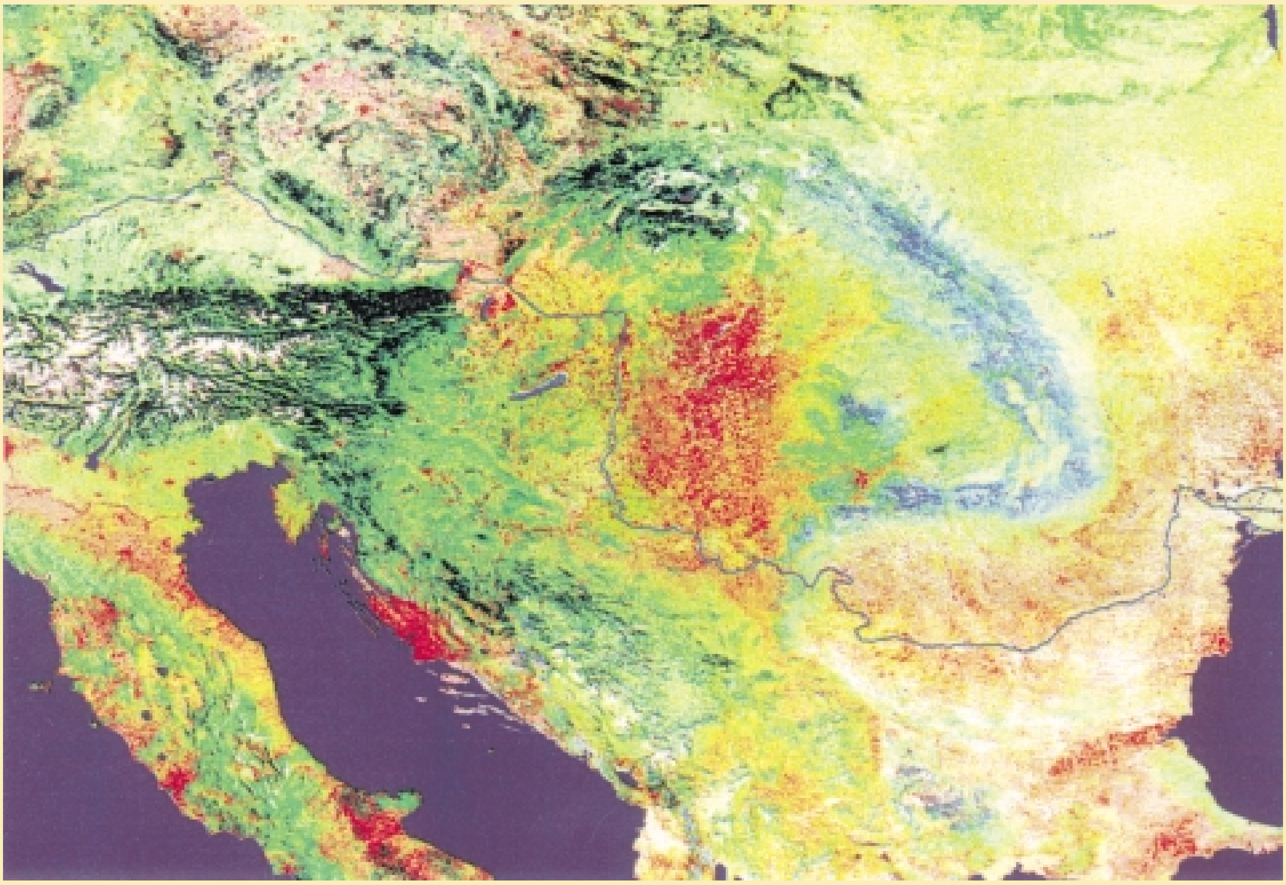
DANUBE POLLUTION REDUCTION PROGRAMME

DANUBE WATER QUALITY MODEL SIMULATIONS

IN SUPPORT TO THE

TRANSBOUNDARY ANALYSIS AND THE POLLUTION REDUCTION PROGRAMME

JUNE 1999



Programme Coordination Unit
UNDP/GEF Assistance

prepared by
Jos Van Gils/Delft Hydraulics

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Preface

The Danube Water Quality Model (DWQM) Report was prepared in the frame of the Danube Pollution Reduction Programme (PRP). The simulations have been conducted to support the Transboundary Analysis as well as to support the definition of priority measures (investment portfolio) of the Pollution Reduction Programme.

The present report addresses firstly transbundary issues related to the transport of nutrients (phosphorus and nitrogen) from the Danube River Basin to the Black Sea. The analysis presented herein has originally been p0roduced in January 1999, in support to the Transboundary Analysis. At that point, it was concluded that the input data taken from the Mass Balance Model (MBM) from the Technical University of Vienna, were based on data from the National Reviews. These updated input data have been used to support the definition of priority measures (investment portfolio) to the Pollution Reduction Programme, The simulations with the DWQM to this end are presented in the second part of the present report.

It should be noticed that water quality data input from the various Danubian countries (National Review reports) and from reports of the ICPDR working groups need further verification. Certain parameters of the EWQM should only be considered as ont of the possible indicators to determine transport of nutrients from the different Danubian countries to the Black Sea.

The actual report was prepared by Jos van Gils, Delft Hydraulics, Delft, The Netherlands, under the guidance of the UNDP/GEF team of experts and consultants of the Danube Programme Coordination Unit (DPCU) in Vienna, Austria. Conceptual preparation and organisation of activities were carried out by Joachim Bendow, UNDP/GEF Project Manager and Andy Garner, Environmental Specialist, who participated also in the Technical Working Group. The report was edited by Michael Sokolnikov.

To assure scientific support and guidance for the operation of the Model, a Technical Working Group was created with members from participating countries, defining the appropriate methodological approach, the choice of relevant data and developing pertinent simulations. The members of the Technical Working Group were invited from the following Institutions:

➢	UNDP/GEF	Don Graybill, Water Quality Expert, Chairman of the Group
➢	TU Vienna	Helmut Kroiss, Matthias Zessner (MBM project)
➢	ICPDR	Hellmut Fleckseder, Technical and Scientific Issues (ICPDR)
➢	EMIS Group	Bernd Mehlhorn (Umweltbundesamt Berlin)
➢	MLIM Group	Liviu Popescu (Research and Engineering Institute, Romania)
➢	VITUKI	Geza Jolankai (Water Research Center, Hungary)
➢	Delft Hydraulics	Jos van Gils, Modelling Expert
➢	Landesamt f. Wasser	Steffen Mueller, Modelling Expert (Munich, Germany)
➢	PCU/Phare/Tacis	Ilya Natchkov, Deputy team Leader Phare/Tacis

The Technical Working Group shall continue to assist in the further development of the DWQM and will assure integration of results with the MBM. The DWQM shall become in the future a management tool for the ICPDR for monitoring , planning and decision making.

The findings, interpretation and conclusions expressed in this publication are entirely those of the authors and should not be attributed to any manner to the UNDP/GEF and its affiliated organizations.

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1. Introduction

The present working paper discusses the following aspects related to the Danube Water Quality Model (DWQM) and its application:

1. A further elaboration of the methodology, as a continuation of the first Working Paper (Annex 11) in chapters 2, 3 and 4.
2. A discussion of the available data and their use in and around the DWQM in chapter 5.
3. The results of the DWQM validation in chapter 6.
4. The application of the DWQM in support to the Transboundary Diagnostic Analysis in chapter 7.
5. The application of the DWQM in support to the Pollution Reduction Programme in chapter 8.

2. Schematization of the Danube Basin

The schematization of the Danube basin has two aspects: the schematization of the river network, and the schematization of the catchment.

The *river network* is divided into segments. The subdivision should not be too coarse to avoid an insufficient accuracy. On the other hand, it should not be too fine to avoid long computation times. As a starting point, the network schematization of the Danube Basin Alarm Model (DBAM) was used (Vituki, 1996). The following modifications have been made:

- segments smaller than 10 km were joined into larger units (especially the Slovak rivers);
- parallel stretches were joined to singular stretches with a comparable cross section and length (Gabcikovó Channel, two Drava stretches, Borcea and Macin).

The DBAM does not contain the German part of the Danube. Therefore, the schematization of DBAM was extended based on data supplied related to the National Review of Germany. The result was a schematization of 189 segments (see Figure 2.1 and Figure 2.2). Annex 1 provides an overview of all segments. Annex 2 summarises the data used for the German part of the Danube. Note that the Austrian part of the Mura and Drava rivers is not included in the schematization.

The schematization of the *catchment* is very simple: the catchment is divided over the Danube countries. This is done since the assessment of the diffuse sources is done at the country level.

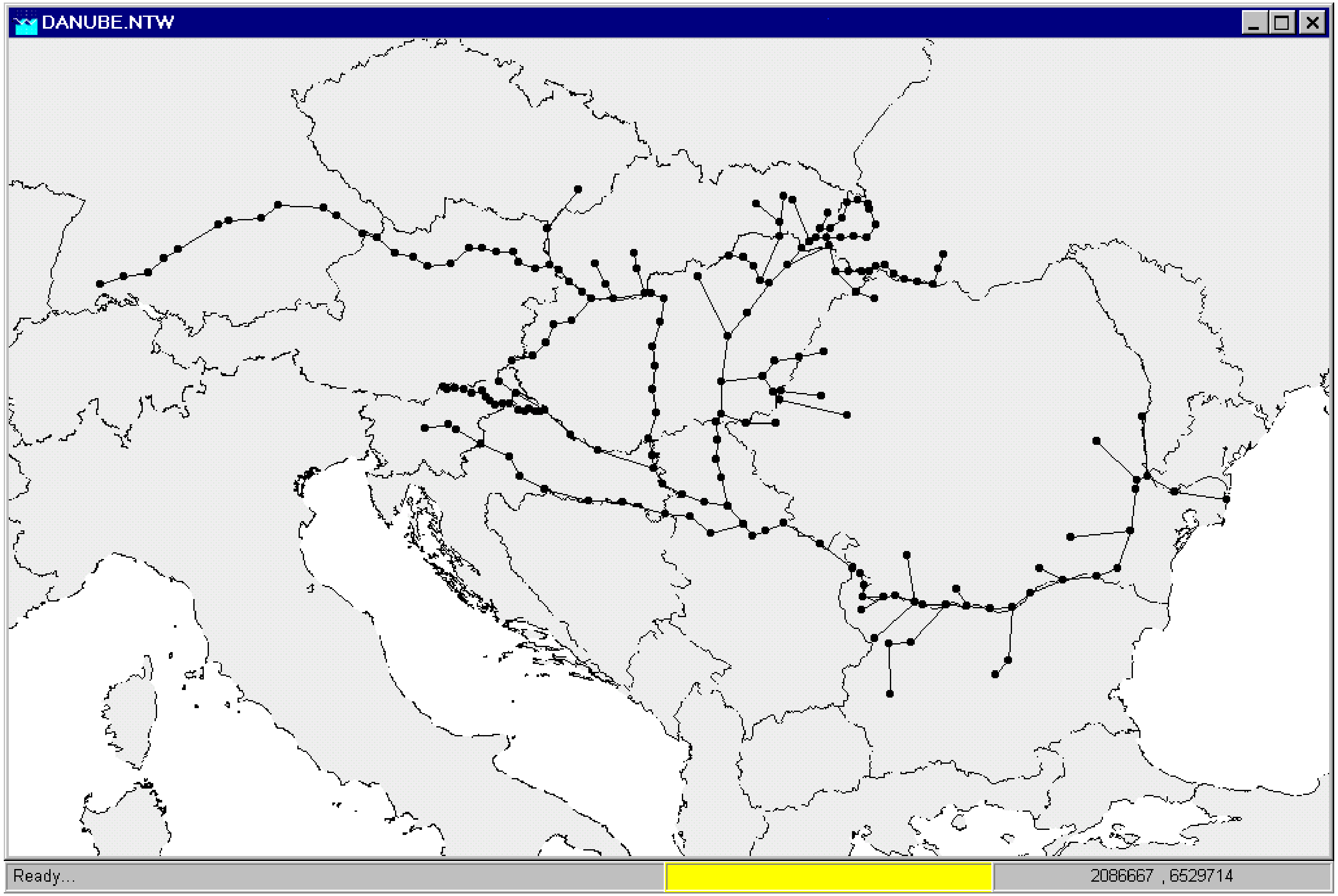


Figure 2.1. Map of the Danube area with the river network schematization.

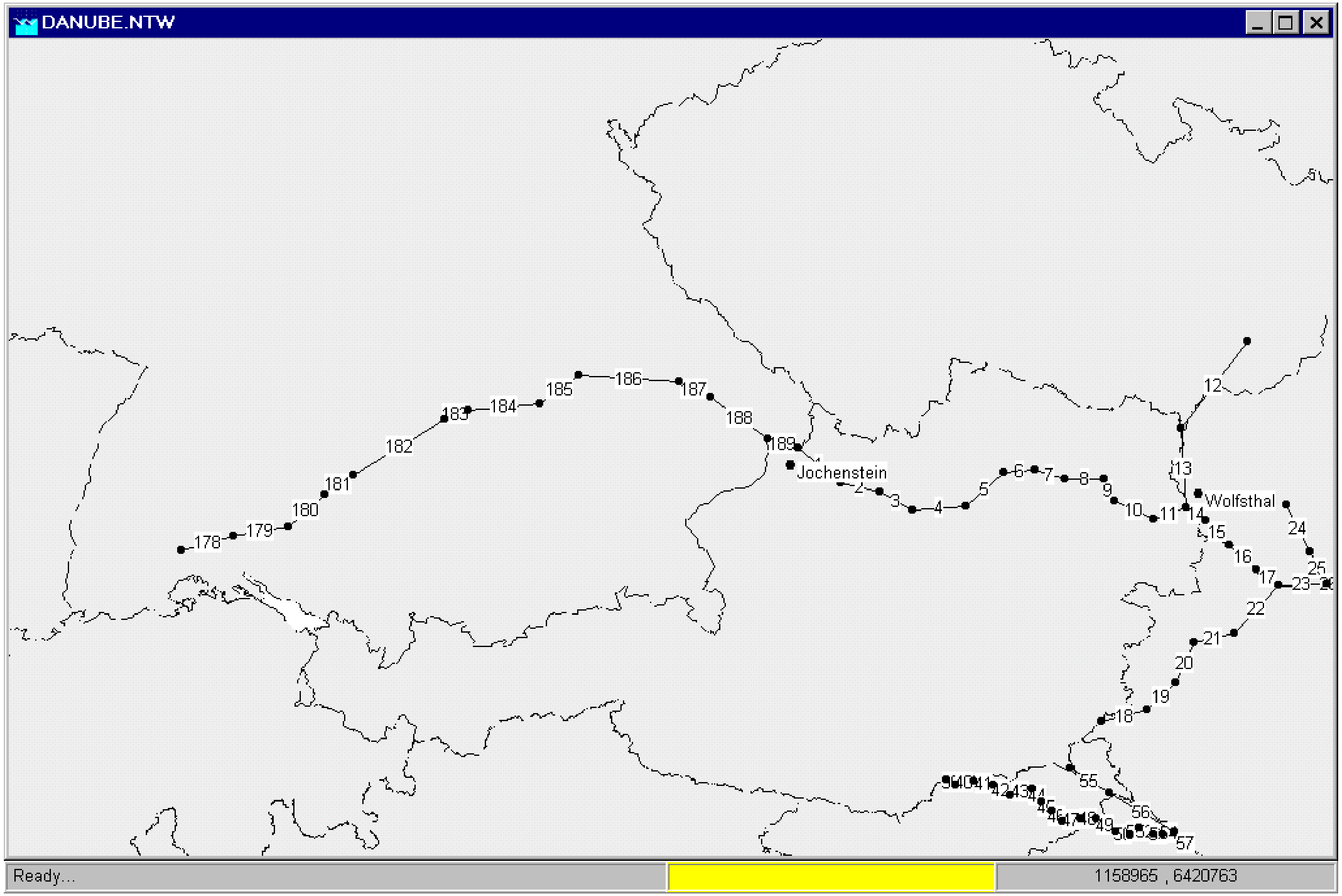


Figure 2.2a: Model segments and main water quality stations in the Upper Danube basin.

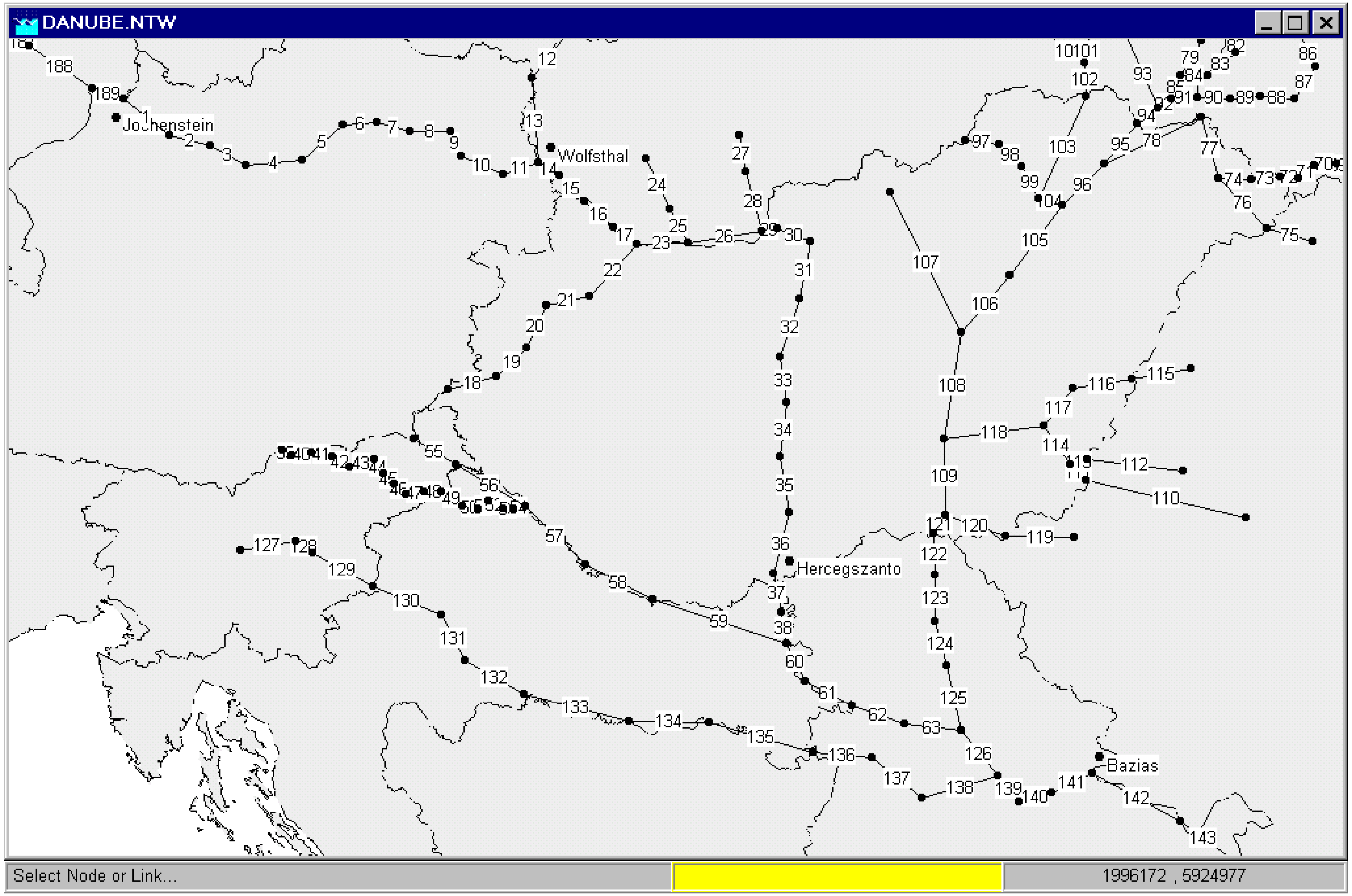


Figure 2.2b: Model segments and main water quality stations in the Middle Danube basin.

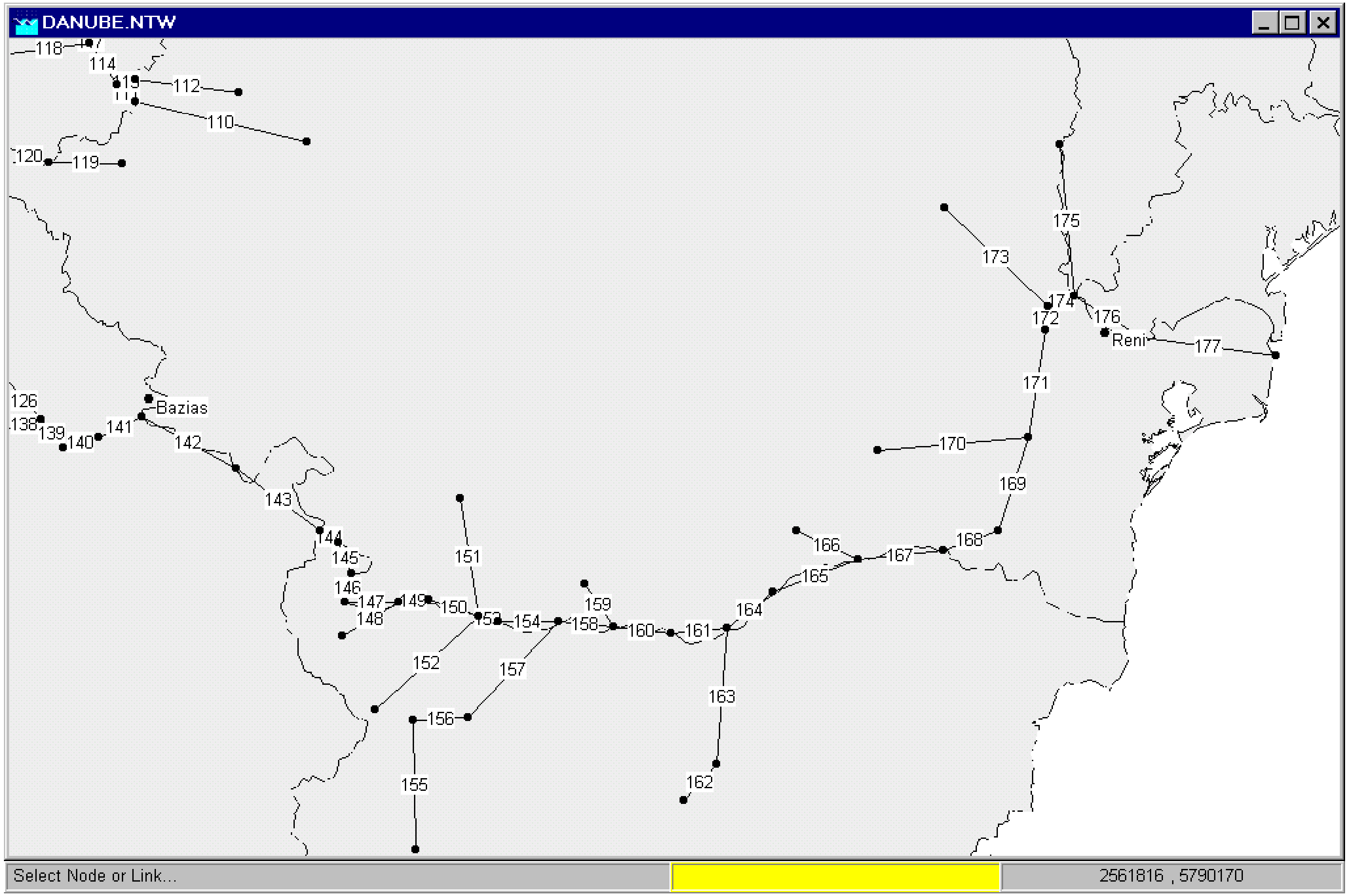


Figure 2.2c: Model segments and main water quality stations in the Lower Danube basin.

3. Set-up of the Water Balance Model

3.1. Introduction

The water balance model forms the necessary basis for the water quality model. Its purpose is to compute the water balances for all computational segments. In particular, the following quantities should be computed for the segments, as a function of time:

- the inflows and outflows (m^3/s);
- the water volume (m^3);
- the streamflow velocity (m/s);
- the water depth (m).

The set up of the water balance model is done in three steps:

1. the mapping of the catchment of the Danube;
2. the computation of the flows;
3. the computation of the remaining segment characteristics.

The composition of the water balances is based on measured flow data for a number of specific stations. In between those stations, the diffuse inflows are back-computed. In this procedure, the unknown diffuse inflows are assumed proportional to the increase of the catchment area along the river. For this purpose, a mapping of the catchment to the river network is made.

3.2. Mapping of the Catchment

The mapping of the catchment is based on information about the total catchment area along the river and the division of the total catchment over the Danube countries, from different information sources:

- the National Reviews;
- the Danube Hydrology review by Stancik ea. (1988).

The data used for the model are listed in Annex 3.

Based on this information an interpolation was made to find the total catchment and the division over the Danube countries for all river network segments. The interpolation was made proportional to the length of the river segments. The result is shown in Figure 3.1 for the segments along the Danube. From this information also the *increase of the catchment per river segment* could be computed, divided over the Danube countries.

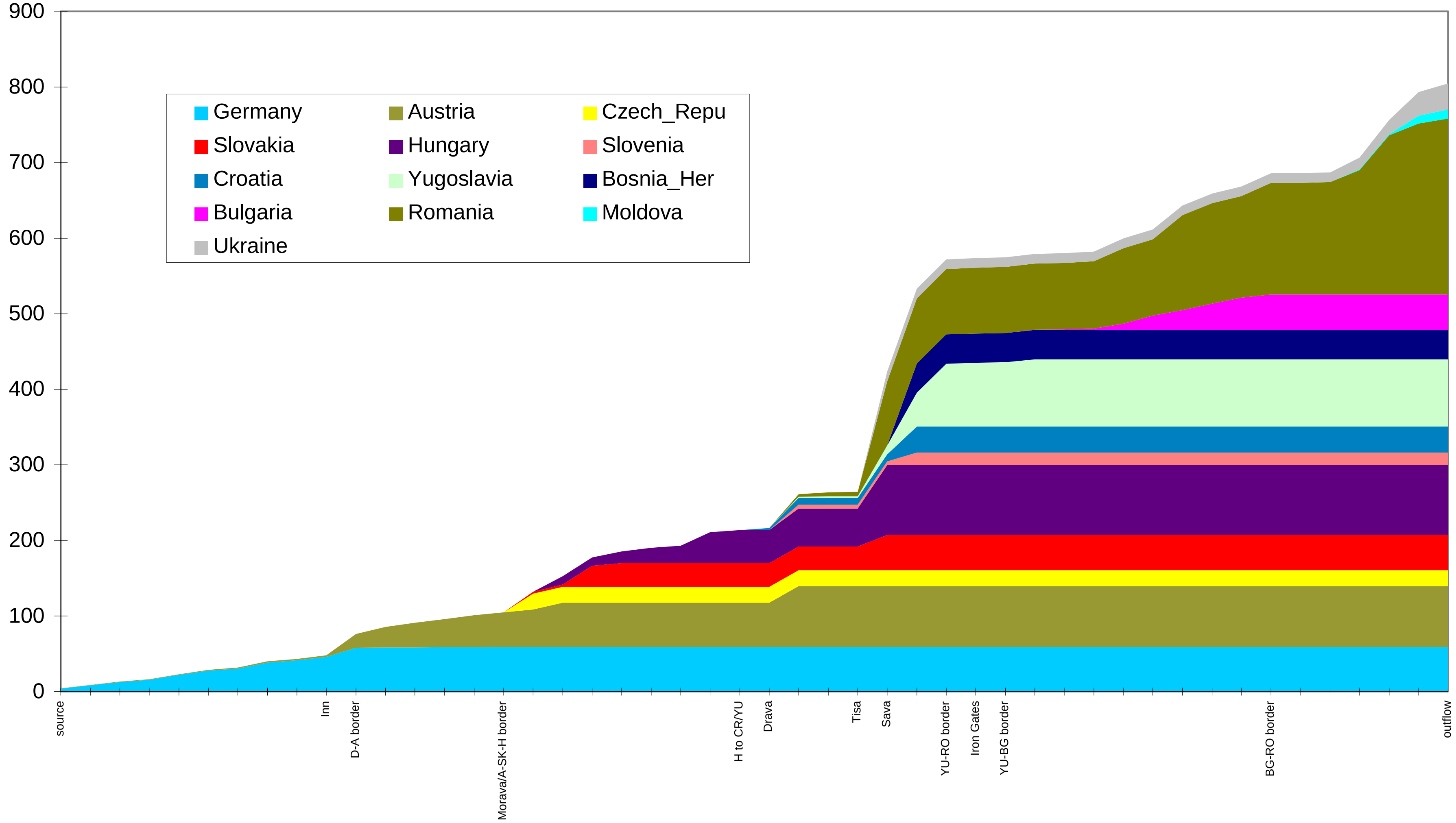


Figure 3.1: Longitudinal profile of the catchment area (in 1000 km^2) along the Danube, subdivided over the Danube countries.

3.3. Methodology for the Computation of the River Flows

For a number of locations the river flows are measured. For the segments between two measured locations, the flows are interpolated. The interpolation is made proportional to the catchment area, which was computed earlier. Meanwhile, the diffuse inflows per river segment are computed from the steady state water balance equation per segment:

$$\frac{\partial Q}{\partial x} = q \qquad (0.1)$$

or, for one discrete segment:

$$\frac{Q_{out} - Q_{in}}{L} = q \qquad (0.2)$$

with Q discharge (m^3/s)
q lateral inflow ($m^3/s/m$)
x longitudinal co-ordinate (m)
L segment length (m)

The lateral inflow for every segment is divided over the Danube countries, proportional to the division over the countries of the catchment increase of the segment in question. This division is relevant for the computation of the diffuse pollution loads later on. The procedure described above is done for subsequent hydrological periods. So far, we work with monthly averaged hydrological conditions: so we work with periods of one month.

The methodology described above has some advantages. The method works even with only one measured time series for the river flow: if the flow at the delta is given, all other flows can be computed. A simple longitudinal interpolation is made, proportional to the longitudinal distribution of the catchment area. Of course, this approach would not be accurate. The accuracy can be increased freely by adding more time series for the flow at other locations in the Danube basin. In other words: the method offers an optimal flexibility. As a result of this flexibility, the method allows for local refinements whenever that is necessary to analyse specific projects or clusters of projects.

The method also has a disadvantage. The method can not deal with bifurcations. For this reason, some parallel stretches were artificially joined in the schematization (see paragraph 2).

3.4. Methodology for the Computation of the Remaining Segment Characteristics

The computation of the remaining segment characteristics is based on:

- ➢ the steady-state river flow patterns which are computed for every hydrological period (see paragraph 3.3);
- ➢ river cross section data;
- ➢ river slope data.

Again, the data within the Danube Basin Alarm Model are used as a starting point. The DBAM contains tabulated *cross section data*, which can be one of the following types:

a. table of water level, wet cross section and river width;
b. table of river flow, wet cross section and river width;
c. table of river flow, streamflow velocity and river width.

For the tables of type c), the wet cross section A is computed by dividing the flow Q by the velocity V. Also, the water depth H is computed for all tables by dividing the wet cross section A by the width W. For the tables of type a) the river flow is computed by means of the Manning formula. This is a simplified momentum equation, valid for free flowing river stretches:

$$Q = \frac{1}{n} A R^{2/3} \sqrt{S} \qquad (0.3)$$

with
Q discharge (m^3/s)
n Manning coefficient ($s/m^{1/3}$), value used: 0.03
A wet cross section (m^2)
R hydraulic radius (m), approximated by the water depth
S slope (m/m)

Data for the river slope were again initially used from the DBAM. For quite a number of segments the DBAM does not provide river slope data. Missing information was completed from the National Reviews and Stancik ea. (1988). From the resulting tables, the following analytical functions are derived:

$$V = aQ^b \qquad H = cQ^d \qquad (0.4)$$

with
V streamflow velocity (m/s)
H water depth (m)

Annex 1 shows the result of this analysis.

For every hydrological period and for every computational segment, the following procedure is followed:

- the steady state flow Q is used to compute the velocity V and depth H by formula (0.4);
- the wet cross section A is computed as Q/V;
- the segment volume is computed by multiplying the cross section A and the segment length L.

The final step is a correction of the river flows Q, to account for the variation of the wet cross-sections A. This is done to satisfy the water balance equation for all segments:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \qquad (0.5)$$

or, for one discrete segment:

$$\frac{Q_{out} - Q_{in}}{L} + \frac{A^{t+\Delta t} - A^t}{\Delta t} = q \qquad (0.6)$$

with
Q discharge (m3/s)
A wet cross section (m2)
q lateral inflow (m3/s/m)
x longitudinal co-ordinate (m)
t time (s)
L segment length (m)

4. Set-up of the Water Quality Model

4.1. Pollution Sources

During the development and the validation of the DWQM a methodology has evolved to look at pollution sources and their effects, which can be briefly summarised by figure 4.1.

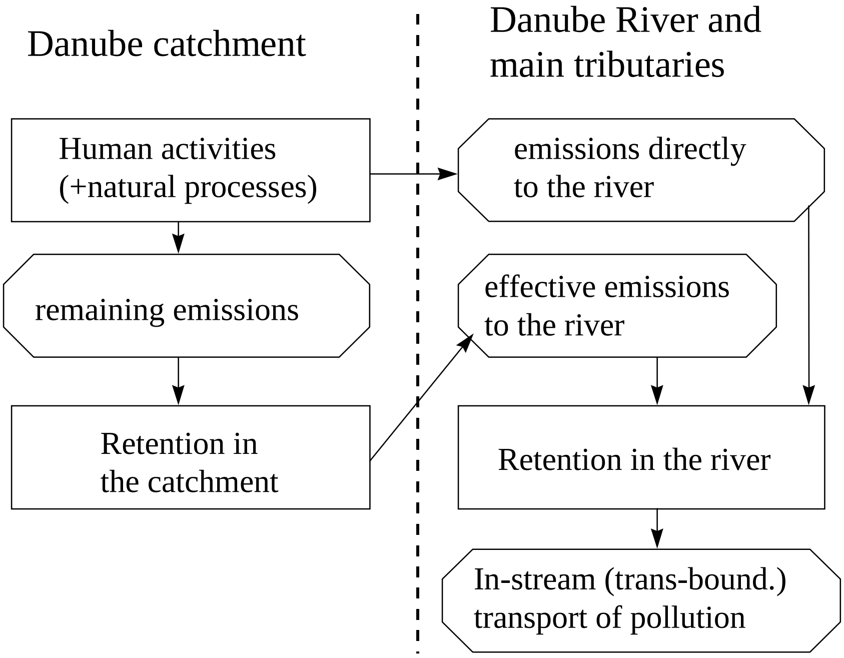


Figure 4.1. Overview of the overall methodology

Figure 4.1 is split in two parts: on the right side the Danube and its main tributaries ("the river network", see paragraph 2), on the left side the remaining catchment. The main element of the methodology is that what we usually call "emissions", does not directly reach the river where it contributes to the "in-stream (transboundary) transport of pollution". A substantial part of the emissions is subject to "retention in the catchment", which reduces the resulting "effective emissions to the river", and therefore the "in-stream (transboundary) transport of pollution". The remainder of this paragraph will further elaborate the methodology.

The pollution sources can be introduced in the model in four ways:

- as a point emission;
- as a distributed emission, causing a constant load in the river;
- as a distributed emission, causing a constant concentration in the river;
- as a distributed emission, causing a concentration proportional to the river flow.

If point sources are located on or very close to those river stretches which are explicitly included in the model (see paragraph 2), they are introduced in the model as a point emission at the correct location in the network. ("emissions directly to the river", figure 4.1). The remaining point sources ("remaining emissions", figure 4.1) are treated as a distributed emission causing a constant load in the river. The difference between these two options is very significant. The latter are subject to a substantial "retention in the catchment" (figure 4.1), whereas the former will *not* be subject to this retention (see paragraphs 4.3 and 4.4).Diffuse sources are always treated as "remaining emissions" and introduced in the model as a distributed emission, of one of the three types mentioned above.

In order to describe the introduction in the model of the distributed emissions, we start with the following formula. It describes the concentration in the river as a result of the three types of distributed sources mentioned above (Jolankai, 1992):

$$C(t) = \frac{a}{Q(t)} + b + cQ(t)$$

with:

C concentration (g/m^3)
Q flow (m^3/s)
a constant (g/s), *constant load* part of distributed pollution sources
b constant (g/m^3), *constant concentration* part of distributed pollution sources
c constant (gs/m^6), *increasing concentration* part of distributed sources

The introduction in the model is explained in table 4.1 below. We suppose that the average load of each of the three types is known: W_a, W_b and W_c (g/s). Table 4.2 below describes the division into the classes described above of the pollution sources which have been distinguished in the ARP Project EU/AR/102A/91 “Nutrient balances for Danube countries” study.

Table 4.1. Mathematical description of the methodology to introduce distributed sources into the model

	constant load	constant concentration	concentration ~ flow
momentaneous load (g/s)	a	bQ	cQ^2
length of hydrological period (s)	Δt	Δt	Δt
mass per hydrological period (g)	a Δt	$bQ\Delta t$	$cQ^2\Delta t$
total simulation period (s)	$\sum \Delta t$	$\sum \Delta t$	$\sum \Delta t$
total mass in simulation (g)	$a\sum \Delta t$	$b\sum Q\Delta t$	$c\sum Q^2\Delta t$
average load in simulation (g/s)	$a\frac{\sum \Delta t}{\sum \Delta t} = a = W_a$	$b\frac{\sum Q\Delta t}{\sum \Delta t} = W_b$	$c\frac{\sum Q^2\Delta t}{\sum \Delta t} = W_c$
value of constant	$a = W_a$	$b = \frac{W_b}{\frac{\sum Q\Delta t}{\sum \Delta t}}$	$c = \frac{W_c}{\frac{\sum Q^2\Delta t}{\sum \Delta t}}$
momentaneous concentration (g/m^3)	$\frac{W_a}{Q}$	$\frac{W_b}{\frac{\sum Q\Delta t}{\sum \Delta t}}$	$\frac{W_c Q}{\frac{\sum Q^2\Delta t}{\sum \Delta t}}$

Table 4.2. **Classification in modelling terms of the pollution sources described in the Nutrient Balances project**

Point Sources	Classification	Code
discharges from sewer systems (treated and untreated)	point source, or distributed with constant load	(a)
discharges of industry (treated and untreated)	point source, or distributed with constant load	(a)
effluents from manure treatment plants	point source, or distributed with constant load	(a)
Diffuse Sources	**Classification**	**Code**
direct discharges of private households	distributed with constant load	a
storm water overflow	distributed with constant load	a
direct discharge of manure	distributed with constant load	a
base flow	distributed with constant concentration	b
erosion, runoff (from agriculture land)	distributed with concentration proportional to flow	c
erosion, run-off from forests and others	distributed with concentration proportional to flow	c

4.2. Updating and Completing the Pollution Sources Estimates

The baseline values for the pollution sources estimates have been derived from the ARP Project EU/AR/102A/91 “Nutrient balances for Danube countries” for 1992. Table 4.3 below summarises a methodology which could be used to apply corrections to these numbers to account for the time difference between 1992 and the target years 1994-1997 for the present analysis. Note that the uncertainty in the Nutrient Balances emissions estimates is “in the order of magnitude of 50% or so” (quote from the final report). This uncertainty is not equal for all emissions however: the discharges from WWTP’s for example are computed with a much smaller uncertainty.

Table 4.3 **Overview of Updating of Pollution Source Data**

Point Sources	Correction	Code
discharges from sewer systems (treated and untreated)	updated based on EMIS inventory and Hot Spots list from National Reviews	(a)
discharges of industry (treated and untreated)	updated based on EMIS inventory and Hot Spots list from National Reviews	(a)
effluents from manure treatment plants	updated based on Hot Spots list from National Reviews	(a)
Diffuse Sources	**Correction**	**Code**
direct discharges of private households	correction proportional to the change of the population number not connected to sewers	a
storm water overflow	correction proportional to the change of the population number connected to sewers (not applicable to Austria and Germany)	a
direct discharge of manure	correction based on change in number of cattle	a
base flow	*no correction applied for calibration run* (time scale for reactions is long), for mid-term predictions correction proportional to change of percolation, percolation of human waste corrected proportional to change of population, percolation of agriculture areas corrected proportional to change of area of agricultural land and change in fertiliser application; percolation of other areas corrected proportional to change of area.	b
erosion, runoff (from agriculture land)	correction proportional to change of area of agricultural land and change in fertiliser application	c
erosion, run-off from forests and others	correction proportional to change in area	c

Note: The corrections described in this table will NOT be applied in the remainder of this report, because of a lack of coherent data.

In some cases it was necessary to estimate data rather than update them, e.g. for Yugoslavia, Bosnia and Croatia. These countries were not a part of the Nutrient Balances project. We tried to derive “average emission factors” from the countries that were included in the Nutrient Balances project and applied those to the countries for which data were missing. Table 4.4 below provides an overview. Note that the emission factors are derived after the corrections listed in table 4.3 have been applied.

Table 4.4. Overview of methods for estimating pollution source data for Yugoslavia, Bosnia and Croatia.

Point Sources	Method for estimate	Code
discharges from sewer systems (treated and untreated)	data used from EMIS inventory and Hot Spots lists in National Reviews, if necessary estimated from average emission per inhabitant connected to sewer systems	(a)
discharges of industry (treated and untreated)	data used from EMIS inventory and Hot Spots lists in National Reviews, if necessary estimated from average emission per inhabitant	(a)
effluents from manure treatment plants	data used from Hot Spots lists in National Reviews	(a)
Diffuse Sources	**Method for estimate**	**Code**
direct discharges of private households	based on average emission per inhabitant not connected to sewers	a
storm water overflow	based on average emission per inhabitant connected to sewers	a
direct discharge of manure	based on average discharge per unit cattle	a
base flow	based on average ratio between percolation and base flow, estimate percolation from agriculture areas based on average percolation per unit area of agricultural surface, estimate percolation of human waste based on average percolation per inhabitant, estimate percolation of other areas based on average percolation per unit surface area	b
erosion, runoff (from agriculture land)	based on average per unit area of agricultural surface	c
erosion, run-off from forests and others	based on average per unit surface area	c

4.3. Modelling the Behavior of Phosphorus

4.3.1. Synthesis of Phosphorus Retention Model

Different authors have demonstrated that the observed in-stream loads of phosphorus are much smaller than the emissions estimates (Behrendt ea., in press, Behrendt ea., 1997, Behrendt, 1996, University of Vienna ea., 1997, Zessner ea. 1998). This difference, called "retention in the catchment", is not yet fully understood. Zessner and other references argue that the retention in the catchment is a function of the area specific run-off. The natural system is apparently more effective in "flushing" phosphorus into the river under high area specific run-off conditions. Phosphorus retention is believed to be related to sedimentation and (temporal) storage in the sediments of the phosphorus absorbed to suspended solids. Under high flow conditions, this material may be eroded, carried away by the flood and deposited elsewhere. Since we almost never measure under high flow conditions, the associated in-stream load is almost never observed. It is possible that a more or less lasting retention is obtained in the floodplains of the river.

The retention of phosphorus can not be explicitly modelled, for different reasons:

1. The associated phenomena are not yet completely understood.
2. The transport of phosphorus is governed by peak flows, which are not modelled explicitly.

With the modelling objectives in the present project in mind, it is very well possible to parametrize the retention phenomenon. The phosphorus emissions can be reduced by an empirically derived "immission/emission-ratio". A range for this factor was derived from Behrendt ea. (in press). The values reported by Behrendt are intended to be applied to the estimated emission to the surface water. Therefore, in the present exercise these values can be applied directly to the emission data from the ARP Project EU/AR/102A/91 “Nutrient balances for Danube countries” (University of Vienna ea., 1997). Table 4.5a provides an overview of the immission/emission-ratios.

Table 4.5a Immission/emission ratios for phosphorus, based on research presented in (Behrendt, in press).

Country	Area specific runoff (l/km2/s)	high estimate for immission/emission factor P	low estimate for immission/emission factor P
D	13.1	90	66
A	19.3	100	72
CZ	5.1	53	30
SK	5.1	53	30
H	2.3	36	5
SL	17.5	100	70
CR	6.4	61	41
YU	7.7	67	50
BiH	17.5	100	70
BG	4.6	50	25
RO	4.6	50	25
MD	6.4	61	41
UA	12.0	86	64

The area specific runoff data are derived from Stancik ea., and afterwards proportionally reduced in order to match the average Danube flow in 1994-1997 (6491 m3/s).

Paragraph 4.3.2 tries to estimate whether the yearly accumulation of phosphorus in the Danube catchment floodplains can be responsible or not for a more or less lasting retention of phosphorus. Paragraph 4.3.3 quantifies another retention process *inside the river system*, which is believed to be important for the Danube: the retention in the Iron Gates lakes.

4.3.2. Retention of P in Floodplains

A typical net sedimentation rate in floodplains in the Rhine catchment, measured as a long term average, is between 0.2 to 10 mm/a (Middelkoop, 1997). Typical total concentrations of phosphorus in non-flood conditions are around 100-200 µg/l, half of which is adsorbed to around 50-100 mg/l of suspended matter. Thus, the average phosphorus content of suspended matter is between 500 and 2000 mg/kg. The surface of the floodplains in the Danube basin can be estimated from National Review data. The total of all floodplains reported per country can be estimated at around 25,000 km^2 (Appendix 10). The most detailed National Review in this respect is that from Romania, which reports 7,452 km^2 of floodplains. If we scale that up to the whole basin we get about 26,000 km^2 of floodplains. So, a number in this order of magnitude can be expected.

We estimate the yearly net sedimentation of phosphorus based on a long term average sedimentation rate of 1 mm/a. To convert this to dry weight we use a density of 2000 kg/m3. Together with an estimated floodplain area of 26,000 km2 and an estimated phosphorus content of 1000 mg/kg, we compute an indicative number for the corresponding long term averaged phosphorus storage of 52 kt/a. Although the uncertainty in this number is very high, it indicates that the floodplains in the Danube catchment are capable of retaining on average an amount of phosphorus which is of the same order of magnitude as the current yearly emissions.

4.3.3. Retention of P in Large Reservoirs

Iron Gates reservoirs

Perišic ea. investigated the changes of the water quality in the Iron Gates lakes (Perisic ea., 1990). Between kilometres 1116 (Smederovo) and 943 (Kladovo) the suspended solids concentration was found to decrease with 100% for low flows to around 40% for high flows. In particular they found the following correlation between the flow Q and the suspended solids concentration SS in mg/l:

$$SS_{smederovo} = -1.2918 + 0.0057603\,Q \qquad SS_{kladovo} = -11.044 + 0.0043396\,Q$$

The authors did not report on which flow these correlations are based: the entrance flow or the local flow.

A flow-duration-curve for the station Orsova (km 958), obtained from the Romanian National Review, was used to analyse the overall trapping efficiency for suspended sediments. The resulting number is 53% of the annual suspended sediments load. This number can be converted to a "removal coefficient" using estimates for the total residence time which have been provided by Perišic ea. as well. The result is a value of 0.18 per day, which is more or less constant for the whole range of discharges. The average velocity varies between 0.15 and 0.80 m/s. The effective sedimentation velocity is computed for a typical water depth of 15 m: the result is 2.7 m/day.

Perisic ea. provide not enough information to estimate the retention of total N and total P. Also, the National Review of Yugoslavia did not provide enough information to this end.

Gabcikovó/Bös-Nagymaros complex

We have investigated the effect on the water quality of the Gabcikovó/Bös-Nagymaros complex using data for a station just upstream (e.g. Bratislava, Wolfsthal) from the National Reviews and data from a station just downstream (e.g. Medve), supplied by Jolankai (pers.comm.). The results of the investigation do not show any unambiguous proof of retention in the Gabcikovó/Bös-Nagymaros complex. Therefore, we choose not to include such a phenomenon in the model.

4.4. Modelling the Behavior of Nitrogen

4.4.1. Synthesis of Nitrogen Model

Different authors have demonstrated that the observed in-stream loads of nitrogen are much smaller than the emissions estimates (Behrendt ea., in press, Behrendt ea., 1997, Behrendt, 1996, University of Vienna ea., 1997, Zessner ea. 1998). The difference is considered to be primarily caused by denitrification, and to a much lesser extent by a similar retention as with phosphorus. This removal process too seems to be a function of the area specific run-off. The denitrification process is believed to take place in the ground water and in the surface water sediments. Apparently, it is less effective under high area specific run-off conditions.

Most of the denitrification process can not be explicitly modelled, for different reasons:

1. The ground water is not explicitly included in the model.
2. The smaller surface waters are not modelled explicitly (only the Danube itself, some primary and a few secondary tributaries).

With the modelling objectives in the present project in mind, it is very well possible to parametrize the denitrification. The nitrogen emissions can be reduced by an empirically derived "immission/emission-ratio". A range for this factor was derived from Behrendt ea. (in press). The values reported by Behrendt are intended to be applied to the estimated emission to the surface water. Therefore, in the present exercise these values can be applied directly to the emission data from the ARP Project EU/AR/102A/91 “Nutrient balances for Danube countries” (University of Vienna ea., 1997). Table 4.5b provides an overview of the immission/emission-ratios.

Table 4.5b Immission/emission ratios for nitrogen, based on research presented in (Behrendt, in press).

Country	area specific runoff (l/km^2/s)	high estimate for immission/emission factor N	low estimate for immission/emission factor N
D	13.1	73	54
A	19.3	88	59
CZ	5.1	47	22
SK	5.1	47	22
H	2.3	36	5
SL	17.5	85	58
CR	6.4	52	30
YU	7.7	56	37
BiH	17.5	85	58
BG	4.6	45	19
RO	4.6	45	19
MD	6.4	52	30
UA	12.0	70	52

The area specific runoff data are derived from Stancik ea., and afterwards proportionally reduced in order to match the average Danube flow in 1994-1997 (6491 m^3/s).

Paragraph 4.4.2 argues that the denitrification is not constant over the year: it is subject to a distinct temperature dependency. Therefore, the factors provided in table 4.5 have not been applied directly, but with a sinusoidal variation over the year. The lowest reduction has been applied in the winter, the highest in the summer. After some tuning we found that good results were obtained if the winter load was about three times the summer load. Paragraph 4.4.3 tries to quantify the denitrification in the Danube River and its modelled tributaries. This is taken into account as an *additional* retention process.

4.4.2. Correlation between Nitrates and Temperature

Van Dijk ea. (1997) describe a method to estimate the denitrification from water quality measurements. The basis for this method is a correlation between the nitrates concentration and the water temperature. The method assumes that the difference between the nitrates concentration at a low temperature and at higher temperature is due to denitrification. In order to investigate the presence of such a correlation, we have processed data for the stations Jochenstein, Wolfsthal and Hercegszanto. The results are presented in Appendix 4.

The correlation is there for all three stations. It is stronger for Jochenstein and Wolfsthal and less pronounced for Hercegszanto. Van Dijk ea. (1997) argue that a stronger correlation may be expected if the catchment is more homogeneous. Our observations would be in agreement with this, since the character of the catchment is homogeneous up to Wolfsthal and changes towards Hercegszanto.

4.4.3. Nitrates Concentrations along the Hungarian Danube

The Hungarian stretch of the Danube, downstream of Budapest may be a good stretch to study the nitrogen removal in the stream. On this stretch, the flow does not increase significantly and there are no significant point sources. We have investigated the concentrations of nitrogen between Budapest and the Hungarian border in different ways.

The EU/AR/203 project (Vituki, 1997) presents data that allow us to compute the decrease in the *yearly averaged concentration of nitrates*. For the years 1989-1994 the result is a decrease of 7% on average.

Data provided by an Hungarian expert (Jolankai, personal communication) allowed us to analyse the difference between a station downstream of Budapest (Nagytétény) and the Hungarian border for 1994-1997 in detail. The result was as follows:

- there is a systematic decrease in the concentration of N-NO3 of about 10%, which is about constant over the year!;
- there is as systematic decrease in the concentration of total nitrogen of 10% (winter) to 15% (summer).

The length of the analysed river stretch is about 200 km. With a typical streamflow velocity of 0.8 m/s, this accounts for a residence time of 2.9 days. In order to reach a 10% removal on this stretch (summer conditions), a first order removal rate of 0.036 /day is required. This should be converted to a value in m/day using a typical depth of the river stretch in question. A value of 4.5 m yields a denitrification rate of 0.16 m/day.

We believe that this denitrification rate is *not representative* for the Danube. The domestic wastewater and WWTP effluents from Budapest cause the conditions to be extremely favourable for a rapid denitrification, because:

1. there is an abundance of organic carbon to support the denitrification reaction;
2. the oxygen concentration in the water may be reduced;
3. there is a large stock of denitrifying bacteria from the WWTP effluents.

Tonderski found a very strong denitrification in the Vistula river downstream of Warsaw, and argued that it was caused by the facts mentioned above (Tonderski, 1997).

Consequently, a lower value should be selected. We have used 0.05 m/day.

4.5. Computation of In-Stream Nutrient Loads

4.5.1. Methodology

For the computation of the (in-stream) nutrient loads we adopt the methodology proposed by Buijs ea. (1998).

4.5.2. Total Phosphorus Data

The measurement of total phosphorus and the computation of phosphorus loads from the results, presents a number of problems.

The first potential problem, the reliability of the sampling and analysis, will not be further analysed here. There is an ongoing effort in the framework of the MLIM group and the TNMN to improve the sampling and analysis. We will work with the best available data.

The second problem has to do with the sampling frequency in relation to the occurrence of peak flows. Recent work by Kroiss and Zessner (Zessner ea., 1998) indicates that there is a correlation between the river discharge and the total P concentration which shows a more than linear increase for high discharge values. Consequently, floods may carry a more than proportionally large part of the yearly load. In Vienna, 35% of an annual phosphorus load passed in 6 days during the 1997 flood. With the common sampling frequency of once per month, the computed yearly load depends strongly on the flows during the sampling days. With such a low frequency, chances are high that a flood is missed and consequently, a large part of the load is overlooked.

We have plotted the available measurements of total P against the discharge for 5 stations: Jochenstein, Wolfsthal, Hercegszanto, Bazias and Reni (see Appendix 5). For the stations Jochenstein and Wolfsthal the correlation is relatively good, while for the other stations the correlation is weak. Following the assumption that there is a correlation between the river discharge and the total phosphorus concentration, it is possible to estimate the phosphorus load more accurately if daily flow measurements are available. This has been done tentatively for the station of Wolfsthal, assuming a linear relation between the total P concentration and the river flow. The in-stream load estimated based on the daily discharge measurements turned out to be 3 to 41% higher than the load computed by the method proposed by Buijs ea. (1998). The difference was the highest for the year 1996 (41%, with the high summer flood!) and the lowest for the year 1995 (3%). For the years 1994 and 1997 the difference was 10% and 13%. A similar exercise for other stations was not successful, since no clear relation between the total phosphorus concentration and the river discharge could be established.

A third problem is related to the fact that samples are usually taken from the surface only. It can be expected that there exists a vertical gradient in the suspended solids concentration. Consequently, the suspended solids concentration at the water surface is not representative for the whole water column. A sample from the surface causes an underestimation of the vertically averaged suspended solids concentration. Since phosphorus is partly adsorbed to particles, also the total phosphorus concentration derived from a surface sample will be underestimating the vertically averaged concentration.

The *high flow problem* and the *stratification problem* have not yet been investigated thoroughly on a basin-wide scale. As a working hypothesis we will assume that both problems can easily cause an underestimation of about 30% of the river phosphorus load. The combined effect might be an underestimation of up to 50%. In this case the observed value should be multiplied *with a factor of 2!* This factor will be used in the remainder of this report.

4.5.3. Immission Data: Organic Nitrogen

A common problem in the water quality monitoring is the availability of measurements of organic nitrogen. In some cases we have completed the missing data by estimating the total organic nitrogen: the estimated fraction of organic nitrogen is 5% in Germany, 10% in Austria, 15% in Hungary, 18% (Bazias) to 22% (Reni) in Romania.

The share of organic nitrogen (as a percentage of the total inorganic nitrogen) has been estimated to the best knowledge of the Technical Working Group. The number of values to substantiate this knowledge was limited. Should future detailed observations show that these percentages differ strongly from the chosen percentages, this must have subsequent impacts on the results.

5. Available Data and Their Use in the DWQM

5.1. Hydrology

River flow data have been provided in the National Reviews for many locations in the Danube basin. To set up the water balance equation, we use the average flows for a certain hydrological period. In this case the period is one month. The monthly averages should be based on daily observations, in order to obtain realistic averages. Table 5.1 provides an overview of the information processed.

Table 5.1. Overview of monthly averaged flow data

Station	River	Km	TNMN code	Years	Daily data	Source
Jochenstein	Danube	2204	L2130	‘94-‘97	only ‘97	NR Germany
Wolfsthal	Danube	1874	L2170	‘94-‘97	yes	NR Austria
Bezdan	Danube	1425	-	‘94-‘97	yes	NR Yugoslavia
Bogojevo	Danube	1367	-	‘94-‘97	yes	NR Yugoslavia
Novi Sad	Danube	1255	-	‘94-‘97	yes	NR Yugoslavia
Smederovo	Danube	1116	-	‘94-‘97	yes	NR Yugoslavia
Bazias	Danube	1073	L0020	‘95-‘97	no	NR Romania
Gruia	Danube	857	-	‘95-‘97	no	NR Romania
NovoSelo	Danube	834	L0730	'94-'96	no	NR Bulgaria
Giurgiu	Danube	494	-	‘95-‘97	no	NR Romania
Isaccea	Danube	101	-	‘95-‘97	no	NR Romania
S. Mitrovica	Sava	136	-	‘94-‘97	yes	NR Yugoslavia
Senta	Tisa	123	-	‘94-‘97	yes	NR Yugoslavia
Dravaszabolcs	Drava	68	L1490	‘94-‘97	no	NR Hungary
Oancea	Prut	??	-	‘95-‘97	no	NR Romania
Lungoci	Siret	??	-	‘95-‘97	no	NR Romania
Mako	Maros	25	-	‘94-‘97	no	NR Hungary
Csenger	Somes	45	-	‘94-‘97	no	NR Hungary

We have set up the water balance equation for the years 1994-1997, based on flow time series for the following stations:

- Jochenstein: at the border between Germany and Austria;
- Wolfsthal: at the border between Austria and Slovakia;
- Bezdan: just downstream of the border between Hungary and Yugoslavia;
- just upstream of the Danube delta;
- stations near the mouth of the tributaries Drava, Tisa, Sava, Siret and Prut;
- stations near the mouth of the Tisa tributaries Somes and Maros.

The data needed some processing, in order to: (1) assure the monotonous increase of the flow along the river and its tributaries, and (2) to complete some time series for the period 1994-1997. The corrections applied were as follows:

- the time series for the Romanian station Gruia was completed from a correlation with the nearby Bulgarian station Novo Selo (the relation used was: $Q_{Gruia} = 0.97\ Q_{NovoSelo}$);

- the time series for the Prut and Siret rivers were completed from a correlation with the station Gruia ($Q_{Prut} = 0.019\ Q_{Gruia}$, $Q_{Siret} = 0.039\ Q_{Gruia}$);
- the time series for the station Isaccea near the delta was completed from a correlation with the station Gruia ($Q_{Isaccea} = 1.22\ Q_{Gruia}$);
- the monotonous increase of the flow between Bezdan and the delta was forced by "constructing" a time series for the flow just upstream of the delta:

$$Q_+(t) = Q_{Bezdan}(t) + Q_{Drava}(t) + Q_{Tisa}(t) + Q_{Sava}(t) + Q_{Siret}(t) + Q_{\mathrm{Pr}\,ut}(t)$$

$$Q_{Delta}(t) = Average\left(\frac{Q_{Isaccea}}{Q_+}\right) \times Q_+(t)$$

Figure 5.1 shows the time series of the monthly averaged flows for the stations Jochenstein, Bezdan and "delta" and for the main tributaries.

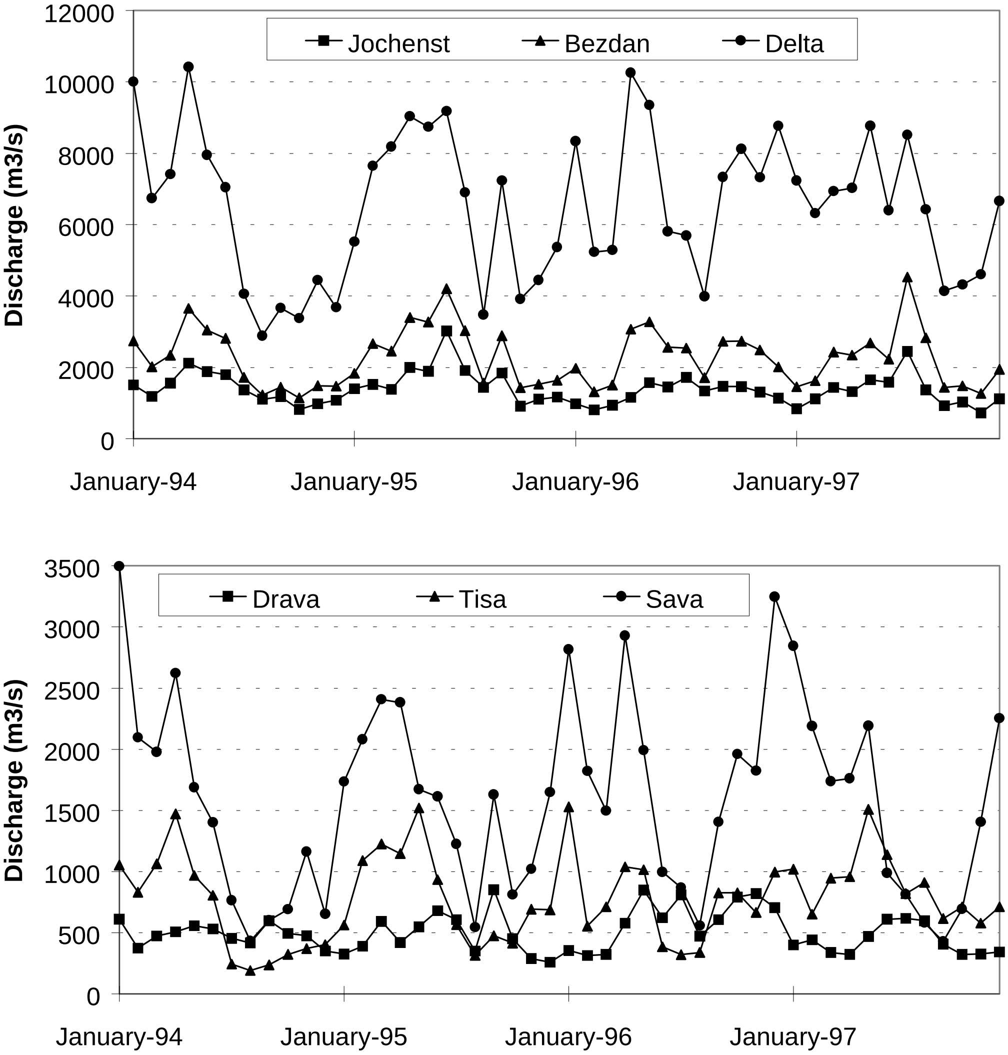


Figure 5.1. **Some time series of monthly averaged flows used in the water balance model: (a) Jochenstein (border Germany and Austria), Bezdan (border Hungary and Yugoslavia) and the delta; (b) the Drava, Tisa and Sava tributaries.**

As it was discussed in paragraph 3, the methodology assumes a constant area specific runoff between stations where the flow is prescribed. In some areas we found that this condition was not satisfied. Therefore, we prescribed the river discharge at a number of additional locations. We did that in a relative way:

- the flow in the Morava river was specified as 5% of the Danube flow in Wolfsthal (based on actual flow data for 1994-1997);
- the flow in the Tisa river at Tiszabecs, near the Ukrainian border, was specified as 25% of the total Tisa flow (based on actual flow data for 1994-1997);
- the flow in the Inn river was specified as 53% of the Danube flow in Jochenstein (based on average data from the National Review of Austria);
- the flow in the Mura river at the Austrian-Slovenian border was specified as 30% of the total Drava flow (based on actual flow data for 1994-1997, supported by average data from the National Review of Austria);
- the flow in the Drava river at the Austrian-Slovenian border was specified as 50% of the total Drava flow (based on actual flow data for 1994-1997, supported by average data from the National Review of Austria).

5.2. Point Sources

The available data regarding point sources are supposed to answer two questions: (1) how big is the total emission of nitrogen and phosphorus from point sources?, and (2) which are the most important individual point sources?

The remainder of paragraph 5.2 and paragraph 5.3 discuss the answers to these questions as they were given during the set-up and validation of the DWQM. With these data, also the simulations in support to the Transboundary Analysis were conducted. These data have one important drawback: the total emissions estimates from the Nutrient Balances project (University of Vienna ea., 1997) are based on data for 1992. During the course of the current project, new data became available about the estimated total emissions, this time based on information from 1996-1997, derived from the National Reviews (University of Vienna, 1999). These new data were used for the simulations conducted in support to the Pollution Reduction Programme, presented in chapter 8.

The data developed for 1996-1997 do not show a clear trend if they are compared to the data for 1992. Either such a trend is not present, or the basic data do not allow an analysis refined enough to detect it.

The newly developed data replace those mentioned in table 5.2 (except for Croatia, Yugoslavia, Bosnia-Herzegovina) and table 5.3. The new data are listed in appendix 12.

5.2.1. Available Information

The following sources of information are available:

- overall estimates of point sources for 1988-1989 and 1992 from the Nutrient Balances project (University of Vienna ea., 1997);
- the current results of the EMIS inventory of point sources from domestic and industrial origin;
- the list of hot spots from the National Reviews compiled in the framework of the present project.

Nutrient Balances project

The point sources estimates from the Nutrient Balances project aim at covering all point sources. They were made for the years 1988/1989 on one hand, and for the year 1992 on the other hand. We used only the data for 1992. A further refinement of the data has been used (Zessner, pers.comm.), see Appendix 7.

EMIS Inventory

The EMIS inventory of municipal point sources has the objective to cover 75% of the raw waste water load discharged into the sewer system. The EMIS chairman estimates that the EMIS inventory numbers need to be multiplied by 1.33 to 2.0 to obtain estimates of the total emissions from municipal point sources (Mehlhorn, pers.comm.). The data have been collected for the years 1996-1997 for most countries, except for the Czech Republic (1994-1996), Bosnia-Herzegovina (1991) and Moldova (1992-1995). The data for Moldova still have the status "draft".

Some modifications were made to the EMIS database for the present exercise: for the untreated waste water of Budapest, and for most sources from Slovakia the missing phosphorus load was obtained by dividing the nitrogen load by a value of 5.

The EMIS database of industrial point sources is still not complete. Therefore, it can be expected that the total emissions from industry are currently underestimated.

Hot spots list from National Reviews

The emissions from the hot spots reported in the National Reviews will be taken into account as well. For some countries they provide the only available information. Note that the hot spots lists were compiled without any objective to give a complete inventory of point sources.

Figures 5.2 to 5.4 present a graphical overview of the available data.

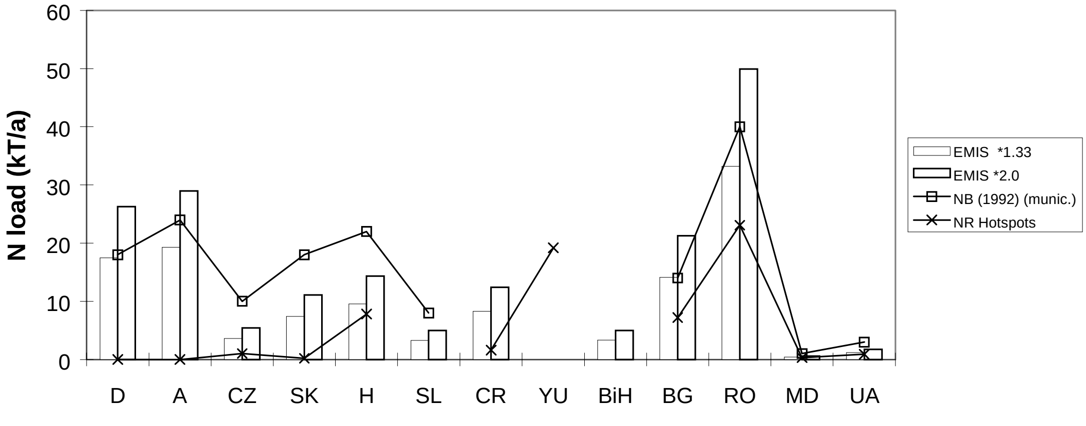


Figure 5.2a **Overview of information about nitrogen loads from municipal point sources.**

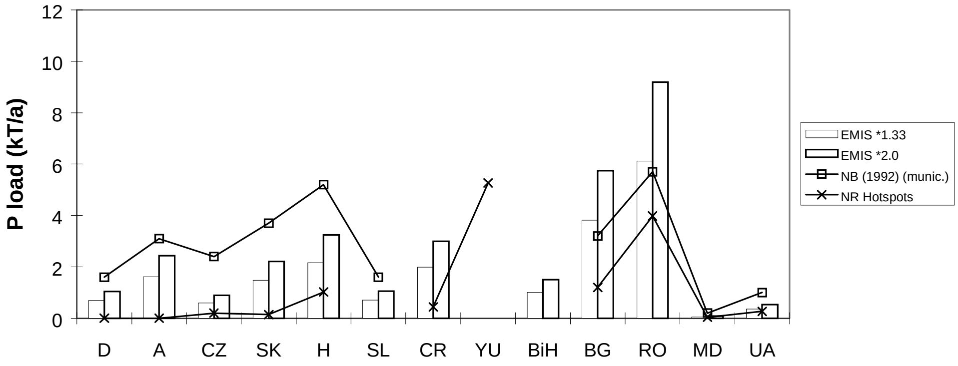


Figure 5.2b **Overview of information about phosphorus loads from municipal point sources.**

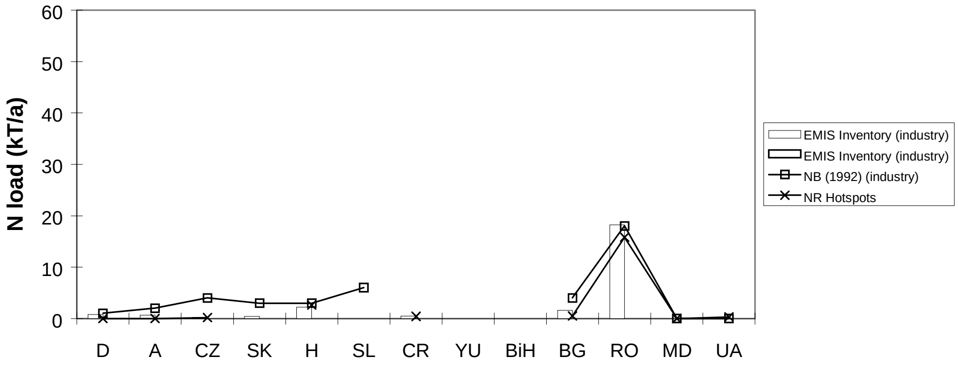


Figure 5.3a **Overview of information about nitrogen loads from industrial point sources.**

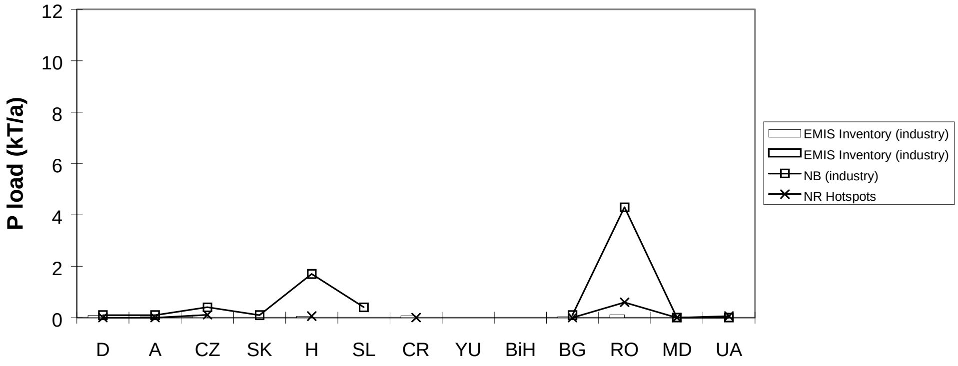


Figure 5.3b **Overview of information about phosphorus loads from industrial point sources.**

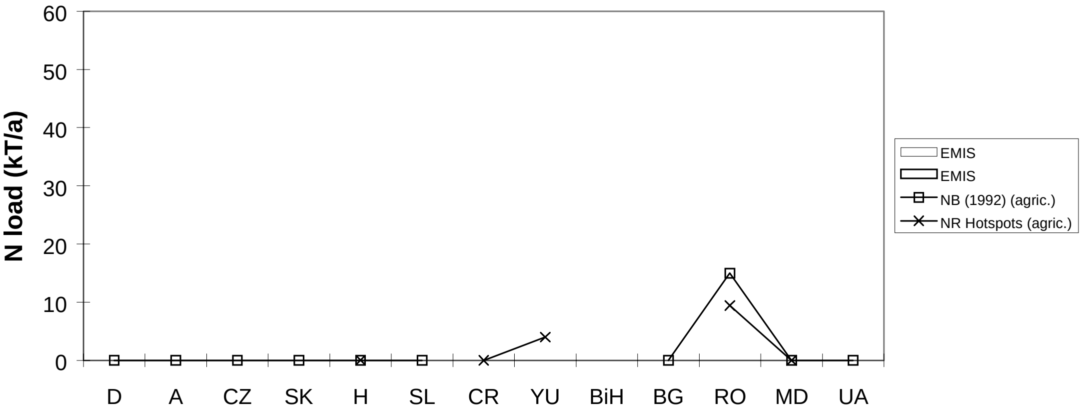


Figure 5.4a **Overview of information about nitrogen loads from agricultural point sources.**

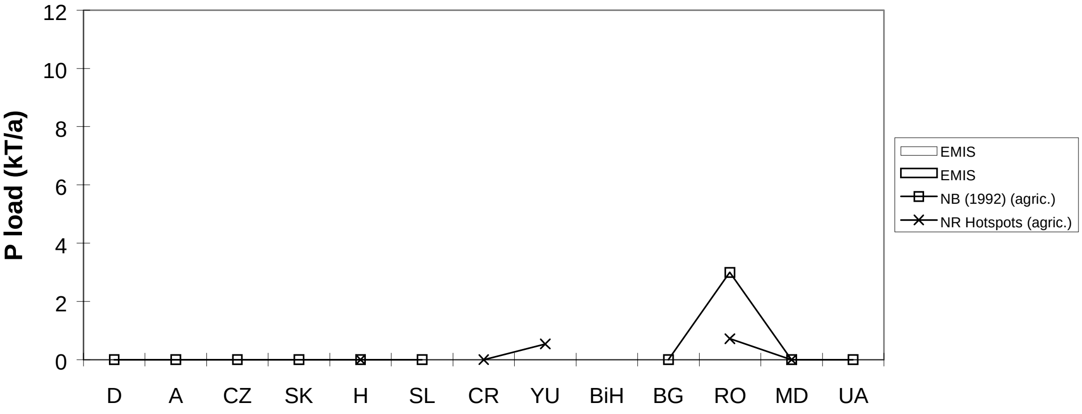


Figure 5.4b: **Overview of information about phosphorus loads from agricultural point sources.**

Only for the municipal point sources it is possible to really compare the data from the Nutrient Balances project and from the EMIS inventory. For some countries we observe that the emission numbers from the EMIS inventory, scaled up by a factor of 1.33 to 2.0, are lower than those from the Nutrient Balances project. This could be due to a smaller coverage of the EMIS inventory than we have assumed. However, if we compare the total PE’s in both information sources, we find that EMIS covers 50% to 86% of the PE’s in the Nutrient Balances study. So, the applied multiplication factor of 1.33 to 2.0 seems adequate. Another possible explanation for the difference is a decrease of point sources between 1992 (Nutrient Balances) and 1996-1997 (EMIS inventory). This is indeed the case for some countries e.g. Germany and Austria.

5.2.2. Total Emissions from Point Sources

From the information described above, we had to make estimates of the total emission from point sources. Since the uncertainty in these numbers is considerably high, we work with a high and a low estimate. Table 5.2 below provides an overview of the selected values, plus the main considerations.

Table 5.2. Estimates of emissions from point sources.

	Municipal				Industrial				Agricultural			
	N (kt/a)		P (kt/a)		N (kt/a)		P (kt/a)		N (kt/a)		P (kt/a)	
	low	high	low	high	low	high	low	high	low	high	low	high
D	17.5	17.5	0.69	0.69	0.8	1.0	0.08	0.10	0.0	0.0	0.0	0.0
A	19.3	19.3	1.62	1.62	0.7	2.0	0.03	0.10	0.0	0.0	0.0	0.0
CZ	3.6	10.0	0.59	2.40	0.2	4.0	0.10	0.40	0.0	0.0	0.0	0.0
SK	7.4	18.0	1.48	3.70	0.4	3.0	*0.05*	0.10	0.0	0.0	0.0	0.0
H	9.5	22.0	2.15	5.20	2.2	3.0	0.05	1.70	0.0	0.0	0.0	0.0
SL	3.3	8.0	0.70	1.60	*3.0*	6.0	*0.20*	0.40	0.0	0.0	0.00	0.00
CR	5.7	8.3	1.00	1.99	0.5	2.0	0.07	0.37	0.0	0.0	0.00	0.00
YU	17.4	19.2	3.04	5.27	*2.8*	5.5	*0.52*	1.04	4.0	6.0	0.54	0.81
BiH	3.3	6.6	1.00	1.15	*0.9*	1.8	*0.17*	0.34	0.0	0.0	0.00	0.00
BG	14.0	14.1	3.20	3.81	1.6	4.0	0.03	0.10	0.0	0.0	0.0	0.0
RO	33.2	40.0	5.70	6.12	18.0	18.2	0.11	4.30	9.4	15.0	0.72	3.00
MD	0.4	1.0	0.05	0.20	*0.0*	0.0	*0.00*	0.00	0.0	0.0	0.0	0.0
UA	1.2	3.0	0.36	1.00	*0.0*	0.0	0.00	0.00	0.0	0.0	0.0	0.0
Total	135.8	187.0	21.6	34.8	31.2	50.5	1.4	9.0	13.4	21.0	1.3	3.8

Main considerations:

- the municipal sources from Austria and Germany were estimated as 1.33 times the EMIS inventory results;
- a high and a low estimate of the municipal sources from Yugoslavia were obtained by the method explained in table 4.4 (see table 5.4) and by taking the sum of the hot spots identified in the National Review;
- a high and a low estimate of the municipal sources from Bosnia-Herzegovina and Croatia were obtained by the method explained in table 4.4 (see table 5.4) and by taking 1.33 times the EMIS inventory results;
- for the municipal sources from the other countries 1.33 times the EMIS inventory results were chosen as a lower value, and the Nutrient Balance results were chosen as a higher value;
- for the industrial point sources we used the data from EMIS and from the Nutrient Balances study as a high and a low estimate (for Austria, the Nutrient Balances numbers have been corrected to reflect the closing of a fertiliser plant);
- for the industrial point sources from Yugoslavia, Croatia and Bosnia-Herzegovina the method presented in table 4.4 (see table 5.4) was selected as a higher estimate;
- for Slovenia (N and P), Bosnia (N and P), Yugoslavia (N and P) and Slovakia (P) only one estimate was present, the lower estimate was set to 50% of this value;
- a high and a low estimate of the agricultural point sources from Romania were obtained by taking the values on the hot spots list and by taking the values from the Nutrient Balances study (the Nutrient Balances numbers have been reduced to 33% of their original values);

- a high and a low estimate of the agricultural point sources from Yugoslavia were obtained by taking the values on the hot spots list and by taking 150% of those values;
- for the agricultural point sources from the remaining countries there are no agricultural point sources.

5.2.3. Important Point Sources

Information about individual point sources has been derived from the EMIS inventory and from the Hot Spots lists in the National Reviews. This information has been processed as follows:

- the lists of point sources from the EMIS inventory and the Hot Spots lists have been merged;
- point sources without (estimates of the) emissions of nitrogen and phosphorus have been removed;
- point sources present in both lists have been identified:
  - if the emission estimates were non-contradictory, the most complete description of the point source has been retained and the other one deleted;
  - if the emission estimates were contradictory, one of the two has been selected on the basis of expert judgement;
- for the remaining list of 730 point sources the total emissions of N and P have been computed: 145.5 kt/a of nitrogen and 21.3 kt/a of phosphorus;
- for each individual source its relative contribution to the total emission of N and P was computed, and the largest number of the two was determined ("maximum relative contribution");
- the point sources sorted according to a descending maximum relative contribution;
- a "small list" of 171 point sources was made up, consisting of the largest point sources which together represent at least 80% of the total emissions of N and P.

Appendix 6 provides the total list of point sources, as well as a number of maps which indicate the position of the point sources on the "small list" in relation to the river network schematization.

5.3. Distributed Emissions

5.3.1. Diffuse Sources from Countries Analysed in the Nutrient Balances Project

The diffuse emissions from all Danube countries, except Croatia, Yugoslavia and Bosnia-Herzegovina have been obtained from the Nutrient Balances project. In appendix 7 we provide an overview of information taken from this project. Paragraph 4.2 describes a approximate methodology to adapt the data from the Nutrient Balances project for the time gap between the target year 1992 in that project and the target period 1994-1997 in the present exercise (table 4.3). We have compiled the necessary "country parameters" to support this correction from the National Reviews. Appendix 8 summarises the results. Looking at the country parameters in appendices 7 and 8 we conclude:

- neither the Nutrient Balances project nor the present National Reviews provide a complete picture of homogeneous quality for all Danube countries;
- there are apparent inconsistencies between data from the Nutrient Balances project and from the present National Reviews;
- it is therefore dangerous to interpret the difference between the information in the Nutrient Balances project and the present National Reviews as "the apparent change of conditions between 1992 and 1994-1997".

For this reason the approximate methodology described in paragraph 4.2 has not been followed. In stead, the data from the Nutrient Balances project have been corrected on the basis of expert judgement only:

- the *direct discharges of manure* from Romania have been reduced by a factor of four;
- the *erosion and runoff of phosphorus* from Hungary has been reduced, since the original numbers correspond to extremely high unit area emissions.

The resulting diffuse sources data are collected in table 5.3.

Table 5.3. Diffuse emissions from countries analysed in the Nutrient Balances project.

Nitrogen (kt/a)	D	A	CZ	SK	H	SL	BG	RO	MD	UA
direct discharges private hh's	n.a.	1.0	3.0	3.0	5.0	1.0	1.0	n.a.	n.a.	n.a.
storm water overflow	2.0	2.0	2.0	1.0	n.a.	1.0	3.0	5.0	n.a.	n.a.
direct discharges of manure	2.0	2.0	n.a.	n.a.	8.0	n.a.	7.0	25.0	n.a.	1.0
base flow	65.0	54.0	13.0	27.0	5.0	4.0	4.0	95.0	3.0	4.0
erosion, runoff (from agriculture land)	11.0	8.0	4.0	10.0	28.0	4.0	6.0	38.0	9.0	17.0
erosion, run-off from forests and others	10.0	9.0	n.a.	n.a.	n.a.	n.a.	2.0	n.a.	n.a.	9.0
Total	90	76	22	41	46	10	23	163	12	31
Phosphorus (kt/a)	D	A	CZ	SK	H	SL	BG	RO	MD	UA
direct discharges private hh's	n.a.	0.20	0.20	0.30	1.50	0.10	0.30	n.a.	n.a.	n.a.
storm water overflow	0.30	0.40	0.30	0.20	n.a.	0.10	0.40	1.10	n.a.	0.10
direct discharges of manure	0.80	0.40	0.10	n.a.	1.60	n.a.	1.80	4.50	n.a.	0.50
base flow	n.a.	0.50	0.10	0.30	n.a.	0.40	0.50	4.30	n.a.	0.40
erosion, runoff (from agriculture land)	5.10	3.10	0.60	1.40	5.00	0.10	0.70	6.80	2.10	2.80
erosion, run-off from forests and others	0.80	0.80	n.a.	n.a.	0.60	n.a.	0.30	n.a.	n.a.	0.90
Total	7.0	5.4	1.3	2.2	8.7	0.7	4.0	16.7	2.1	4.7

n.a.: Insignificant or not reported.

These emission data are valid for the year 1992 (University of Vienna ea., 1997), with modifications regarding the discharges of manure from Romania and the erosion from Hungary (see report text).

5.3.2. Diffuse Sources from the Remaining Countries

The data for Croatia, Yugoslavia and Bosnia-Herzegovina have been estimated based on specific emission factors obtained from the Nutrient Balances project. Paragraph 4.2 describes the methodology which was used (table 4.4). The specific emission factors are presented in appendix 7. The country parameters are presented in appendix 8. The resulting load estimates are presented in table 5.3 below.

Table 5.4. Estimated emissions from Croatia, Yugoslavia and Bosnia-Herzegovina.

	N (kt/a)			P (kt/a)		
	CR	YU	BiH	CR	YU	BiH
industries	2.0	5.5	1.8	0.35	0.98	0.32
direct discharges of private households	0.9	2.3	0.7	0.17	0.43	0.12
storm water overflow	0.6	1.8	0.7	0.10	0.32	0.12
effluents from sewer systems	5.7	17.4	6.6	1.00	3.04	1.15
base flow	14.5	39.3	15.6	0.33	1.01	0.32
erosion, runoff (from agriculture land)	7.1	24.8	7.2	1.45	5.08	1.48
discharge of manure	2.4	8.3	2.4	0.51	1.78	0.52
erosion, run-off from forests and others	1.7	2.4	2.1	0.19	0.28	0.24
TOTAL	34.8	101.7	37.0	4.10	12.93	4.27

This table contains estimates only! The method used for the estimation is explained in paragraph 4.2 of the present report. The basic data used are listed in appendix 8 (country data) and appendix 7 (emission factors, based on the emission estimates from the other Danube countries for 1992). The estimated diffuse emissions are used directly in the remainder of this report. The use of the estimates of point sources is explained in table 5.2!

5.3.3. Introduction in the Model

The diffuse sources from the countries analysed by the Nutrient Balances project (paragraph 5.3.1) and the diffuse sources estimates for Croatia, Yugoslavia and Bosnia-Herzegovina (paragraph 5.3.2) are introduced in the model according to the methodology described in paragraph 4.1. Following table 4.2 the loads are introduced in a distributed way, in three types, e.g. a part causing a constant load in the river, a part causing a constant concentration and a part causing a concentration proportional to the flow.

From the total point sources mentioned in paragraph 5.2.2, a part has been introduced in the model directly as a point emission (paragraph 5.2.3). The remaining load is added to the distributed emissions, of the type that causes a constant load in the river.

5.4. In-Stream Loads

Simultaneous measurements of river flows and concentrations data have been provided in the National Reviews for many locations in the Danube basin. Table 5.5 below provides an overview of the information processed so far.

Table 5.5. Overview of processed concentration and flow data

Station	River	Km	TNMN code	frequency of concentration measurements	flow data available?	organic nitrogen	Data source
Jochenstein	Danube	2204	L2130/-L2220	12 per year	monthly averages	estimated from chlorophyll data	NR Germany and Austria
Wolfsthal	Danube	1874	L2170	12 per year	monthly averages	estimated from chlorophyll data	NR Austria
Hercegszanto	Danube	1435	L1540	about 30 per year	at sampling days only	measured (lower frequency)	NR Hungary
Bazias	Danube	1071	L0020	12 per year	monthly averages	estimated as 18% of total N	NR Romania
Reni	Danube	131	L0430	12 per year	monthly averages	estimated as 22% of total N	NR Romania
Jesenice	Sava	729	L1220/ L1330	6 to 12 per year	monthly averages	measured	NR's Croatia and Slovenia
Zupanja	Sava	254	L1060	12 per year	monthly averages	measured	NR Croatia
Ormoz	Drava	300	L1390	6 to 12 per year	at sampling days only	estimated as 10% of total N	NR Slovenia
D. Miholjac	Drava	78	L1250	12 per year	monthly averages	measured	NR Croatia
Dravaszabolcs	Drava	68	L1610	about 25 per year	at sampling days only	estimated based on measurements as 36% of the total	NR Hungary
Tiszabecs	Tisa	757	-	about 25 per year	at sampling days only	measured	NR Hungary
Tiszasziget	Tisa	162	L1700	about 25 per year	at sampling days only	measured	NR Hungary

Simultaneous measurements of river flows and concentrations data have been used to compute the yearly loads at selected stations. The loads have been computed using the methodology which was proposed in a recent project executed under the responsibility of the MLIM sub group (Buijs ea., 1998). Table 5.6 lists the results.

Table 5.6. Overview of in-stream loads for selected stations.

DANUBE	Year	TN	TP
		kt/a	kt/a
Jochenstein	1994	129	3.8
	1995	139	5.8
	1996	109	3.1
	1997	95	5.3
Wolfsthal	1994	169	6.7
	1995	202	10.0
	1996	179	6.0
	1997	168	7.6
Hercegszanto	1994	179	11.1
	1995	233	13.2
	1996	195	9.9
	1997	166	9.7
Bazias	1994	281	12.9
	1995	385	18.9
	1996	425	15.1
	1997	382	13.2
Reni	1994	366	22.1
	1995	389	30.5
	1996	588	23.0
	1997	473	22.2

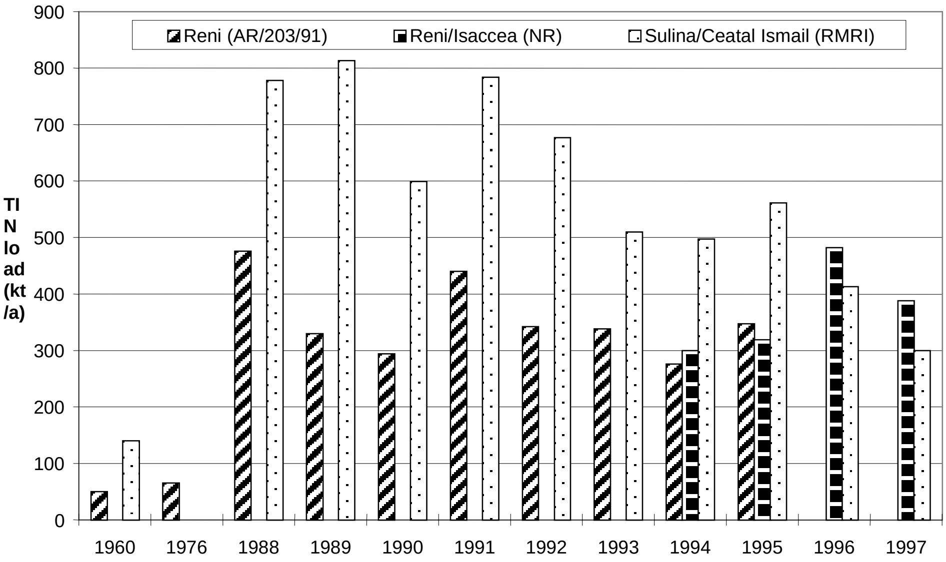
SAVA	Year	TN	TP
		kt/a	kt/a
Jesenice	1994	21	
	1995	29	
	1996	37	
	1997	19	0.5
Zupanja	1994		
	1995	124	
	1996	124	
	1997	130	

DRAVA	Year	TN	TP
		kt/a	kt/a
Ormoz	1994		
	1995		
	1996	16	0.2
	1997		
D. Miholjac	1994	35	1.6
	1995	40	2.9
	1996	46	3.2
	1997	27	1.8
Dravaszabolcs	1994	36	1.8
	1995	47	2.2
	1996	49	2.8
	1997	30	2.2

TISA	Year	TN	TP
		kt/a	kt/a
Tiszabecs	1994	11	0.6
	1995	10	0.8
	1996	5	0.5
	1997	5	0.7
Tiszasziget	1994	53	4.3
	1995	54	4.5
	1996	48	5.5
	1997	63	9.7

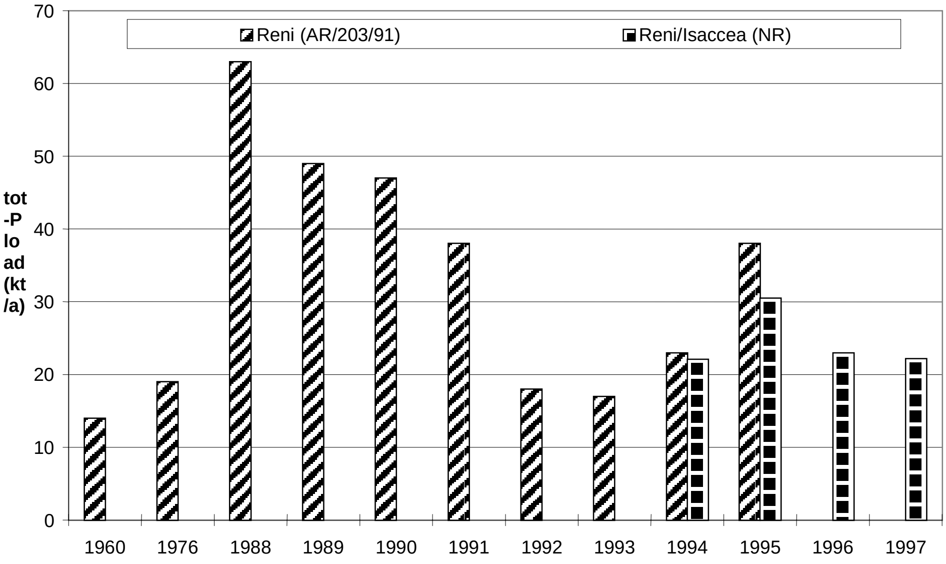
This table contains river load values computed by the author, based on simultaneous measurements of concentrations and discharges, reported in the National Reviews.

It is interesting to compare the Danube nutrient loads at the Delta with historical data. Figure 5.2 provides a comparison with data compiled in the AR/203/91 "water quality targets and objectives" project (Vituki, 1997) and data from (RMRI, 1998).



AR/203/91 uses monthly concentration measurements for the station Reni, Danube km 132 (in the framework of the Budapest declaration) combined with monthly averaged flows. The Romanian National Review uses monthly concentration measurements for the station Reni, Danube km 132 (in the framework of the Budapest declaration) combined with monthly averaged flows for the nearby station of Isaccea.RMRI uses monthly averaged concentration measurements from daily monitoring at Sulina, Sulina branch km 0, combined with monthly averaged flows for the station Ceatal Ismail, Danube km 80.

Figure 5.5a Historic overview of Danube nutrient loads: Nitrogen.



AR/203/91 uses monthly concentration measurements for the station Reni, Danube km 132 (in the framework of the Budapest declaration) combined with monthly averaged flows. The Romanian National Review uses monthly concentration measurements for the station Reni, Danube km 132 (in the framework of the Budapest declaration) combined with monthly averaged flows for the nearby station of Isaccea.

Figure 5.5b Historic overview of Danube nutrient loads: Phosphorus.

Figure 5.5a shows a large difference between the load estimates from different information sources. For 1988-1995 the nitrogen loads reported by (RMRI, 1998) are considerably larger than those reported by (Vituki, 1997) and those computed by the author from data in the National Review of Romania. Only for 1996-1997 the data are more or less consistent. A similar comparison for phosphorus was not possible, since (RMRI, 1998) does not report total phosphorus loads. The large discrepancy in the loads shown in figure 5.5a needs a further investigation. To this end, we plotted the equivalent yearly average flow (figure 5.6a) and the yearly average concentration (figure 5.6b) from the same information sources.

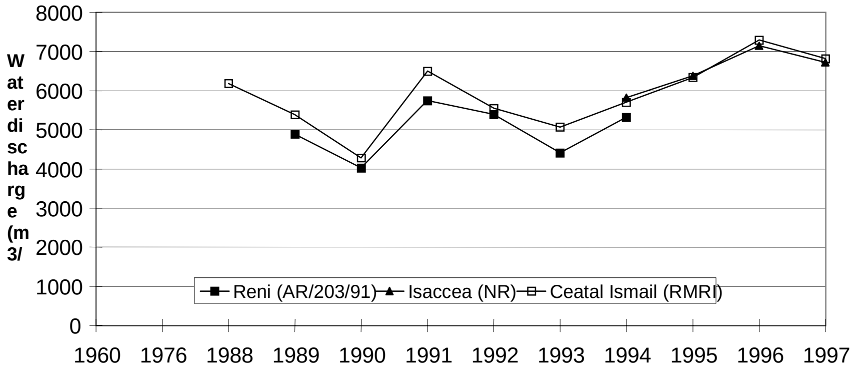


Figure 5.6a **Historic overview of yearly average Danube River discharges.**

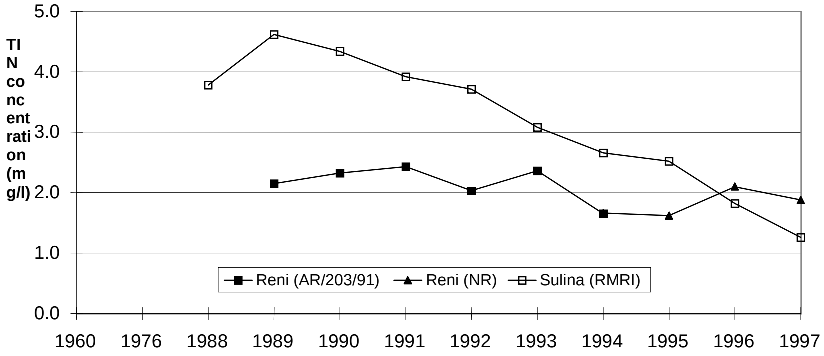


Figure 5.6b **Historic overview of yearly averaged total inorganic nitrogen concentrations near the Danube mouth.**

Figure 5.6 demonstrates a clear explanation for the discrepancies in the inorganic nitrogen loads. The yearly averaged flows are more or less equal in all three information sources. The yearly averaged concentrations however, show dramatic differences between the RMRI data and the other two information sources. It is hard to say what the reason is for this difference. Some possible explanations can be identified:

- the large distance (about 130 km) between the two concentration sampling points, including the complete Danube delta (pers.comm. Popescu);
- differences in sampling and analysis methodologies and quality control procedures.

6. Model Results

The water quality model has been run with the data discussed in paragraph 5. The following 2 “scenarios” have been calculated:

- A “low” scenario: with the lower estimate for the point sources, with 80% of the diffuse sources, and with the lower estimate for the immission/emission ratio.
- A “high” scenario: with the higher estimate for the point sources, with 120% of the diffuse sources, and with the higher estimate for the immission/emission ratio.

6.1. River Discharges

The computed river flows are presented for the following important cross-boundary stations (see Appendix 9):

- station Jochenstein, at the D-A border (where flows have been prescribed);
- station Bezdan, at the H-YU border (where flows have been prescribed);
- station Delta (where flows have been prescribed);
- station Wolfsthal, at the A-SK border (where flows have been prescribed);
- station Smederovo, downstream of the Tisa and Sava tributaries (where flows have been interpolated, based on the prescribed flows in Bezdan, at the Delta, in the Drava, Tisa, Sava, Prut and Siret rivers, and on the catchment profile in between).

The model performance is satisfactory, with one remark.

The modelled flow series at the Delta show higher peaks and lower minima than the observed flow series. This is probably due to an artefact created by the final correction step to satisfy the water balance equation (described in paragraph 3.5). When the flow is going to decrease in the next hydrological period, the model anticipates the expected fall of the water level and increases the flow to compensate for it. This phenomenon sharpens a flow peak. The opposite happens when the flow is bound to increase. It is probably not necessary to apply a correction.

6.2. Nutrient Concentrations

The computed nutrient concentrations are presented for the following important cross-boundary stations :

- station Jochenstein, at the D-A border;
- station Wolfsthal, at the A-SK border;
- station Hercegszanto, close to the H-YU border;
- station Bazias, at the beginning of the common YU-RO Danube stretch;
- station Reni, near the Delta;
- at stations close to the mouth of the Drava (D. Miholjac, km 78, Dravaszabolcs, km 68);
- station Tiszasziget, at km 162 in the Tisa at the H-YU border;
- station Zupanja, at km 254 in the Sava near the CR-YU border.

For nitrogen the following parameters are presented:

- TotN-high: the computed total nitrogen concentration for the “high” scenario;
- TotN-low: the computed total nitrogen concentration for the “low” scenario;
- TotN-obs: the measured total nitrogen concentration (if available);

- TIN-obs: the observed concentration of total inorganic nitrogen, with the estimated organic nitrogen shown as an "error bar" (if TotN is not measured, see paragraph 4.5.3);
- N-NO3-obs: the observed concentration of nitrates (in some cases).

For phosphorus, the following parameters are presented:

- TotP-high: the computed total phosphorus concentration for the “high” scenario;
- TotP-low: the computed total phosphorus concentration for the “low” scenario;
- TotP-obs: the observed total phosphorus concentration, with an error bar representing the *high flow* problem and the *stratification* problem (see paragraph 4.5.2).

If the total nitrogen concentration (including the organic fraction) is not measured, the measured concentrations of total inorganic nitrogen are shown. In this case, an "error bar" is added indicating the estimated organic nitrogen (see paragraph 4.5.3).

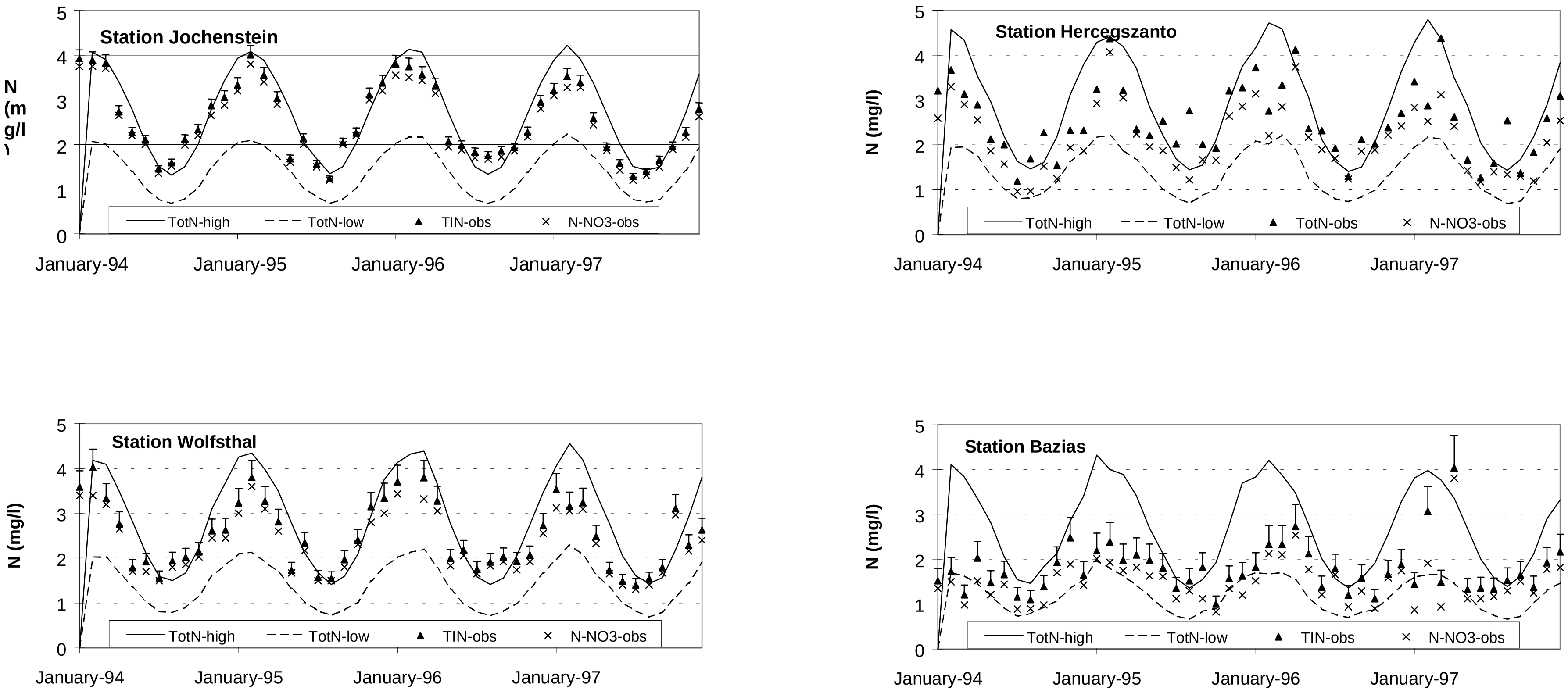
The observed total phosphorus concentrations are shown with an “error bar” on the upper side. This bar has a length of 100% of the measured value, so the top is at 200% of the measured value. Its intention is to visualise the fact that the measured concentrations are not representing the average river load, due to the *high flow* problem and the *stratification* problem (see paragraph 4.5.2).

The results for nitrogen are satisfactory. Except for the Sava river, the “high” and “low” scenario enclose the observed concentrations. We could say that the “high” scenario tends to be closer to the measured concentrations than the “low” scenario, especially for Jochenstein, for the Drava and for the Sava. The large difference between the “high” and the “low” scenario on the Tisa is remarkable.

The results for phosphorus are also satisfactory, except for the station Bazias. Later on, when we will look at the river loads, we will see that the observed values for Bazias can hardly be correct. Except for the station Bazias, the “high” and “low” scenario enclose a large part of the observed concentrations and the associated “error bars”. This time we could say that the “low” scenario tends to be closer to the measured concentrations than the “high” scenario, especially for Wolfsthal and Reni. Again, the large difference between the “high” and the “low” scenario on the Tisa is remarkable.

The large difference between the "high" and "low" scenario for the Tisa station can be explained as follows. The Tisa basin is characterised by a low specific runoff. Under such circumstances, the high and low estimates of the immission/emission-factor (tables 4.5a and 4.5b) are far apart. Hungary in particular presents an extreme case: the high estimate of this factor is 36%, and the low estimate 5%. This means that due to this factor alone the high and low estimates of the nutrient emission from Hungary which reaches the river network, differs by a factor of 7! Therefore, the predicted river concentrations in the Tisa differ a lot between the "high" and "low" scenarios.

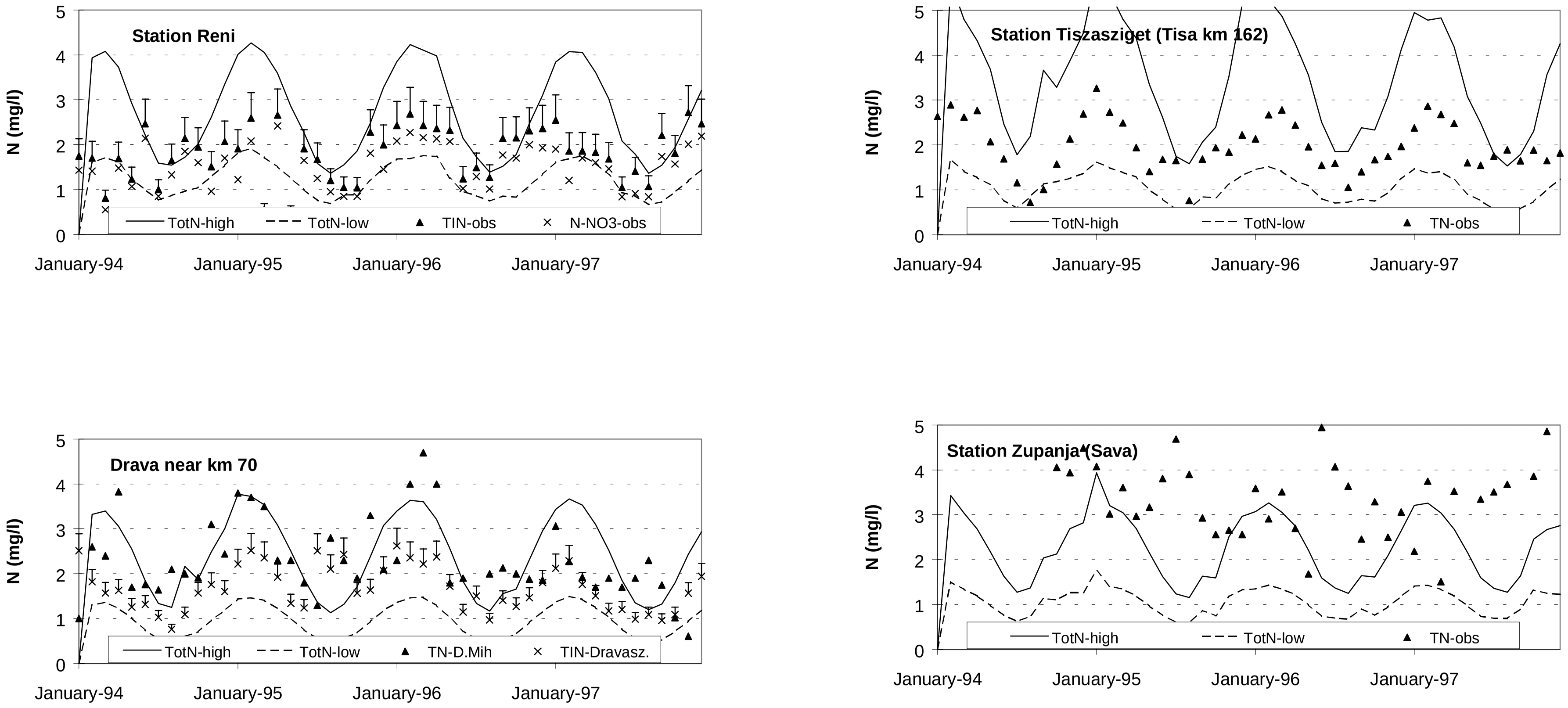
In general we observe a better agreement between the model results and the measured concentrations for the upper part of the Danube than for the lower part. One factor to explain this difference is the following. Between Hercegszanto the major tributaries Sava, Tisa and Drava flow into the Danube. These tributaries drain large parts of the countries Croatia, Yugoslavia and Bosnia-Herzegovina. For these three countries, we do not have real estimates of the diffuse emissions. The numbers which were used in the computations are based on average emission factors, valid for the other 10 Danube countries in the year 1992 (see paragraphs 4.2 and 5.3). Taking into account this major difficulty, the model results are satisfactory.



The lines represent in-stream concentrations computed by the Danube Water Quality Model. “High” indicates a high estimate for the emissions combined with a weak retention in the basin.

Figure 6.1a **Computed and observed concentrations of total nitrogen**

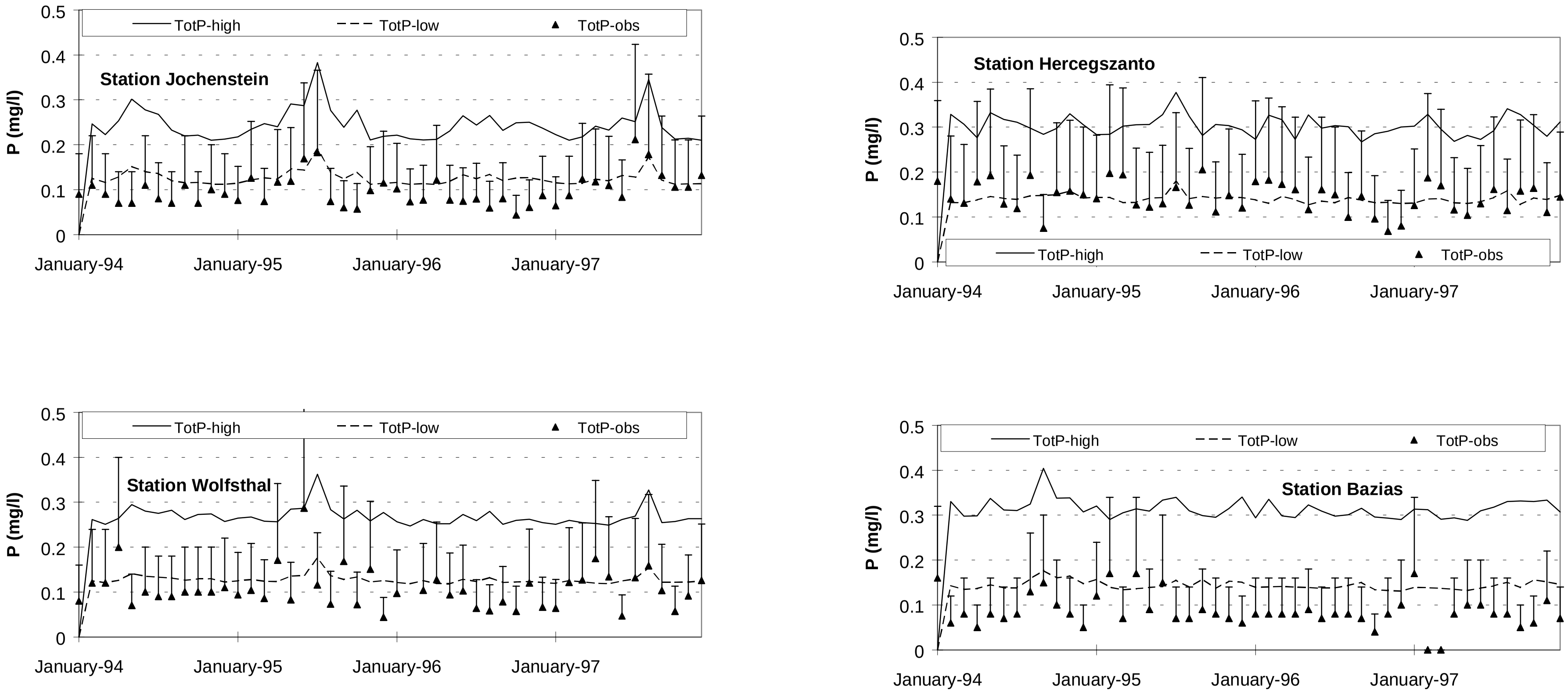
“Low” indicates a low estimate for the emissions combined with a strong retention in the basin. The points represent measured concentrations. Note that the accuracy of such measurements is never perfect. Note also that for most stations the measurements of total nitrogen are estimated from total inorganic nitrogen rather than really measured (see paragraph 4.5.3).



The lines represent in-stream concentrations computed by the Danube Water Quality Model. “High” indicates a high estimate for the emissions combined with a weak retention in the basin.

“Low” indicates a low estimate for the emissions combined with a strong retention in the basin. The points represent measured concentrations. Note that the accuracy of such measurements is never perfect. Note also that for most stations the measurements of total nitrogen are estimated from total inorganic nitrogen rather than really measured (see paragraph 4.5.3).

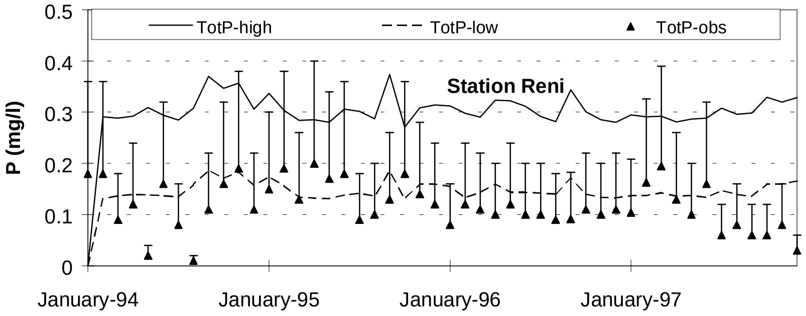
Figure 6.1b Computed and observed concentrations of total nitrogen.

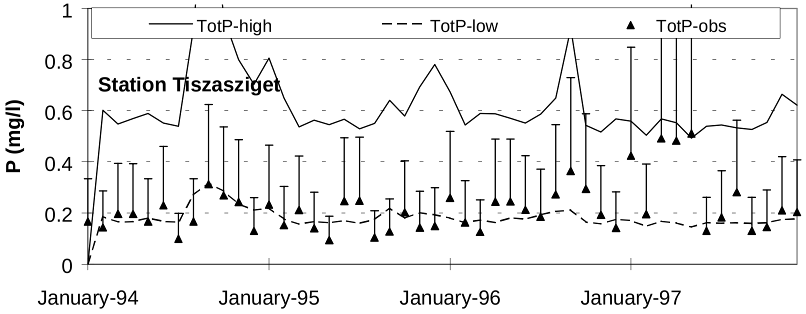


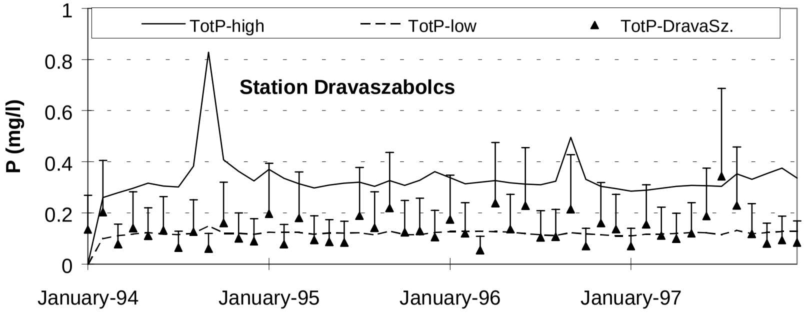
The lines represent in-stream concentrations computed by the Danube Water Quality Model. “High” indicates a high estimate for the emissions combined with a weak retention in the basin.

“Low” indicates a low estimate for the emissions combined with a strong retention in the basin. The points represent measured concentrations. Note that the accuracy of such measurements is never perfect. Note also that the error bars represent the *high flow* problem and the *stratification* problem (see paragraph 4.5.2).

Figure 6.2a **Computed and observed concentrations of total phosphorus.**







The lines represent in-stream concentrations computed by the Danube Water Quality Model. “High” indicates a high estimate for the emissions combined with a weak retention in the basin.

“Low” indicates a low estimate for the emissions combined with a strong retention in the basin. The points represent measured concentrations. Note that the accuracy of such measurements is never perfect. Note also that the error bars represent the *high flow* problem and the *stratification* problem (see paragraph 4.5.2).

Figure 6.2b **Computed and observed concentrations of total phosphorus.**

6.3. Nutrient Loads

The computed and observed loads of nitrogen and phosphorus are presented in figure 6.3 below. The computed loads are presented as lines, the observed loads as bars.

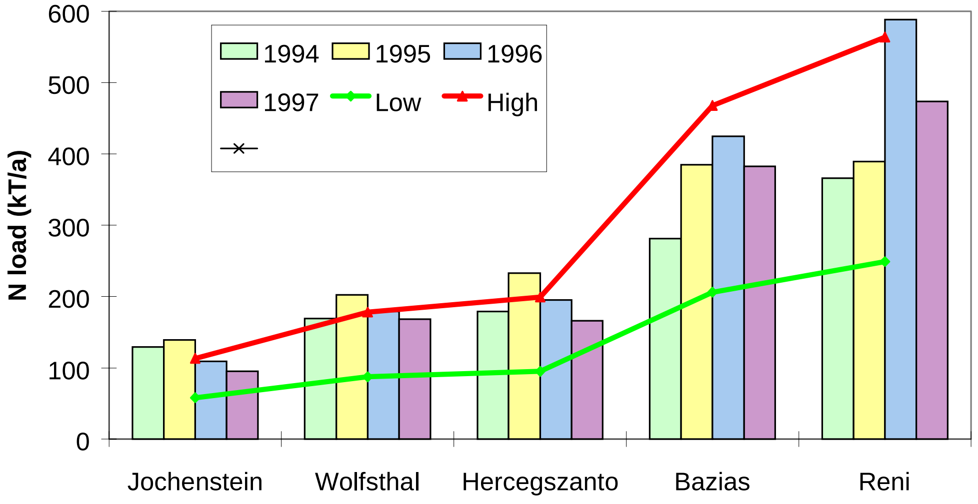
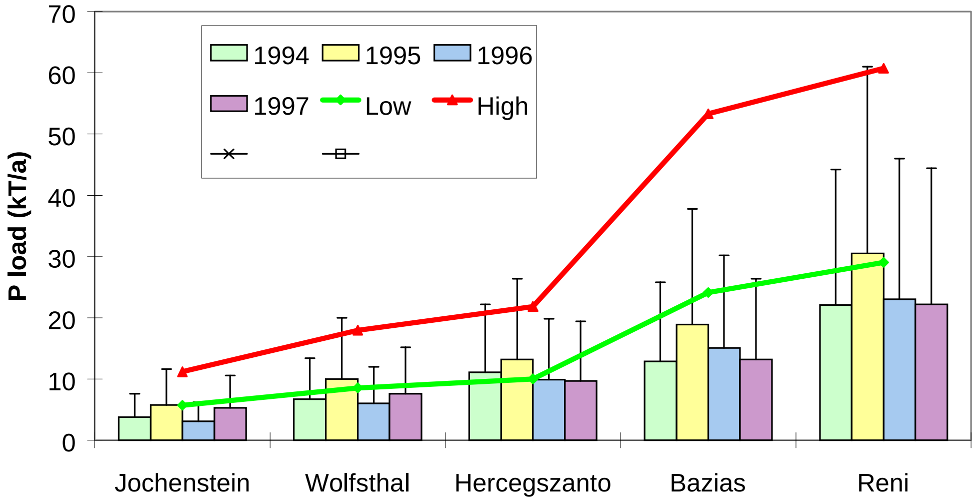


Figure 6.3a Observed and computed nutrient loads (nitrogen).

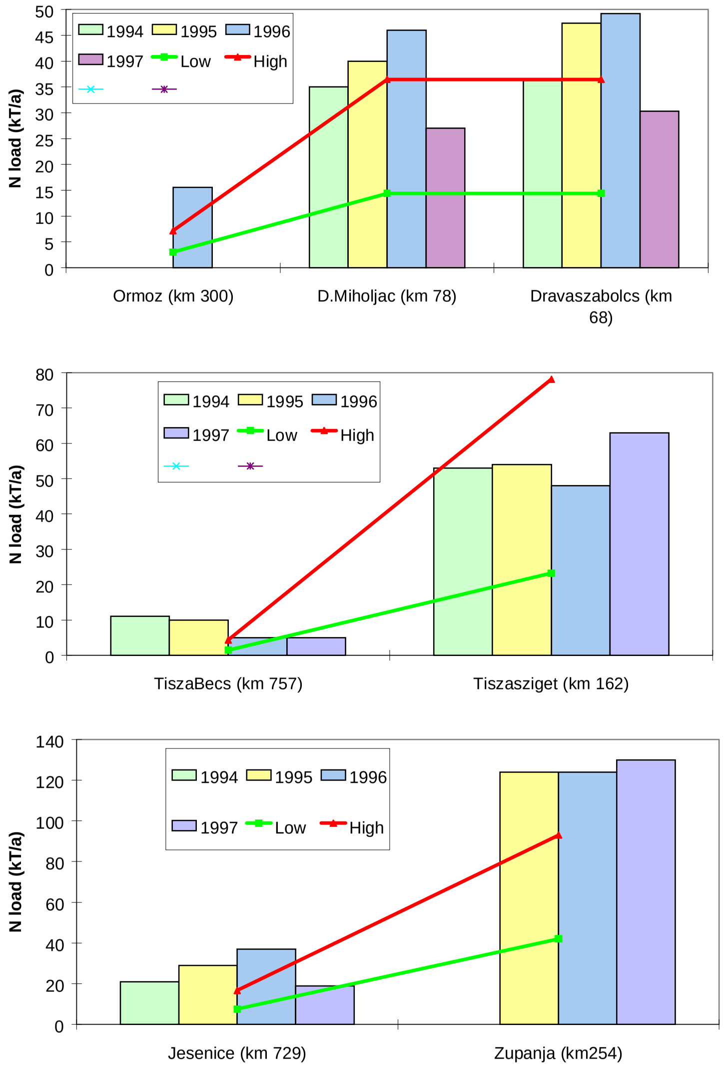


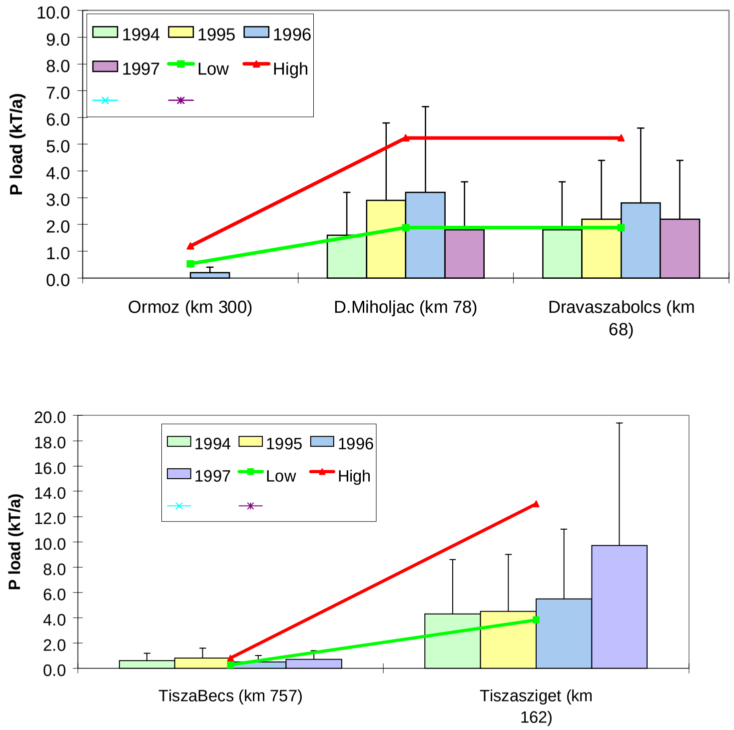
The lines represent the in-stream concentrations computed by the Danube Water Quality Model. "High" indicates a high estimate for the emissions combined with a weak retention in the basin. "Low" indicates a low estimate for the emissions combined with a strong retention in the basin. The bars represent the in-stream loads computed from simultaneous measurements of concentrations and discharges (see paragraph 5.4). Note that the accuracy of such measurements and the subsequent load calculation is never perfect. Note also that the nitrogen loads in the bars are for most stations based on total nitrogen concentrations which have been estimated from the measured total inorganic nitrogen concentrations (see paragraph 4.5.3). Note also that the phosphorus loads have error bars (factor 2) which represent a correction for the high flow problem and the stratification problem (see paragraph 4.5.2).

Figure 6.3b Observed and computed nutrient loads (phosphorus).

The results are satisfactory for both nitrogen and phosphorus. Note that the “observed loads” have been multiplied by a factor of 2, to account for the *high flow* problem and the *stratification* problem. Note also that for phosphorus the model predicts the largest increase in the river load between Hercegszanto and Bazias, due to the inflow of the Drava, Sava and Tisa tributaries. The observations however, show the largest increase between Bazias and Reni, which we do not really understand.

Figure 6.4 shows similar graphs for the tributaries. For nitrogen, the Drava and Tisa rivers are modelled more or less correct, whereas the Sava load is underestimated. For phosphorus, the Drava and Tisa rivers are also modelled more or less correct. There was no information to check the Sava load.





Note that phosphorus data for the Sava were not available.

Figure 6.4. **Observed and computed in-stream loads of nitrogen (left) and phosphorus (right) in the main tributaries Drava (top), Tisa (middle) and Sava (bottom).**

7. Simulations in Support to the Transboundary Diagnostic Analysis

7.1. General

7.1.1. Computational Procedure

In the framework of the Transboundary Diagnostic Analysis (TDA), one of the interesting question is to show a longitudinal profile of the load along the river Danube, which is subdivided over the countries from which these loads originate. From a mathematical point of view, such a result can be produced with the Danube Water Quality Model as long as the removal processes are linear (proportional with the concentration of the disappearing substance). This is by approximation the case. Trial computations have been made as follows:

- in stead of 1 set of emission data, 13 sets have been prepared, each holding the emissions of one country;
- 13 runs with the DWQM have been made, and the resulting load profiles written to file;
- the 13 profiles have been added into one graph.

We have checked that the joint individual result of all 13 countries equals the overall result from a run with all 13 countries together. This was indeed the case within 1% of accuracy.

7.1.2. Emissions

The emission estimates used for the TDA calculations should be somewhere in between the “high” and the “low” scenarios discussed in paragraph 6, in order to be consistent with our analysis so far. For nitrogen, we chose them in such a way that the load to the Delta equals the Danube nitrogen load reported by (RMRI, 1998). We selected their average value for 1994-1997, being 443 kt/a, and increased this value with 22% to account for the organic nitrogen fraction (see paragraph 4.5.3). The result was 540 kt/a, which corresponds to 96% of the “high” scenario. For phosphorus, we chose the average Danube in-stream load for 1994-1997, as it was computed in the present report, and increased that value with a factor of two, to account for the *high flow* problem and the *stratification* problem (see paragraph 4.5.2). The result was 48 kt/a, which corresponds to 79% of the “high” scenario.

7.1.3. In-Stream Denitrification

The river load profile for nitrogen is affected by the in-stream denitrification coefficient. In paragraph 6, the “high” and “low” scenario were made with a constant value of 0,05 m/d. Here, we made two TDA calculations: one with a weaker denitrification (0.033 m/d) and one with a stronger denitrification (0.075 m/d). In order to keep the load to the Delta more or less constant, the emissions needed to be decreased in one case and increased in the other. Finally, we did the two calculations with the emissions equal to 92% and 101% of those in the “high scenario”.

7.2. The Water Volume along the Danube

Before proceeding to the in-stream load profiles of nitrogen and phosphorus, we first present the computed water volume in the Danube, subdivided over the countries of origin. The computation was made in agreement with the methodology presented in paragraph 3.

The main Danube tributaries of the Danube are clearly visible in figure 7.1, as points where the water volume shows a discontinuous increase. The increase is particularly strong at the inflows of the Drava, Tisa and Sava tributaries. If we compare this figure to figure 3.1 (catchment area), we observe that the relative share of the water volume from the upper Danube countries is much bigger than their share of the catchment. This reflects their high area specific runoff.

7.3. The Nutrient Loads along the Danube

Figure 7.2 presents the phosphorus load profile along the Danube, subdivided over the countries of origin. The graph follows the water volume graph (figure 7.1) with one major difference. Just downstream of the load increase caused by the Drava, Tisa and Sava inflows, a substantial part of the load is retained in the backwater area of the Iron Gates dams. This is caused by sedimentation of a part of the phosphorus which is adsorbed to suspended solids.

Figure 7.3 presents the nitrogen load profile along the Danube, subdivided over the countries of origin. The graph follows the water volume graph (figure 7.1), but in this case the loads all slowly diminish due to the denitrification process. This is not a strong effect however, and consequently the graphs made for a weaker (figure 7.3a) and for a stronger (figure 7.3b) denitrification rate do not show large differences.

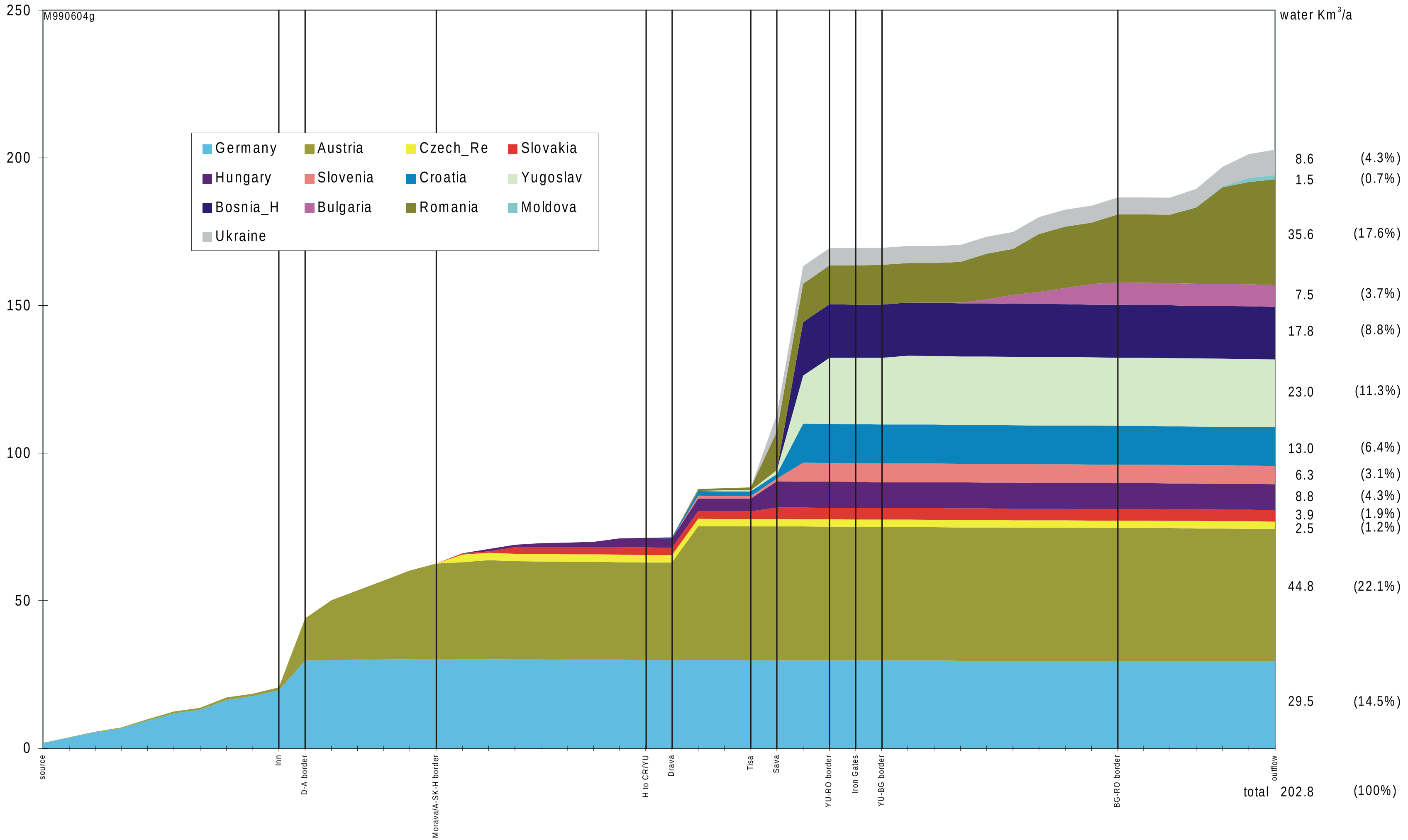


Figure 7.1. **Longitudinal profile of the annual water volume in the Danube (in km^3/a), subdivided over the countries of origin.**

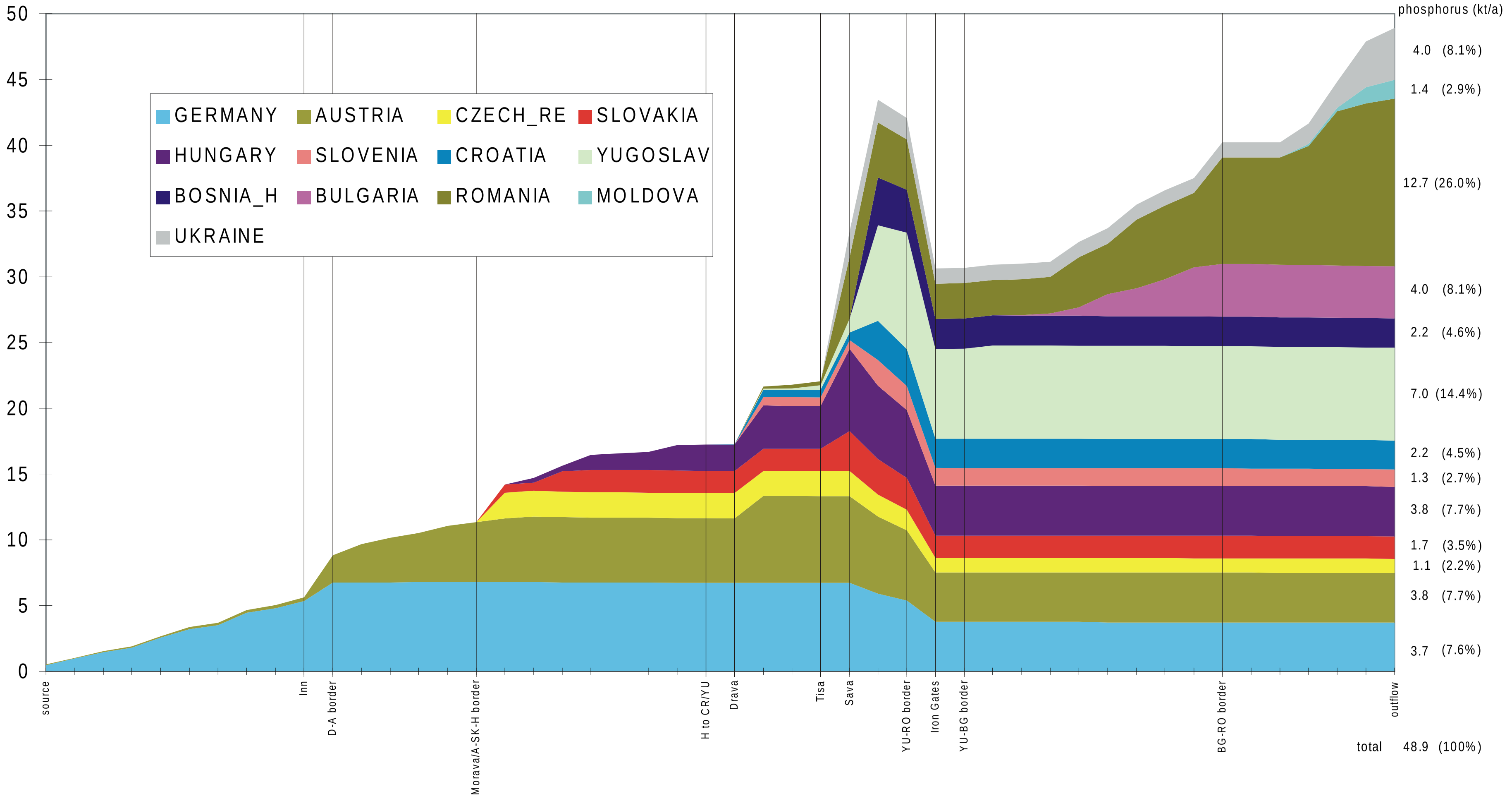


Figure 7.2. **Longitudinal profile of the annual phosphorus load in the Danube (in kt/a), subdivided over the countries of origin.**

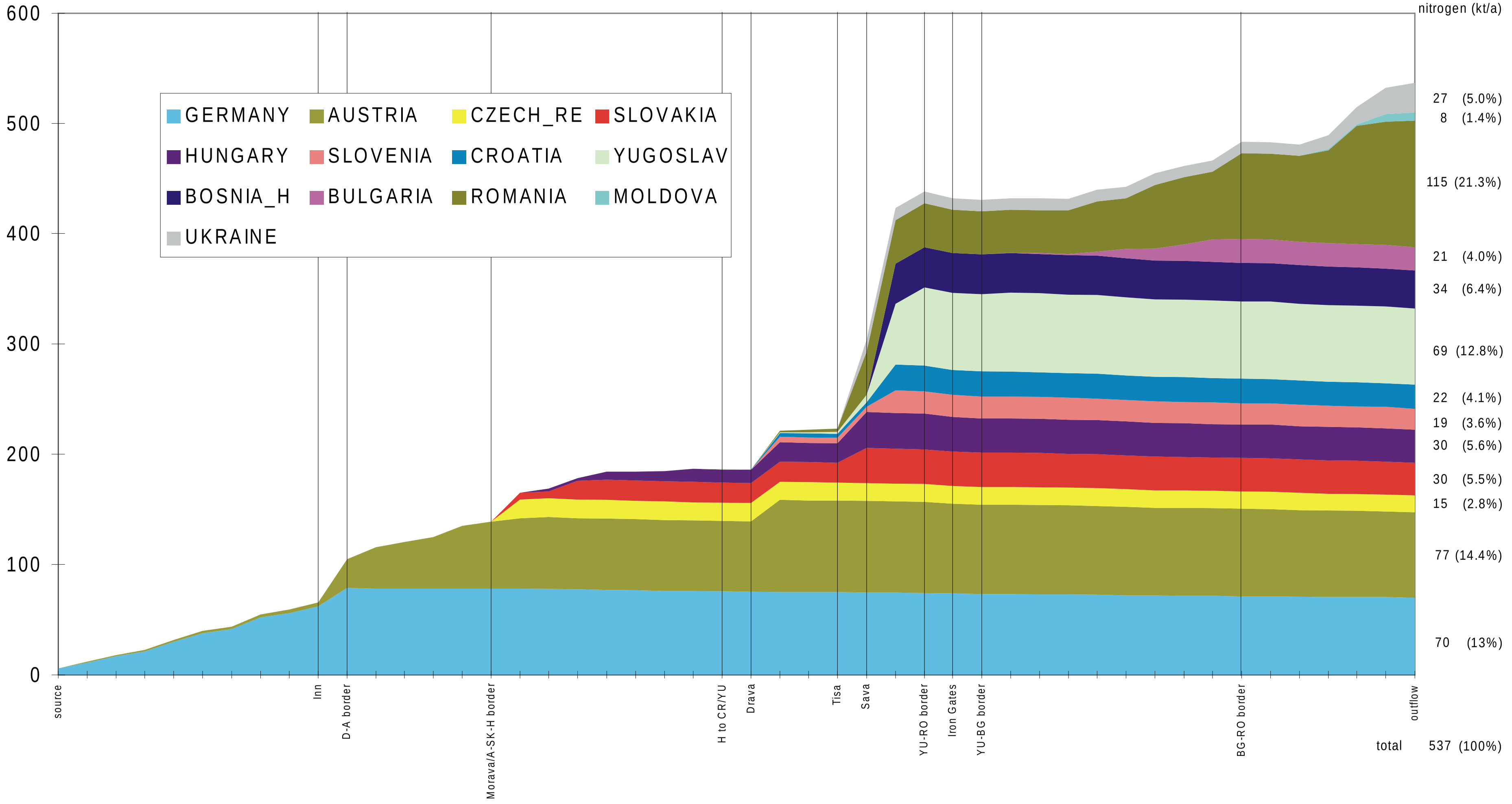


Figure 7.3a Longitudinal profile of the annual nitrogen load in the Danube (in kt/a), subdivided over the countries of origin, with a low estimate for the in-stream denitrification (= removal) rate.

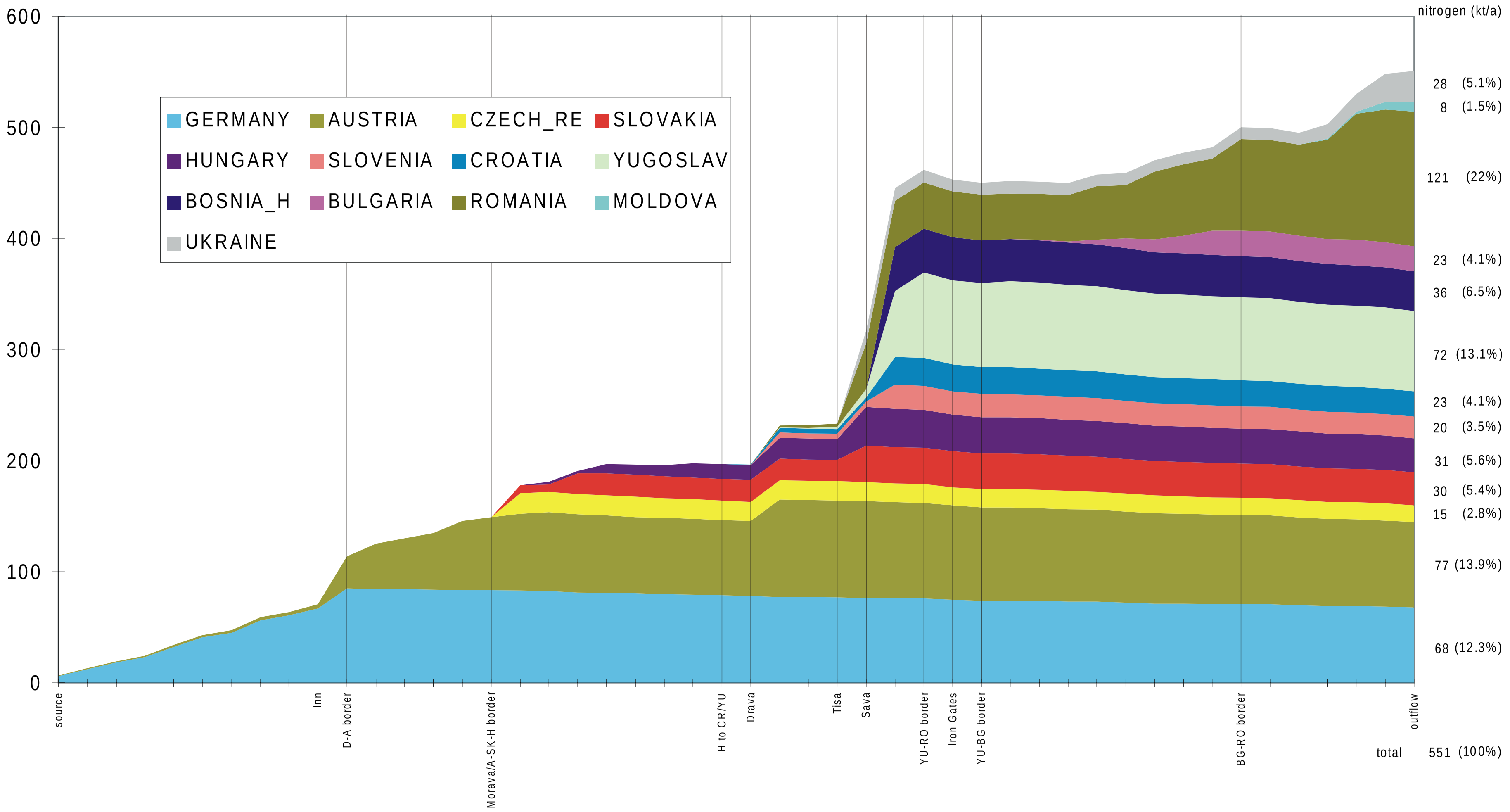


Figure 7.3b Longitudinal profile of the annual nitrogen load in the Danube (in kt/a), subdivided over the countries of origin, with a high estimate for the in-stream denitrification (= removal) rate.

8. Simulations in support to the Pollution Reduction Programme

8.1. General

8.1.1. Definition of the Projects in the PRP

The simulations with the DWQM in support to the Pollution Reduction Programme (PRP) have the objective of estimating the effects of the projects proposed in the PRP on the in-stream transboundary transport of pollution. The precise definition of the projects in the PRP was taken from the PRP report (GEF Danube Pollution Reduction Programme, 1999).

For the DWQM simulations the projects in the PRP are divided in 2 groups, which are treated differently: (1) projects aimed at the reduction of emissions, (2) projects aimed at increasing the self-purification capacity of the river, in particular the restoration of wetlands.

8.1.2. Consequences of the Projects in the PRP for the Pollution Sources in the DWQM

The procedure below was followed:

- the existing list of “emissions directly to the river” (i.e. introduced as a point source in the model, on the actual position in the river network, see Appendix 6) had to be updated:
    a. some projects in the PRP were not yet in the list: those were added;
    b. for some pollution sources which are present in the PRP the estimated emission was smaller than the reduction after implementation of the PRP: in those cases the emission estimates were increased;
- a complete list was made of all PRP projects;
- those which actually quantify an emission reduction were selected;
- from the selected projects, the largest individual projects were selected, which all together make up 80% of the total emission reduction;
- the reductions of the list of “80%” were applied to the list of “emissions directly to the river” (figure 4.1);
- the remaining reductions were applied to the “remaining emissions” (figure 4.1).

The updated list of “emissions directly to the river”, with and without implementation of the PRP, is listed in appendix 13.

8.1.3. Consequences of Wetlands Restoration Projects in the PRP for the DWQM

The wetlands in the Danube basin in its current state are included in the "retention in the catchment" as it is described in paragraphs 4.3 and 4.4 of the present report. For the wetlands proposed to be restored in the PRP we followed a different technique. The starting point was the *additional* nutrient removal by these restored wetlands as estimated in (GEF Danube Pollution Reduction Programme, 1999). A boundary condition was that a presentation of the results per country and per sector (see below) must be possible. As a consequence, the *additional* nutrient removal by restored wetlands needed to be implemented as a fully *linear* process. This goal was achieved by a local increase of the intensity of the existing linear in-stream removal processes: denitrification (nitrogen) and sedimentation (phosphorus) at the projected locations of the restored wetlands.

The area of the restored wetlands was computed from their total nutrient removal by a factor expressing the nutrient removal capacity of the wetlands: 0.1 tN/y/ha and 0.01 tP/y/ha. The local increase of the equivalent linear removal processes in the DWQM was determined by making trial runs and matching the total nutrient removal by the wetlands with the desired values in the PRP. The result was: an effective net settling velocity for total phosphorus of 0.016 m/d, and a denitrification rate at 20 °C of 0.025 m/d. These values can be compared to those for the existing removal processes in the DWQM: an effective net settling velocity for total phosphorus of 1.3 m/d in the Iron Gates lakes, and a denitrification rate at 20 °C of 0.05 m/d.

8.1.4. Emissions data

New data about the emissions estimates from the years 1996-1997 have been incorporated in the simulations in support to the PRP. This causes a small difference between the "baseline" computations in the PRP simulations and the computations made for the Transboundary Analysis. This difference should not be interpreted as a trend between the years 1996-1997 on one hand and the year 1992 on the other hand. Either such a trend is not present, or the basic data do not allow an analysis refined enough to detect it. The difference should be interpreted in stead as a reflection of the inaccuracies related to our imperfect knowledge of the system.

8.1.5. Computational procedure

The computational procedure included one new element: similar to the subdivision over the 13 Danube countries which was made before, we now also made a subdivision over the emissions from "sectors": population, industry, agriculture and others (mainly emissions from natural areas). Some small corrections and refinements had to be introduced in the data, to allow a consistent subdivision over the sectors:

- the diffuse sources term “base flow” was subdivided over “population”, “agriculture” and “other” with an average ratio for all Danube countries, derived from the 1992 Nutrient Balances data (University of Vienna, 1997), see table 8.1;
- for some countries and some sectors the estimated total emissions according to (University of Vienna, 1999) were smaller than the “emissions directly to the river”, which leads to a negative number for the “remaining emissions”: corrections have been applied to the estimated totals;
- for some countries and some sectors the total emissions according to (University of Vienna, 1999) were smaller than the total reduction of pollution in the PRP, which leads again to a negative number for the “remaining emissions”: further corrections have been applied to the estimated totals.

Table 8.1. Distribution of the "base flow" emissions over the sectors.

Sector	Fraction of “base flow”, nitrogen (%)	Fraction of “base flow”, phosphorus (%)
Population	12	33
Agriculture	50	33
Other	38	33

8.2. Overview of Total Emissions in the Baseline Simulation

The total emissions data are presented below, as totals over the Danube basin, subdivided over the sectors (figure 8.1) and subdivided over point sources and diffuse sources (figure 8.2).

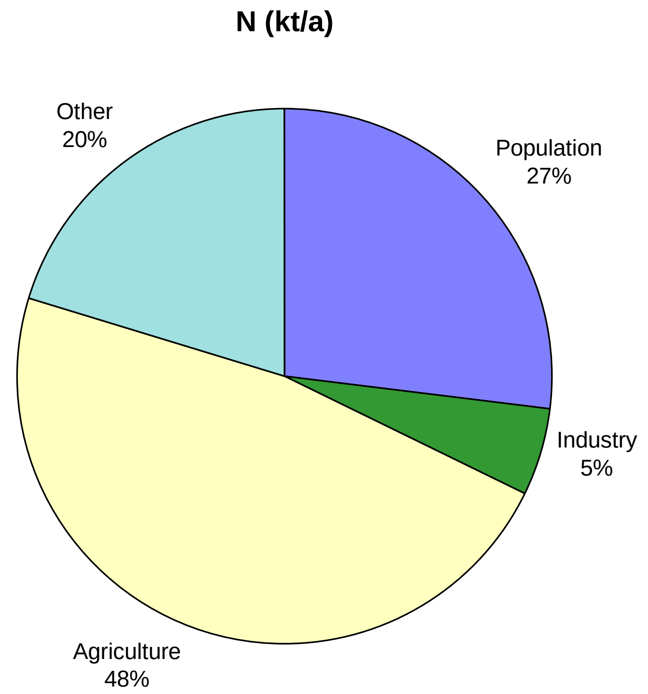


Figure 8.1a Total nitrogen emissions, subdivided over the sectors.

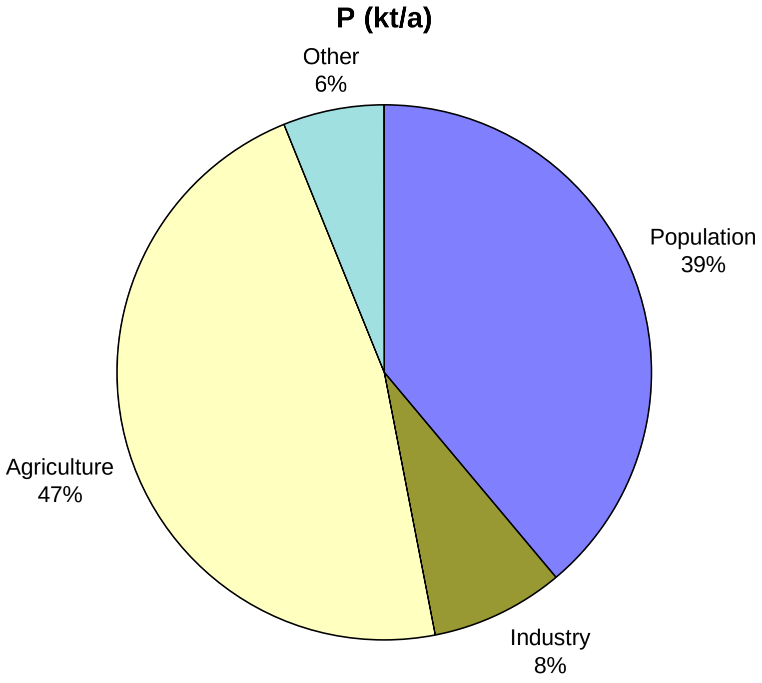


Figure 8.1b Total phosphorus emissions, subdivided over the sectors.

Figure 1 demonstrates that the share of the sector “population” is much larger for phosphorus than it is for nitrogen. The difference is compensated by the share of the sector “other” (e.g. forest and nature areas).

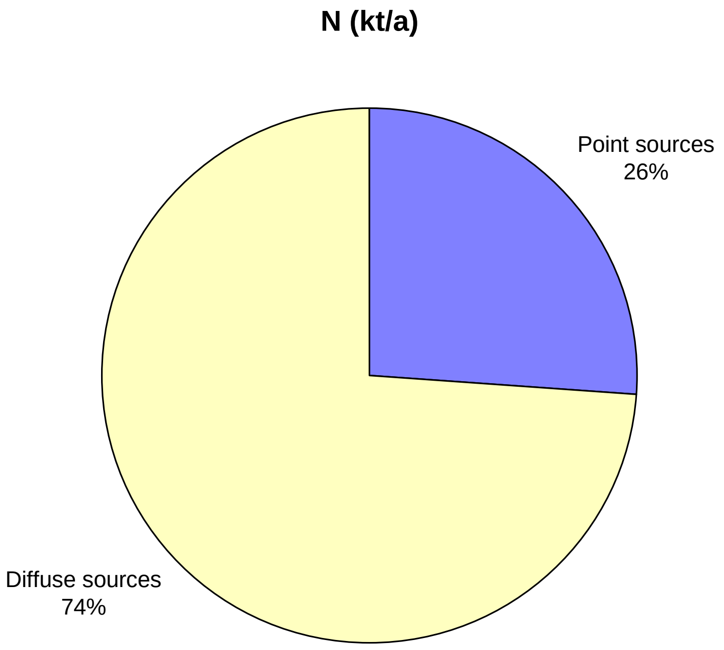


Figure 8.2a **Total nitrogen emissions, subdivided over point sources and diffuse sources.**

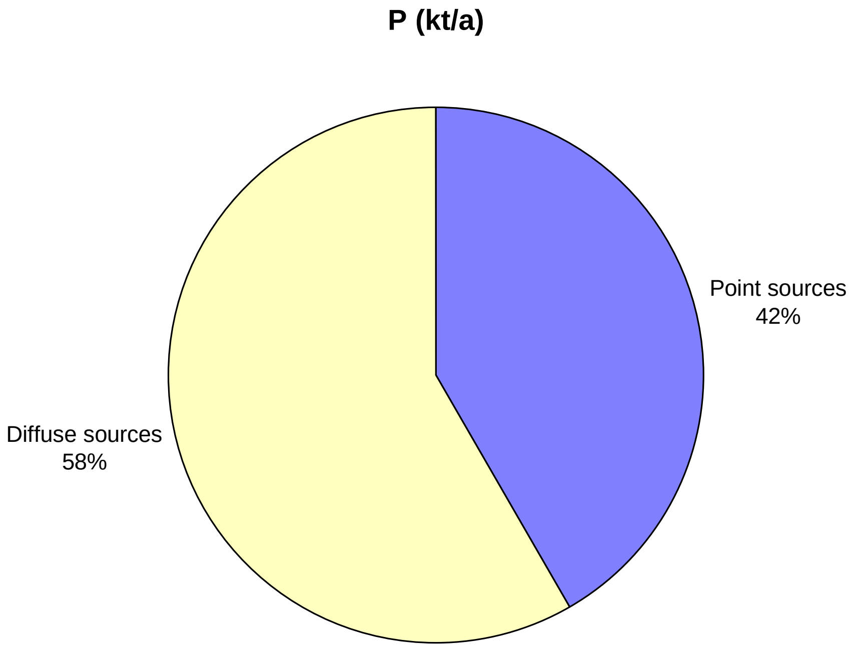


Figure 8.2b **Total phosphorus emissions, subdivided over point sources and diffuse sources.**

Figure 2 demonstrates that the share of the point sources is much larger for phosphorus than it is for nitrogen.

8.3. Computed Longitudinal In-Stream Load Profiles, Subdivided per Country

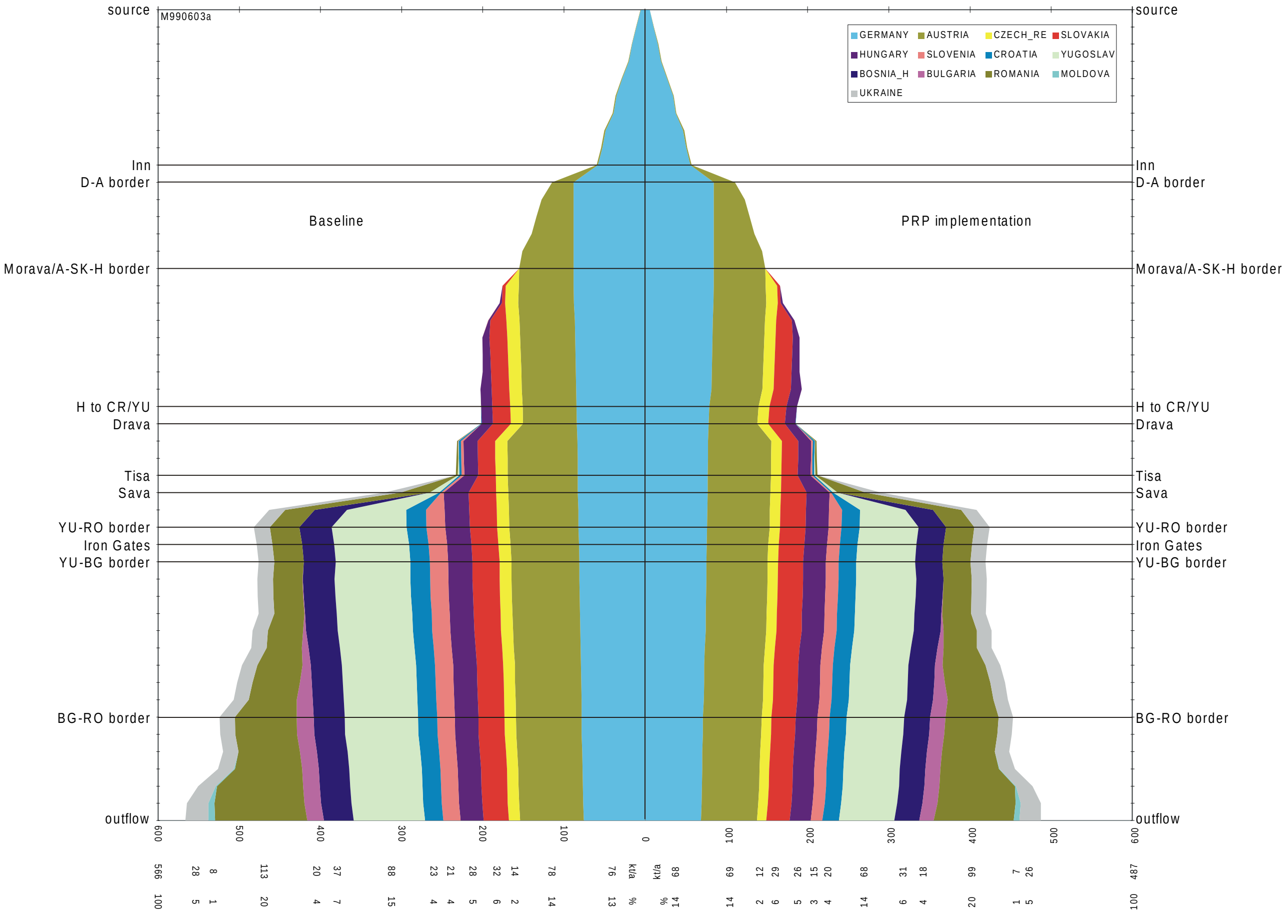


Figure 3

Figure 8.3. In-stream nitrogen load profiles per country for the Danube river, before (left side) and after (right side) implementation of the PRP.

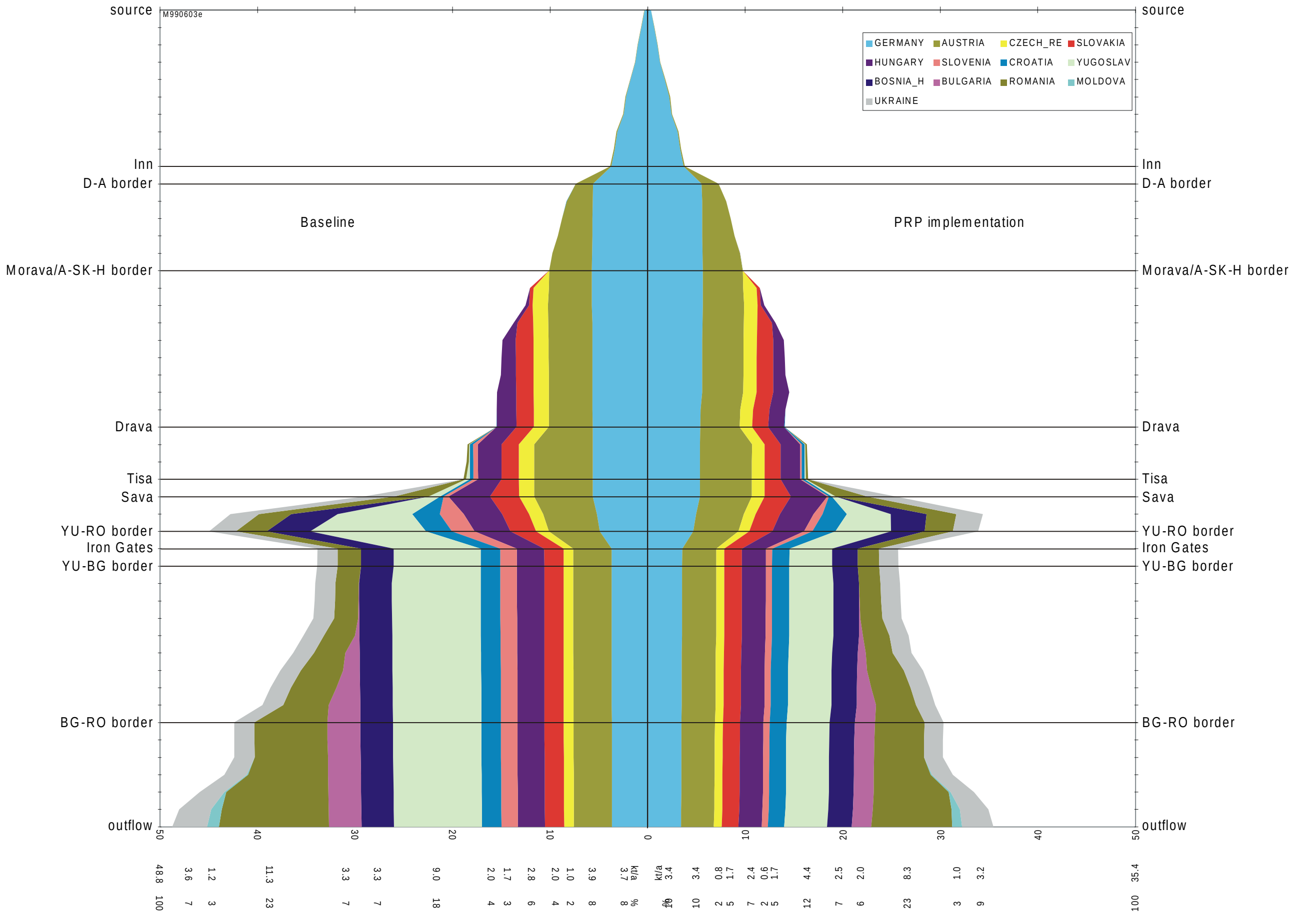


Figure 4

Figure 8.4. In-stream phosphorus load profiles per country for the Danube river, before (left side) and after (right side) implementation of the PRP.

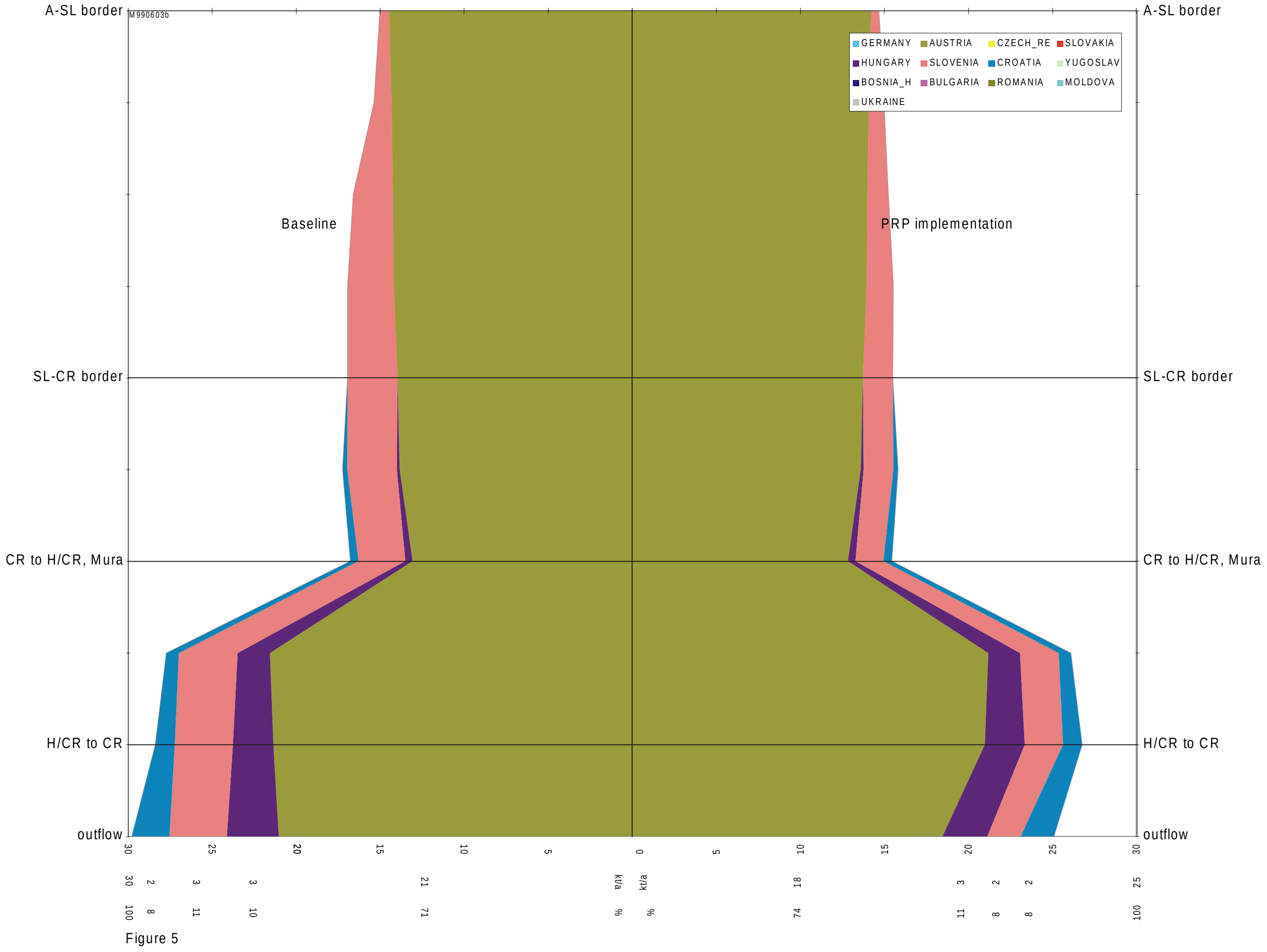


Figure 8.5. In-stream nitrogen load profiles per country for the Drava river, before (left side) and after (right side) implementation of the PRP.

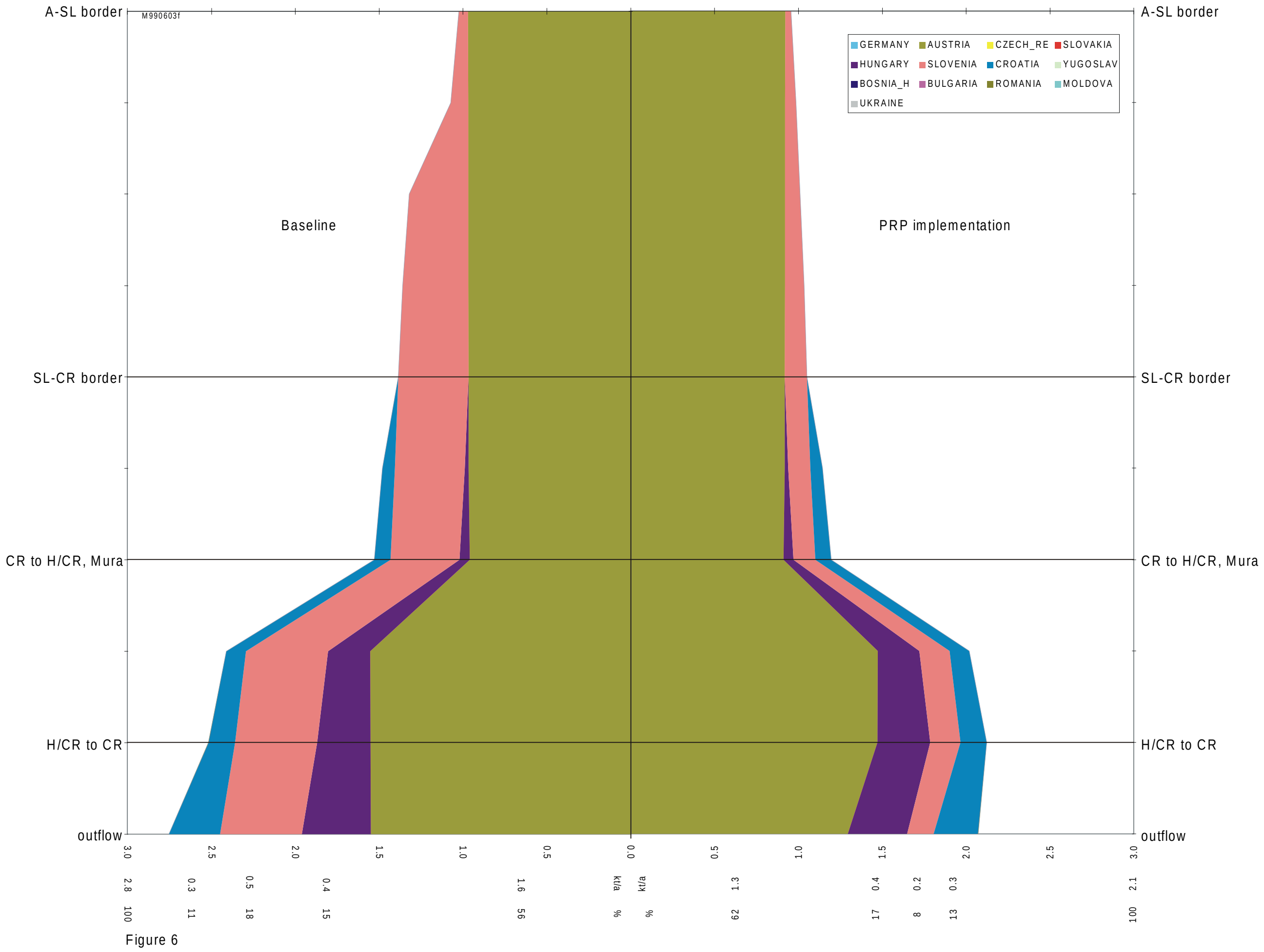


Figure 8.6. In-stream phosphorus load profiles per country for the Drava river, before (left side) and after (right side) implementation of the PRP.

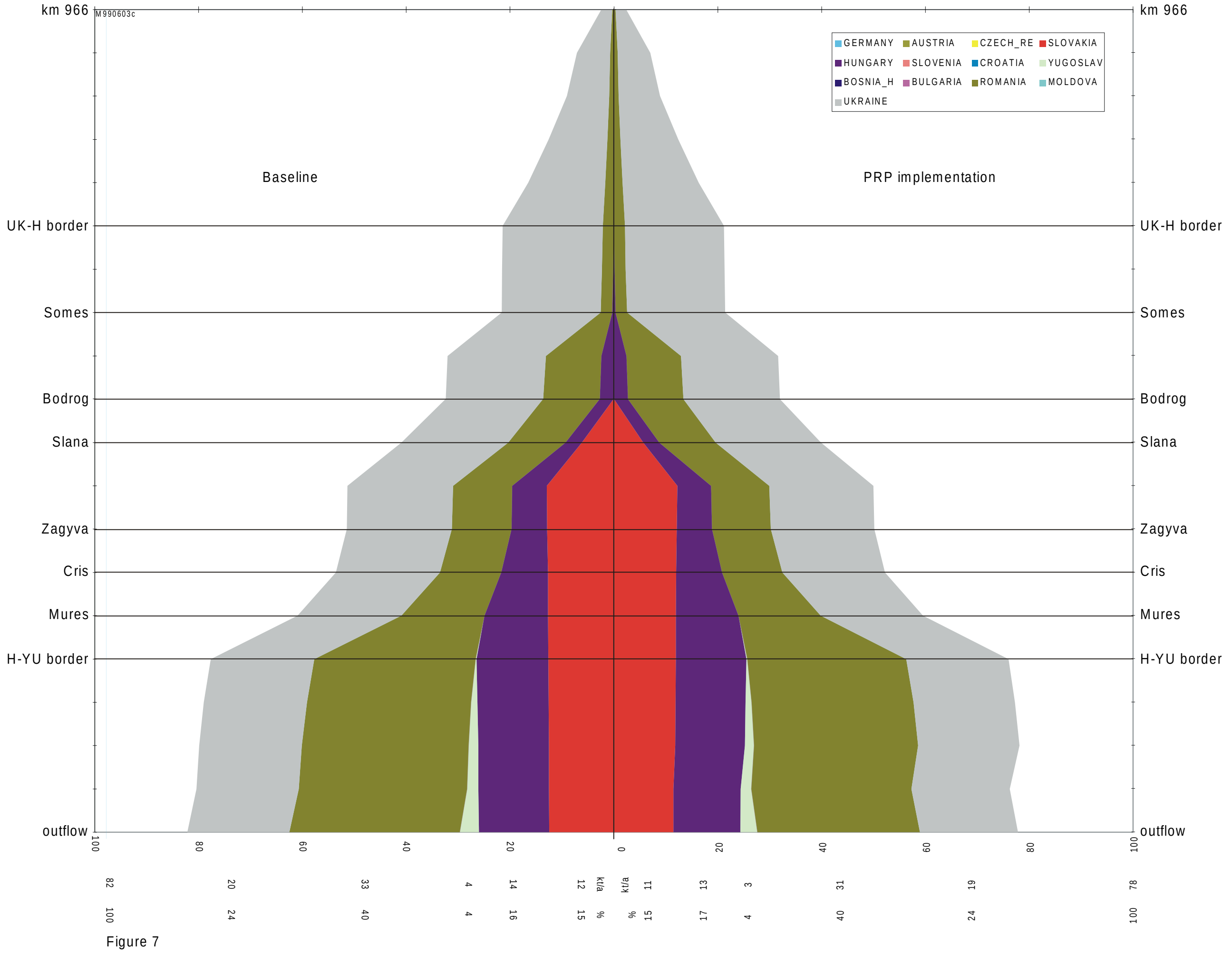


Figure 8.7. **In-stream nitrogen load profiles per country for the Tisa river, before (left side) and after (right side) implementation of the PRP.**

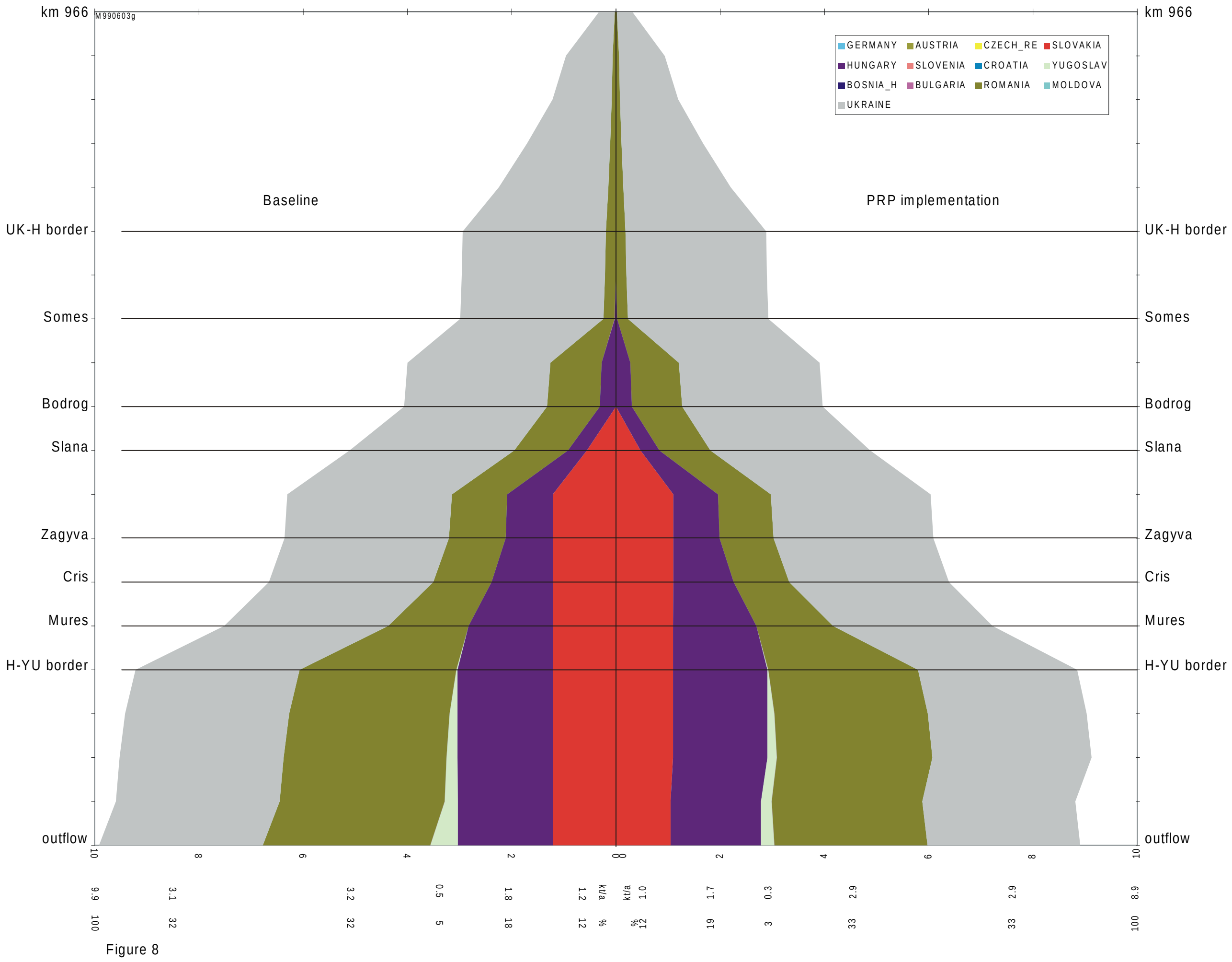


Figure 8.8. **In-stream phosphorus load profiles per country for the Tisa river, before (left side) and after (right side) implementation of the PRP.**

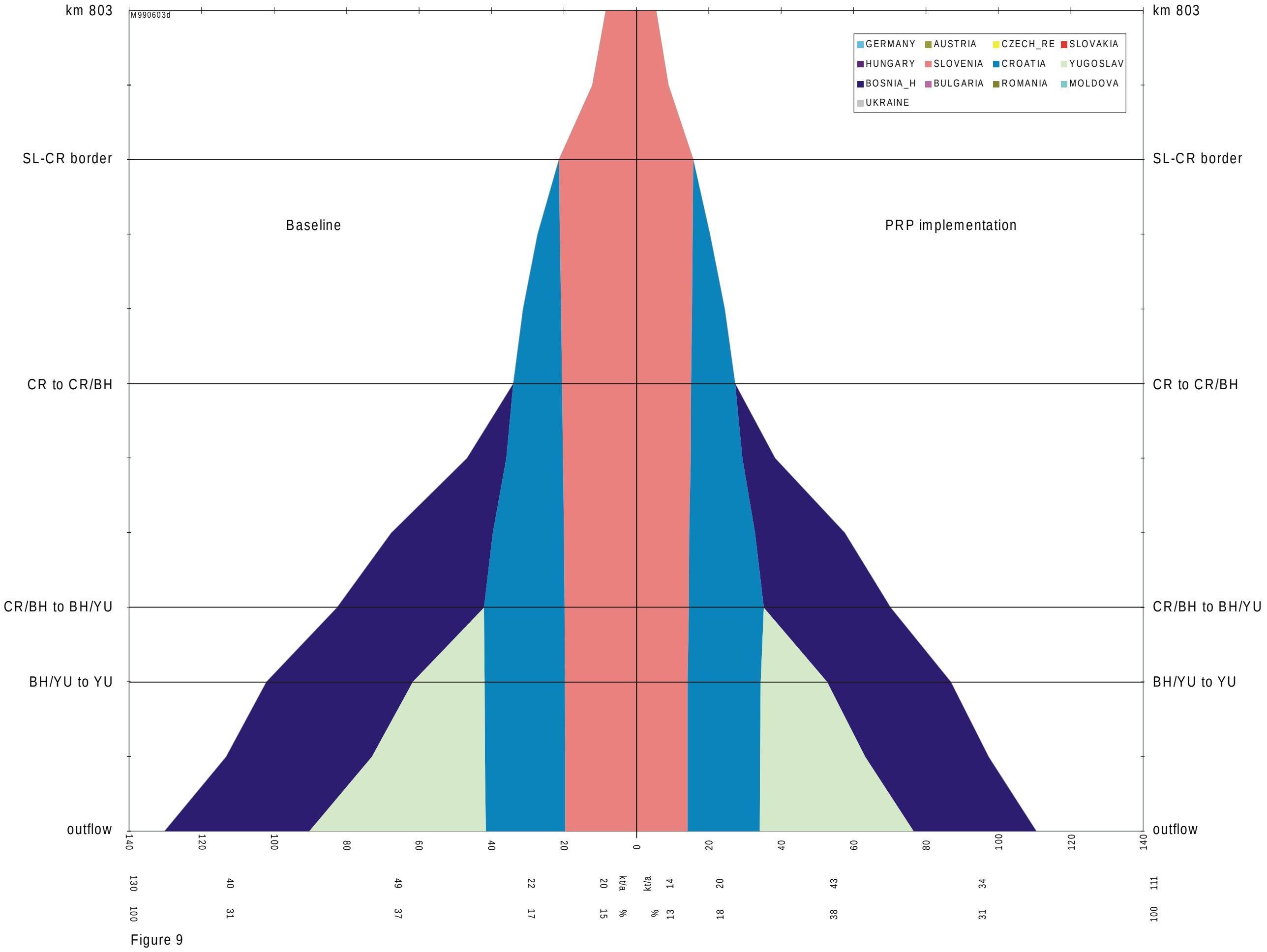


Figure 8.9. **In-stream nitrogen load profiles per country for the Sava river, before (left side) and after (right side) implementation of the PRP.**

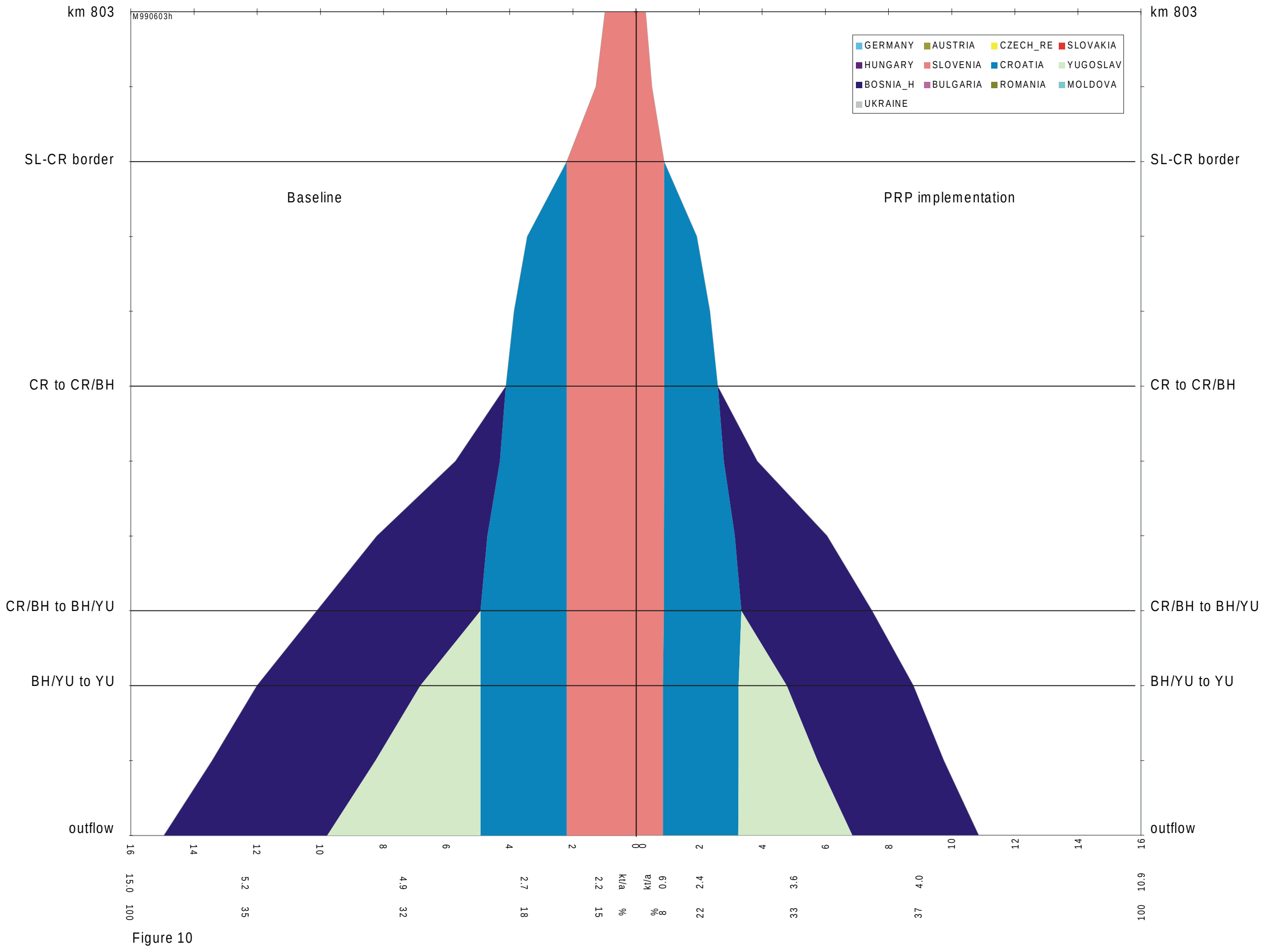


Figure 8.10. **In-stream phosphorus load profiles per country for the Sava river, before (left side) and after (right side) implementation of the PRP.**

8.4. Comparative Effect of Emissions Reductions and Wetlands Restoration

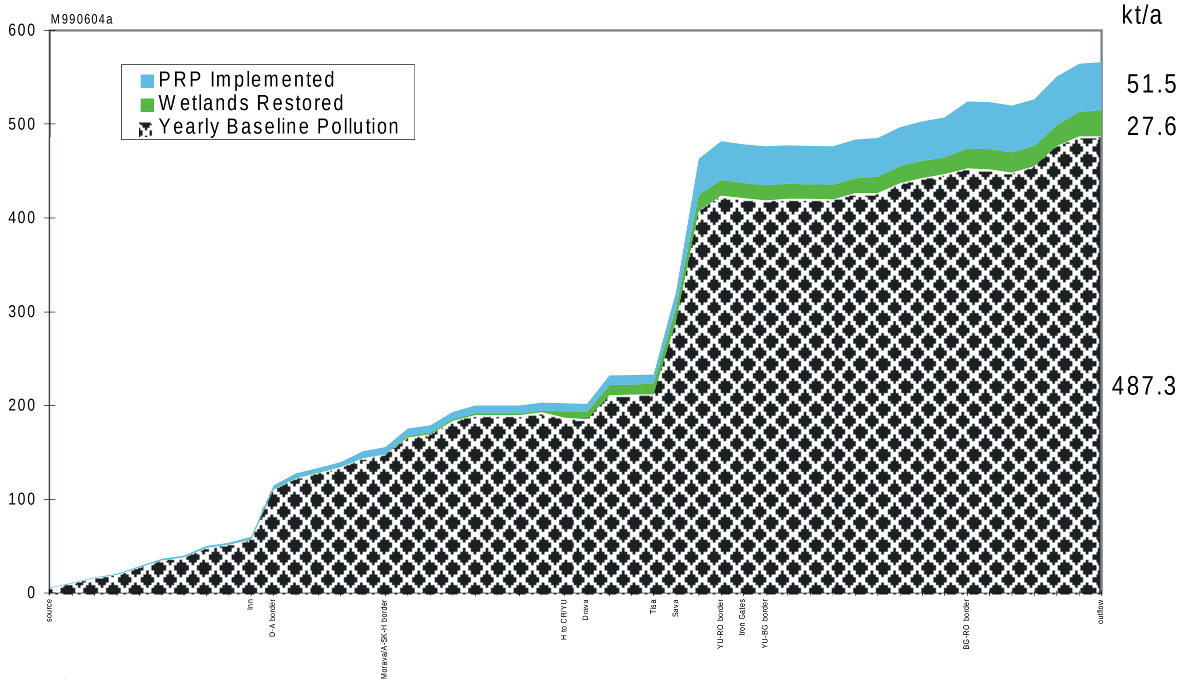


Figure 11

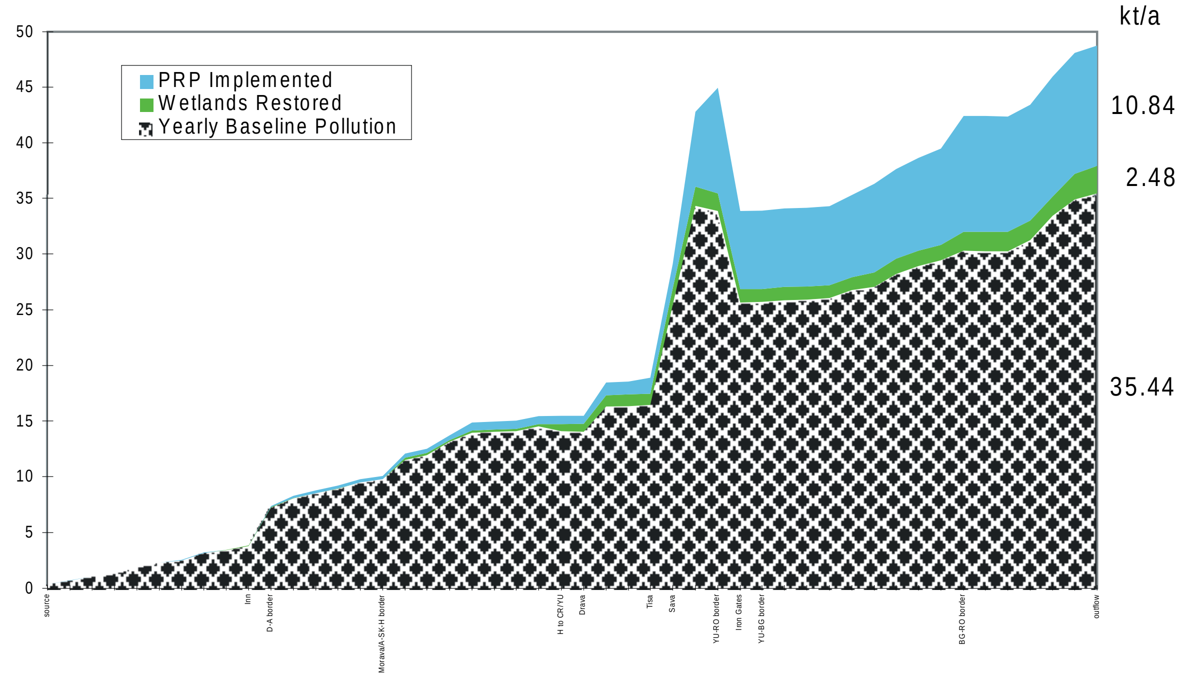


Figure 12

Figure 8.11. In-stream nitrogen load profile for the Danube river, before and after implementation of the PRP, with the additional effect of the restoration of 17 wetlands (top).

Figure 8.12. In-stream phosphorus load profile for the Danube river, before and after implementation of the PRP, with the additional effect of the restoration of 17 wetlands (bottom).

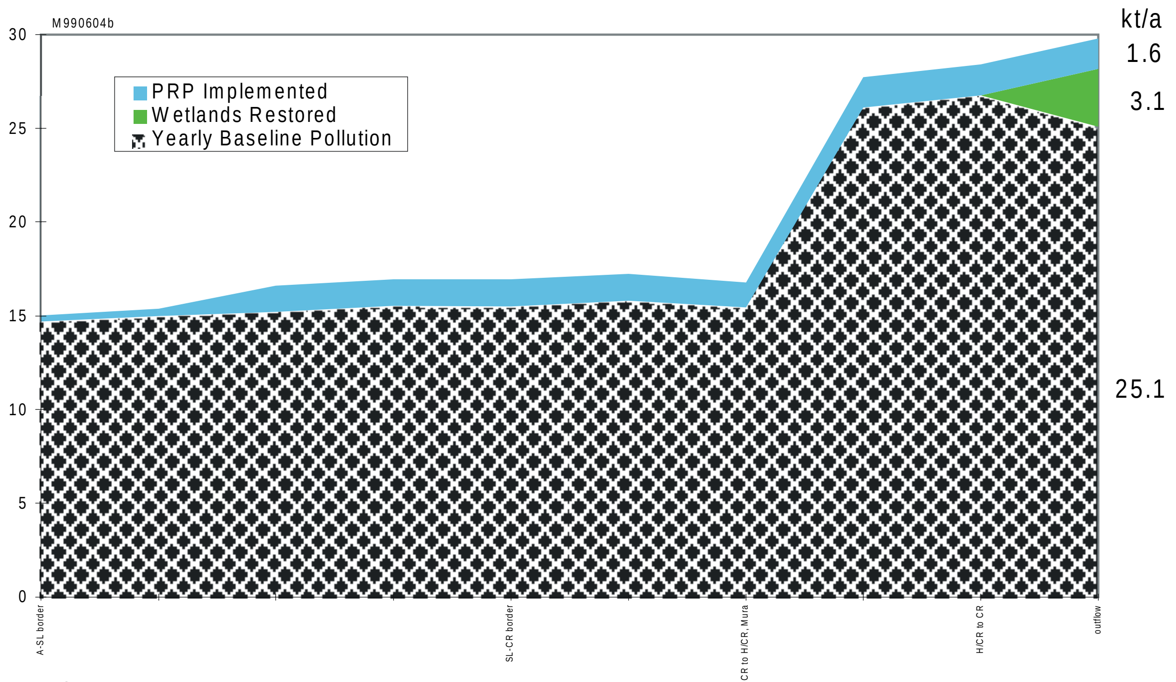


Figure 13

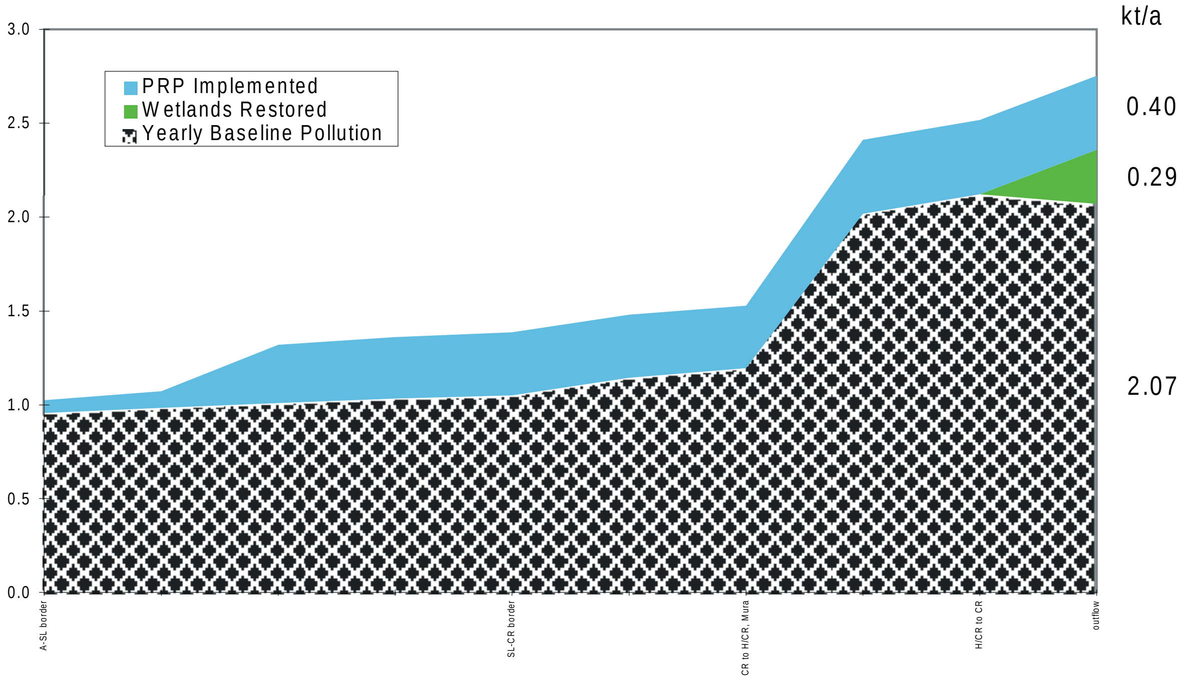


Figure 14

Figure 8.13. In-stream nitrogen load profile for the Drava river, before and after implementation of the PRP, with the additional effect of the restoration of 17 wetlands (top).

Figure 8.14. In-stream phosphorus load profile for the Drava river, before and after implementation of the PRP, with the additional effect of the restoration of 17 wetlands (bottom).

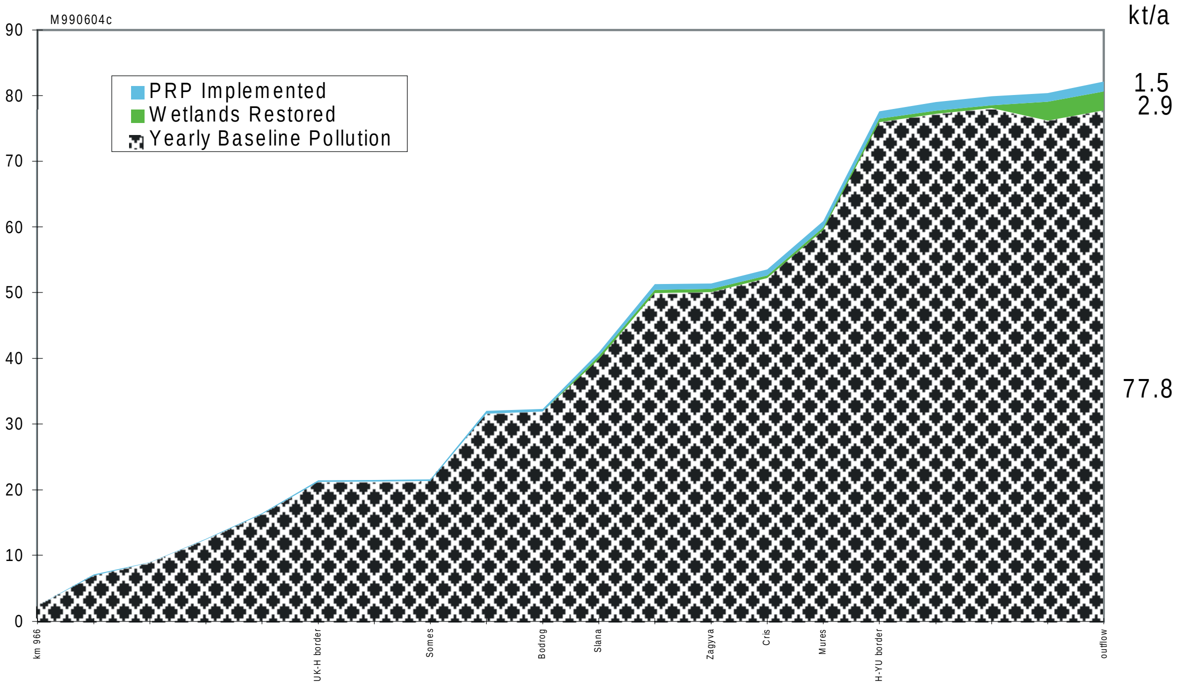


Figure 15

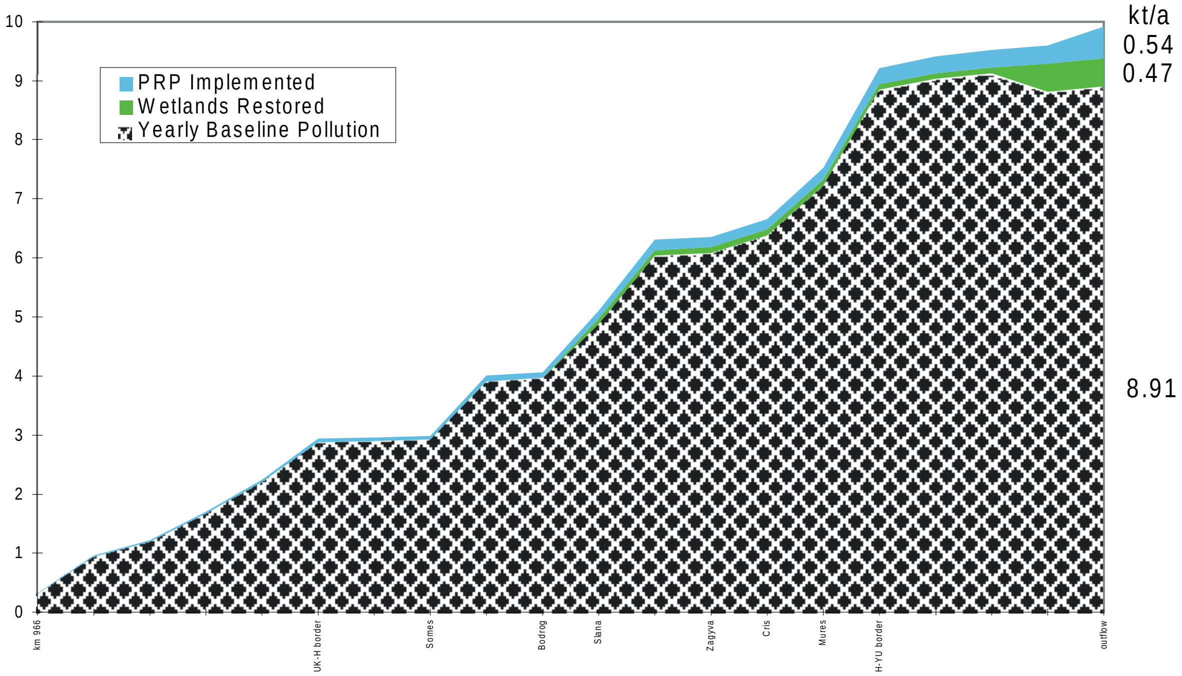


Figure 16

Figure 8.15. In-stream nitrogen load profile for the Tisa river, before and after implementation of the PRP, with the additional effect of the restoration of 17 wetlands (top).

Figure 8.16. In-stream phosphorus load profile for the Tisa river, before and after implementation of the PRP, with the additional effect of the restoration of 17 wetlands (bottom).

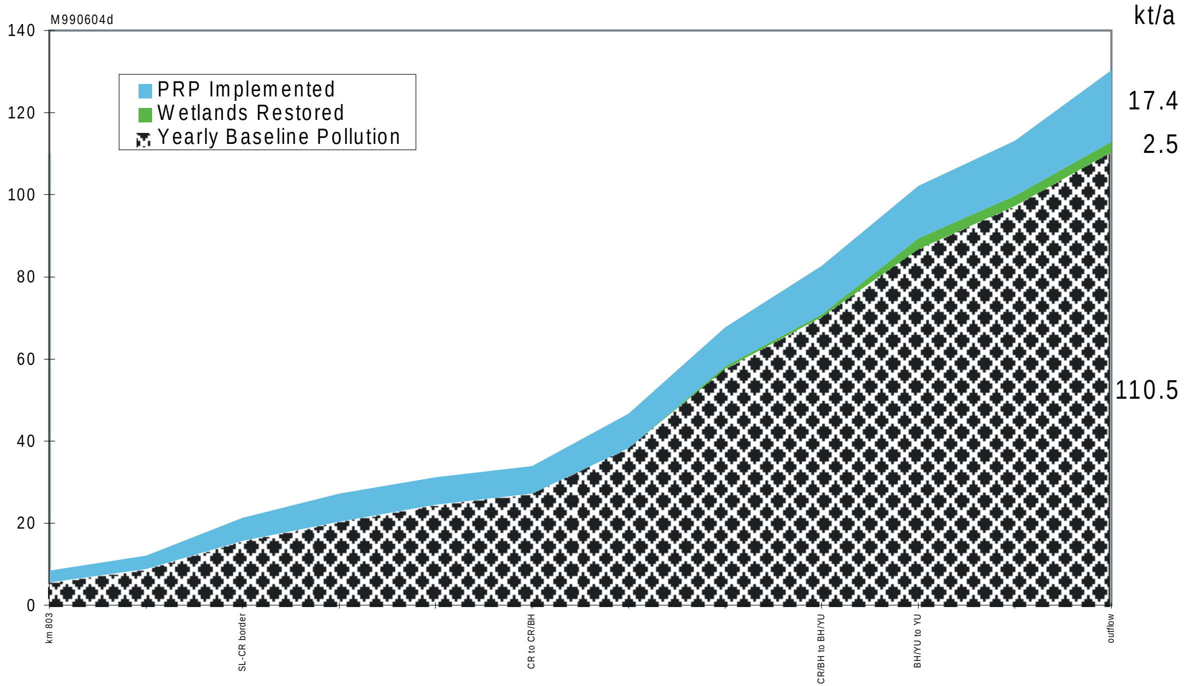


Figure 17

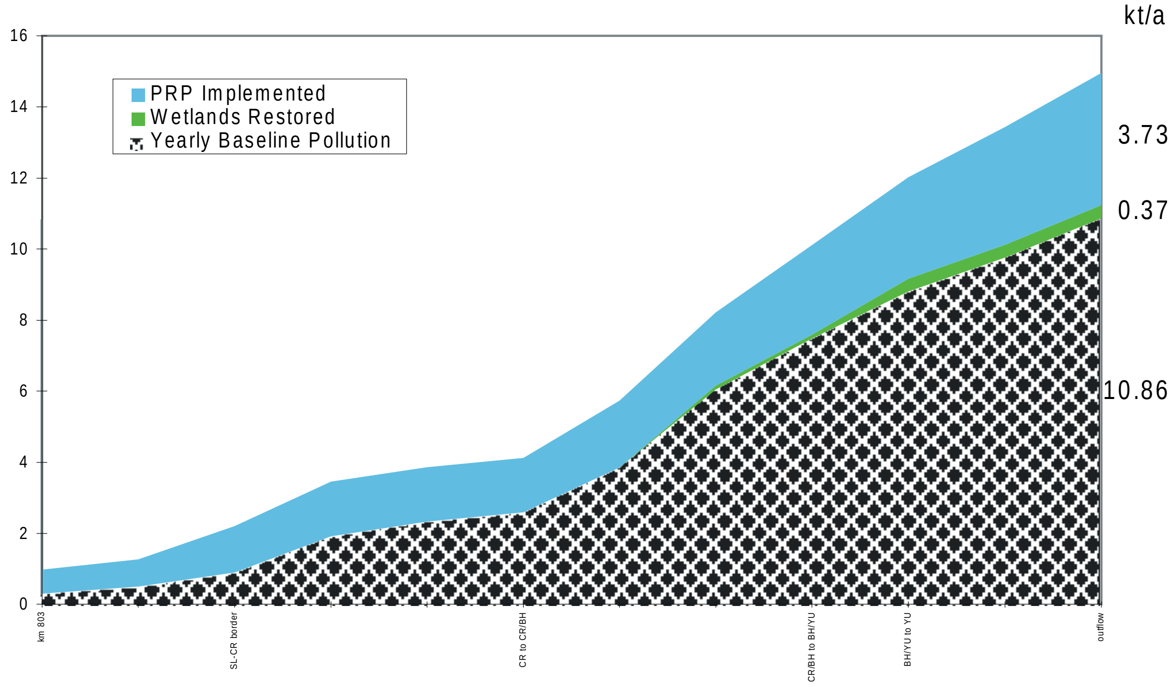


Figure 18

Figure 8.17. In-stream nitrogen load profile for the Sava river, before and after implementation of the PRP, with the additional effect of the restoration of 17 wetlands (top).

Figure 8.18. In-stream phosphorus load profile for the Sava river, before and after implementation of the PRP, with the additional effect of the restoration of 17 wetlands (bottom).

8.5. Computed Longitudinal In-Stream Load Profiles, Subdivided per Sector

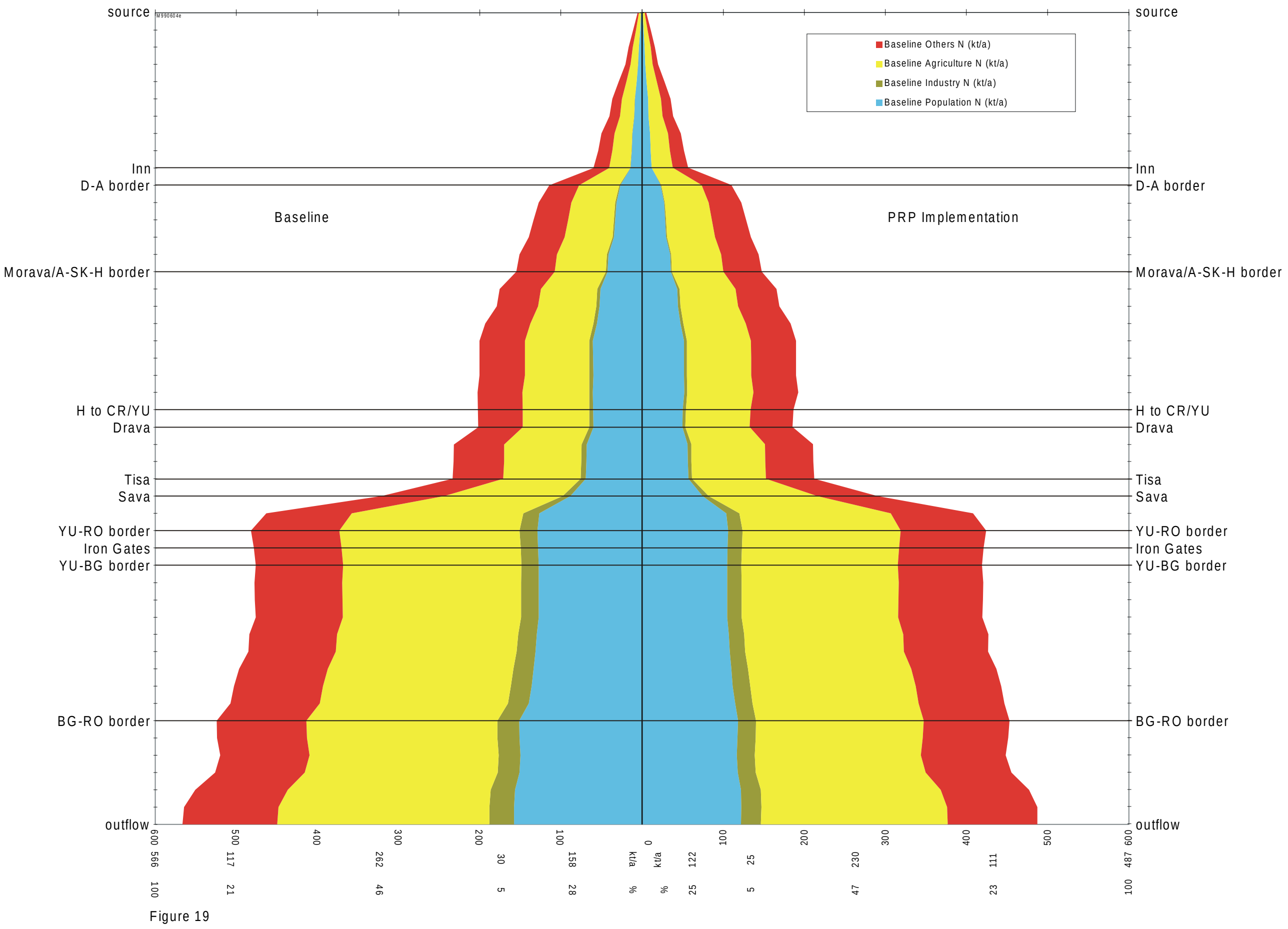


Figure 8.19. In-stream nitrogen load profile for the Danube river, before (left side) and after (right side) implementation of the PRP, subdivided over the sectors population, industry, agriculture and others.

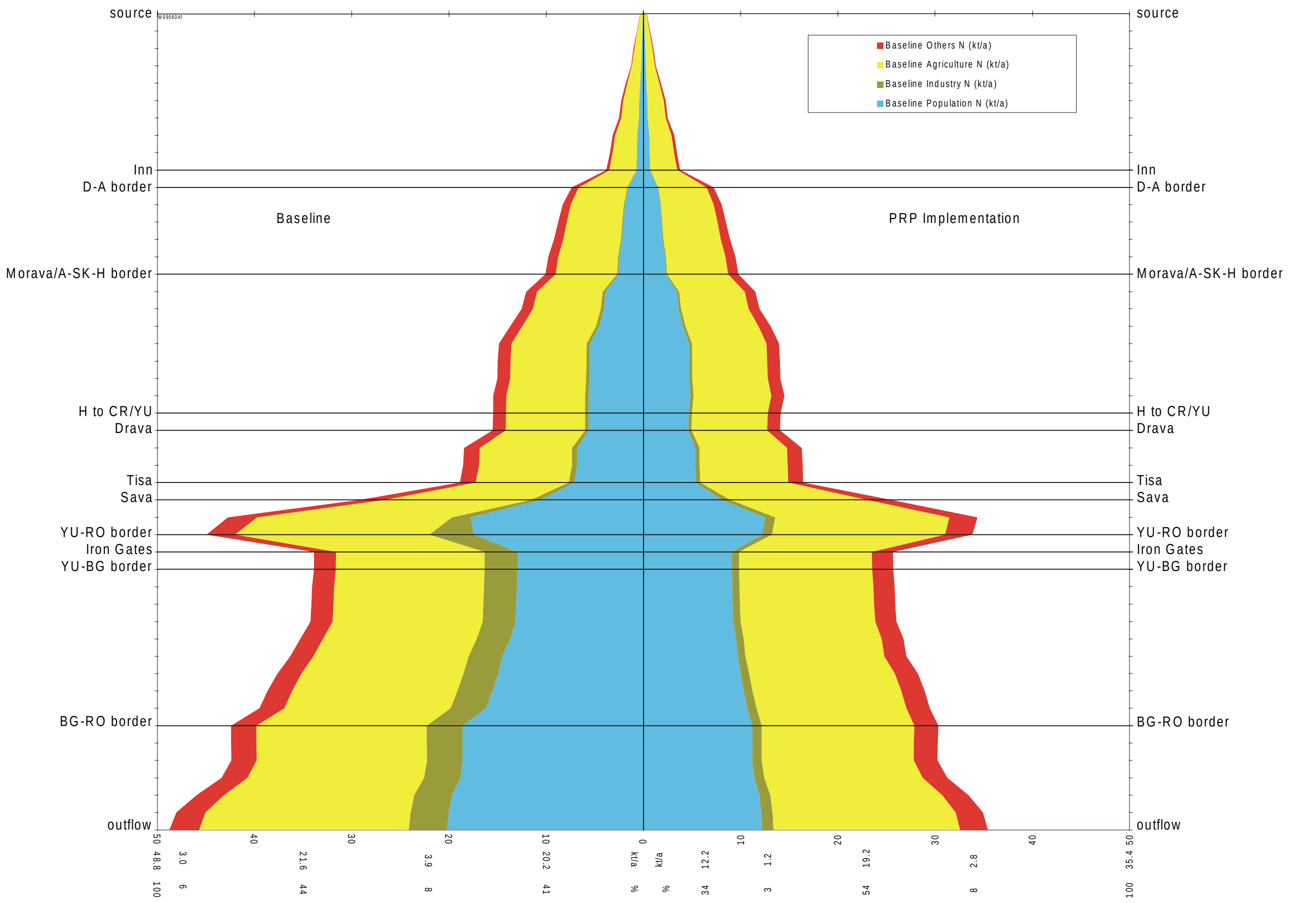


Figure 8.20. **In-stream phosphorus load profile for the Danube river, before (left side) and after (right side) implementation of the PRP, subdivided over the sectors population, industry, agriculture and others.**

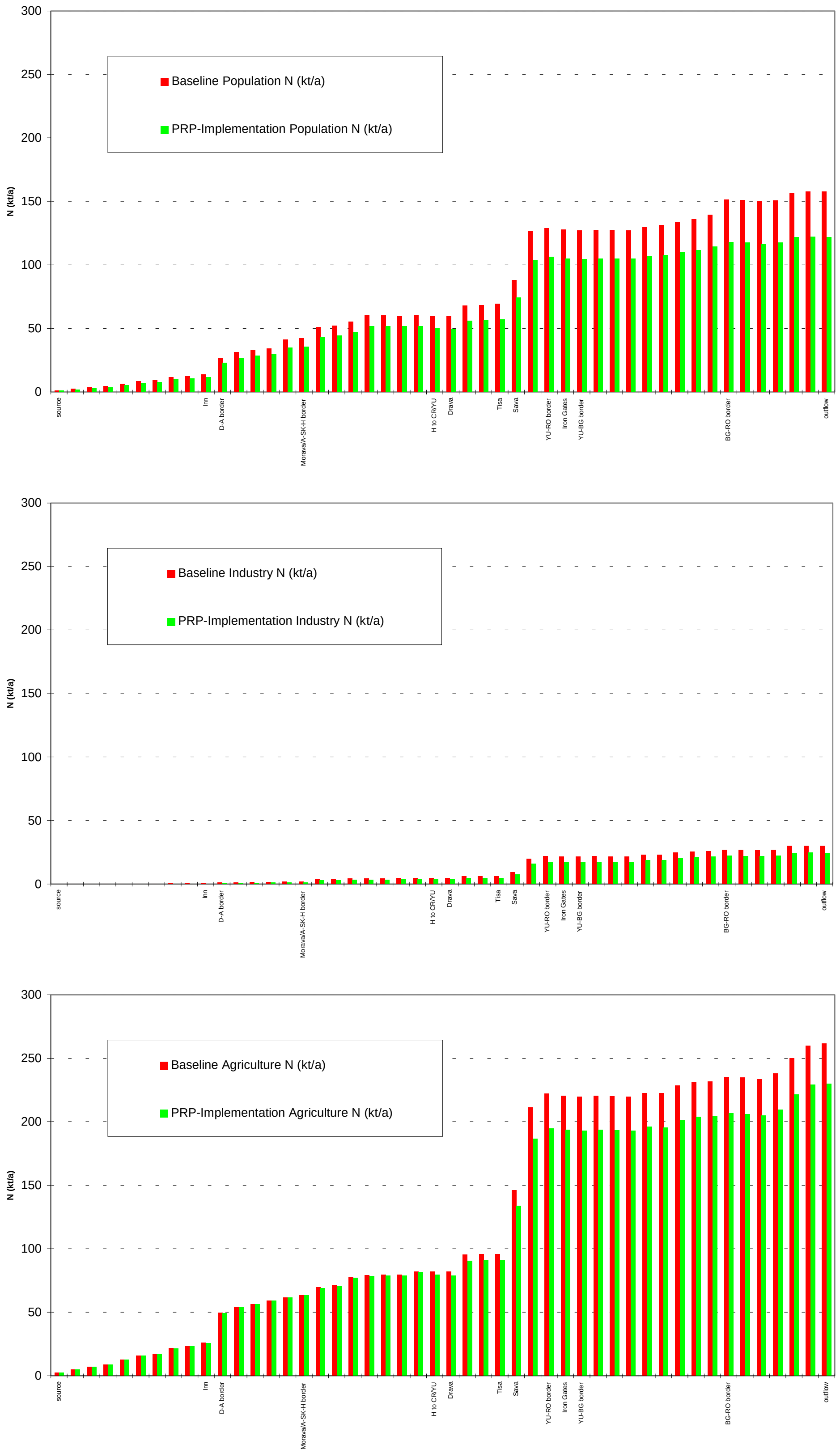


Figure 8.21. In-stream nitrogen load profiles for the Danube river, before and after implementation of the PRP, for the sectors population, industry and agriculture.

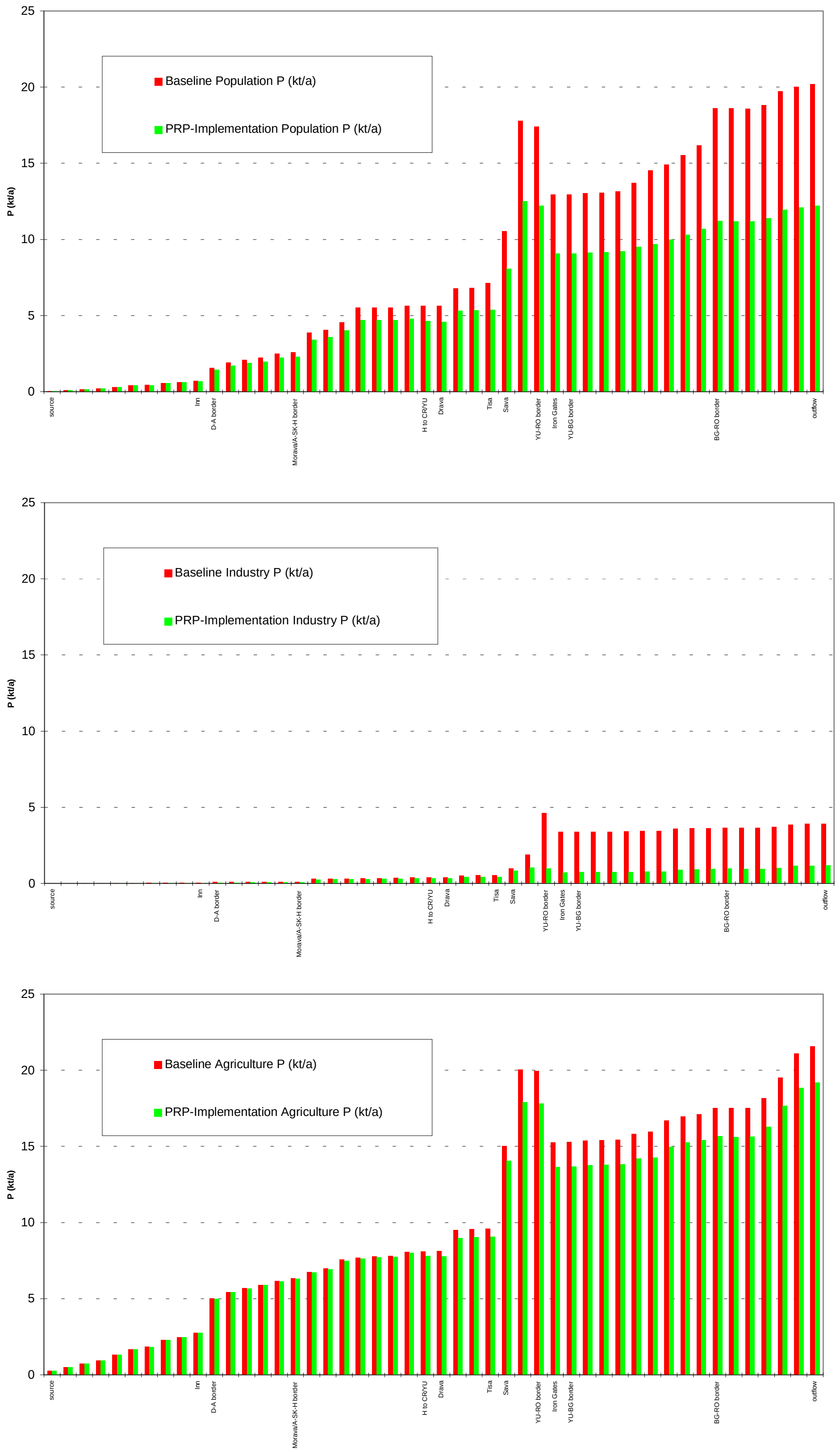


Figure 8.22. In-stream phosphorus load profiles for the Danube river, before and after implementation of the PRP, for the sectors population, industry and agriculture.

Annexes