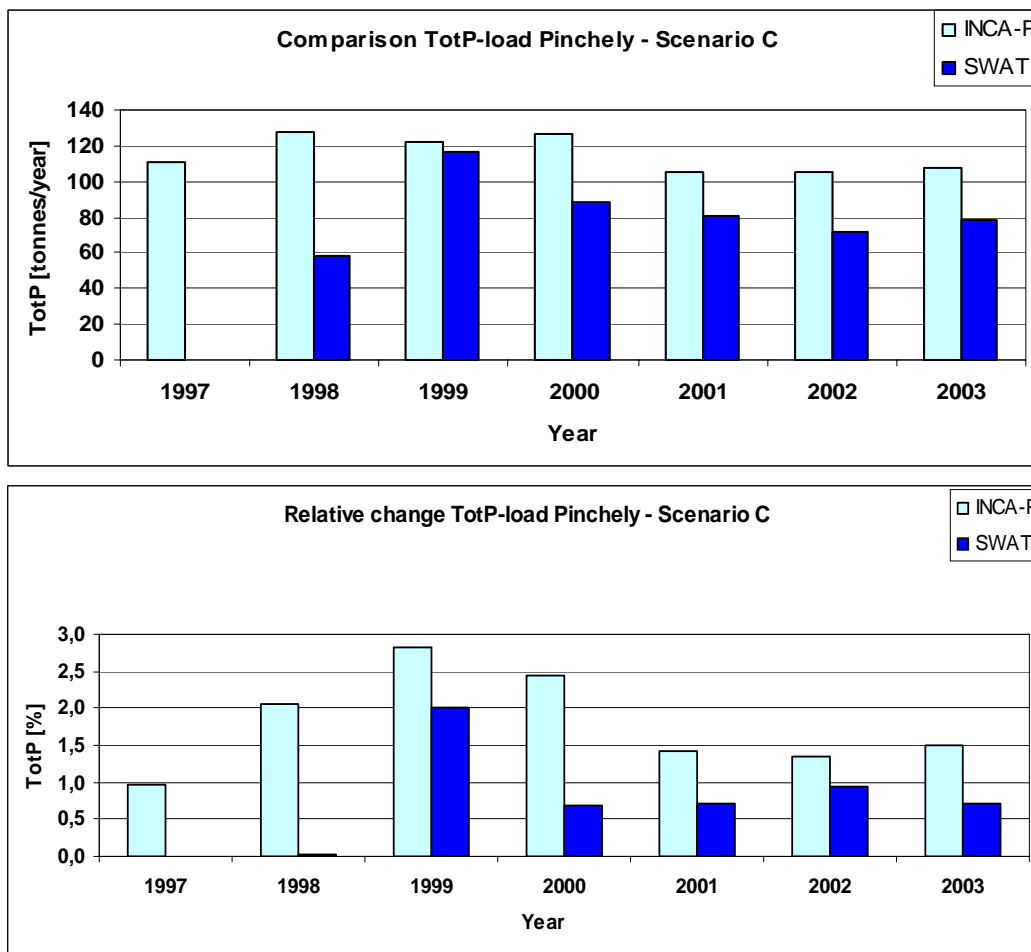


Figure 7.4. Comparison of the annual load of TotP at Pinchely (close to the outlet of Kapos), given scenario C, calculated by two different quantification methods. The upper part shows absolute values, while the lower part shows the relative change from the calibration.

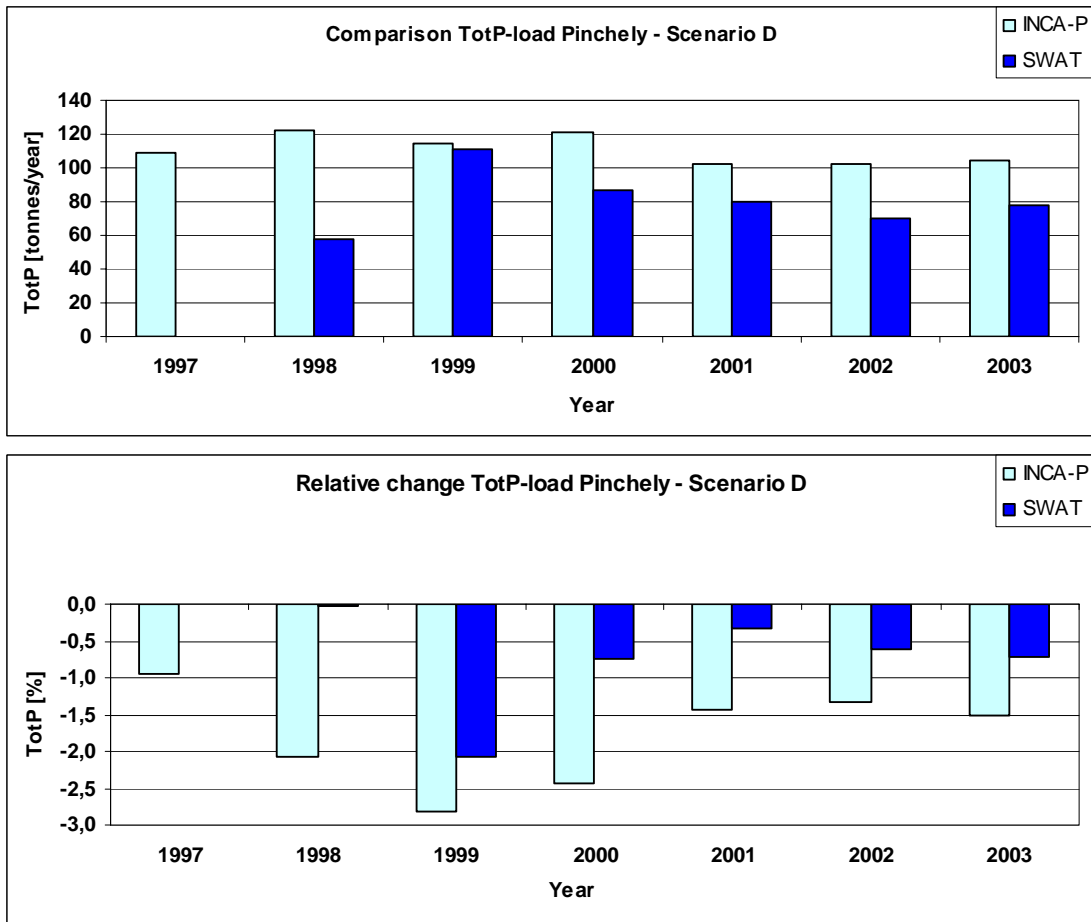


Figure 7.5. Comparison of the annual load of TotP at Pinchely (close to the outlet of Kapos), given scenario D, calculated by two different quantification methods. The upper part shows absolute values, while the lower part shows the relative change from the calibration.

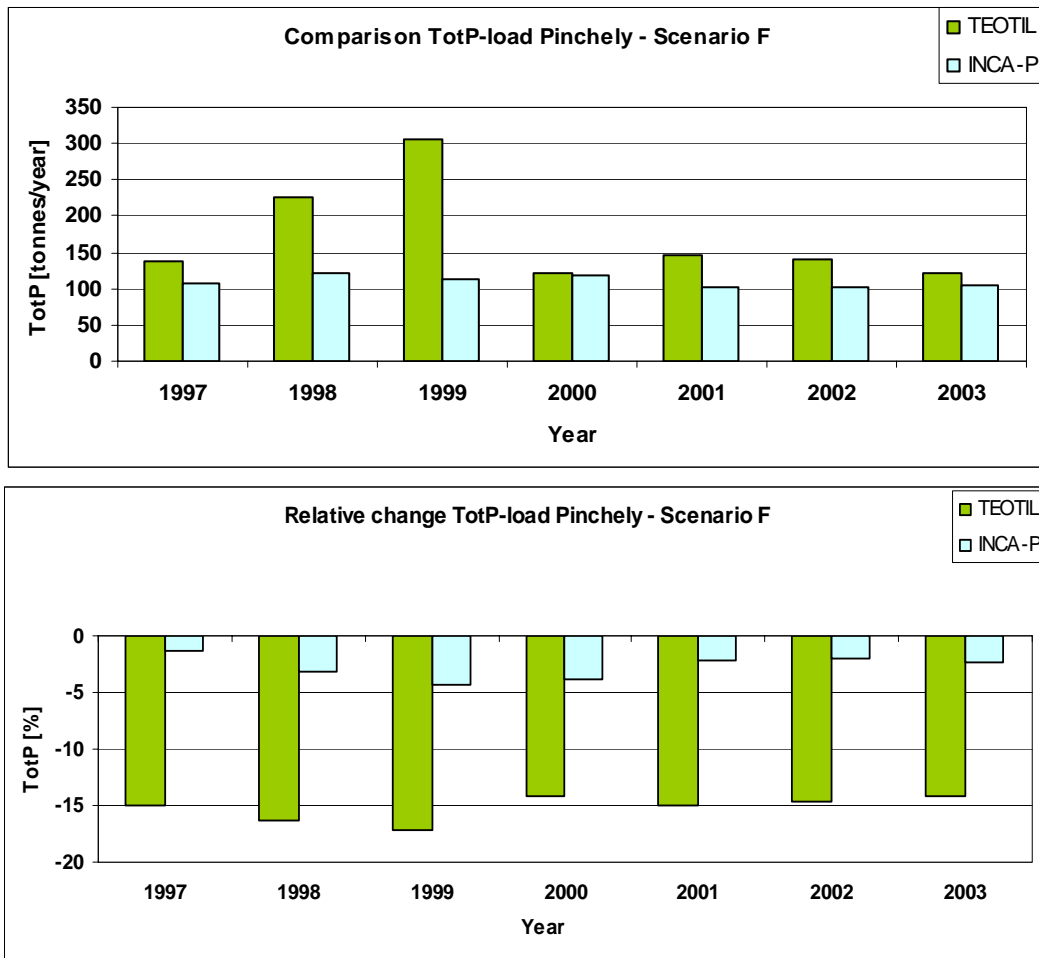


Figure 7.6. Comparison of the annual load of TotP at Pinchely (close to the outlet of Kapos), given scenario F, calculated by two different quantification methods. The upper part shows absolute values, while the lower part shows the relative change from the calibration.

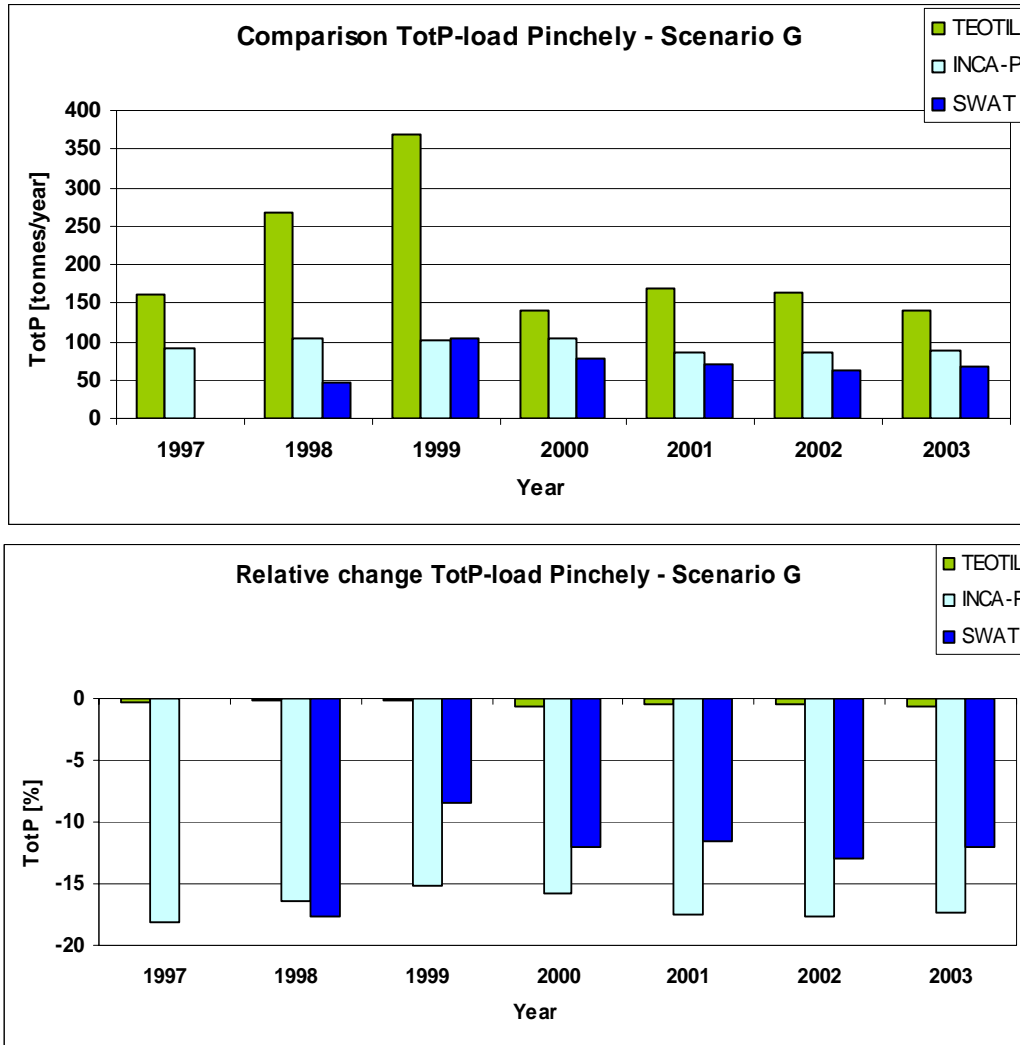


Figure 7.7. Comparison of the annual load of TotP at Pincehely (close to the outlet of Kapos), given scenario G, calculated by three different quantification methods. The upper part shows absolute values, while the lower part shows the relative change from the calibration.

Table 7.3. Comparison of annual load of TotP [tonnes/year], given scenario G (20 % decrease in N and P discharges by the point pollution sources) at the location Pincehely (outlet of section/sub-catchment 9), close to the outlet of the Kapos catchment.

Year/ quantification method	TEOTIL	INCA-P	SWAT
1993	184.6	NA	NA
1994	195.1	NA	NA
1995	217.8	NA	NA
1996	230.4	NA	NA
1997	162.0	90.2	NA
1998	268.8	104.7	47.8
1999	367.7	100.3	104.4
2000	140.6	104.1	77.1
2001	170.0	86.0	70.7
2002	162.8	85.2	61.8
2003	139.7	87.7	68.8

7.3 Discussion

7.3.1 Characteristics

Table 7.1 shows the methods/models ranged from very to simple to very complex in the order they are listed. This is reflected in almost all modelling aspects discussed, including the data requirements, handling of temporal resolution and span, embedded process description and capability of simulating management scenarios.

The data requirements of the tools presented in table 7.1 range from very low (SA), low (TEOTIL), moderately (INCA-P) to very extensive (SWAT). The differences in data requirements imply that much more resources are needed to the setup of SWAT than the simpler approaches. Since the number of parameters to be calibrated is also higher, this model would generally need more resources to be appropriately calibrated. TEOTIL and INCA-P are more similar in terms of data requirements. The main difference is that INCA-P needs data on fertiliser application (amount, timing), plant uptake and soil parameters for the six different land use categories.

SWAT and INCA-P run on daily time step, while the Source Apportionment (SA) and TEOTIL usually are run on annual values, even though TEOTIL can simulate also on finer time resolutions. This means that INCA-P and SWAT, at least theoretically, can provide results on a more detailed time scale and different types of analysis can be supported with model results. It should be underlined that the use of the results will determine the requirements of the time resolution and need for results on daily basis are often exaggerated or 'out of scope'. For biological assessment purposes, results on monthly basis are often sufficient. Computations of output with daily time step can require extensive computer resources, but this study proved that there are no problems with computing time that would disqualify any of the tested tools in the calculation of long-term trends in water quality.

The spatial resolution is, for all methods/models, first of all dependent on the spatial resolution of the input data and the time to be dedicated of calibrating the tool on each sub-unit of the total catchment. It is a limitation in INCA-P that it does not handle a branched system unless each branch is aggregated into one unit.

The three aspects "process description", "handling of scenarios" and "output variables related to management" are very closely related. Basically, the relevant processes must be described if the model shall be able to handle management scenarios, but this is still no guarantee. In the case of SWAT, handling of scenario F (20% of the agricultural area are abandoned and replaced by forest) would require a complete restructuring of the model (including re-calibration), which was too labour-intensive for the purpose of this project. In this model testing project, the SA approach was not capable of simulating any scenarios. However, it should potentially be able to handle some of the scenarios (potentially scenarios F and G) if the calibration had succeeded, despite its very simplified approach. TEOTIL is capable of handling scenarios F and G easily (20 % of the agricultural areas are abandoned and replaced by forestry, and 20 % decrease of point source loads). INCA-P can handle these scenarios easily as well, by just multiplying the existing input by the desired reduction factor. Furthermore, INCA-P has limitations in the manner that it handles only phosphorus processes, while for instance SWAT is capable of simulating nitrogen and organic carbon. It is, however, foreseen that INCA will be able to handle N, C and P in the future within one and the same shell. As a separate model, INCA-N has already been available and used for several years. All tools in the AQUAPOL-project seem to provide the output variables that are directly applicable for the management of the water resources, as TotP is considered the most important output related to catchment-based management of eutrophication.

The user documentation of all methods/models could be improved. It is very limited for both SA and TEOTIL, but as they are simple tools and the TEOTIL-developers provided sufficient support, the tools could be easily applied in the Kapos catchment. The INCA-P documentation was in principle sufficient, but guidance provided from an experienced INCA-N user was very valuable as an extra source of information. The same was the case for SWAT. The existing SWAT manual is very extensive, but still some parameter descriptions are weakly described; therefore, the help from experienced SWAT users was necessary.

The connection to external tools for further processing is for all methods/models sufficient, (except for some of the data extraction routines of SWAT, see section 6.5), as results can be exported. The possibilities for map presentations of TEOTIL results are very impressive, as it is built-into ArcView/ArcGIS. Similarly, the map presentation of SWAT results is available, but only one parameter and one time-step (or average values) can be presented on a map. The data input of SWAT is strongly based on GIS techniques that helps significantly the model setup. The seamless communication with these GIS-tools is also strengthened when map-based input data should be prepared for the models.

The use of four nutrient quantification tools in the Kapos catchment was very much a learning process for all the modellers involved, but the integration of Hungarian and Norwegian experts and expertise proved valuable and in line with project objectives. Setting up the tools for the first time required extra time in the collection and formatting of the data, and for the calibration. Manual calibration was very much a question about 'a feeling' of the sensitivity of the different parameters, as tools for systematic sensitivity analysis were not available. Future applications of the tools are expected to be much quicker than the application in the Kapos catchment.

It was very quick to calibrate both SA and TEOTIL as soon as the data were organised in the appropriate format, and also quick to run scenarios with TEOTIL. INCA-P needed more resources to be appropriately calibrated than SA and TEOTIL. At the current stage, the calibration of the hydrological modules of INCA-P is labour-intensive, but this is expected to be improved in the close future as there is on-going development work on this issue. SWAT represents another shift in the demand of labour-time as the model needed a large amount of data and the calibration was very time-consuming. Another challenge of running SWAT 2000 appropriately was the extraction of results from the occasionally gigantic output files.

None of the tools are strong on analysing model sensitivity/uncertainty, even though SWAT provides some possibilities when the user wants to apply uniform and global changes in model parameters.

7.3.2 Performance

The results selected for comparison represent a very small sub-set of the total results produced. Especially INCA-P and SWAT produce an extensive amount of outputs (daily time step) and a selection of output to use for comparison had to be made. The rationale for the selection of this sub-set of data for comparison is given in section 7.2.1.

Results in table 7.2 and figure 7.1 are somewhat misleading, because the methodology of the Source Apportionment (SA) is quite the opposite of any other models. It means that the bases of the calculations are the observed amounts instream, and the diffuse losses are calculated from the known, observed information (back-tracking). The SA-method can be considered as a 'black box'-model, because no physical processes are considered. Since the SA approach applied in the Kapos catchment provided unrealistic results for the diffuse pollution sources, it was concluded that this method is not applicable for phosphorus with the sets of data available from the Kapos catchment.

TEOTIL performs well for most years of calibration. TEOTIL can also be considered as a black box model, meaning that the in-field processes are not described, and the in-stream processes are described only to a limited extent. Transformation and sedimentation in the water bodies and on the fields are lumped into export coefficients. Based on this approach, the parameters can more or less freely be calibrated, within the range of possible minimum and maximum values. A powerful Monte Carlo method for optimising the model output was applied in this project, and the model output fitted the observations well for most years. TEOTIL overestimated the TotP-load all years, except the two years with highest loads (1996, 1999). TEOTIL overestimated the load by 70 % the year with the lowest load (2002), and underestimated the load by only 13 % the year with the highest load (1999). The results from the scenario testing indicate that the importance of point sources on the load is underestimated by the model (see more details in section 7.3.3) when compared to the results of INCA-P and SWAT.

INCA-P underestimated the TotP-load significantly those years with high load (1998 and 1999), but performed well the other years. Possible reasons for the deviation are limitations on the hydrological routines and no land surface erosion calculations (see further details in sections 5.4.2 and 5.6). It should be noted that the INCA-P calculation of SRP, which is an important P-fraction related to algae growth, shows good correlation with the observations. SWAT underestimated the load all years, including the years with low Tot-P load. SWAT performed slightly better than INCA-P only in 1999, a year with still a large deviation between the observations and the calculated loads. Although it seems that INCA-P performs better than SWAT (for TotP) given the performance criteria above, there were also minor methodological differences in gaining the measured sediment and nutrient loads during the calibration.

Sections 3.4, 4.5, 5.5 and 6.5 describe the individual model/method applications and provide the basis for a further and deeper interpretation of the model results. It should again be noted that only a small sub-set of the results (annual load of TotP at Pincehely) are discussed in section 7.2. SA, TEOTIL and SWAT also calculate load of TotN, and SWAT calculates several other N-fractions as well (NH_4N , NO_2N and NO_3N).

Furthermore, the modelling results might be biased by errors in the input and the calibration data. There may errors in both the point source discharge data, which are probably overestimated in the upper parts (in the Kaposvár area); and the spatial distribution of fertilised areas and fertiliser timing, which are based on expert judgement. Details about possible errors in the input data are discussed in earlier sections (i.e. 5.4.1, 5.4.2, 6.3.2 and 6.5).

7.3.3 Scenarios

INCA-P and SWAT are the only models that are able to perform scenarios A and B (figures 7.2 and 7.3). The results from the simulations of these scenarios show that INCA-P is more sensitive to changes in application of inorganic fertiliser than SWAT, meaning that a change in fertiliser application in INCA-P causes a larger effect on the simulated load than SWAT. A significant change in inorganic fertiliser application (± 20 %) causes a relatively small effect on the nutrient load, from approximately 1.7 % as the maximum (INCA-P in 1999) to almost 0 % (SWAT in 2003). SWAT shows little effect in load the first year (1998), but this is to a large extent explained from problems with the 'filling-up phenomena' (see section 6.3.2).

Scenarios C and D show (see figures 7.4 and 7.5) to a large extent the same pattern as scenarios A and B. INCA-P is again more sensitive to changes than SWAT, and the maximum change (in percent) can be seen for INCA-P in 1999, where the increase in load is

approximately 2.8 % compared to the calibration run. As a minimum, SWAT simulates an increase on approximately only 0.7 % in 2000 and 2001. The change in load in year 1998 is by SWAT simulated to close to 0 %, which again is explained from the ‘filling-up phenomena’. Comparing scenarios C and D with A and B, it can be seen that a 20 % change in organic fertiliser application (C and D) causes a bigger change in load than a similar (20 %) change in inorganic fertiliser application. Only INCA-P and SWAT were capable of simulating scenarios C and D.

None of the four quantification tools were able to simulate scenario E (Area of the predominant crop increases to cover the entire agricultural land) without extensive restructuring the models. This means that analysis of such types of measures could not be analysed if an abatement strategy for the Kapos catchment were to be developed.

Scenario F (20% of the agricultural area are abandoned and replaced by forestry) were simulated by TEOTIL and INCA-P (see figure 7.6), and the results show a significant difference between these tools. TEOTIL considers the agricultural land to be a much more dominant pollution sources than INCA-P. The reduction in loads from replacing agricultural land with forest is much larger with TEOTIL than with INCA-P. A 20 % reduction in agricultural land is by TEOTIL calculated to give a reduction in load on approximately 15 % (average for the whole period).

Scenario G is defined by a 20 % reduction in point sources (effluent from waste water treatment plants and industries, scattered dwellings) and is simulated by TEOTIL, INCA-P and SWAT. According to TEOTIL, the change in load from such a scenario is very small and less than 0.5 % almost all the years in the calculation period. On the other extreme, INCA-P is very sensitive to changes in point pollution sources. The same reduction in the input data gives a reduction in P-load at Pincehely of approximately 17 %, which means that INCA-P considers point pollution sources to be the dominant sources in the Kapos catchment. SWAT is also sensitive to changes in the point pollution input data, but less extreme than INCA-P. Without considering 1998 (‘filling-up phenomena’), the average reduction in TotP-load at Pincehely, given scenario G, is 11.4 % when simulated by SWAT.

One reason why the INCA-P output is very sensitive to changes in point pollution sources is that the effluent time series (point sources/scattered dwellings) are added/linked directly to the river system without any prior local retention. This probably overestimates the point sources load entering the main water bodies. This touches the dilemma of spatial scale and resolution in river basin models. Incorporating the whole catchment area in one model setup might lead to imprecise representation of local-scale processes. This can for instance be the case with the discharges from both the scattered dwellings and the WWTP effluents. Also small fish ponds might have significant impact on the phosphorus transport in the catchment as they might work as sediment traps, but can hardly be represented individually as their spatial extents are so small compared to the size of the catchment.

8. Conclusions and recommendations

Saloranta et al. (2003) concluded that the selection of appropriate modelling/quantification tools is highly case specific, depending on issues such as:

- Purpose of modelling study (i.e. of a 'screening' of the historical loads are to be produced, if management scenarios are to be analysed, requirements of the spatial and temporal resolution of the output, etc.)
- Availability of data (i.e. which data and at what temporal and spatial resolution, density of the monitoring network, etc.)
- Availability of resources for modelling (i.e. how much time can be invested in setting up and running the model)

These can be considered as obvious conclusions, but are still often neglected when a new modelling study is launched. Based on the statements above, it can also be concluded that it is not possible to appoint 'the best model' since all the given aspects, and more, must be considered prior to the selection of which model to apply. Hutchins et al. (2005) provides guidelines for such a process of selecting a potentially appropriate model candidate.

Within the EUROHARP project one important success factor for modelling is also linked to the skills and experiences of the modellers of using that specific model. The same model data, same model and same time allocation can provide considerably different results depending on who performs the modelling.

The Kapos catchment is considered being representative for Hungarian catchments, with respect to types of problems (eutrophication) and data availability/quality, viewed in the context of the EU WFD. The types of mitigation measures that are relevant in the Kapos catchment and analysed in this project are also considered being relevant in other Hungarian catchments. This means that the findings of the AQUAPOL-project in the Kapos catchment should be transferable to other catchments in Hungary. However, none of the models could provide individual results for each water body (river section, reservoir, lake), since the model schematisations follow the boundaries of the sub-catchments, which are larger units than each water body.

From the application of the **Source Apportionment (SA)** method it can be concluded that in the case of nitrogen, the results are acceptable when compared with the measured data. In the case of phosphorus, this calculation method does not work properly, even though the results from one of the locations (Törökkoppány) seem realistic. In the case of all other locations, the load from agricultural areas is negative. In reality, it is more likely that agriculture is one of the main nutrient sources in the Kapos catchment. It is not clear why SA fails for phosphorus, but seems to work fine for nitrogen. It should therefore be further analysed why SA fails in the Kapos catchment before the SA can be applied for management purpose in the catchment. SA can handle simple analysis of management scenarios, if the model is well calibrated.

The overall conclusion from the **TEOTIL** application is that the model was found to be a simple, but very useful tool that uses easily available information and data. The model is easy to understand and use, it does not require huge PC resources to store data and run the model. It provides quick and acceptable results (trends, magnitudes). TEOTIL handles both TotN and TotP as long as input data (point sources discharges and diffuse losses) is available on both parameters. The model operates, in principle, on the same temporal and spatial resolutions as the input data are available in, but is typically configured to run on annual data (possible

monthly if load discharge/loss data is available on monthly basis) and spatially on sub-catchment level. TEOTIL is limited in terms of handling scenarios. Only scenarios F and G could be simulated, because the input dataset of TEOTIL does not contain parameters that reflect the changes proposed in scenarios A-D. There are some technical improvements that would make the tool more useful and user-friendly, such as simultaneous simulation of several years and parameters, improved routines for data preparation, and improved handling of building user-defined functions/equations. Despite these shortcomings, TEOTIL can be recommended as a useful and efficient screening tool in river basin analysis and the implementation of the EU WFD in Hungary.

INCA-P is a promising ‘newcomer’ in the calculation of P-concentrations and loads at catchment scale, despite its limited success in the calculation of TotP-loads in the Kapos catchment. The main reason for this is that the land surface erosion is not properly handled, which then significantly underestimate the TotP-load. The simulation of SRP is much better, and the results are definitely within an acceptable range. The hydrological peaks are also underestimated, which also adds to the deviation between observed and simulated loads. The model is expected to be improved on these issues, and new versions will probably be ready for testing later this year. INCA-P is a semi-complex model, which makes the model fairly easy to understand and use, and it matches the available data and information well. INCA-P handled the simulations of all scenarios well, except for scenario E, and without any time-consuming restructuring of the model. This indicates that it can be a very interesting tool for management purposes. Updated versions of INCA-P would be a powerful, but still not very resources-demanding, tool during the implementation of the EU WFD in catchments highly influenced by agricultural activities.

SWAT is a very comprehensive and sophisticated tool to study the runoff of nitrogen and phosphorus from agricultural land. The model can be used to simulate the effects on the water quality from changes in land use and cultivation practice. The main drawback of SWAT is that it is very time- and resources consuming to apply the model in a new catchment, because the data requirements are very extensive and the calibration process is complex. It can take several weeks and months setting the model up on a new catchment (will depend on the skills and experiences of the modellers), which can disqualify the model unless necessary resources are available for the modelling tasks. The model produces several N and P-fractions as output. This can be important and useful when abatement measures are proposed, and when the user wants to analyse internal processes (P and N-transport and transformation). SWAT handled easily most of the defined scenarios in the AQUAPOL project, except for scenario F that would have needed a somewhat significant restructuring of the model setup. SWAT has a very good reputation and high credibility among researchers and managers in Europe.

The four tools applied in AQUAPOL-project can to some extent also be considered complementary. **The simpler tools (SA, TEOTIL)** can work as ‘screening tools’ to provide an overview of the pollution situation in a catchment. In an initial phase of a study, the simpler tools can be used to identify (i) the main pollution sources, (ii) which parts of the catchments have the most important problems and (iii) those parts that can be left out for further investigations (‘not at risk’, according to the WFD-terminology). For more detailed studies where a deeper insight in processes determining the origin and fate of the nutrients and analysis of mitigative measures are required, more **comprehensive tools (INCA-P, SWAT)** can be applied, either on the whole catchment or on smaller ‘problem areas’.

Finally, based on experience, the importance of quality checking of data prior to starting the modelling activities (calibration and scenario simulation) should be emphasised. The more complex model, the more extensive data requirements and the more resources must be invested in the data checking. Despite the effort of the initial screening of the quality of the data; inconsistencies, errors and gaps were found in the data series during the calibration exercises in the Kapos catchment. This impeded the modelling activities and even caused

time-consuming recalibration of some of the models. Based on this experience, a thorough checking of the data checking prior to the modelling is highly recommended.

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Appendix A. TEOTIL model – user instructions

Introduction

The TEOTIL model is a model maker tool specialised for calculations of loads in sub-catchment with known interior drainage. The model consists of a package of pre-defined functions that the user may apply to make his own model for transport of a selected constituent in a specified drainage basin or basins. The model is written in Visual Basic.

In the model we have an empty two dimensional array. We can think of it as an Excel table. In this description we will call it: **Model table**. The headings or the name of each individual array are in this text called **field** name. Each column in the table represents one field name. Input data that are stored in tables in text files can be read into the model table by use of order lines. The table can be filled for example by code names of individual drainage areas, area in km² as shown below. Other order lines may be used to make new variables or change old ones by calculations and to make output. In the order lines only names of variables is entered, then the order is done for all its elements.

Model table:

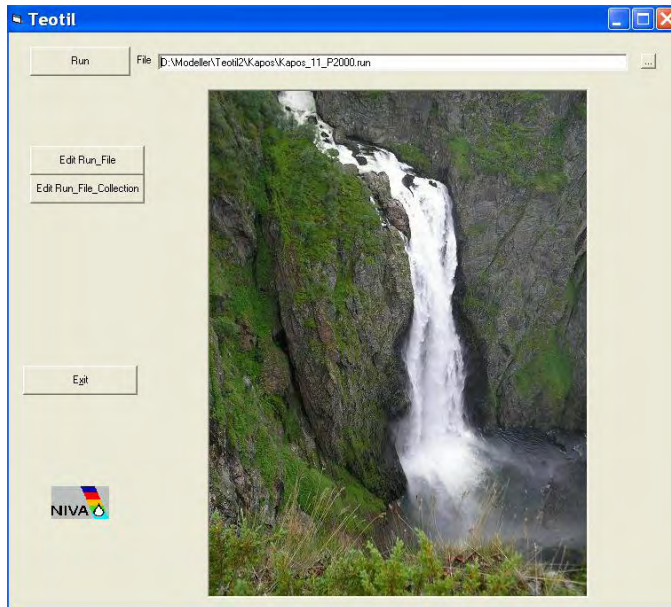
	ID	TO_ID	area	Qspes	Q
1	Catchment1	Catchment2	10	10	100
2	Catchment2	Catchment3	5	10	50
3	Catchment3	Catchment4	15	10	150
4	Catchment4	Catchment5	20	5	100
5	Catchment5	Catchment6	30	5	150
6	Catchment6	Catchment7	50	10	500

^

Element numbers/line numbers

The programme is explained by using some example from the modelling of the Kapos catchment. TEOTIL was used to make a model for calculating yearly loads of total phosphorus, totP, for the Kapos catchment. The catchment was divided into 11 sub-catchments with known interior drainage. Each sub-catchment had known value of land use area: forest, agriculture etc., look at the Appendix B, file:Catchment.txt. The loss from each type of land was calculated from known area specific loss coefficients, Appendix B, file:Coefficients.txt. Loads from the point sources industry and municipal waste water plant were added to their sub-catchments, Appendix B, files industry.txt and WWTP.txt. The water flow was calculated from known specific run off. The loads from each source were calculated for each sub-catchment and thereafter transported downstream. The results were written to the file: result_11_P2000.txt in Appendix B.

The TEOTIL main form

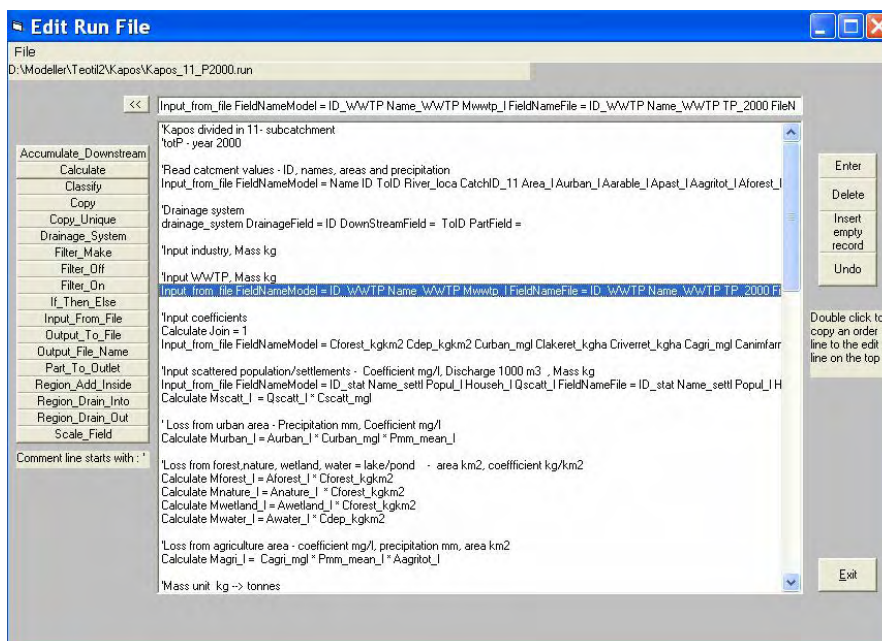


When executing the TEOTIL.exe file, the TEOTIL main form is shown. Prepared calculations for a region are executed by selecting/writing the run-file name in the run-file window and click on the run-button.

An alternative to the run file is to order a run file collection file. This is a text file that consists of a list of run files, one file name on each line. In that way the run files in the list may be executed one after each other.

For the Kapos catchment the name of the run-file is: Kapos_11_P2000.run, look in Appendix B. The orders that executes the calculations for the Kapos catchment is coded in this file.

Edit Run File



The run file is edited in the Edit Run File window. Each line consists of a calculation order or comment. When the model is run, the orders are executed one after each other from top to bottom.

The orders may be written by selecting the order list on the left side of the Edit window. Then a form pops up to help you to write the order.

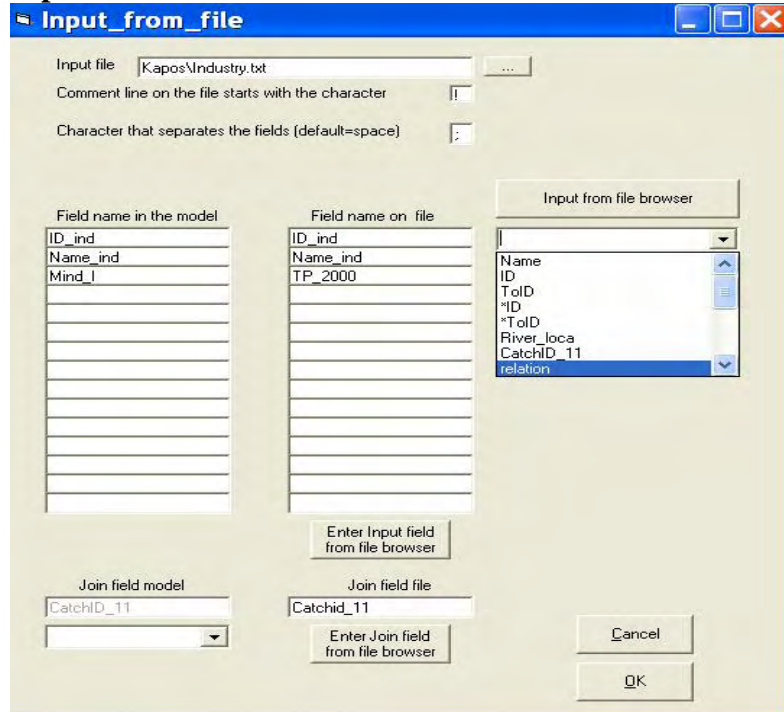
Comment line

If the first non blank character on the line is the comment character: ‘ ’, the rest of the line is not read.

Example:

‘This is a comment line’

Input From File



By clicking the OK button, the order line from the form above is written to “Edit run file window” as:

```
Input from file FieldNameModel = ID_ind Name_ind Mind_1 FieldNameFile = ID_ind
Name_ind TP_2000 FileName = Kapos\Industry.txt CommentChar = ! Field_Separator_Char
= ; JoinFieldModel = CatchID_11 JoinFieldFile = Catchid_11
```

The input order reads specified column in a table from a text file into the model. In the model the data are stored in a 2-dimensional array (you may think of it as in an Excel spread sheet with the field name on the top and the values downward in the column). Lines starting with the entered “comment line” character in the text file are not used by the model. The first readable line must consist of headings/field names, the following of data separated by the entered separator character. Remember to enclose data that consists of the separator character with goose eyes “ ”.

The input file may be selected and the field names/headings may be chosen by clicking by the mouse from the “Input from the browser” list. The “Field name in file” lists the field names in the input file that shall be read into the model. The corresponding field names in the model are entered in the “Field name in the model” list.

If no join fields are filled, the data are copied from the file table into the model table. The join fields may be used to enter data from a file table with few elements into a field with many elements in the model table through a common join field value.

Example :

Join field Model = county and Join field file = county_file

In the file table the fields "county_file" and "Pforest" consist of names of counties and run off concentration of phosphorus from forest each km² respectively. The model table consists of fields with data for each computational element including a field "county" with the name of the counties. A value "30" read from the file table with a corresponding county name "4" in the field "county_file", will be entered into the model table in the ordered field in each line where the name "4" are found in the field "county".

Model table:

ID_catcment	County	totP
Catchment1	1	40
Catchment2	1	40
Catchment3	4	30
Catchment4	4	30
Catchment5	1	40
Catchment6	4	10
Catchment7	3	30
Catchment8	3	30
Catchment9	1	40

File table:

County_file	Pforest
1	40
2	10
3	20
4	30

In the Kapos example, the table in the file industry.txt (load from a industry plant located in a specified sub-catchment, Catchid_11 name = 1) is entered into the model table to the column with field name field Mind_1 and in the line with the same sub-catchment name (Catchment_11 name = 1).

Point sources are usually stored in a file table with one line per source, for example discharge from an industry plant in one column and the sub-catchment/drainage element code in another. The normal way is to enter this discharge into the model table by use of the drainage element code as join field. If many point sources are localized in the same sub-catchment, the load is **added** to the existing value. In other words **each of the model table elements consists of the sum of all the loads added to the sub-catchment/drainage element**. If the value is a string/text the old value is over written by the new.

In the model table fields are of type numeric or string/text. You can for example not do numeric calculations with strings. Be aware of that **in the model an empty input value is defined as a string**. Therefore it is important to put in 0 “zero” instead of the empty value if the value is of numeric type. The model will give you a warning before abort if you try to do numerical calculations with a string field value.

Drainage system

Drainage System

DrainageField	DownStreamField	PartField
Field with ID-codes of drainage elements	Field with ID-codes of downstream elements	Field with Part (0.0-1.0) that drain from the Drainage ID to the Downstream ID (necessary if more than one Downstream field else 1.0 is default value)
id	toid	
	Combo1	Combo1
	Delete	Delete

If the DrainageField element is the most downstream element, its DownStreamField element must be given the the "out of system" value: 0 or -

The Drainage ID Field is always handled as STRING values in the model. That means even if all the element values is numbers, the field can't be used in numerical calculations.

Cancel OK

By clicking the OK button, the order line from the form above is written to “Edit run file window” as:

drainage_system DrainageField = ID DownStreamField = ToID PartField =

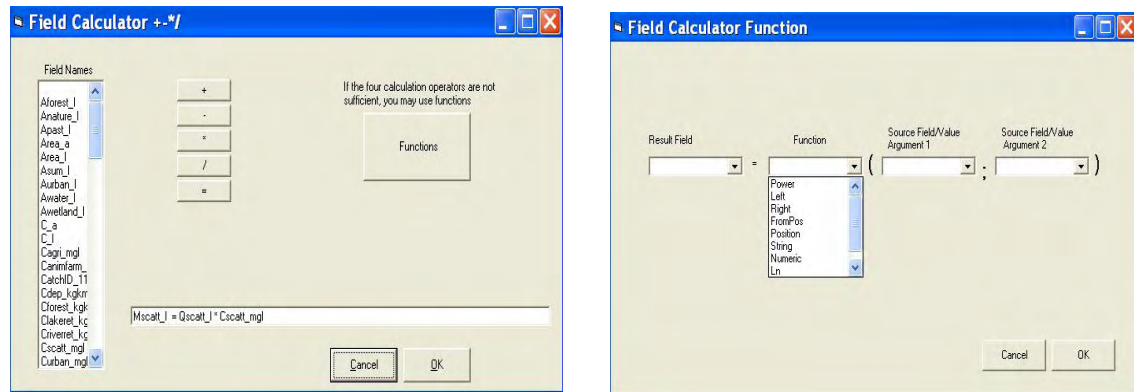
The model may handle a flexible drainage system. The water course may divide and confluent in a flexible way.

The drainage system is defined. We have to enter the field names of the Drainage element codes and the corresponding codes of the downstream elements. A drainage element/sub-catchment may divide in two or more downstream elements. If so, extra “DownStreamField” may be entered along with “Partfield” which tells how much of the flow that enters each parts by downwards transport. The “Part Field” values must be between 0 and 1. If all the drainage elements have only one downstream element, it is not necessary to fill out “PartField”.

The most downstream drainage element must be given the “DownStreamField” value = 0 or – (minus sign), which means out of system.

Many of the orders in TEOTIL need information about the drainage system. A good working habit is to read the “Drainage system” fields in the first order line and define it in the next.

Field calculator



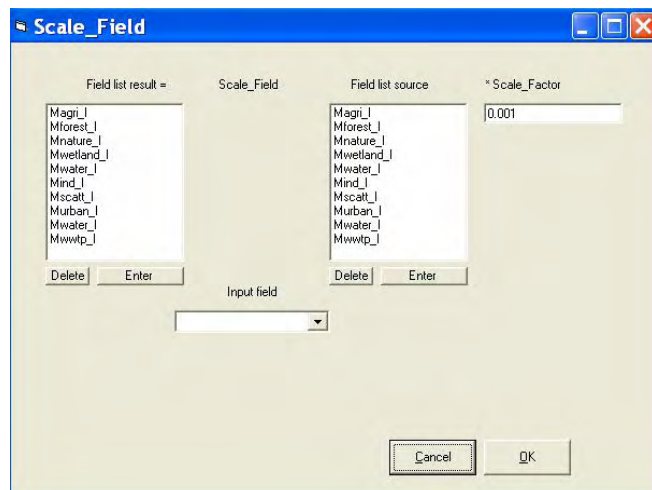
By clicking the OK button, the order line from the form above is written to “Edit run file window” as:

Calculate $Mscatt_1 = Qscatt_1 * Cscatt_mgl$

The operations are valid for the whole column in the model-table. In the example above each of the elements that belongs to the Qscatt_1 field are multiplied with the corresponding value for the Cscatt_mgl field and the results are stored in a column with field name Mscatt_1.

The calculator handles the four normal operators: + - * / without use of parenthesis. In addition some functions are available by clicking the function button in the “Field calculator” form. For numeric operation the power and logarithmic function may be useful. The rest of the functions handle string fields.

Scale_Field

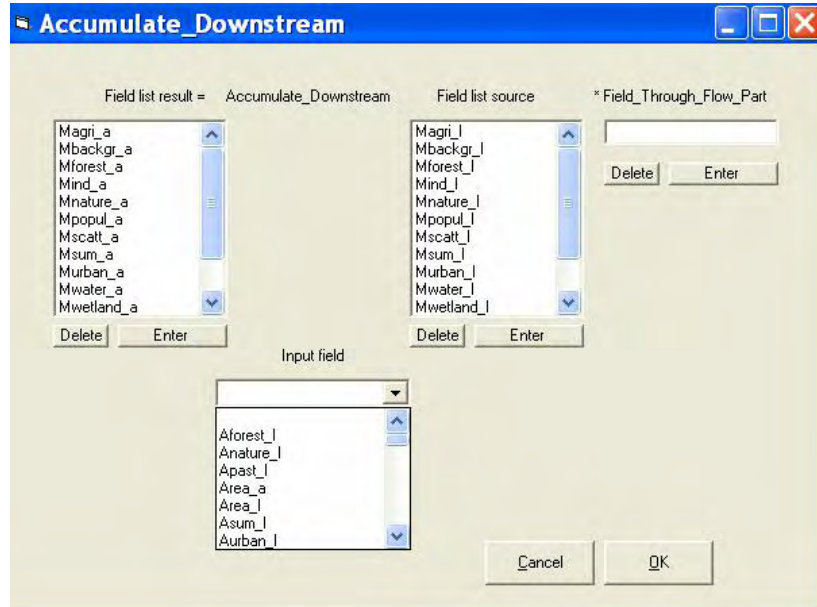


By clicking the OK button, the order line from the form above is written to “Edit run file window” as:

Scale_Field ResultField = Magri_1 Mforest_1 Mnature_1 Mwetland_1 Mwater_1 Mind_1 Mscatt_1 Murban_1 Mwater_1 Mwwtp_1 SourceField = Magri_1 Mforest_1 Mnature_1 Mwetland_1 Mwater_1 Mind_1 Mscatt_1 Murban_1 Mwater_1 Mwwtp_1 Scale_Factor = 0.001

The order is useful, as in the example above, to scale units from kg to tonnes for fields in the list. Alternatively we could have used the Calculate order 10 times.

Accumulate_Downstream



By clicking the OK button, the order line from the form above is written to “Edit run file window” as:

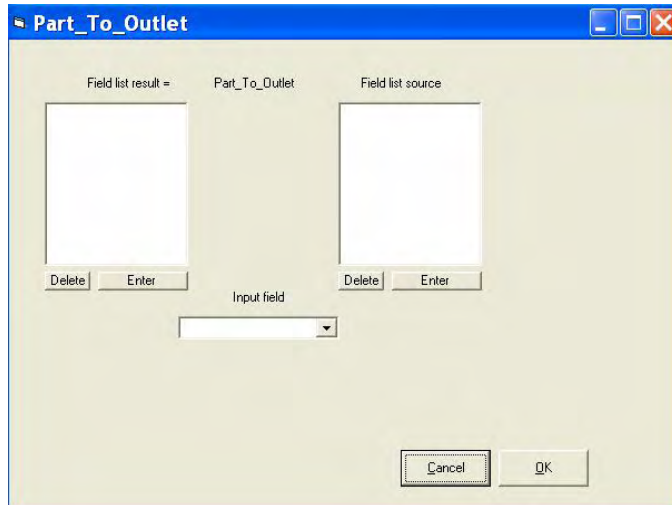
```
Accumulate_Downstream ResultField = Magri_a Mbackgr_a Mforest_a Mind_a Mnature_a
Mpopul_a Mscatt_a Msum_a Murban_a Mwater_a Mwetland_a Mwwtp_a Q_a Area_a
SourceField = Magri_l Mbackgr_l Mforest_l Mind_l Mnature_l Mpopul_l Mscatt_l Msum_l
Murban_l Mwater_l Mwetland_l Mwwtp_l Q_l Area_l
```

The order calculates the transport downstream. The local value for a field in the upper most drainage element is added to the value in the element downstream etc.

The “Through_Flow_Part” field makes it possible to handle retention processes, like phosphorus retention in lakes. In advance a field for the through flow part with values between 0 and 1 must be available. All the loads that pass out of an element, sum of upstream transport into the element + local value, are multiplied with the corresponding “Through_Flow_Part” field value.

If “Through_Flow_Part” field is empty, all of the load will pass the element. The result will be the same with a “Through_Flow_Part” field with all elements equal 1.

Part_to_outlet

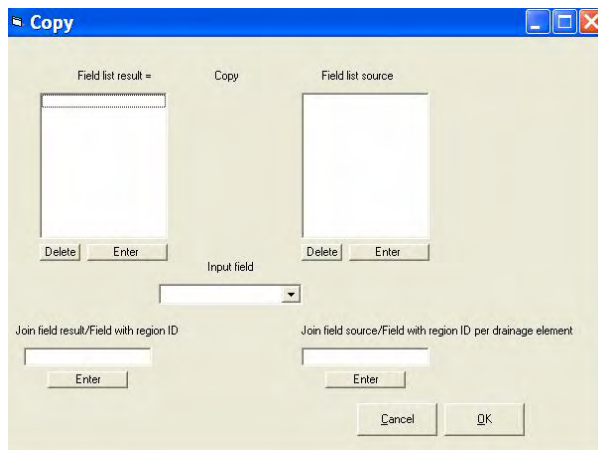


The result in each element is the product of all the source field values in downstream direction. The result is the part of the load from each of the sub-catchment that reaches the most downstream defined element. The entered fields in the source list must have value between 0 and 1 which give information about the part of the load that passes the element. The Field is the same as “Field_Trough_Flow_Part” (1-retention) in the order “Accumulate_Downstream”.

The order has only meaning in water courses with retention.

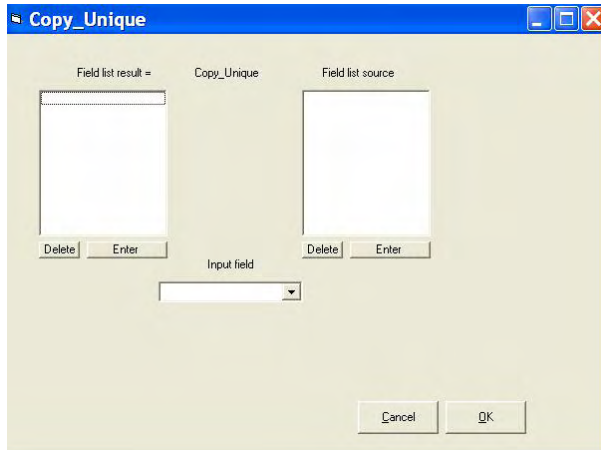
Such calculation may be used to localize cost effective pollution reducing effort.

Copy



The “Copy” order handles string fields. The join fields may be left empty. The use of the join fields are described in the “Input From File” order.

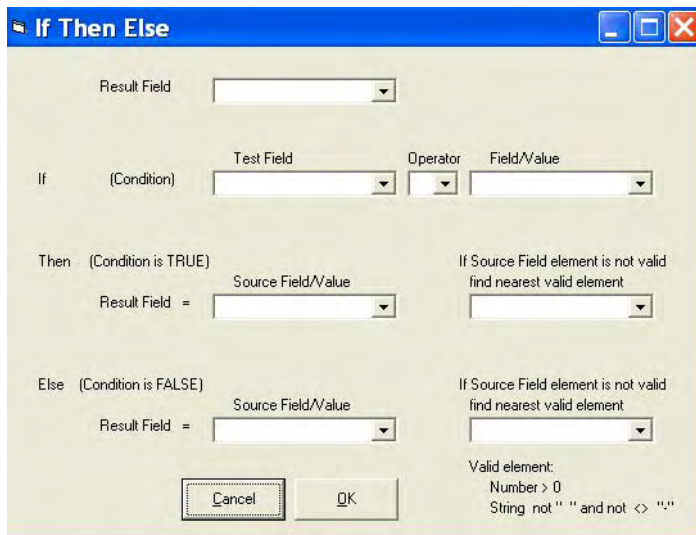
copy_unique



The result field consists of the unique values of the source field values.

Char_source	Char_Result
A	A
B	B
B	
A	

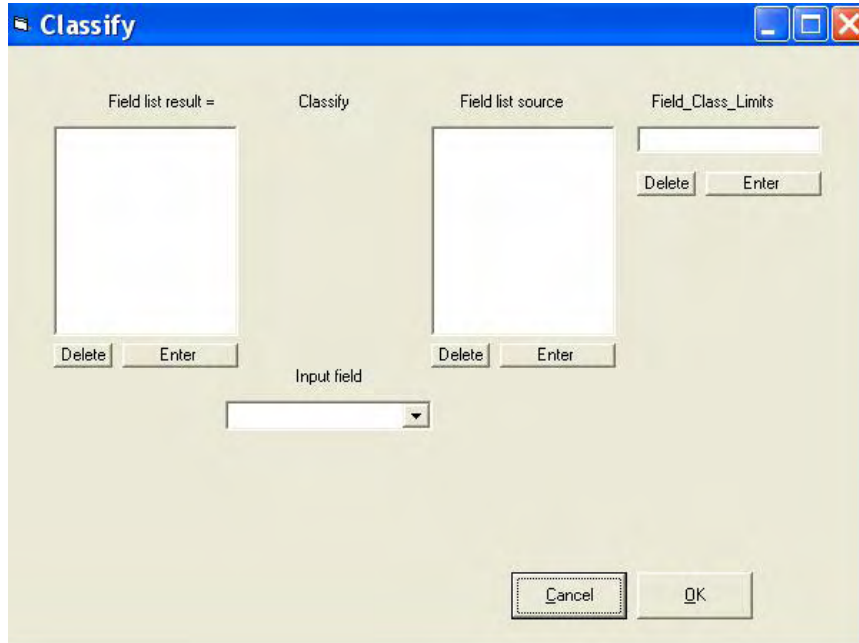
If_Then_Else



The order may be used to make new fields based on conditional circumstances. The form is self explanatory. We will just make a comment of the two fields marked with “If the Field element is not valid, find nearest valid element”. You may select “Downstream” or “Upstream”. The order is useful to extrapolate scattered known values upstream or downstream in the catchment. For example known water flow per km² in some measuring points may be extrapolated to the nearest areas.

The order also may be used to make output filter (see below). For example: To order output only for sub-catchments more then 500 meter above the sea level covered by 50 % forest.

Classify



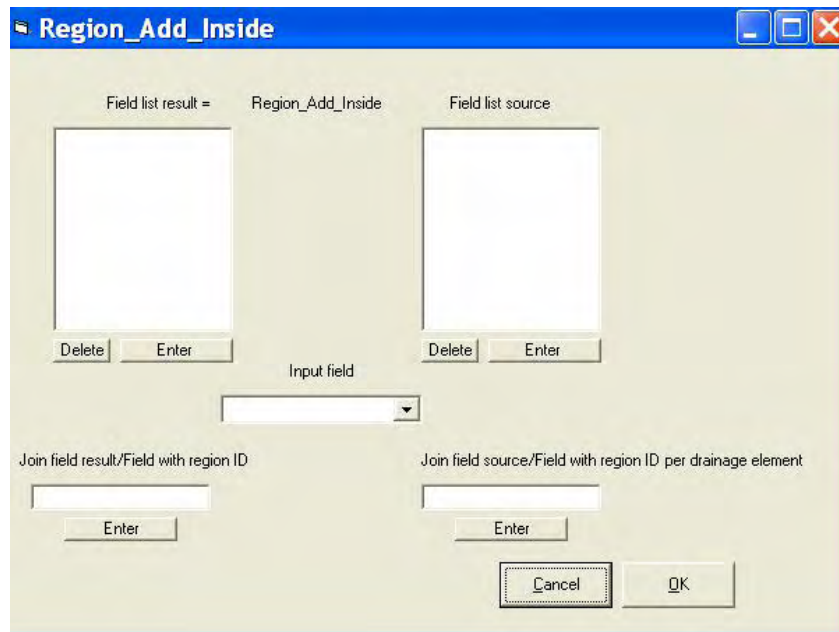
The order is used to classify values in a field against class limit values in a specified classification field (“Field_class_Limits”).

The class follows the line number in the model table, look at CLASS_LIMIT_A and CLASS_LIMIT_B in the table below. The first class is always 1, the next 2 etc. The user must define the class limits with increasing values or decreasing values according to that.

Example:

Class_Limit_A	Class_limit_B	X	X_class_A	X_class_B
10	40	5	1	5
20	30	14	2	4
30	20	40	4	2
40	10	16	2	4
		19	2	4
		29	3	3
		89	5	1

Region_Add_Inside



The order is used to find the sum of a field value inside a region.

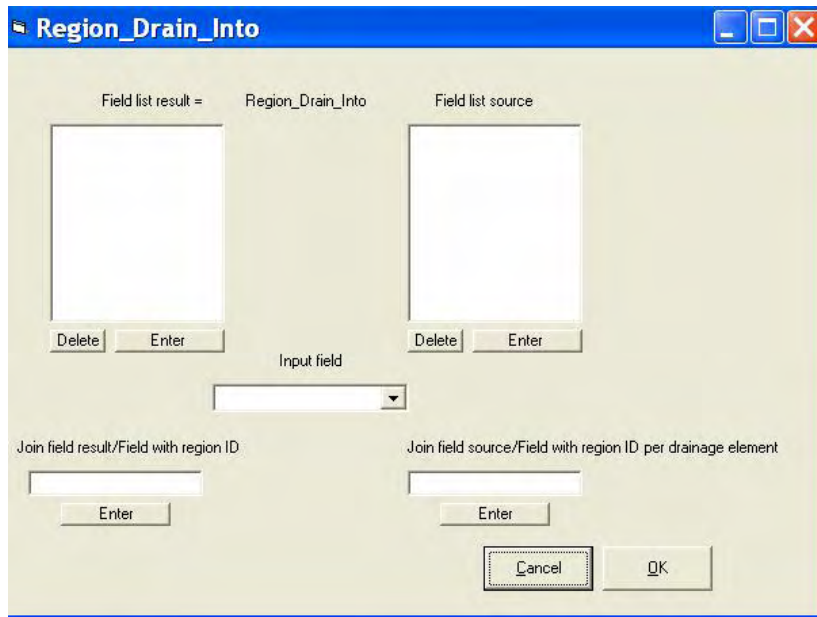
Example:

We want to find the sum totP that are added to water inside each county. Source field = totP, Join field source = County, Join field result = County_Unique. From these three known fields, the calculated result field = P_into is shown in the table below.

The field “County_unique” may have been made by the order: “Copy_Unique” by use of “County” as source field.

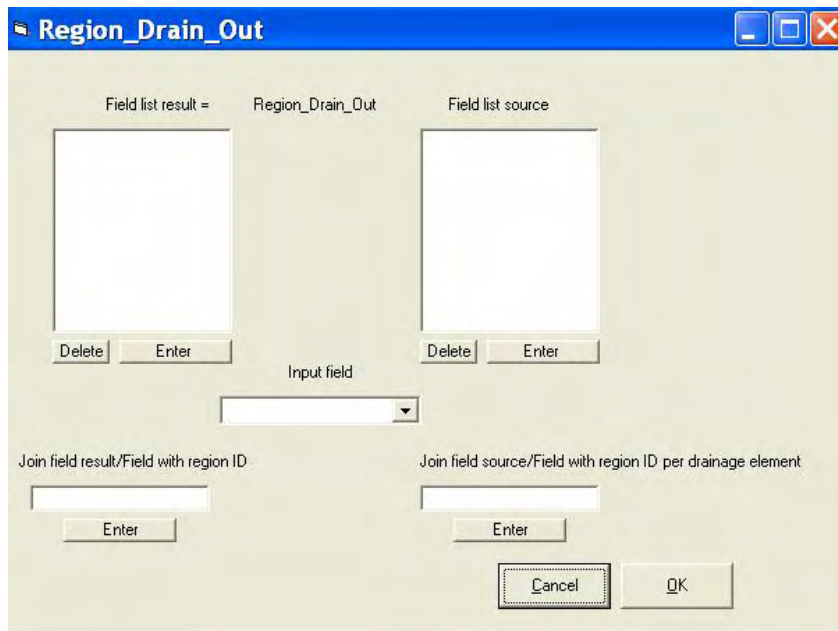
ID_catcment	County	totP	County_Unique	P_into
Catchment1	1	10	1	40
Catchment2	1	10	2	0
Catchment3	4	10	3	20
Catchment4	4	10	4	30
Catchment5	1	10		
Catchment6	4	10		
Catchment7	3	10		
Catchment8	3	10		
Catchment9	1	10		

Region_Drain_Into



The order is used to find the sum of a field value that drains into a region, for example how much of a constituent drain into each county from above. For use of the join field etc., look at the “Add_inside” order.

Region_Drain_Out



The order is used to find the sum of a field value that drains out of a region. For example how much of a constituent drain out of each county. For use of the join field etc., look at the “Add_inside” order.

Filter_make

Filter Field/ Result Field

Source Field

with Element value

from

to

The source Field is by default the Drainage Element Field

With the Elements + number of elements upstream

with the Elements + all the elements upstream

Enter

A filter field has element value 1 = True or 0 = False
 The filter is activated by the order: Filter_on
 The following output orders writes only lines with filter field value = 1/true
 or if several filter field is activated, with the total result of the filter field
 values = 1/true

Cancel OK

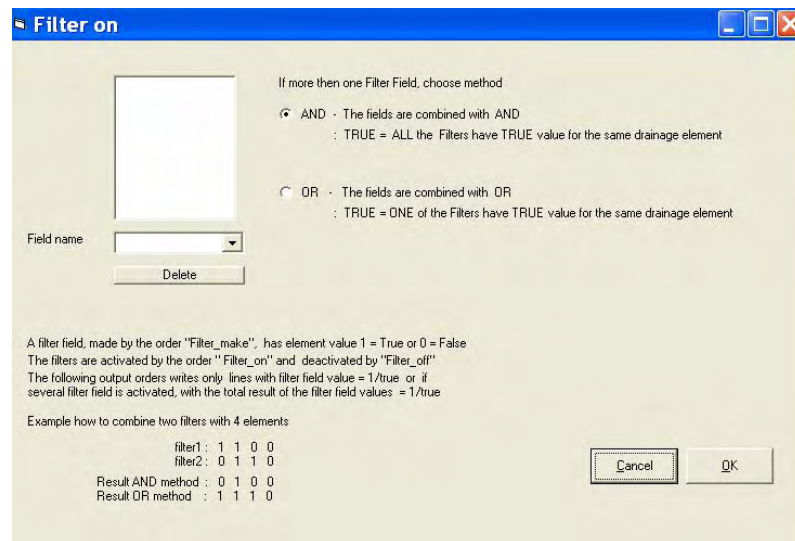
A filter field has value equal 1 = True or 0 = False. The filter is activated by the order "Filter_on" The following output orders writes only lines in the model table with filter field equal one or if several filter fields are activated, with the total result of the filter fields equal 1.

An output order writes by default the ordered field values for each of the sub-catchment/lines in the model table. If the modelled area consists of thousands of sub-catchments/drainage elements, the output amount may be overwhelming. The purpose of a filter is to reduce the output exactly to what we need.

You may choose the left or the right square in the "Filter_make" form. In the left square you may order output for given field values. For example choose sum-catchment between 500 and 1000 m above sea level or sub-catchment with covered by over 50 % forest. The right square of the form make filter according to the drainage elements. You may choose specific drainage elements or for example choose only the elements that drain to the sea by entering the name of the sea element and order one element upstream.

A filter field may not necessary be made by the "Filter_Make" order. The "If_then_else" order may also be suitable or you may use an already existing field with 0 and 1 values.

Filter_on



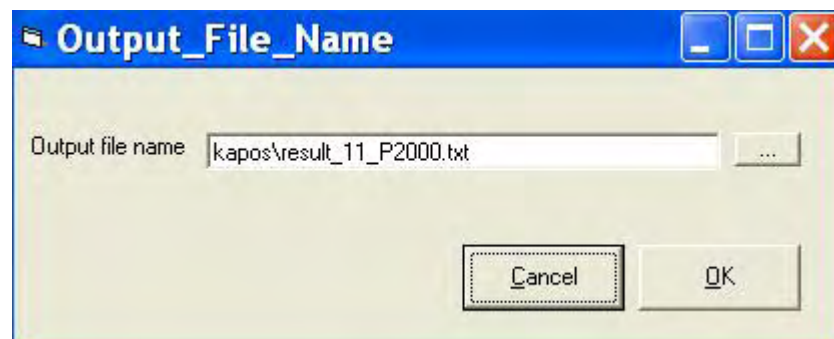
The filters may be activated by the “filter_on” order. In case of several filters, the total result is dependent of the method “AND” or “OR”. By use of the “AND” method, the total result is the product of the filter fields. If one of the filters for a sub-catchment/drainage element is equal 0, the total result is equal 0. By use of the “OR” method the total result is equal 0 if all of the filter values are equal 0.

Filter_Off

The filter activated by the “Filter_On” order is deactivated by the “Filter_Off” order. If a filter is active, a new “Filter_On“ order may be written directly without any “Filter_Off” order between.

The “Filter_Off” order is entered directly (no dedicated form for this order), into the edit window by clicking the “Filter_Off” button in the “Edit Run File” form.

Output_File_Name



By clicking the OK button, the order line from the form above is written to “Edit run file window” as:

output_file_name = kapos\result_11_N2000.txt

The output will be written to the entered file. If the file exists, the content will be over written.

Output_To_File

By clicking the OK button, the four order lines from the form above is written to “Edit run file window” as:

output_to_file New_line = 3

output_to_file Head_line = Drainage system

output_to_file Head_line = ID ToID CatchID_11 Name River_loca

output_to_file Field = id toid catchid_11 name river_loca Format = *

The output from these orders are shown in Appendix B, File: result_11_P2000.txt

The order writes a table to the file activated by the last “Output_File_Name” order. The table consists of one column for each field. If no filter fields are activated, one line is written for each sub-catchment/drainage element. If filter fields are activated, only lines with total filter field value equal 1 are written.

The TEOTIL model integrated by the Arcview

TEOTIL is a stand alone model. However the model also may be run from Arcview, Arc-GIS version 9. A menu is built with three choices. You may execute the TEOTIL.exe file in the same way as described above. In addition there are a pre- and post processor. The pre processor is used to make input files from existing layers on the map. For example find the sub-catchments codes that surround each of the industry plants. The post processor may help you to present results on the map. For example points classified with special water quality colours or pies proportional to load.

The Kapos example

In Appendix B you will find a run-file for calculations in the Kapos catchment. The appendix also includes the input files read and output files written. A fast way to get experience with

the model is to go through the run-file order by order and check the appropriate input files, output files and orders explained above.

Appendix B. TEOTIL run-file, Result files and Input files for Kapos catchment

File: Kapos_11_P2000.run

'Kapos divided in 11- subcatchment
'totP - year 2000

'Read catcment values - ID, names, areas and precipitation

Input_from_file FieldNameModel = Name ID ToID River_loca CatchID_11 Area_1 Aurban_1 Aarable_1 Apast_1 Aagritot_1 Aforest_1 Anature_1 Awetland_1 Awater_1 Pmm_mean_1
FieldNameFile = Name ID ToID River_loca CatchID_11 Area_1 Aurban_1 Aarable_1 Apast_1 Aagritot_1 Aforest_1 Anature_1 Awetland_1 Awater_1 Pmm_mean_1 FileName =
Kapos\catchment_11.txt CommentChar = ! Field_Separator_Char = ;

'Drainage system

drainage_system DrainageField = ID DownStreamField = ToID PartField =

'Input industry, Mass kg

Input_from_file FieldNameModel = ID_ind Name_ind Mind_1 FieldNameFile = ID_ind Name_ind TP_2000 FileName = Kapos\Industry.txt CommentChar = ! Field_Separator_Char = ;
JoinFieldModel = CatchID_11 JoinFieldFile = Catchid_11

'Input WWTP, Mass kg

Input_from_file FieldNameModel = ID_WWTP Name_WWTP Mwwtp_1 FieldNameFile = ID_WWTP Name_WWTP TP_2000 FileName = Kapos\wwtp.txt CommentChar = !
Field_Separator_Char = ; JoinFieldModel = CatchID_11 JoinFieldFile = Catchid_11

'Input coefficients

Calculate Join = 1

Input_from_file FieldNameModel = Cforest_kgkm2 Cdep_kgkm2 Curban_mgl Clakeret_kgha Criverret_kgha Cagri_mgl Canimfarm_mgl Cscatt_mgl FieldNameFile = Pforest_kgkm2
Pdep_kgkm2 Purban_mgl Plakeret_kgha Priverret_kgha Pagri_mgl Panimfarm_mgl Pscatt_mgl FileName = Kapos\coefficients.txt CommentChar = ! Field_Separator_Char = ; JoinFieldModel
= Join JoinFieldFile = Cjoin

'Input scattered population/settlements - Coefficient mg/l, Discharge 1000 m3 , Mass kg

Input_from_file FieldNameModel = ID_stat Name_settl Popul_1 Househ_1 Qscatt_1 FieldNameFile = ID_stat Name_settl Popul_1 Househ_1 Qscatt_1 FileName = Kapos\settlement.txt
CommentChar = ! Field_Separator_Char = ; JoinFieldModel = CatchID_11 JoinFieldFile = CatchID_11
Calculate Mscatt_1 = Qscatt_1 * Cscatt_mgl

'Loss from urban area - Precipitation mm, Coefficient mg/l

Calculate Murban_1 = Aurban_1 * Curban_mgl * Pmm_mean_1

'Loss from forest,nature, wetland, water = lake/pond - area km2, coefficient kg/km2

Calculate Mforest_1 = Aforest_1 * Cforest_kgkm2

Calculate Mnature_1 = Anature_1 * Cforest_kgkm2

Calculate Mwetland_1 = Awetland_1 * Cforest_kgkm2

Calculate Mwater_1 = Awater_1 * Cdep_kgkm2

'Loss from agriculture area - coefficient mg/l, precipitation mm, area km2

Calculate Magri_1 = Cagri_mgl * Pmm_mean_1 * Aagritot_1

'Mass unit kg --> tonnes

Scale_Field ResultField = Magri_1 Mforest_1 Mnature_1 Mwetland_1 Mwater_1 Mind_1 Mscatt_1 Murban_1 Mwater_1 Mwwtp_1 SourceField = Magri_1 Mforest_1 Mnature_1 Mwetland_1

Mwater_1 Mind_1 Mscatt_1 Murban_1 Mwater_1 Mwwtp_1 Scale_Factor = 0.001

'Group sources ++

Calculate Mbackgr_1 = Mforest_1 + Mnature_1 + Mwetland_1 + Mwater_1

Calculate Mpopul_1 = Mscatt_1 + Murban_1 + Mwwtp_1

Calculate Asum_1 = Aforest_1 + Anature_1 + Aurban_1 + Awater_1 + Awetland_1 + Aagritot_1

Calculate Msum_1 = Magri_1 + Mbackgr_1 + Mind_1 + Mpopul_1

Calculate Q_1 = Area_1 * Pmm_mean_1 * 1000/ 86400 / 365

Calculate C_1 = Msum_1 * 1000000 / Q_1 / 86400 / 365

output_file_name = kapos\result_11_N2000.txt

output_to_file Head_line = totN 2000 for Kapos catchment devided in 11 subcatchment

output_to_file New_line = 3

output_to_file Head_line = Drainage system

output_to_file Head_line = ID ToID CatchID_11 Name River_loca

output_to_file Field = id toid catchid_11 name river_loca Format = *

output_to_file New_line = 3

output_to_file Head_line = Land use

output_to_file Head_line = ID Aforest_1 Anature_1 Aurban_1 Awater_1 Awetland_1 Aagritot_1 Asum Area_1 Pmm_mean

output_to_file Head_line = km2 km2 km2 km2 km2 km2 km2 km2 mm

output_to_file Field = id aforest_1 anature_1 aurban_1 awater_1 awetland_1 aagritot_1 asum_1 area_1 pmm_mean_1 Format = *

output_to_file New_line = 3

output_to_file Head_line = Coefficients

output_to_file Head_line = ID Cforest_kgkm2 Cscatt_mgl Curban_mgl Cagri_mgl Cdep_kgkm2

output_to_file Head_line = kg/km2 mg/l mg/l mg/l kg/km2

output_to_file Field = id cforest_kgkm2 cscatt_mgl curban_mgl cagri_mgl cdep_kgkm2 Format = *


```

output_to_file New_line = 3
output_to_file Head_line = Local yearly load
output_to_file Head_line = ID      Magri_l   Mind_l   Mscatt_l  Murban_l  Mwwtp_l  Mwater_l  Mbackgr_l  Mpopul_l  Msum_l   Q_l     C_l
output_to_file Head_line =          tonnes  tonnes  tonnes   tonnes   tonnes   tonnes   tonnes   tonnes   tonnes  m3/s   mg/l
output_to_file Field = id magri_l mind_l mscatt_l murban_l mwwtp_l mwater_l mbackgr_l mpopul_l msum_l q_l c_l Format = *
    
```

```

Accumulate_Downstream ResultField = Magri_a Mbackgr_a Mforest_a Mind_a Mnature_a Mpopul_a Mscatt_a Msum_a Murban_a Mwater_a Mwetland_a Mwwtp_a Q_a Area_a
SourceField = Magri_l Mbackgr_l Mforest_l Mind_l Mnature_l Mpopul_l Mscatt_l Msum_l Murban_l Mwater_l Mwetland_l Mwwtp_l Q_l Area_l
Calculate C_a = Msum_a * 1000000 / Q_a / 86400 / 365
    
```

```

output_to_file New_line = 3
output_to_file Head_line = Accumulated yearly load
output_to_file Head_line = ID      Magri_a   Mind_a   Mscatt_a  Murban_a  Mwwtp_a  Mwater_a  Mbackgr_a  Mpopul_a  Msum_a   Q_a     C_a     Area_a
output_to_file Head_line =          tonnes  tonnes  tonnes   tonnes   tonnes   tonnes   tonnes   tonnes   tonnes  m3/s   mg/l   km2
output_to_file Field = id magri_a mind_a mscatt_a murban_a mwwtp_a mwater_a mbackgr_a mpopul_a msum_a q_a c_a Area_a Format = *
    
```

File: result_11_P2000.txt

totP 2000 for Kapos catchment divided in 11 subcatchment

Drainage system

ID	ToID	CatchID_11	Name	River_loca
1	4	1.000	Kapos-riv1	Kapos_up
2	4	2.000	Orczi-crek	Kapos_up
3	4	3.000	Surjan-cre	Kapos_up
4	6	4.000	Kapos-riv2	Kapos_up
5	6	5.000	Baranya-ch	Baranya
6	7	6.000	Kapos-riv3	Kapos_mid
7	11	7.000	Kapos-riv4	Kapos_mid
8	9	8.000	Koppany-r1	Koppany
9	10	9.000	Koppany-r2	Koppany
10	11	10.000	Koppany-r3	Koppany
11	0	11.000	Kapos-riv5	Kapos_low

Land use

ID	Aforest_1 km2	Anature_1 km2	Aurban_1 km2	Awater_1 km2	Awetland_1 km2	Aagritot_1 km2	Asum km2	Area_1 km2	Pmm_mean mm
1	152.440	2.030	35.730	3.170	2.640	378.580	574.590	574.600	647.000
2	8.390	0.000	4.060	0.000	5.260	99.930	117.640	117.650	689.000
3	66.470	0.090	2.180	0.530	0.390	51.080	120.740	120.740	670.000
4	53.410	0.000	33.480	9.040	1.490	478.410	575.830	575.830	695.000
5	213.150	2.310	18.650	1.330	0.410	229.980	465.830	465.830	671.000
6	68.650	2.090	13.380	4.310	1.150	217.430	307.010	307.010	654.000
7	61.730	1.010	7.950	0.320	0.000	148.220	219.230	219.240	653.000
8	61.140	1.480	5.530	0.340	3.560	190.040	262.090	262.100	672.000
9	60.940	0.540	13.210	4.680	0.000	306.010	385.380	385.380	662.000
10	15.820	0.350	2.890	2.550	0.000	71.090	92.700	92.690	654.000
11	23.870	0.070	5.700	1.060	2.440	139.430	172.570	172.570	647.000

Coefficients

ID	Cforest_kgkm2 kg/km2	Cscatt_mg1 mg/l	Curban_mg1 mg/l	Cagri_mg1 mg/l	Cdep_kgkm2 kg/km2
1	4.000	10.000	0.600	0.860	0.000

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2	4.000	10.000	0.600	0.860	0.000
3	4.000	10.000	0.600	0.860	0.000
4	4.000	10.000	0.600	0.860	0.000
5	4.000	10.000	0.600	0.860	0.000
6	4.000	10.000	0.600	0.860	0.000
7	4.000	10.000	0.600	0.860	0.000
8	4.000	10.000	0.600	0.860	0.000
9	4.000	10.000	0.600	0.860	0.000
10	4.000	10.000	0.600	0.860	0.000
11	4.000	10.000	0.600	0.860	0.000

Local yearly load

ID	Magri_l tonnes	Mind_l tonnes	Mscatt_l tonnes	Murban_l tonnes	Mwwtp_l tonnes	Mwater_l tonnes	Mbackgr_l tonnes	Mpopul_l tonnes	Msum_l tonnes	Q_l m3/s	C_l mg/l
1	210.649	0.000	5.367	13.870	13.453	0.000	0.628	32.690	243.968	11.789	0.656
2	59.213	0.000	1.570	1.678	0.000	0.000	0.055	3.248	62.515	2.570	0.771
3	29.432	0.000	0.722	0.876	0.000	0.000	0.268	1.598	31.298	2.565	0.387
4	285.946	0.000	7.262	13.961	0.175	0.000	0.220	21.398	307.564	12.690	0.769
5	132.712	0.000	3.563	7.508	10.954	0.000	0.863	22.026	155.601	9.912	0.498
6	122.291	0.000	3.170	5.250	0.499	0.000	0.288	8.919	131.498	6.367	0.655
7	83.237	0.000	2.057	3.115	0.000	0.000	0.251	5.171	88.660	4.540	0.619
8	109.828	0.000	1.224	2.230	0.000	0.000	0.265	3.454	113.546	5.585	0.645
9	174.218	0.000	3.381	5.247	0.000	0.000	0.246	8.628	183.092	8.090	0.718
10	39.984	0.000	0.732	1.134	0.000	0.000	0.065	1.866	41.915	1.922	0.691
11	77.582	0.000	1.395	2.213	0.000	0.000	0.106	3.608	81.295	3.540	0.728

Accumulated yearly load

ID	Magri_a tonnes	Mind_a tonnes	Mscatt_a tonnes	Murban_a tonnes	Mwwtp_a tonnes	Mwater_a tonnes	Mbackgr_a tonnes	Mpopul_a tonnes	Msum_a tonnes	Q_a m3/s	C_a mg/l	Area_a km2
1	210.6	0.0	5.4	13.9	13.5	0.0	0.6	32.7	244.0	11.789	0.656	574.600
2	59.2	0.0	1.6	1.7	0.0	0.0	0.1	3.2	62.5	2.570	0.771	117.650
3	29.4	0.0	0.7	0.9	0.0	0.0	0.3	1.6	31.3	2.565	0.387	120.740
4	585.2	0.0	14.9	30.4	13.6	0.0	1.2	58.9	645.3	29.615	0.691	1388.820
5	132.7	0.0	3.6	7.5	11.0	0.0	0.9	22.0	155.6	9.912	0.498	465.830
6	840.2	0.0	21.7	43.1	25.1	0.0	2.3	89.9	932.4	45.893	0.644	2161.660
7	923.5	0.0	23.7	46.3	25.1	0.0	2.6	95.1	1021.1	50.433	0.642	2380.900
8	109.8	0.0	1.2	2.2	0.0	0.0	0.3	3.5	113.5	5.585	0.645	262.100
9	284.0	0.0	4.6	7.5	0.0	0.0	0.5	12.1	296.6	13.675	0.688	647.480
10	324.0	0.0	5.3	8.6	0.0	0.0	0.6	13.9	338.6	15.597	0.688	740.170
11	1325.1	0.0	30.4	57.1	25.1	0.0	3.3	112.6	1441.0	69.570	0.657	3293.640

File Catchment.txt

!Name;Cactment_ID;Catchment_ToID;;ID;ToID;River_ID;CatchmentID_11;HydrologicalRelation11;TotalArea;Urban;ArableLand;Pastures;AgriTotal;Forest;Nature;Wetlands;Waters;P_mean
 _l;,,,,;mm;,,,,;
 !,,,,;km2;km2;km2;km2;km2;km2;km2;mm;,,,,;
 Name;ID;ToID;*ID;*ToID;River_loca;CatchID_11;relation;Area_l;Aurban_l;Aarable_l;Apast_l;Aagritot_l;Aforest_l;Anature_l;Awetland_l;Awater_l;Pmm_mean_l
 Kapos-riv1;1;4;KA1;KA4;Kapos_up;1;1;574.60;35.73;299.48;11.84;378.58;152.44;2.03;2.64;3.17;647
 Orczi-crek;2;4;KA2;KA4;Kapos_up;2;2;117.65;4.06;91.94;5.21;99.93;8.39;0;5.26;0;689
 Surjan-cre;3;4;KA3;KA4;Kapos_up;3;3;120.74;2.18;30.97;11.46;51.08;66.47;0.09;0.39;0.53;670
 Kapos-rir2;4;6;KA4;KA5;Kapos_up;4;1+2+3+4;575.83;33.48;418.07;27.87;478.41;53.41;0;1.49;9.04;695
 Baranya-ch;5;6;BA;KA5;Baranya;5;5;465.83;18.65;172.39;20.78;229.98;213.15;2.31;0.41;1.33;671
 Kapos-riv3;6;7;KA5;KA6;Kapos_mid;6;1+2+3+4+5+6;307.01;13.38;195.80;8.27;217.43;68.65;2.09;1.15;4.31;654
 Kapos-riv4;7;11;KA6;KA7;Kapos_mid;7;1+2+3+4+5+6+7;219.24;7.95;114.73;14.63;148.22;61.73;1.01;0;0.32;653
 Koppány-r1;8;9;KO1;KO2;Koppány;8;8;262.10;5.53;162.90;8.61;190.04;61.14;1.48;3.56;0.34;672
 Koppány-r2;9;10;KO2;KO3;Koppány;9;8+9;385.38;13.21;266.68;10.50;306.01;60.94;0.54;0;4.68;662
 Koppány-r3;10;11;KO3;KA7;Koppány;10;8+9+10;92.69;2.89;52.80;6.02;71.09;15.82;0.35;0;2.55;654
 Kapos-riv5;11;0;KA7;-Kapos_low;11;1+2+3+4+5+6+7+8+9+10+11;172.57;5.70;117.00;9.42;139.43;23.87;0.07;2.44;1.06;647

File: Industry.txt

!ID;Name;Type;CatchmentID_11;CatchmentID_73;TP_1997;TP_1998;TP_1999;TP_2000;TN_1997;TN_1998;TN_1999;TN_2000
 !,,,,;kg;kg;kg;kg;kg;kg;kg;kg
 ID_ind;Name_ind;Type;Catchid_11;Catchid_73;TP_1997;TP_1998;TP_1999;TP_2000;TN_1997;TN_1998;TN_1999;TN_2000
 05-035;KAPOSFIL_thread_producing_and_salling_company;Industry;1;11;233;203;114;37;540;121;559;273
 05-037;KAPOSVOLÁN_Plc;Industry;1;13;80;55;81;54.7;447;195;570;285
 05-038;KAPOSCUKOR_RT_cooling_water;Industry;1;10;0;0;53;39;2002;1493;4534;1456
 05-059;KAPOSCUKOR_RT_emergency_reservoir;Industry;1;14;0;0;14;31;0;84;100;368
 05-041;Somogy_County_Cardiology_Hospital;Industry;1;11;365;155;270;249;1007.7;1000;777;2115
 05-043;PERT_Zobak_mine;Industry;5;78;0;22;59;0;1215;860;1266;0
 05-058;KAPOSCUKOR_RT_oxidation_lake_effluent;Industry;1;11;20;0;412;0;1862;2122;2175;0
 05-036;KAPOSPLASZT_brush_and_plastic_plc;Industry;1;12;20;12;0;0;436;131;0;0

File: WWTP.txt

!,,,,;kg;kg;kg;kg;kg;kg;kg;kg
 ID_wwtp;Name_wwtp;Type;Catchid_11;Catchid_73;TP_1997;TP_1998;TP_1999;TP_2000;TN_1997;TN_1998;TN_1999;TN_2000
 04-016;Dombóvár;WWTP;6;31;0;0;0;0;314;1114.16;835.12
 04-017;Tamási;WWTP;10;62;0;0;0;0;5388;149;166.075;2080.5
 05-034;Juta;WWTP;1;9;207;79;113;130;402;480;407;1352
 05-044;Komló;WWTP;5;78;1428;10891;8740;10230.2;110645;38766;12217;33087.25
 05-045;Sikonda;WWTP;5;76;48;43;53;101.4;1067;275;914;608.82
 05-046;Orfu;WWTP;5;77;365;394;326;341.28;2396;2552;2546;4737.7

05-047;Sasd;WWTP;5;79;308;182;98;281.46;4014;455;837;375.23

05-048;Magocs;WWTP;6;26;534;279;910;498.73;3031;2907;3063;3801.84

05-040;Kaposvar;WWTP;1;13;10120;16636;12559;13323;40120;36000;37268;41820

05-042;Igal;WWTP;4;23;135;151;200;175;327;2000;1667;1105

File: Coefficients.txt

!kg/km2;mg/l;kg/km2;kg/ha;kg/ha;mg/l;mg/l;mg/l;kg/km2;mg/l;kg/km2;kg/km2;kg/km2;mg/l;mg/l;mg/l

Pforest_kgkm2;Purban_mgl;Pdep_kgkm2;Plakeret_kgha;Priverret_kgha;Pagri_mgl;Panimfarm_mgl;Pscatt_mgl;Nforest_kgkm2;Nurban_mgl;Ndep_kgkm2;Nlakeret_kgha;Nriverret_kgha;Nagri_mgl;Nanimfarm_mgl;Nscatt_mgl;Cjoin

4;0.6;0;0.000701;0.000055;0.86;335;10;13;6.5;0.016268;0.050947;0.016807;9;1510;40;1