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Koivusalo, H., Varis, O. and Somlyody, L.

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Abstract

Water pollution and water quality management receives increasingly17attention in eastern European countries. More efficient waste water treatment is needed at the same time when the economy of those countries is not on a stable ground. Thus investigation is needed, how to set priorities and invest funds available to get optimal benefits in water quality management. In this study the role of the dischargers along Nitra river in Slovakia was analyzed based on mass balance of biochemical oxygen demand (BOD). Monthly data from 1990 were used. Because of scarce data and large uncertainties involved, a stochastic approach was taken using probability distributions in propagation of uncertainties. The river was subdivided into twelve stretches and the mass balances of each of them were closed using the BOD equation of the Streeter-Phelps model.

Water Quality of Nitra River, Slovakia – Analysis of Organic Material Pollution

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WATER QUALITY OF NITRA RIVER, SLOVAKIA - ANALYSIS OF ORGANIC MATERIAL POLLUTION

Koivusalo, H.[1], Varis, O.[1] & Somlyódy, L.[2]

1. INTRODUCTION

Recent political transitions in eastern Europe have disclosed an urgent need to pay more attention to quality aspects in water resources management. There is a call for priority setting in water pollution control. The need for building more efficient waste water treatment plants is evident. This, however, requires economic investments, from which the benefits looked in a short-term are sparse. Under present economic situation there is not enough money to renew the whole treatment capacity in eastern European countries at once, whereas decisions must be made, how to invest the money available so that the environmental benefit is optimal.

The priority setting requires basic data about the extent and type of pollution. Accordingly tools for computational analysis which are implementable in those areas are needed. They should be easily applicable and usable by water authorities and managers. Therefore complex methods demanding efficient computers are not always useful.

There are various types of water quality problems depending on activities yielding to water pollution. Several different compounds, which can be independent or dependent of each other, can be considered as pollution. For example as the organic material loaded into water degrades, the oxygen in water is consumed, which can be measured as biochemical oxygen demand (BOD). Nutrients like phosphorus or nitrogen can result in eutrophication. Hygienic problems are caused by bacteria, protozoa or other microbes. Solid particles discharged into water can lead to high turbidity. Toxic substances and heavy metals can accumulate in food chains and cause disturbance to biological activity in water.

The aim of this study was to define a mass balance model for organic material pollution in the Nitra in order to recognize the most important BOD dischargers along the river. The analysis was based on existing data using the BOD equation of the Streeter-Phelps model. The uncertainty in the variables of the model were presented using probability distributions and the impacts of those uncertainties were propagated through the system. The information obtained could also be further used in making decisions about what should be done to improve water quality of Nitra river.

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2. SITE DESCRIPTION AND DATA

Nitra river is a tributary of Våh river in Slovakia, CSFR (Figure 2.1.). It has several tributaries, which together with Nitra form a catchment of 5140.6 km^2. The river length of Nitra is about 171 km. The average streamflow in the downstream is 24.5 m^3/s. Its longest tributary is Zitava, with 100 km of length. Other significant tributaries are Handlovka (34 km) in the north, Nitrica (49 km) and Bebrava (50 km). The Nitra is, like most rivers in eastern Europe highly loaded with waste waters from both cities and industrial areas. The overall BOD discharge to the Nitra and its tributaries was 9600 tons in 1990, from which 69 % was municipal load. The total number of inhabitants in the watershed is 646 000 and the biggest city in the area, Nitra, has 93 000 inhabitants. The industry in the area is diverse. The biggest waste water dischargers are chemical industry and electrical and thermal power plants in upper area and sugar beet factories in the lower area around Nitra. The landscape by the side of Nitra is flat in the downstream area. The upstream area is surrounded with mountains reaching the height of over 1000 m above the sea level.

Data of the water quality in Nitra and data of the discharge loadings into river came from Slovak Hydrometeorological Institute in Bratislava. Water quality data were available for two decades and for number of components, but critical was the data on dischargers, which were available only for 1990. Monthly measurements (measured once a month) of BOD_5, DO and temperature, and river flow as a mean value for the sampling day were used from twelve points at Nitra river and from four points at tributaries in 1990. In addition, the average travel times with different flows were available in nine points (see Figure 2.7.).

The effluent discharge data were expressed for 43 dischargers as one BOD_5 value per year 1990. The value was based on several measurements, the frequency of which was stated according to the importance of the source. These measurements were taken by the dischargers and they could be corrected by the local river authorities on the base of their own checking. The less important sources were obliged to take measurements two times a year while the required frequency for the most important dischargers were several times a week. The data is presented in Appendix 1.

The location of measurement points and dischargers is presented in Appendix 2. The measurement points are shown as river kilometers from the downstream to the upstream in Table 2.1.

The monthly BOD_5 concentrations in 1990 along the river are presented in Figure 2.2. Notable are the high concentrations in measurement points 7 and 14 and extensive fluctuation in concentrations during the second half of the year. In Figure 2.3. river flows are shown in the measurement points along the Nitra. The seasonal variation of floods in spring and late autumn are distinct.

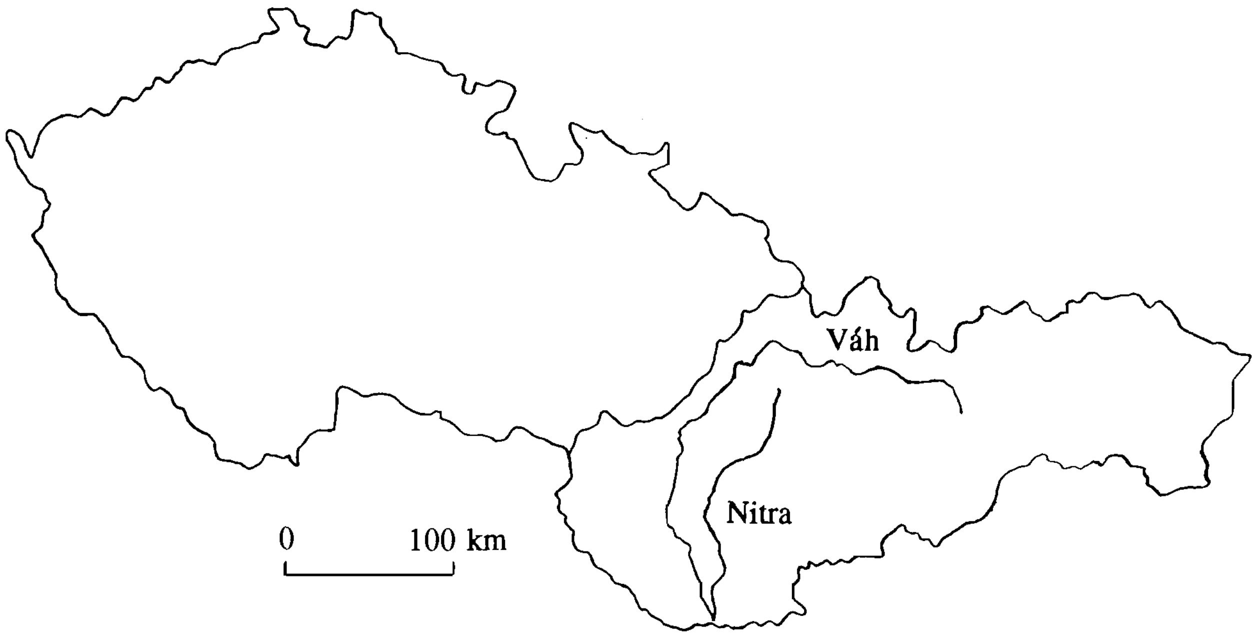


Figure 2.1. Location of the rivers Váh and Nitra in Slovakia.

Table 2.1. Location of measurement points in Nitra river (compare with Appendix 2).

Measurement point	Point number	River km
Klačno	1	165.0
Nedožery	2	149.0
Nováky over	6	132.5
Chalmová	7	123.8
Partizánske over	8	115.7
Chynorany	10	105.5
Bošany nad	11	101.6
Práznovce	14	98.2
Nitr. Streda	15	91.1
Lužianky	16	65.6
Nitrany	17	47.8
Nové Zámky	25	14.5
Komoča	26	6.5

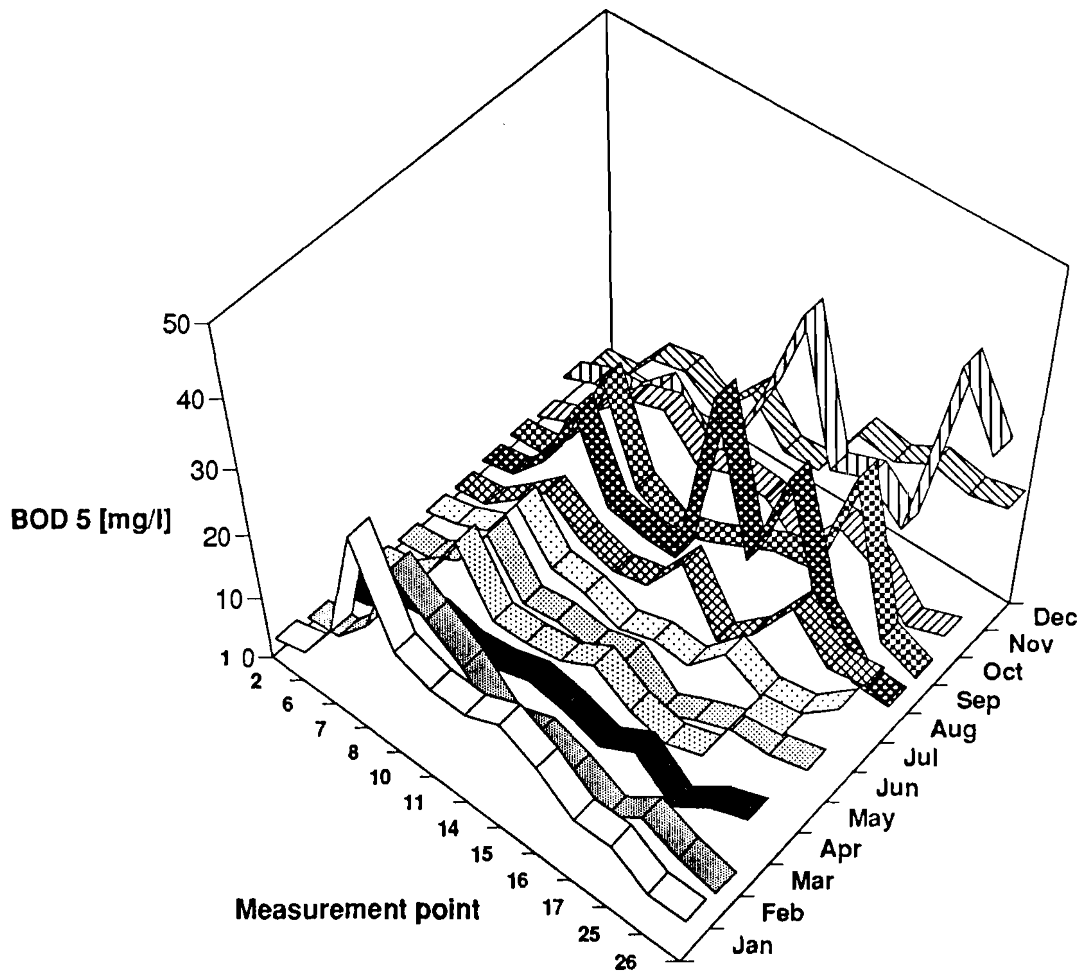


Figure 2.2. Monthly BOD_5 concentrations along Nitra river in 1990.

BOD mass in tons per month was calculated as a product of BOD_5 concentration and river flow:

$$Z_i=(0.0864d)BOD_{5,i}Q_i \tag{1}$$

where Z_i = BOD mass at point i [t/month]
$BOD_{5,i}$ = Biochemical oxygen demand at point i [mg/l]
Q_i = River flow at point i [m^3/s]
d = Number of days in a month

The monthly BOD masses and their variations are shown in Figure 2.4. The temperature and its seasonal variation in 1990 in Nitra river is presented in Figure 2.5. Water tended to be colder in the upstream than in the downstream due to the mountaneous origin of the river.

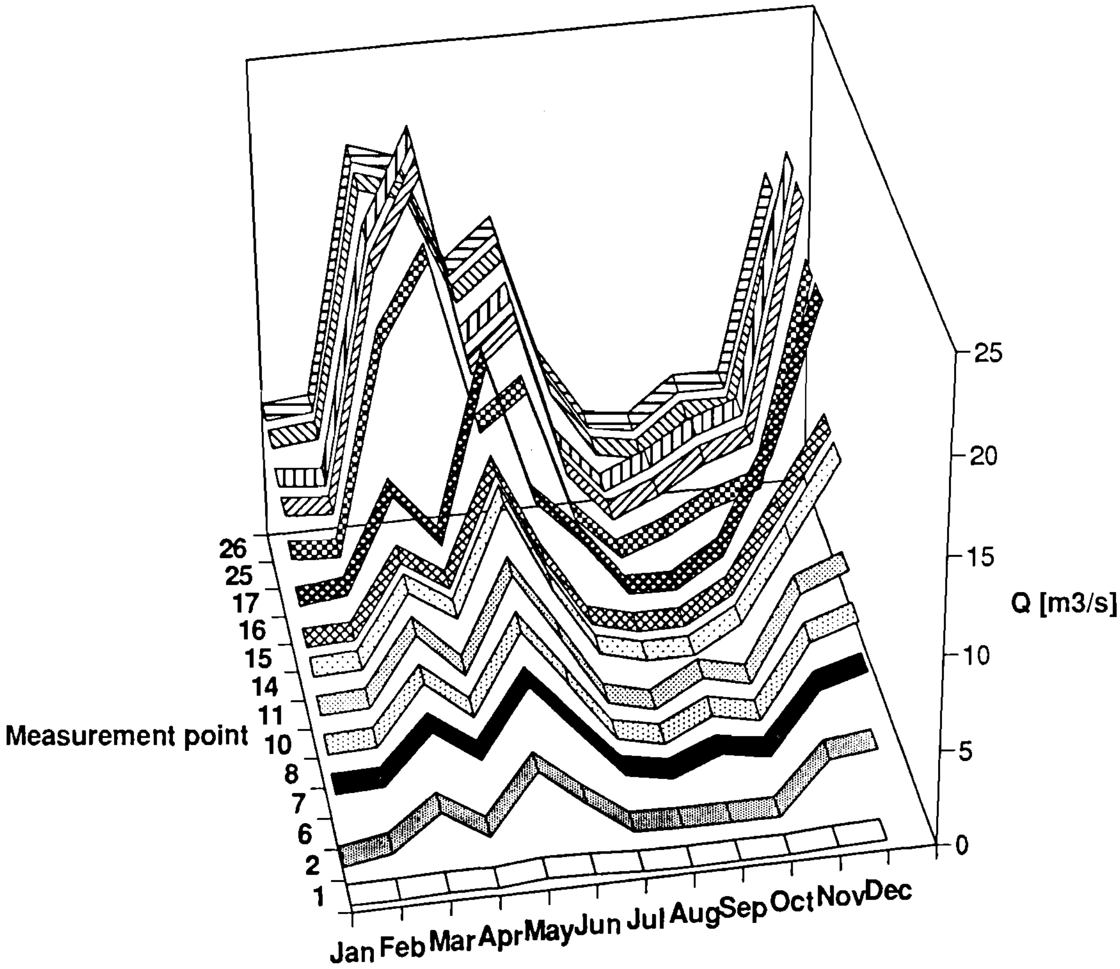


Figure 2.3. River flows and their variations in Nitra river in 1990.

Dissolved oxygen concentrations (DO) along the Nitra are presented as a percentage of oxygen saturation level in Figure 2.6. In the first half of the year 1990 no oxygen depletion took place but in the second half there were remarkable depletions. In the upstream the dissolved oxygen concentrations raised quite often over saturation level, which may be due to, e.g., oxygen produced by primary producers.

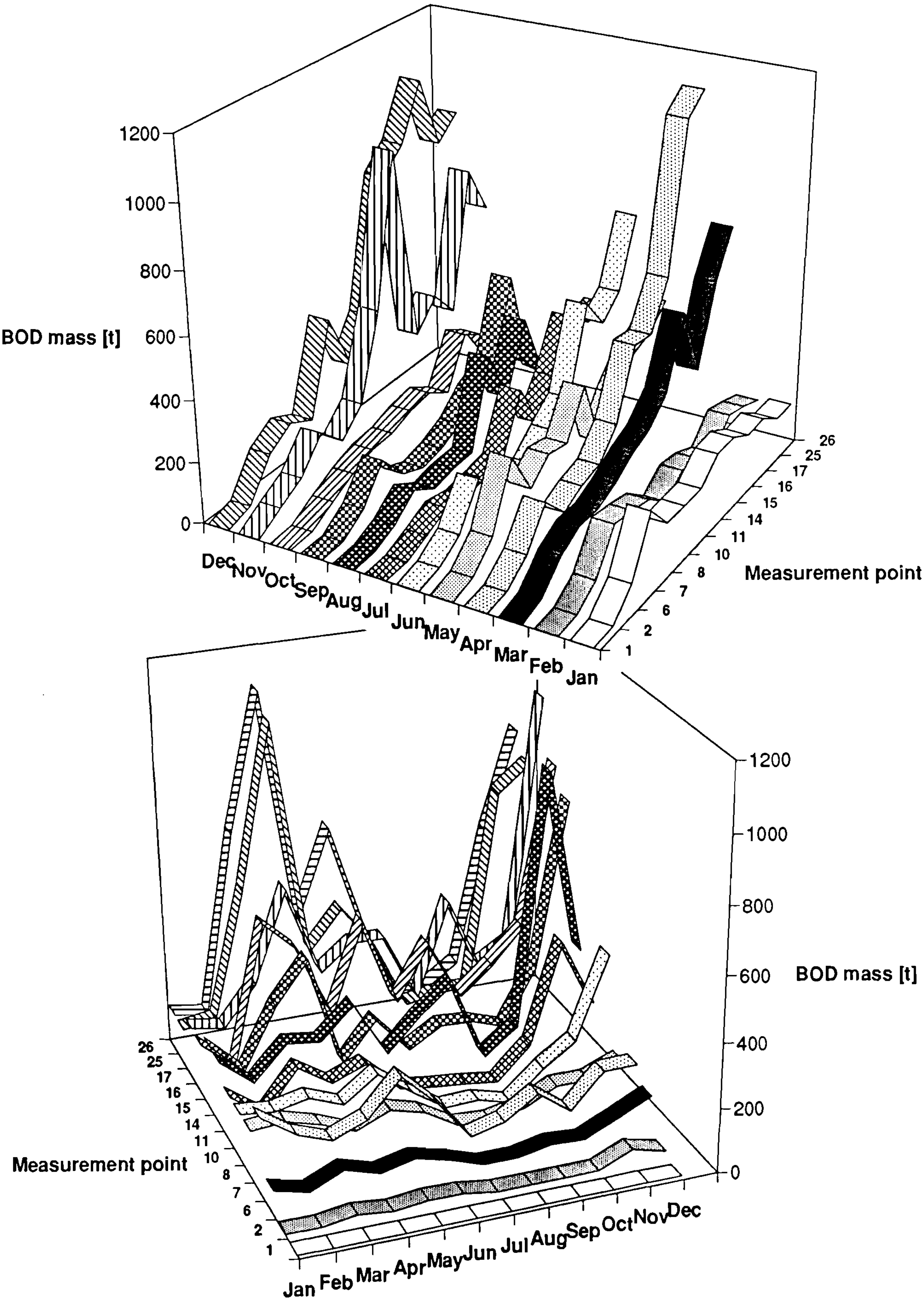


Figure 2.4. Monthly BOD masses and their variations along the Nitra in 1990.

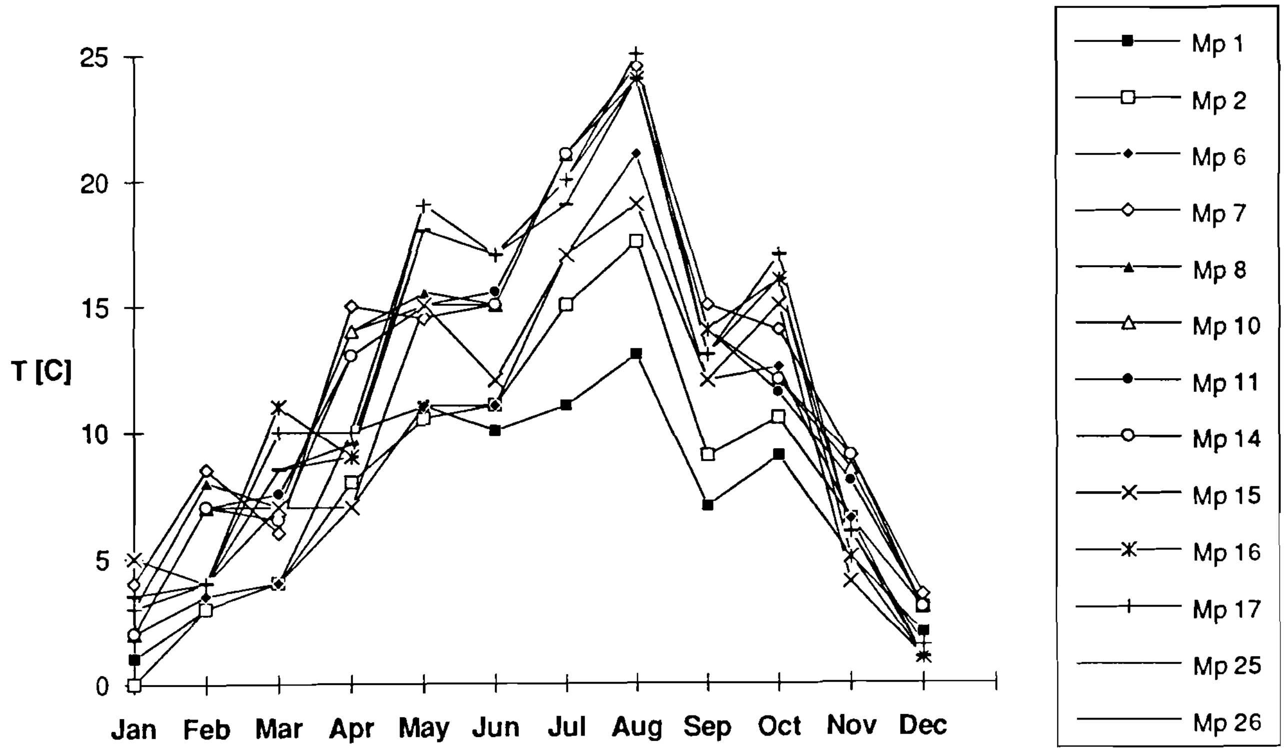
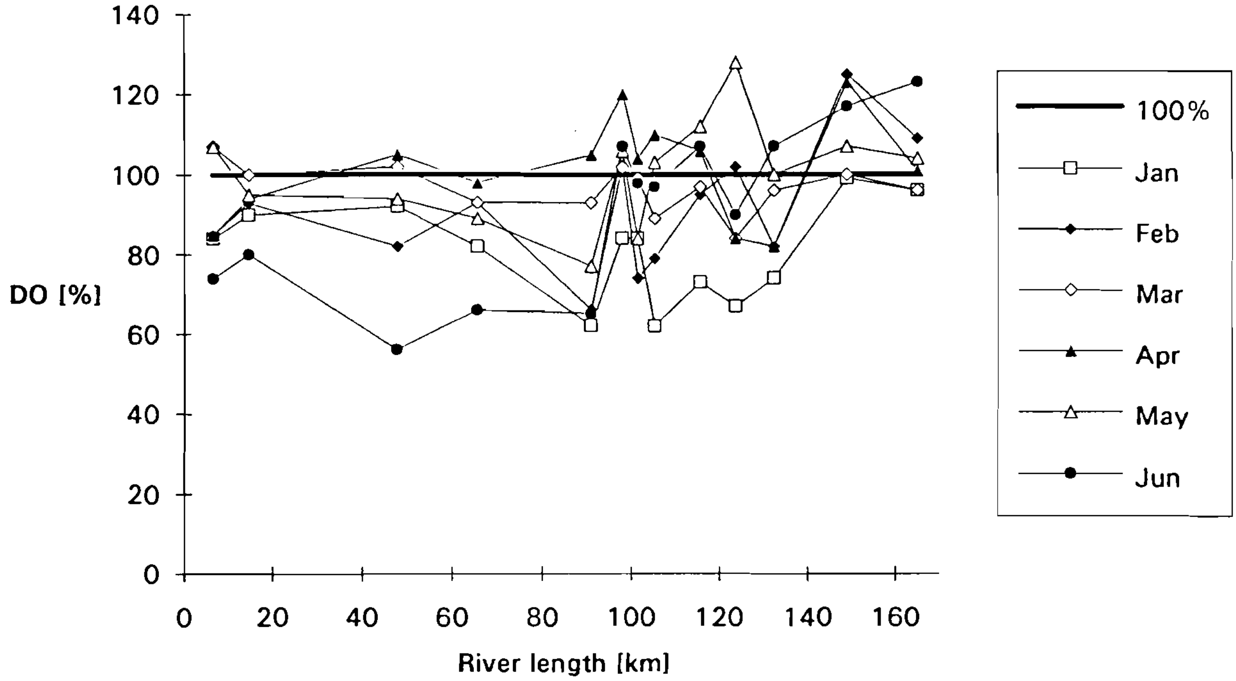


Figure 2.5. Temperature and its monthly variation in Nitra river in 1990.

The Nitra river was subdivided into twelve stretches according to the measurement points (Appendix 2). The average water velocities in each stretch were determined as a function of flow of the downstream point of the stretch. The flows were obtained from steady state hydraulic model computations. The travel times were known between nine points, in which water altitudes were controlled with weirs, and for four different flows. The flows were Q_{355}, Q_{270}, Q_{180} and Q_{90}. The subindex means the number of days in a year, in which the flow was above the given level. The four flow levels in measurement points were approximated based on the known flows in the nine points (see Figure 2.7.). Water velocities related with these four different flows were calculated as a quotient of distance and travel time between every two measurement points. The relation between water velocity and river flow was described by:

$$v_i=f(Q_i)=a(Q_i)^{1/b} \qquad (2)$$

where a and b are parameters, which were estimated by forcing the squared error $(f(Q_i)-v_i)^2$ below 2 percent of the velocity value. Figure 2.8. shows the estimated water velocities as a function of flow, and the observed velocities. Velocities varied from 0.05 m/s up to 0.8 m/s in different stretches of the river.



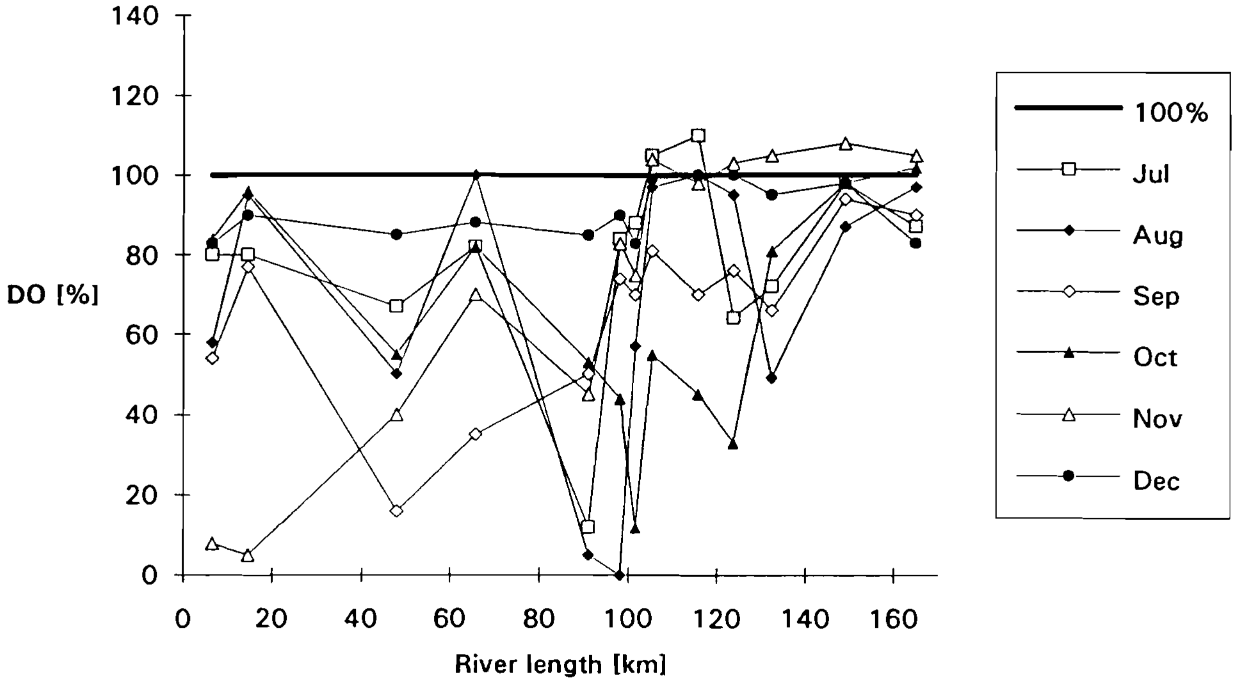


Figure 2.6. DO along the Nitra in the first and the second halfs of the year 1990 as a percentage of saturation level.

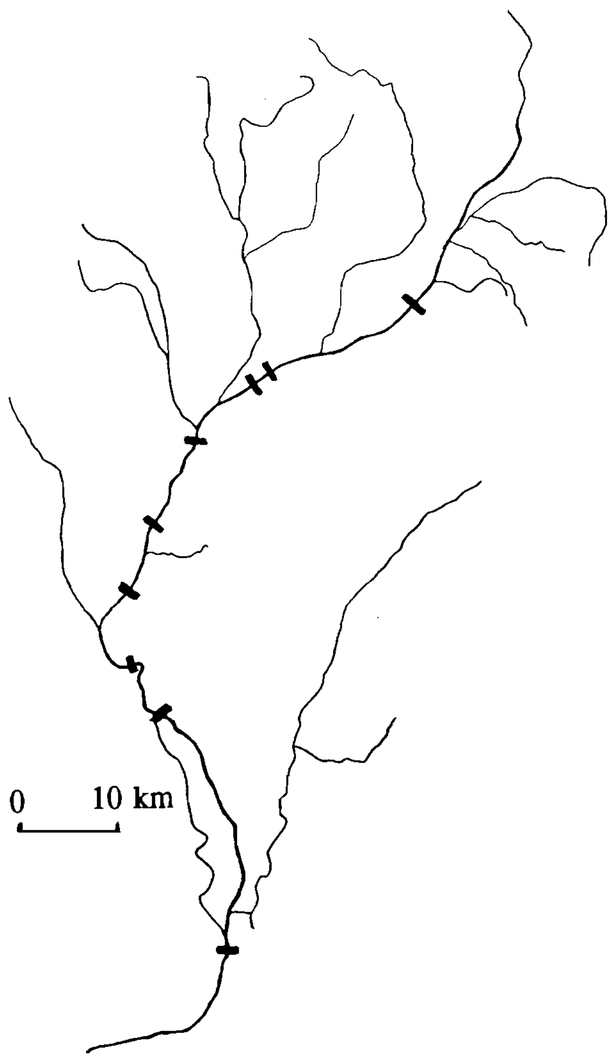


Figure 2.7. The weirs along Nitra river.

Figure 2.9. shows how much BOD mass is discharged into different stretches of the Nitra. Stretches were defined subdividing the river at every measurement point. The names of dischargers with corresponding codes are presented in Appendix 3. BOD_5 loads by the Nitra are presented in Figure 2.10. Here tributaries, from which data existed, were regarded as dischargers. Dischargers located upstream from the measurement points of tributaries were not considered. Notable is the big variation in BOD loadings of dischargers.

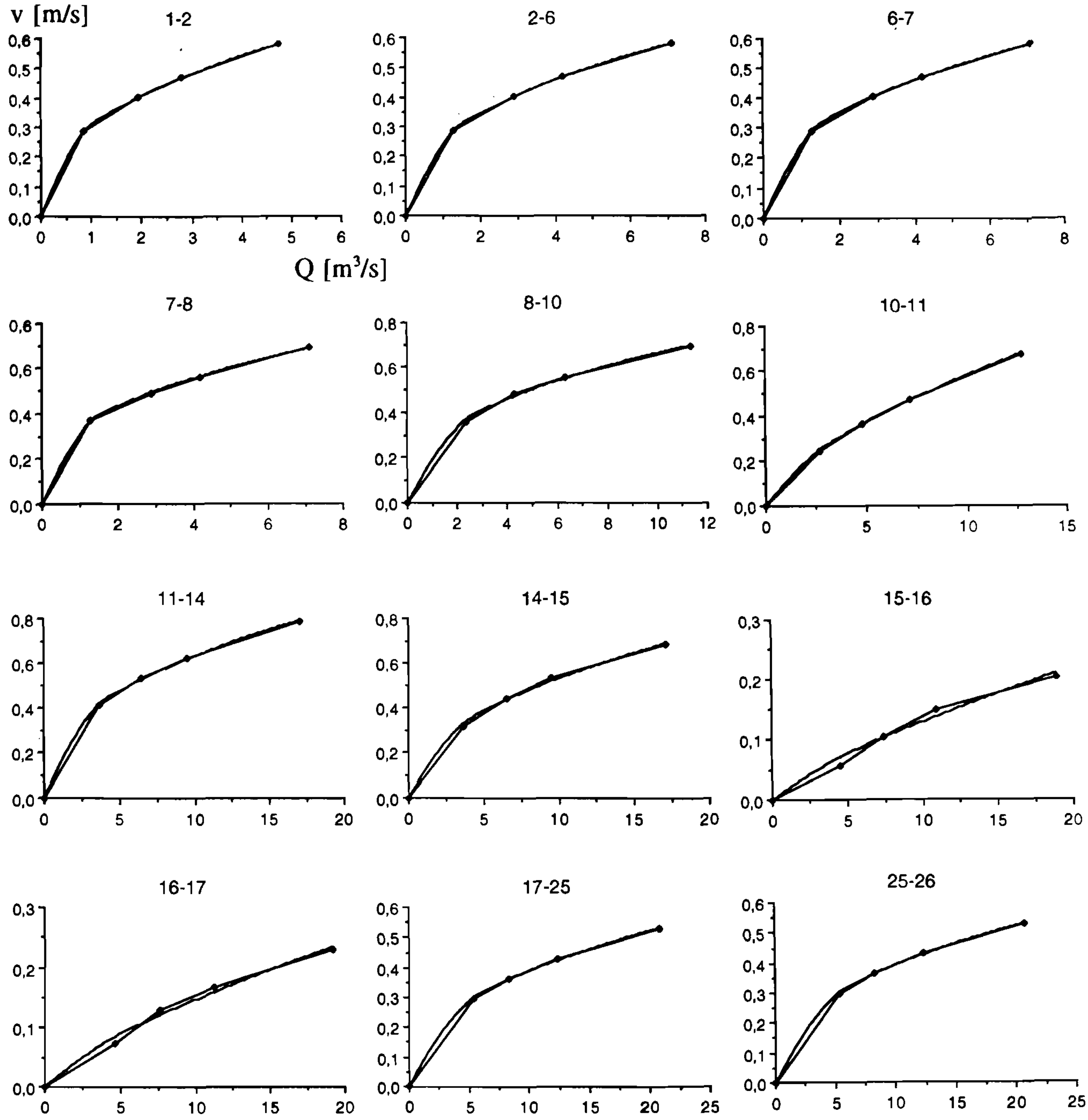


Figure 2.8. Relations between water velocity and river flow in the Nitra. Angular line is drawn through data points and curve shows the corresponding outcome of the function $v_i=f(Q_i)$. Note the significant variation in the downstream velocities.

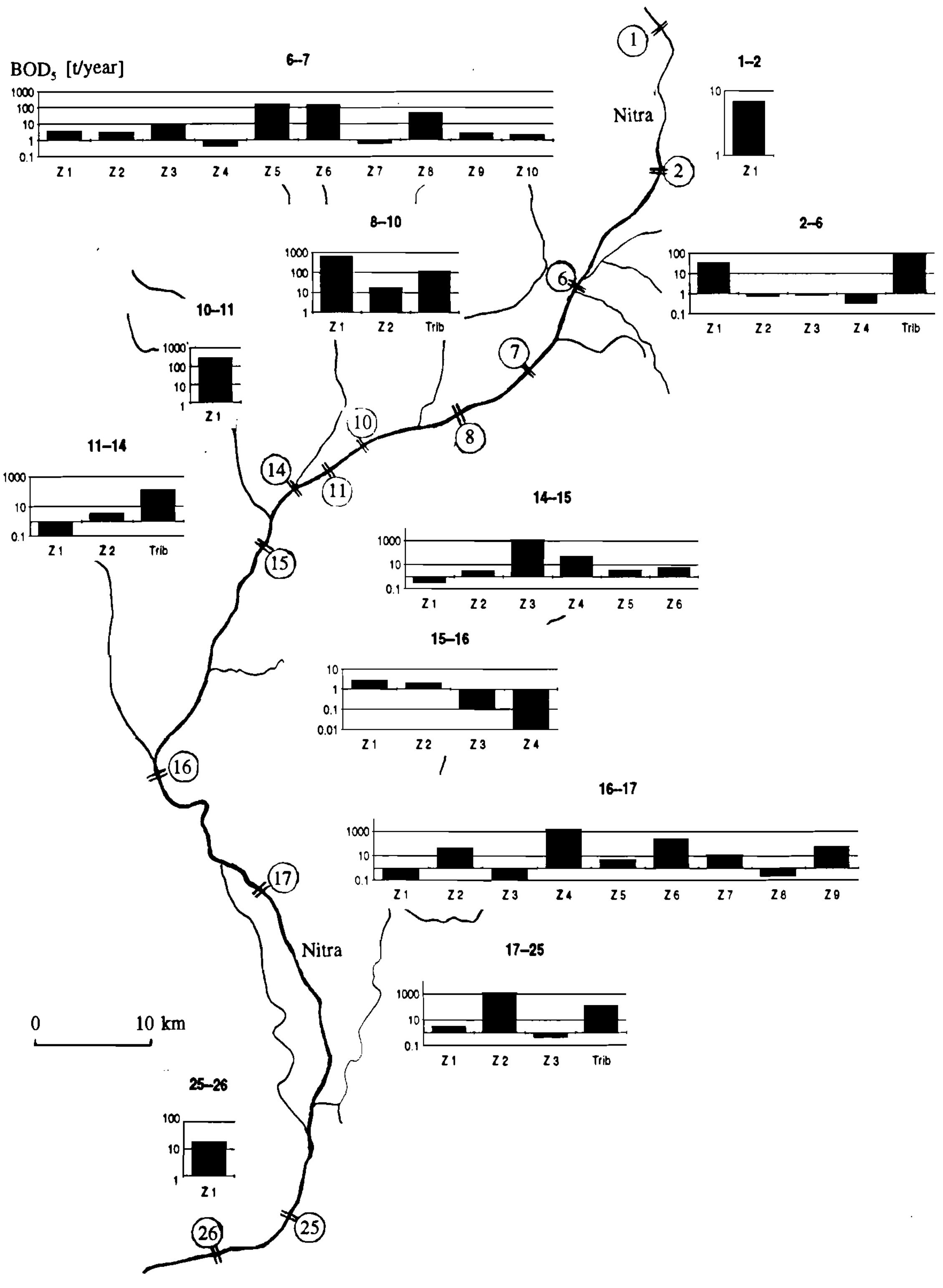


Figure 2.9. Annual BOD loads into different stretches of the Nitra in 1990. The names of the dischargers corresponding to codes are presented in Appendix 3.

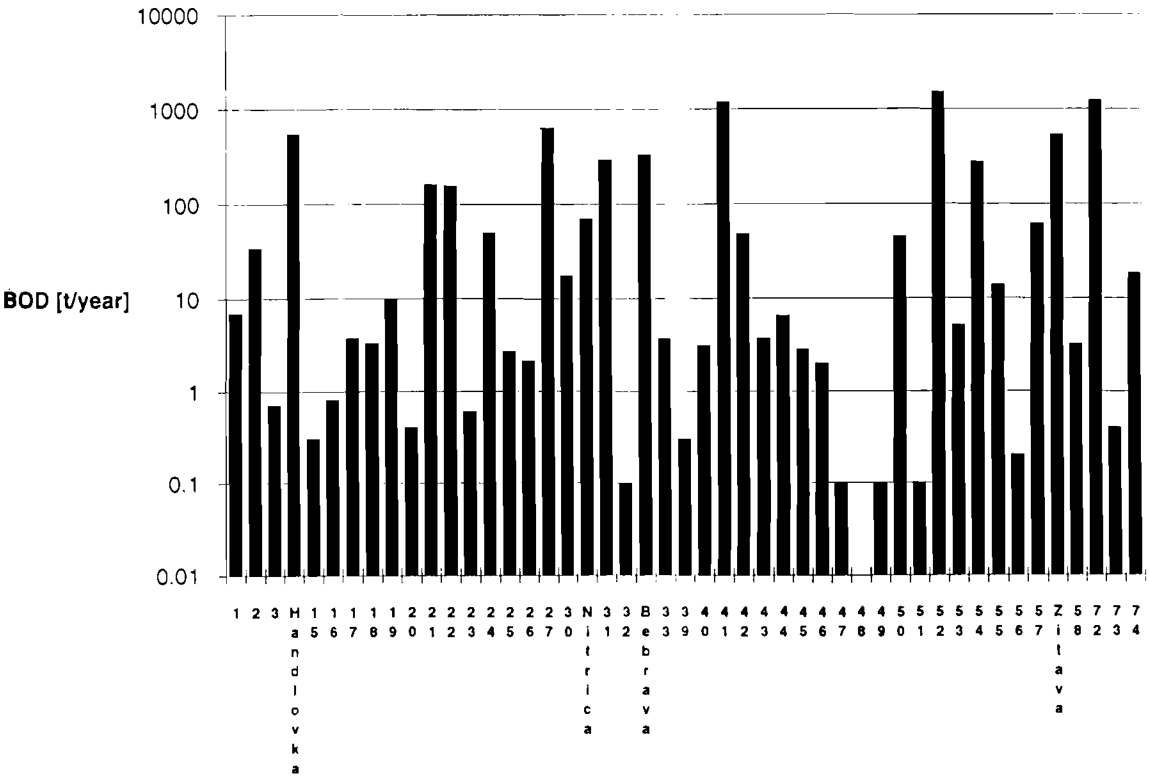


Figure 2.10. BOD loads in tons per year in 1990. The tributaries, from which data existed, were regarded as loads to the Nitra.

3. MASS BALANCE ANALYSIS

3.1. Modelling BOD and DO

In the 1920s, the Ohio River Commission developed one of the first mathematical models of an aquatic environment. This was the Streeter-Phelps equation describing the balance of biochemical oxygen demand and dissolved oxygen in a stream. Until the advent of modern computational hardware and techniques, the Streeter-Phelps model was restricted in its usefulness. When computational methods and knowledge improved, the Streeter-Phelps equations were extended to take account new processes affecting the BOD and DO balance. Until the late 1970s the comparatively simple Streeter-Phelps model was appeared in a variety of computational forms (Orlob, 1982).

The major impact of the organic material pollution into surface waters is the removal of dissolved oxygen (DO). This is most often measured as biochemical oxygen demand (BOD), which is the result of the activity of aerobic heterotrophic micro-organisms responding to the addition of pollution. However, not all pollution is biodegradable and oxygen consuming. Much pollution may be in a form of inert mineral material or toxic and thus inhibiting the activity of heterotrophic micro-organisms. So BOD cannot at every case be a metric of pollution. The removal of dissolved oxygen, in other words deoxygenation, is countered by natural reaeration process as atmospheric oxygen is redissolved through the water surface. The rate of this reaeration is proportional to the difference between oxygen saturation level and actual DO concentration, called oxygen deficit. These processes are illustrated in Figure 3.1.1. as BOD and DO sag curves (Ellis, 1989).

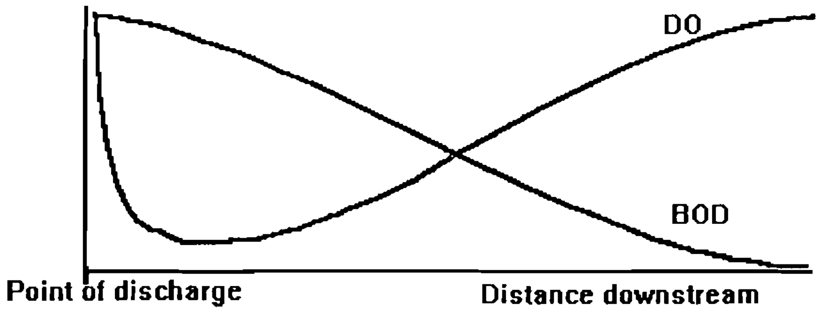


Figure 3.1.1. BOD and DO sag curves (Ellis, 1989).

The Streeter-Phelps model describes mathematically the deoxygenation and reaeration processes. It is based on following assumptions (Rinaldi et al, 1979):

(i) The BOD decay rate is proportional to BOD concentration.
(ii) The deoxygenation and BOD decay rate are equal.
(iii) The reoxygenation rate is proportional to the oxygen deficit.

Model equations are:

$$\frac{\partial b}{\partial t}+v\frac{\partial b}{\partial l}=-k_1 b \tag{3}$$

$$\frac{\partial c}{\partial t}+v\frac{\partial c}{\partial l}=-k_1 b+k_2(c_s-c) \tag{4}$$

where b = Biochemical oxygen demand BOD [mg/l]
c = Dissolved oxygen DO [mg/l]
c_s = Oxygen saturation level [mg/l]
v = Water velocity [m/d]
l = Distance [m]
t = Time [d]
k_1 = Deoxygenation coefficient [1/d]
k_2 = Reaeration coefficient [1/d]

Assuming time independent river flow, BOD and DO concentrations and parameters, and multiplying both equations by river flow, we get a mass balance equations 5 and 6 for river length:

$$v\frac{dZ}{dl}=-k_1Z \tag{5}$$

$$v\frac{dX}{dl}=-k_1Z+k_2(X_s-X) \tag{6}$$

where Z = BOD mass [g/d]
X = DO mass [g/d]
X_s = Oxygen saturation mass [g/d]
Q = River flow [m^3/d]

Initial conditions are:

$$Z(l_0)=Z_0$$
$$X(l_0)=X_0 \tag{7}$$

The analytical solutions to these differential equations are given by Rinaldi et al (1979):

$$Z(l)=Z_0\exp(-k_1\frac{l}{v}) \tag{8}$$

$$X(l)=X_s-(X_s-X_0)\exp(-k_2\frac{l}{v})+\frac{k_1Z_0}{k_1-k_2}[\exp(-k_1\frac{l}{v})-\exp(-k_2\frac{l}{v})] \tag{9}$$

Now a situation is considered, where BOD mass Z_{in} is coming from upstream into a river stretch of length l_{in}, BOD mass Z_{out} is going downstream out of the stretch and furthermore a discharge of BOD mass Z_1 is loaded into river at distance l_1 from the downstream end of the stretch. Mass balance equation can be derived for the stretch so that the incoming BOD mass is equal to the outgoing mass. This is illustrated in Figure 3.1.2. The effect of temperature can be taken account as a power function:

$$f(T)=\Theta^{(20-T)} \tag{10}$$

where T = Temperature of water [°C]
Θ = Coefficient of temperature

The mass balance equation for BOD becomes:

$$Z_{out}=Z_{in}\exp(-k_1\frac{l_{in}}{v}\Theta^{(20-T)})+Z_1\exp(-k_1\frac{l_1}{v}\Theta^{(20-T)}) \tag{11}$$

If incoming and outgoing DO masses are known, a mass balance equation can be written also for dissolved oxygen including the effect of temperature, see Figure 3.1.2.

$$X_{out}=X_s-(X_s-X_{in})\exp(-k_2\frac{l_{in}}{v}\Theta^{(20-T)})+\frac{k_1Z_{in}}{k_1-k_2}[\exp(-k_1\frac{l_{in}}{v}\Theta^{(20-T)})-\exp(-k_2\frac{l_{in}}{v}\Theta^{(20-T)})]$$
$$+\frac{k_1Z_1}{k_1-k_2}[\exp(-k_1\frac{l_1}{v}\Theta^{(20-T)})-\exp(k_2\frac{l_1}{v}\Theta^{(20-T)})] \quad \textbf{(12)}$$

where Z_{in} = BOD mass input [g/d]
Z_{out} = BOD mass output [g/d]
Z_1 = BOD mass loading [g/d]
X_{in} = DO mass at input point [g/d]
X_{out} = DO mass at output point [g/d]

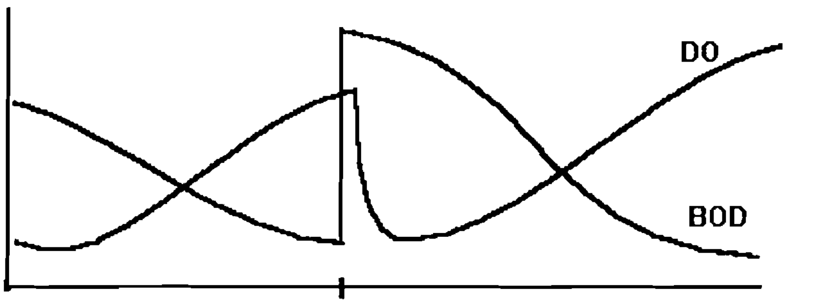


Figure 3.1.2. BOD and DO curves in river stretch with one effluent loading.

With several discharges into the stretch the mass balance equations can be written as equations 13 and 14.

$$Z_{out}=\sum_{i=1}^{n} Z_i\exp(-k_1\frac{l_i}{v}\Theta^{(20-T)}) \quad \textbf{(13)}$$

$$X_{out}=X_s-(X_s-X_{in})\exp(-k_2\frac{l_{in}}{v}\Theta^{(20-T)})$$
$$+\frac{k_1}{k_1-k_2}\sum_{i=1}^{n} Z_i[\exp(-k_1\frac{l_i}{v}\Theta^{(20-T)})-\exp(-k_2\frac{l_i}{v}\Theta^{(20-T)})] \quad \textbf{(14)}$$

where Z_i is BOD loading of discharger, tributary or incoming load from the upstream.

There are two ways in estimating the parameter values of the Streeter-Phelps model. This can be done either by estimating the deoxygenation parameter k_1 first from the BOD equation (5) and thereafter the reaeration parameter from the DO equation (6), or by estimating the parameters simultaneously. Here the focus will be on the BOD equation and the corresponding parameter.

The Streeter-Phelps model is a restricted description of the BOD system which is influenced by many more factors. It does not take into account the reactions of sediment affecting the

BOD concentration. The primary production in nutrient rich water can be a source of dissolved oxygen, which can bring about oxygen concentrations over the saturation level. The ammonia discharged from waste water treatment plants can consume oxygen simultaneously with BOD. Pollutants such as heavy metals and toxic substances can prevent all oxygen consuming biological activity in water. The existing nutrients and the hygienic quality influence the biochemical oxygen demand. If the BOD is to be modelled precisely, all these reactions and quantities of the substances should be known.

3.2. BOD inputs and outputs

As was mentioned in section 2, the Nitra river was subdivided into twelve stretches according to the measurement points (Appendix 2). The BOD masses were calculated separately in every stretch including incoming masses from upstream, tributaries and effluent discharges as positive and outgoing mass to the downstream as negative. These inputs, outputs and their differences are presented in Figure 3.2.1.

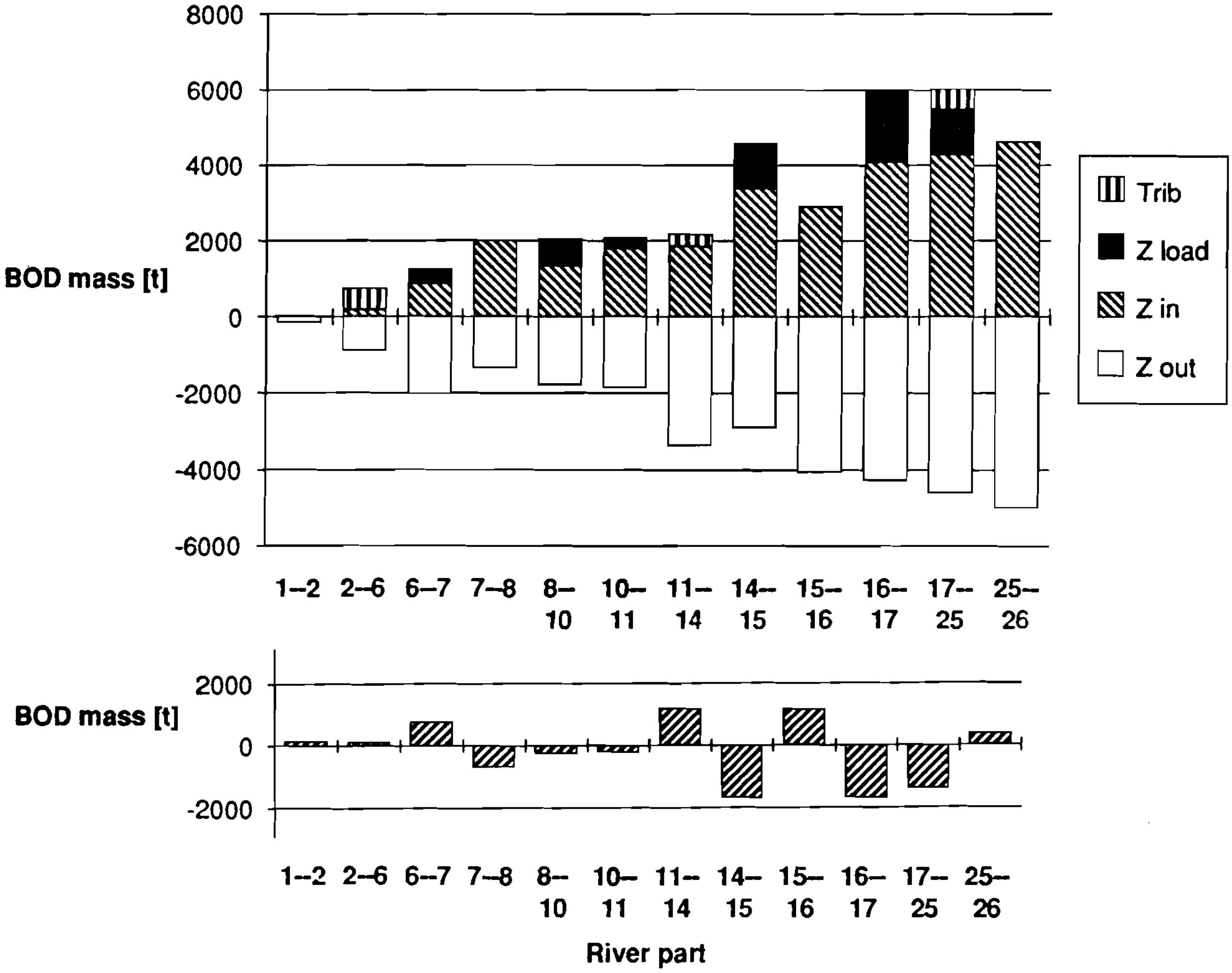


Figure 3.2.1. BOD mass inputs and outputs and their differences in the stretches of the Nitra in 1990. The sum of the differences is -2260 tons. It implies that the total BOD loss in the river was 2260 tons, roughly one fourth of the gross discharge.

In some stretches the outgoing BOD mass was smaller than the sum of inputs, which indicated purification of water in that stretch. On the contrary, in some stretches the outgoing BOD mass was bigger than the sum of inputs, which indicated that actually there were more dischargers in that stretch than was evident on the basis of the data. This can be due to interaction with sediment, measurement errors or infrequent observations.

3.3. Parameter estimation

The deoxygenation parameter k_1 of the Streeter-Phelps model was estimated separately for the twelve stretches of the Nitra. The estimation was based on data. The incoming BOD masses were assumed to be purified in the river according to the BOD equation of the Streeter-Phelps model. The parameter value of k_1 was found at the point where the output of the stretch was equal to the purified inputs:

$$f(k_1)=Z_{out}-\sum_{i=1}^{n} Z_i \exp(-k_1\frac{l_i}{v}\Theta^{(20-T)})=0 \tag{15}$$

The mass balance was calculated for the whole year, because the aim was to find a single time independent parameter value of k_1 to each stretch. However, due to the monthly fluctuation in temperature and river flow, the calculations were performed for each month separately:

$$f(k_1)=\sum_{j=1}^{12} Z_{out,j}-\sum_{i=1}^{n}\sum_{j=1}^{12} Z_{i,j}\exp(-k_1\frac{l_i}{v_j}\Theta^{(20-T_j)})=0 \tag{16}$$

where
- i = Index of discharger
- j = Index of month (1 = January, 2 = February...)
- $Z_{out,j}$ = Outgoing BOD mass in month j from the stretch of the river [t/month]
- $Z_{i,j}$ = Incoming BOD mass from upstream, tributaries or discharges in month j into the stretch [t/month]
- l_i = Distance from the downstream point to the BOD mass loading point i [m]
- v_j = Water velocity in month j in the stretch [m/d]
- T_j = Temperature in month j in the stretch [°C]
- Θ = 1.1

The point $f(k_1) = 0$ was defined by the Newton's method with an initial value $k_{1,0} \in [-1,0]$, next values up to $k_{1,8}$ were obtained as stated in equation 17.

$$k_{1,p+1}=k_{1,p}-\frac{f(k_{1,p})}{f'(k_{1,p})} \tag{17}$$

The discharger data were assumed to be uniformly distributed over the whole year and hence the monthly values were obtained by dividing the yearly values by twelve. It is evident that discharges were not divided uniformly to every month, but there was also no ground for any other division.

When calculating the mass balance for the whole year with just few measurement values the uncertainty can be extremely large. This was taken into account by a stochastic approach to the mass balance calculations (Taskinen et al, 1992). The measurement values were taken as mean values for chosen probability distributions. For all variables except temperature, lognormal distribution was used, because it is defined only for positive values and it is based on relative scale. Temperature was assumed to be uniformly distributed. The width of the distributions were fixed with standard deviations of measurement values. Unfortunately no data existed on standard deviations and so they were approximated with a coefficient of variation:

$$s_{\bar{x}}=c_v\bar{x} \quad \textbf{(18)}$$

where s_x = Standard deviation of the measurement value
c_v = Coefficient of variation
x = Mean value

Because the river water quality data were more accurate than data of the dischargers - monthly values of river measurements versus one annual value of dischargers - the coefficients of variation of the river measurements were chosen smaller than those of the dischargers. The selected probability distributions and coefficients of variance were chosen as shown in Table 3.3.1. Examples of the distributions are presented in Figure 3.3.1.

Table 3.3.1. Selected probability distributions and their coefficients of variation.

Variable	Distribution	Coefficient of variation
BOD_5 of dischargers	Lognormal	0.3
BOD_5 of river water	Lognormal	0.2
River flow	Lognormal	0.2
Water velocity	Lognormal	0.2
Temperature	Uniform	mean$\pm$2

We use the following terminology. One probabilistic simulation consists of n iterations. Values are sampled from distributions in Table 3.3.1. In deterministic simulation (section 3.4.) the calculations are performed using the mean values.

Using the chosen probability distributions in the equation 16, stretch specific distributions for the parameter k_1 were obtained. As a sampling method the Latin Hypercube principle was used; each distribution is divided into as many sections equal in probability mass as is the number of iterations. Thereafter a random value is generated for each section, which are in random order. As a result, a distribution is obtained for the unknown variable, in this for the parameter k_1. In comparison to Monte Carlo sampling, Latin Hypercube method gives a better view of distribution with modest number of iterations (Anon, 1990).

The mean values and the 10 and 90 percent confidence intervals of the parameter k_1 after 500 iterations are presented against river kilometers in Figure 3.3.2. The parameter values were smoother in the downstream and fluctuated more in the upstream. Negative parameter values could be explained with unknown dischargers and positive values with the self purification of the river. However, the parameter values were quite far from the values presented in literature (e.g. Thomann and Mueller, 1987).

The standard deviation of the deoxygenation parameter was assumed to describe the overall uncertainty of the BOD mass balance. The sensitivity of the distribution for parameter k_1 to discharge loadings was studied by using also the values 0.6 and 0.001 as their coefficients of variation (Taskinen et al, 1992). The simulations were run again with these new values. The results are presented in Figure 3.3.3.

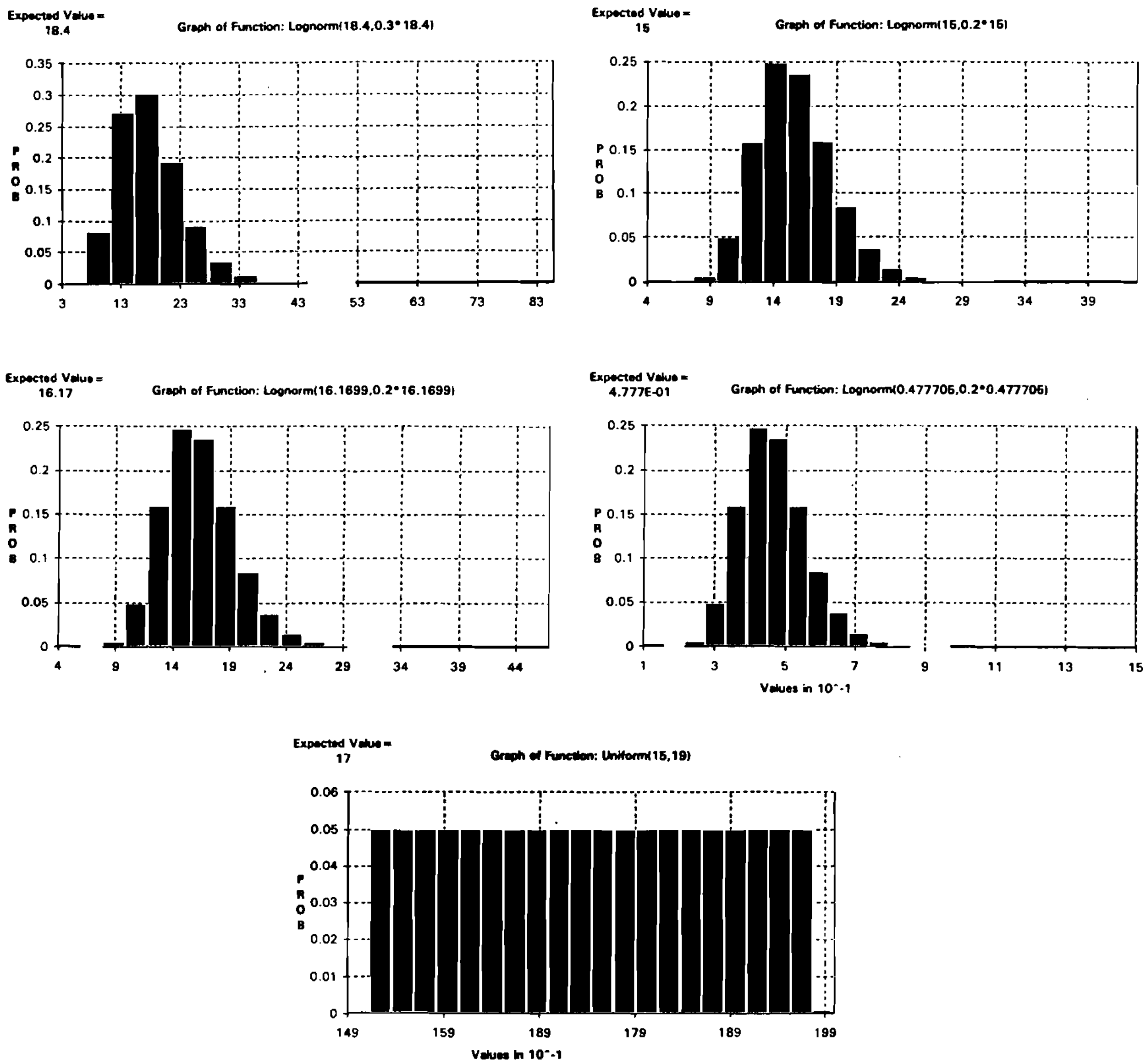


Figure 3.3.1. Examples of probability distribution for measured values of BOD_5 of loading, BOD_5 of river, river flow, water velocity and temperature.

The deoxygenation parameter did not appear to be sensitive to the BOD of dischargers. This was evident in the stretches, where the incoming BOD mass was much larger than the BOD masses coming from dischargers. In contrast the stretch to stretch variation in standard deviations was large. It was most extensive in the ones with short travel times. The longest travel times in the downstream stretches were 3-5 days, while the shortest times in upstream stretches were a few hours.

In measurement points 14 and 7 the BOD masses were surprisingly high. This caused low negative parameter values to the river stretch before measurement points and high positive values to the river stretch following those points. When the stretches 11-14 and 14-15 were combined together as one unit, a parameter value 0.26 was reached, which was quite realistic compared with previous separate values.

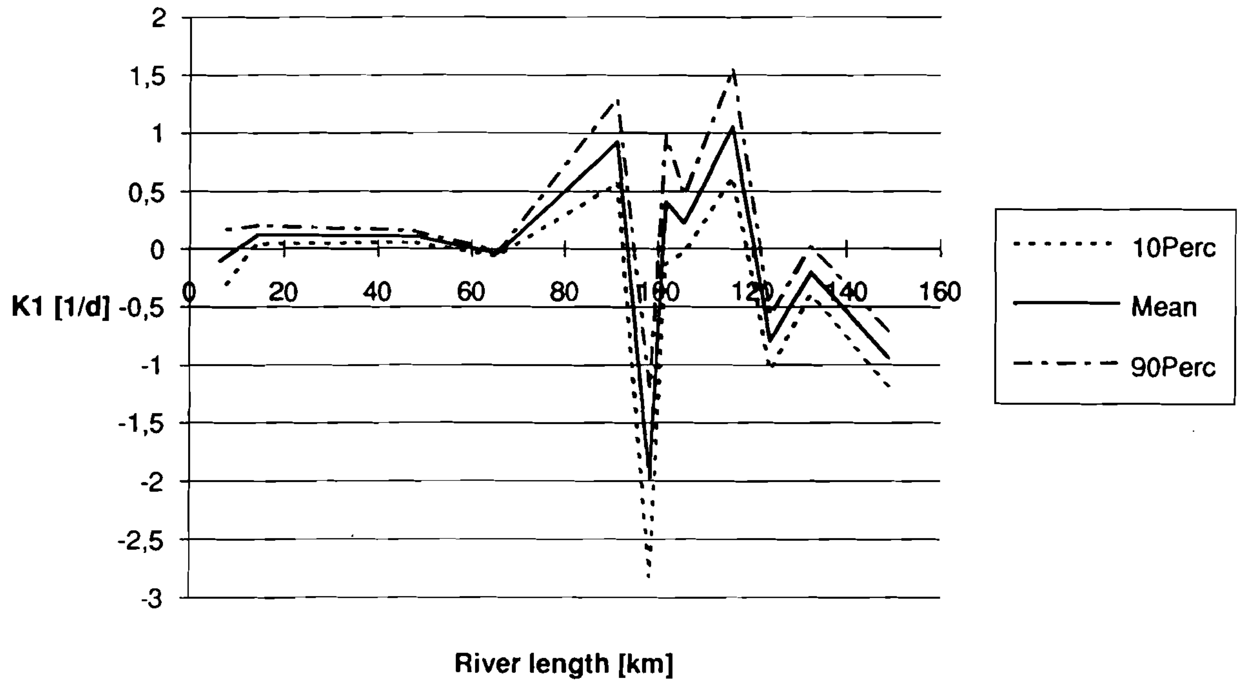


Figure 3.3.2. The estimated, stretch specific Streeter-Phelps parameter k_1 values and their confidence intervals.

In this analysis the parameters k_1 and the BOD of dischargers were assumed to be constant in time. When the BOD masses were calculated in every month separately, the monthly outputs were not equal to the monthly purified inputs (Figure 3.3.4.). The sums of monthly errors were zero in every stretch, because parameters were estimated to the whole year. The deviations indicated that the discharges were not equally divided into different months and/or the deoxygenation parameters were dependent on time.

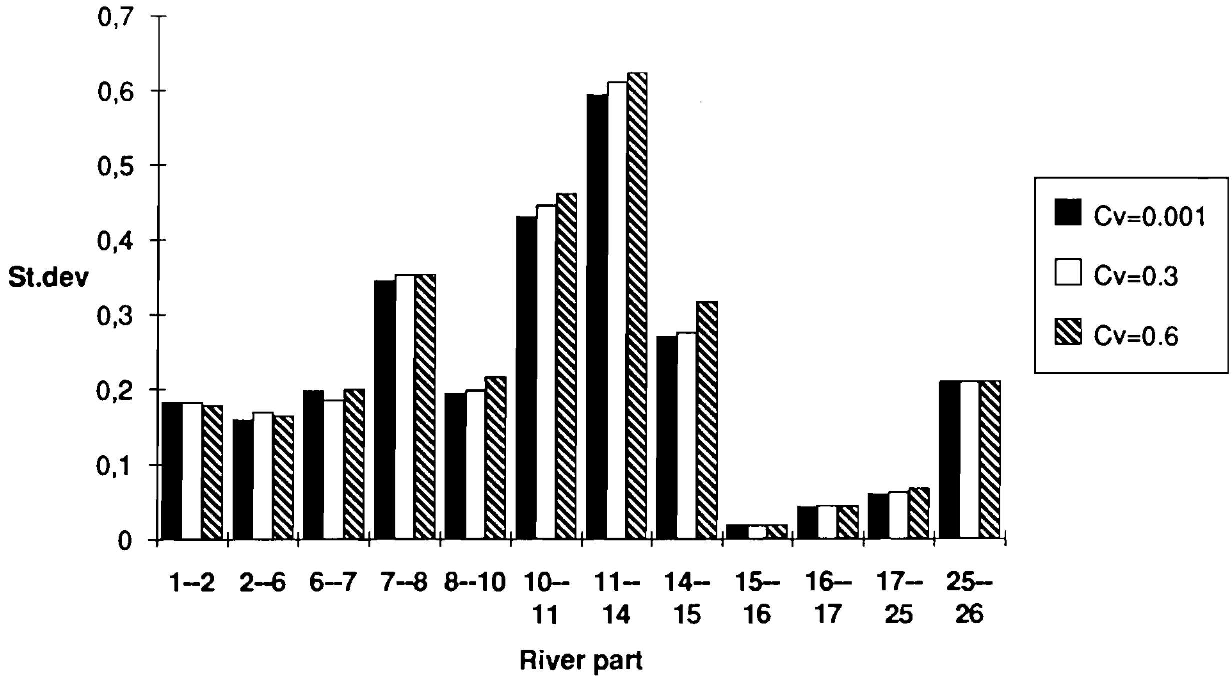


Figure 3.3.3. Standard deviations of parameter k_1 with c_v values 0.001, 0.3 and 0.6 for the BOD of dischargers. The corresponding k_1 values are shown in Figure 3.3.2. Note that the river stretches are in reversed order.

Attempts were also made to estimate the reaeration parameters of the Streeter-Phelps equation with the same principle as the deoxygenation parameters. In some stretches the Newton's method did not find any point where the mass balance function would have gone to zero. The reasons for this were the negative values of deoxygenation parameters and the oversaturated dissolved oxygen concentrations in the upstream stretches of the river. In those cases the oxygen deficit (c_s-c) became negative, which was not taken account in the assumptions of the Streeter-Phelps model.

At the next stage the deoxygenation parameter of the original Streeter-Phelps model was estimated to the entire river. The BOD masses of the discharges, tributaries and the incoming mass of the first measurement point were assumed to be purified from the loading point to the last downstream point according to the BOD equation of the Streeter-Phelps model. The stretch specific models were linked as one model by calculating each BOD loading separately in every stretch and putting them as an incoming BOD mass to the next stretch. The balance was calculated in the last measurement point with the following function:

$$Z_{out}=\sum_{i=1}^{n}\sum_{j=1}^{12}[Z_{i,j}\sum_{k=1}^{m_i}(\exp(-k_1\frac{l_{i,k}}{v_{j,k}}\Theta^{(20-T_{j,k})}))] \qquad (19)$$

where i = Index of loading point
j = Index of month
k = Index of river stretch
m_i = Number of stretches downstream of discharger i
n = Number of dischargers including tributaries and upstream point
$Z_{i,j}$ = BOD mass of discharger i in month j [t/month]
$l_{i,k}$ = Distance from loading point i downstream of the stretch k [m]
$v_{j,k}$ = Water velocity in month j in stretch k [m/d]
$T_{j,k}$ = Temperature in month j in stretch k [°C]

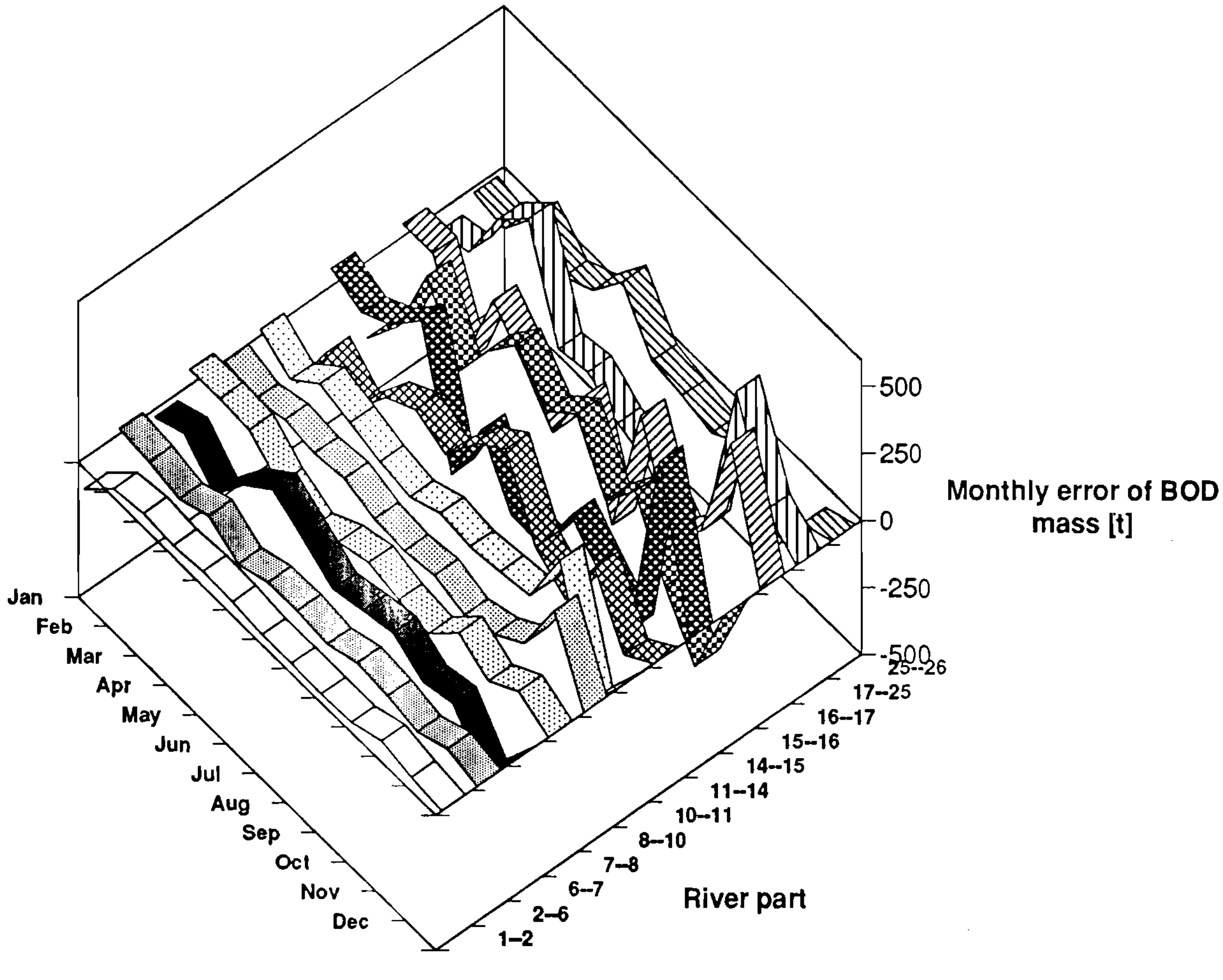


Figure 3.3.4. Monthly errors in the BOD balance calculated by equation 15 with time independent deoxygenation parameters.

The value obtained for the deoxygenation parameter was k_1 = 0.0488 with standard deviation 0.017. Thus the coefficient of variation became 0.356. Latin Hypercube sampling was again used. In comparison to the deoxygenation parameter values in literature (e.g. Thomann and Mueller, 1987) the k_1 value was still small but more realistic than the separate parameter values to the different stretches of the river. The simulated probability distribution of the parameter is presented in Figure 3.3.5.

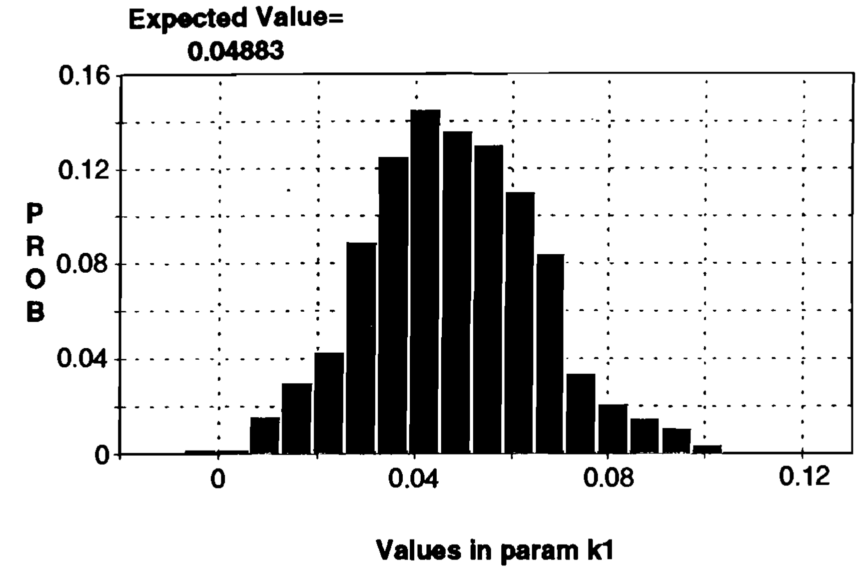


Figure 3.3.5. Probability distribution of the deoxygenation parameter k_1 estimated for the entire river.

3.4. Analysis of the role of the dischargers and tributaries

The previous approach was not suitable to the assessment of the role of the dischargers, because the impacts of the BOD loadings were analyzed only in the next measurement point downstream. Thus the influence of the loading further on downstream was not studied. Also the estimated deoxygenation parameter values deviated from values presented by Thomann and Mueller (1987), see Table 3.4.1.

Table 3.4.1. Deoxygenation parameter values (Thomann and Mueller, 1987).

Treatment level	Range	Mean
None	0.3-0.4	0.35
Primary/secondary	0.1-0.3	0.2
Activated sludge	0.05-0.1	0.075

The parameter value estimated to the entire river was close to the literature values with treatment level of activated sludge. Nevertheless, it was quite groundless to assume that waste water treatment along the Nitra would have been based on activated sludge. Therefore the deoxygenation parameters were concluded to be fixed separately to three values, namely to the estimated value $k_1 = 0.0488$, and to frequently used values $k_1 = 0.1$ and $k_1 = 0.2$. For each of these parameter values stretch specific errors called here as error loads (Figure 3.4.1.) were calculated according to the equation 16. The BOD inputs and outputs were taken from observations.

The error loads were more sensitive to the fluctuation of the deoxygenation parameter in river stretches with a long travel time. The error loads had both negative and positive values. The positive values implied that there were more discharge than the data showed. The negative values indicated self purification of water or cleaner water coming from a tributary. The error loads can also be caused by errors in the measured values.

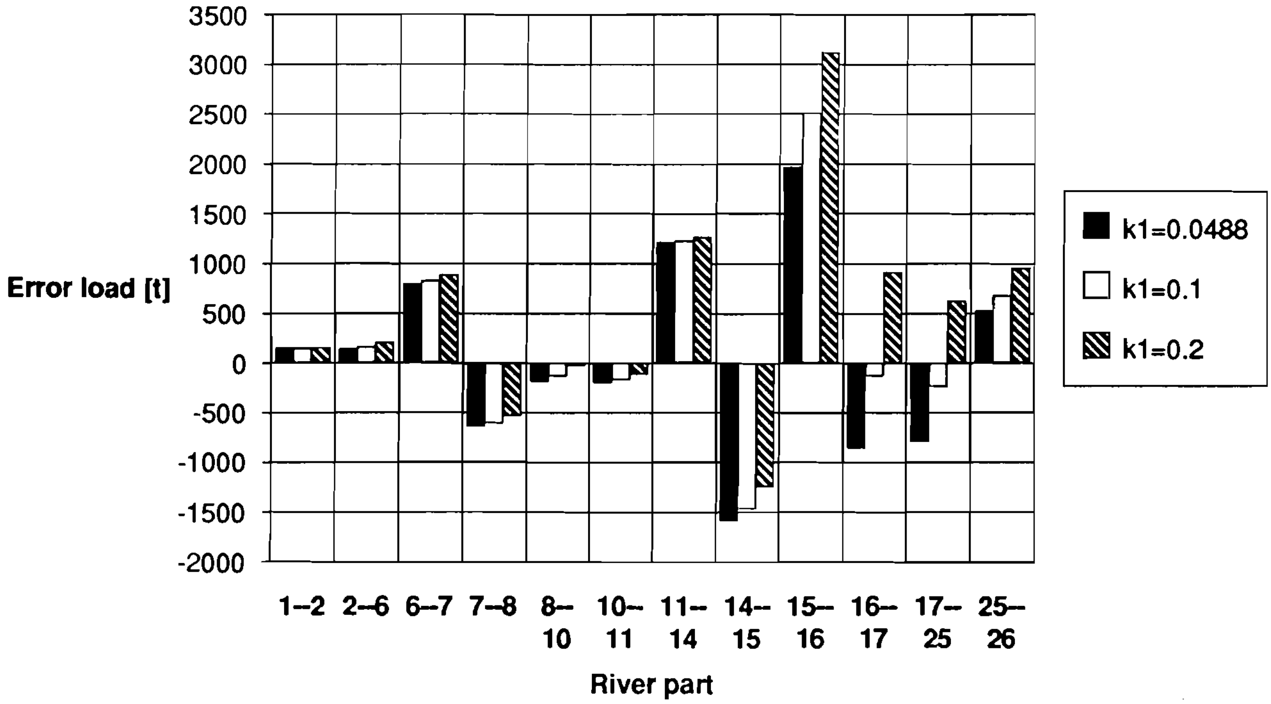


Figure 3.4.1. The error loads into different stretches with fixed deoxygenation parameters k_1.

After determining the error loads they were regarded as dischargers in the downstream point of the river stretch. The twelve separate mass balance equations (Eq. 16) set for twelve subsequent months were linked together by letting every outgoing BOD mass be an input to the next stretch. So the BOD mass in the river from the upstream to the downstream was simulated based on discharges including tributaries and error loads. As the matter of fact the linked BOD mass model was calibrated to the existing data so that the simulated BOD masses in measurement points were equal to the measurements.

The accumulation of the uncertainty in the simulated BOD mass towards the downstream of the river was studied subsequently. Three simulations were performed with the fixed deoxygenation parameter values. They were run as previous ones using Latin Hypercube sampling. The error loads were taken as mean values for normal distributions with coefficient of variation 0.3. Normal distributions were chosen, because the error loads were residual terms affected by several uncertainties. Fixed deoxygenation parameters were taken as mean values for normal distributions with the coefficient of variation estimated for the distribution in Figure 3.3.5.

The simulation of the BOD mass with parameter value 0.2 is presented in Figure 3.4.2. The error in simulated BOD mass increased towards downstream of the river. In Figure 3.4.3. the coefficents of variation are presented in different measurement points using the three deoxygenation parameter values.

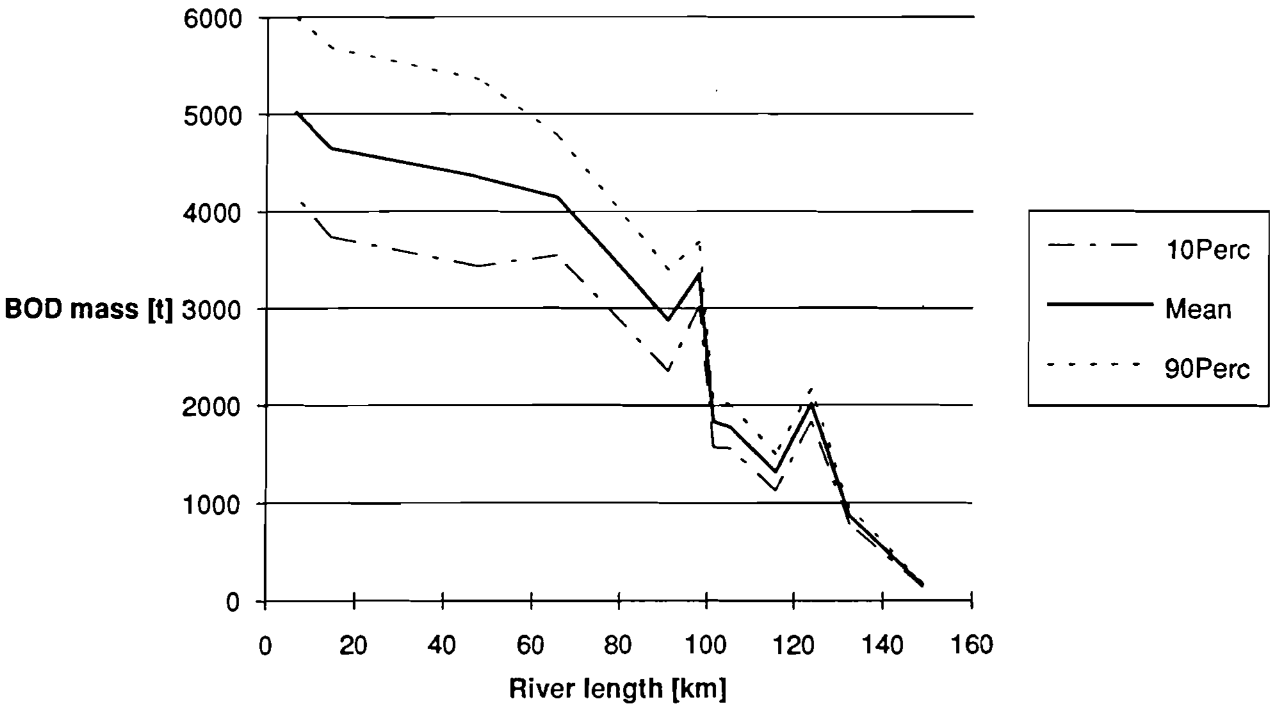


Figure 3.4.2. Uncertainty in the simulated BOD mass along the river with deoxygenation parameter k_1=0.2. The mean values are equal to the observations.

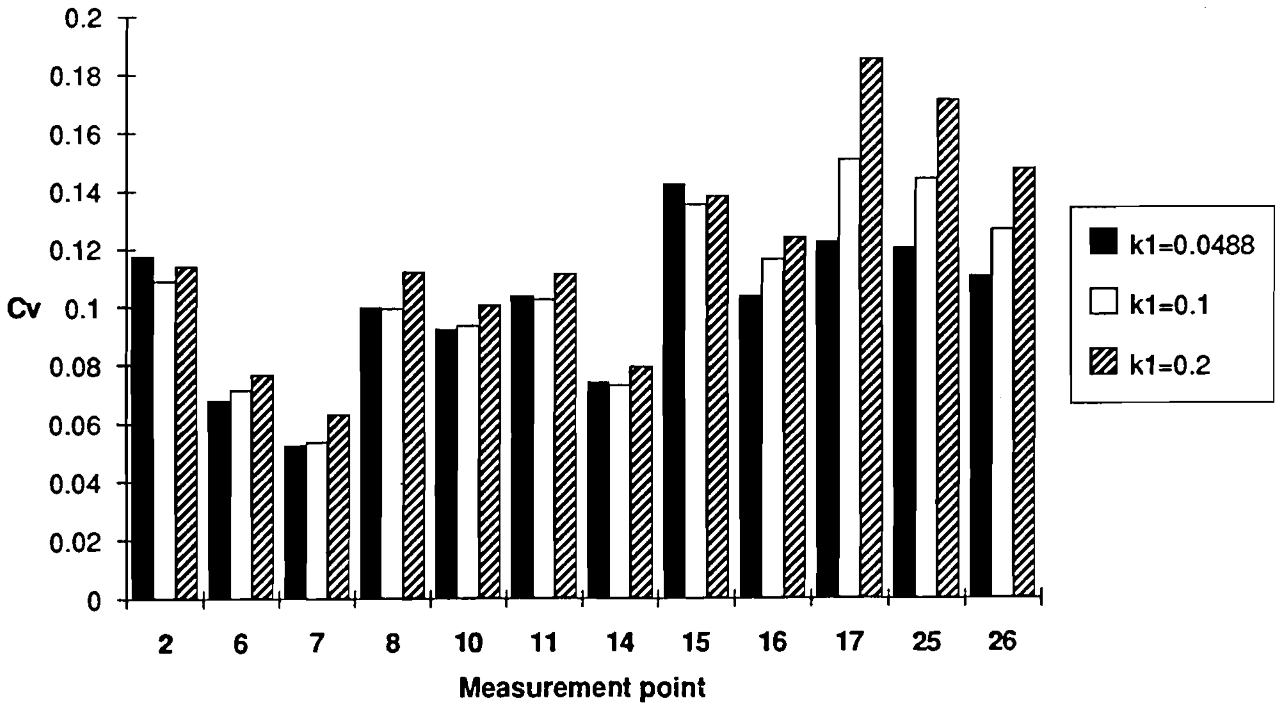


Figure 3.4.3. Coefficients of variation in the simulated BOD mass along the river using the three fixed parameter values.

The above formulation allows the analysis of the importance of the dischargers. This was done deterministically without any probabilistic distributions using the measurement values. The analysis was made in two parts, firstly assessing the downstream impact of each stretch, and secondly the impact of every discharger including tributaries and error loads. The BOD mass of each discharger was set to zero, one by one. Then the mean BOD mass along the river was calculated and the difference between the BOD mass with and without the discharger was obtained.

The percentual impact of each river stretch with the three deoxygenation parameter values are presented in Figures 3.4.4. to 3.4.6. For each stretch all BOD inputs including error loads were set to zero at a time. Apparently, the lower the deoxygenation parameter was, the more marked was the impact of a discharger a couple of stretches downstream.

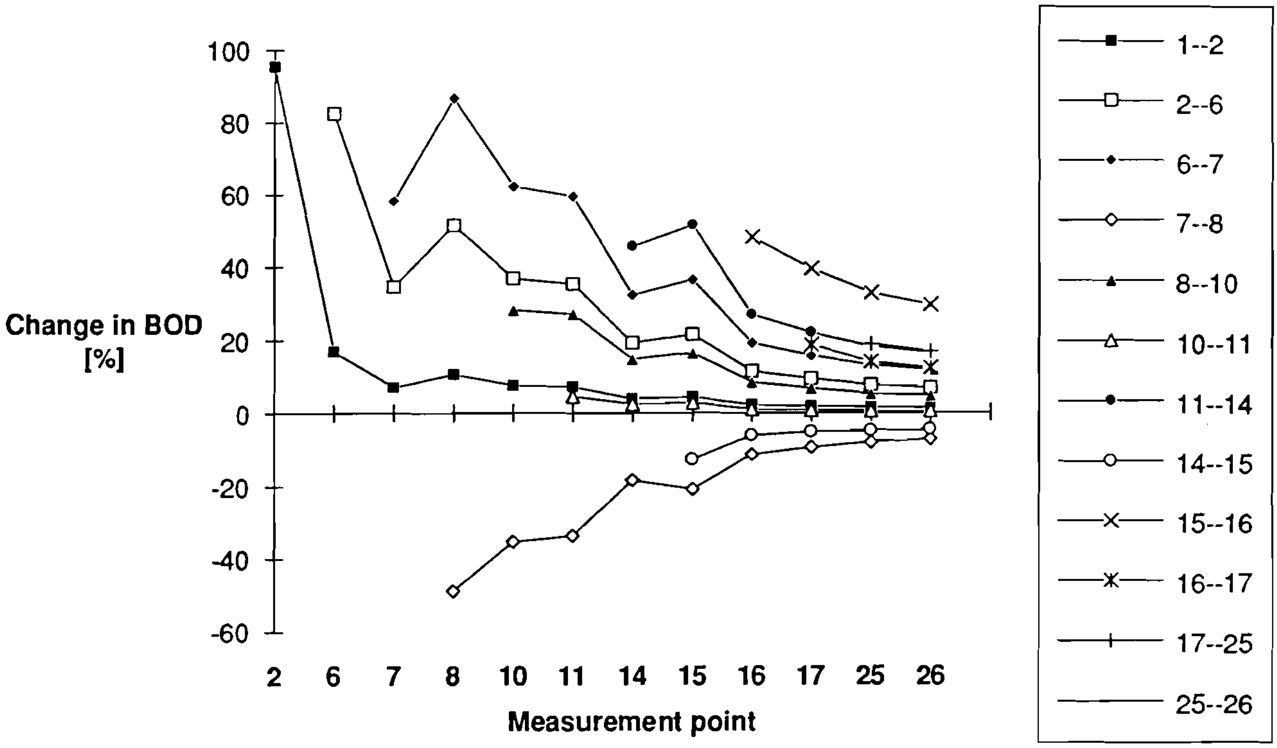


Figure 3.4.4. The relative impact of each stretch to the BOD mass along the river with k_1=0.0488. Every discharger in a stretch was removed and the decrease in the BOD mass was calculated downstream.

The impact of the individual dischargers to the BOD mass along the river with the deoxygenation parameter value k_1=0.2 are presented in Figures 3.4.7. and 3.4.8. The impact of the dischargers of each stretch are shown separately. In several stretches the most significant discharger was the error load. The negative impact of the error load implied a purifying effect on the BOD in the river. If it was removed, the BOD mass increased. A remarkable positive impact of the error load indicated that most of the discharge into the stretch was unknown.

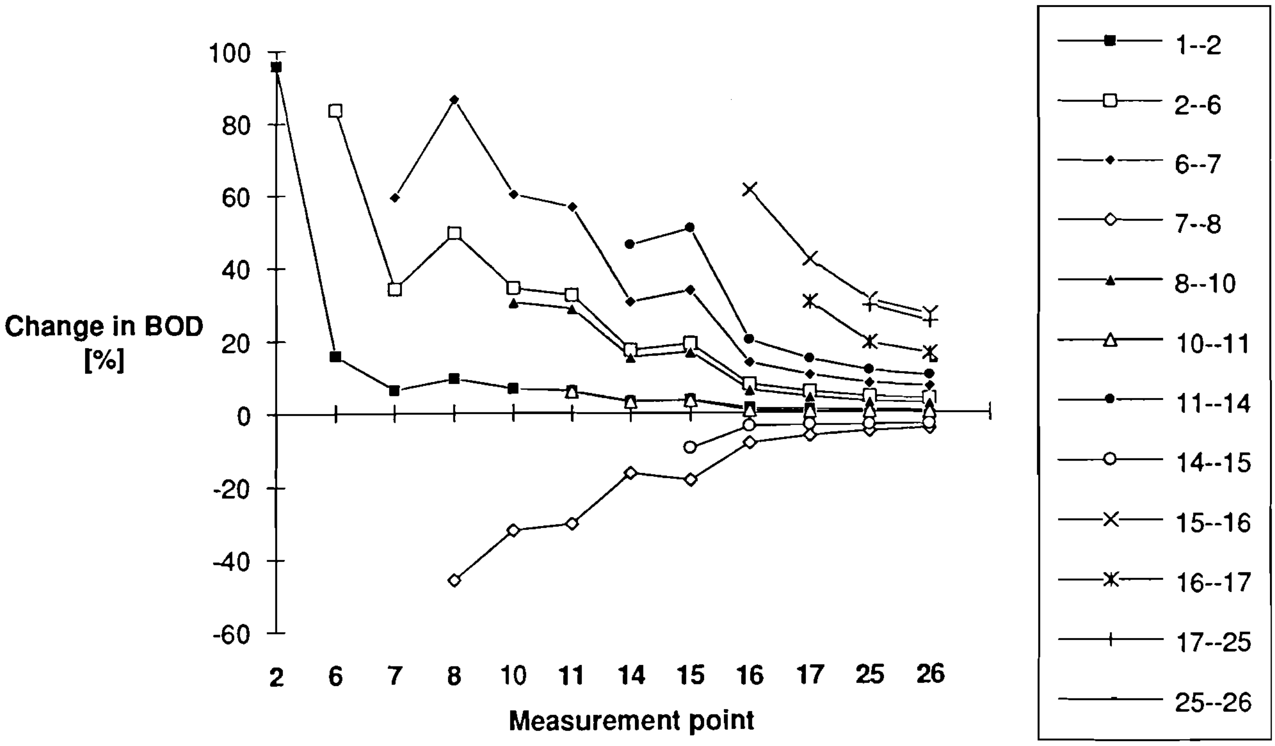


Figure 3.4.5. The relative impact of each stretch to the BOD mass along the river with k_1=0.1.

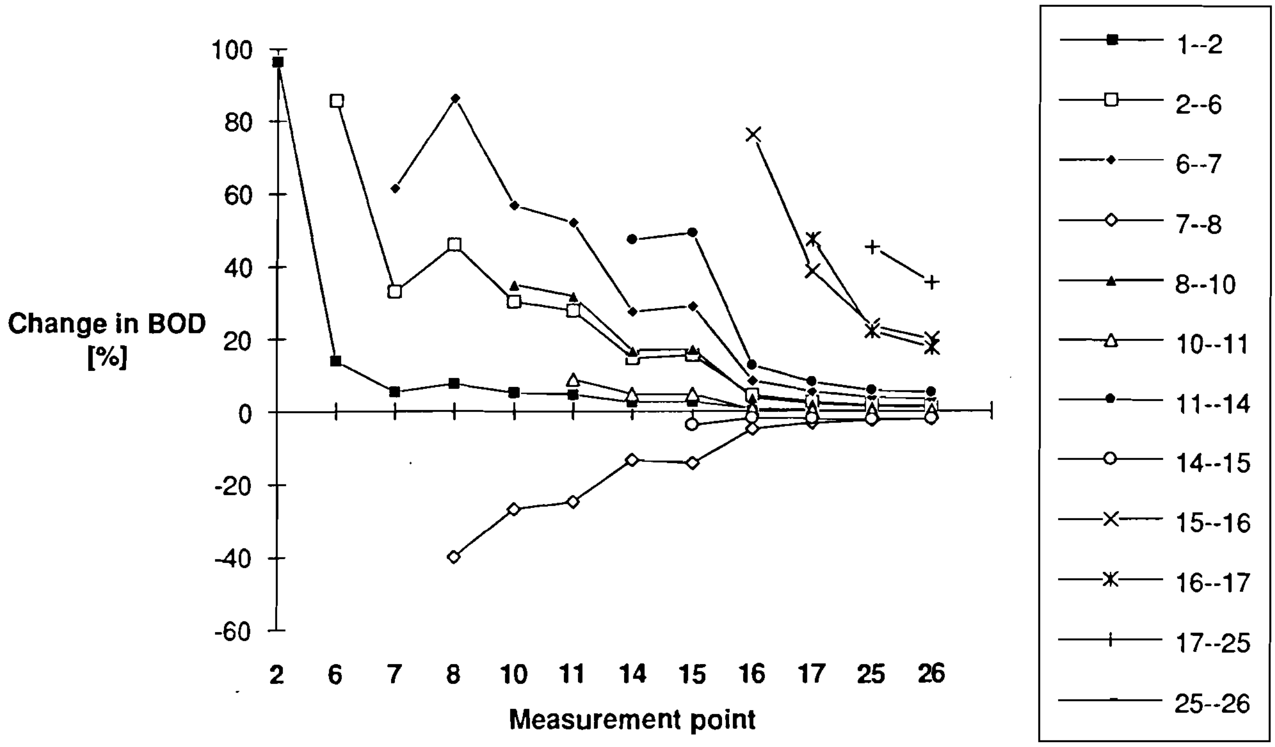


Figure 3.4.6. The relative impact of each stretch to the BOD mass along the river with k_1=0.2.

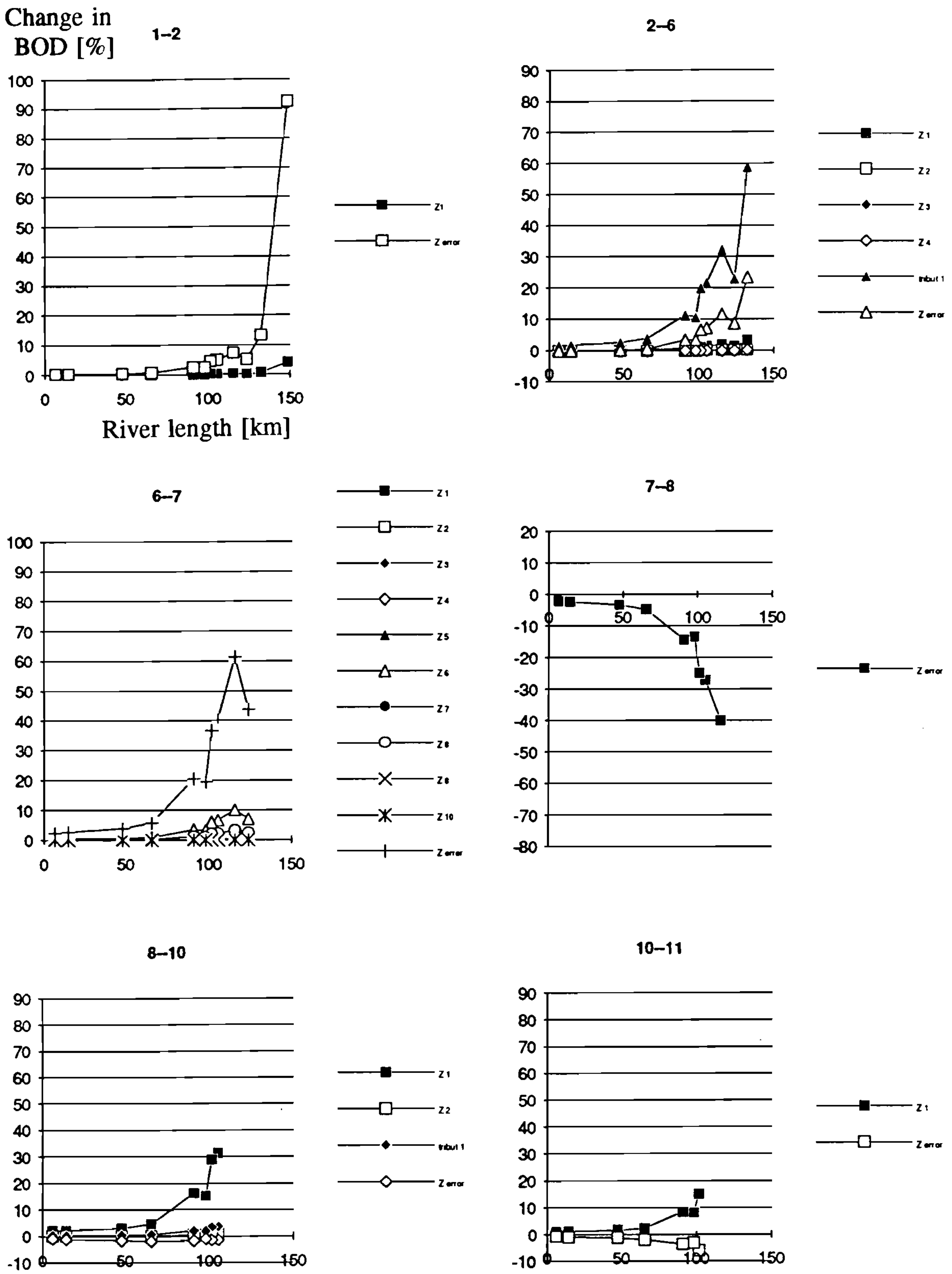


Figure 3.4.7. The relative impact of the individual dischargers of the first six stretches to the BOD mass along the river. Each discharge was set to zero, one by one, and the change in the BOD mass in measurement points downstream was calculated. Positive change implied purification in water and negative more pollution in water. Deoxygenation parameter k_1=0.2.

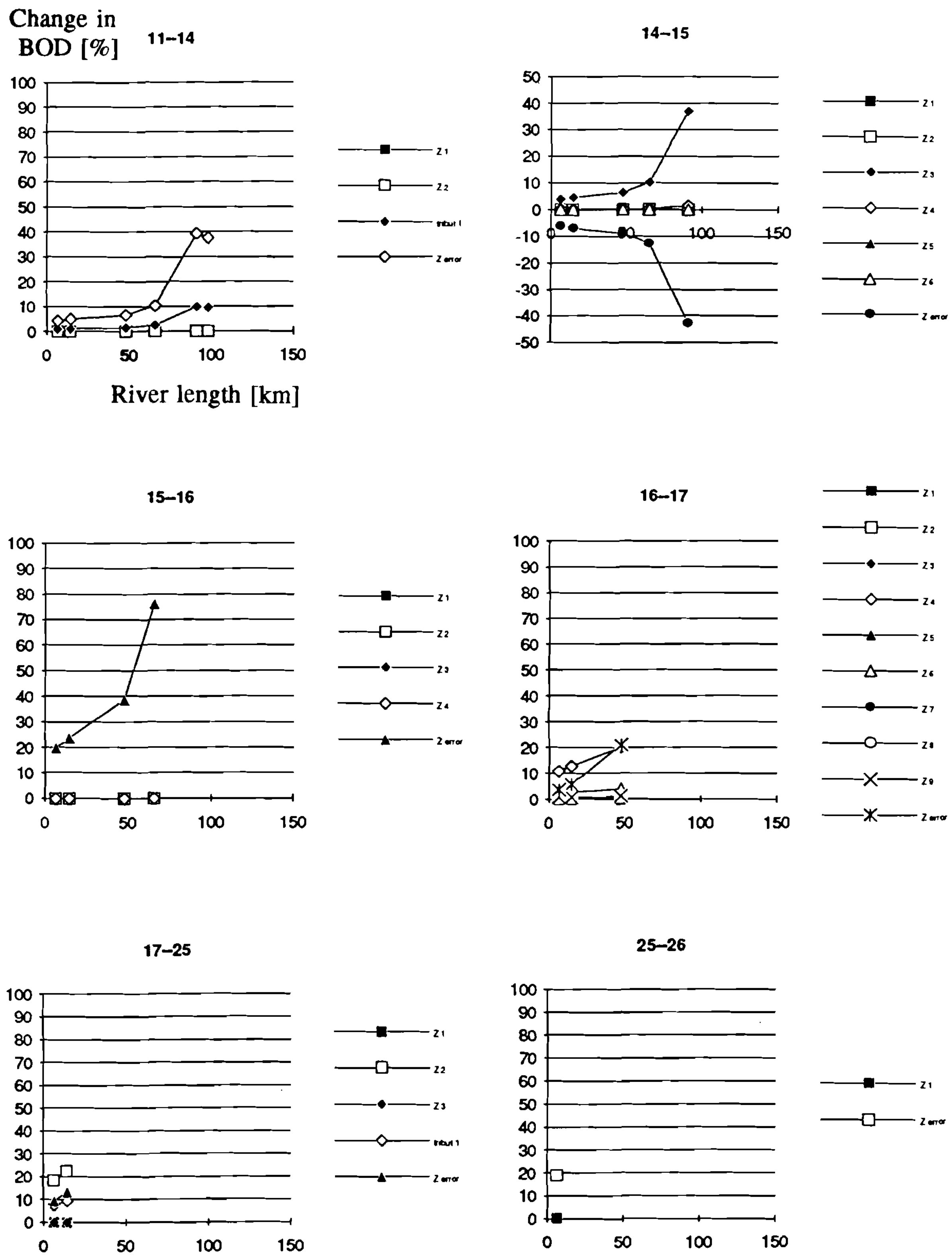


Figure 3.4.8. The relative impact of the individual dischargers of the last six stretches to the BOD mass along the river. Deoxygenation parameter k_1=0.2.

4. DISCUSSION

The mass balance approach is useful to the examination of the importance of different factors in river systems. Results can be achieved with modest data, even if the uncertainties involved are large. In this work, the uncertainties were taken into account using stochastic variables, but as it was, approximating coefficients of variations with scarce data was also very uncertain. The used coefficients can be subjected to discussion, because they were not based on data. It could be justified to use larger values. That would yield in no changes in the model variables, but the confidence intervals would grow. Besides the measured values taken as mean values were not necessarily close to the real mean values.

The calculations were done using a spreadsheet extended with an add-in software running probabilistic simulations. The reading of the original databases was possible directly to the spreadsheet. The user interface with advanced graphics provided an efficient environment for the construction, diagnosis and reporting of the models.

Owing to the modest amount of data, the role of an individual measurement was significant. This was most crucial in the effluent discharge data with only one aggregated value for each BOD mass over the whole year 1990. It would have been desirable to know the annual distribution of these values. The data on the river water quality were monthly measurements in 1990 as one sample per month. It is questionable how one measurement can be used to describe the conditions of the whole month.

Data on the four tributaries of the Nitra allowed the calculation of monthly BOD masses of those tributaries. Actually, in addition to these, there were several small tributaries, from which data did not exist. The results suggested that in some stretches there might be clean water inflow from tributaries causing surprisingly high purification. Also it was evident in some other stretches that unidentified loads were much more important than the loads from the monitored dischargers. The unknown loads may be caused by non-point sources or non-covered processes such as sediment interactions and photosynthesis. Also the properties of the data, measurement errors or infrequent observations, are potential error sources. Due to the canals in the downstream of the Nitra, in some points water is being divided into two river beds. Unfortunately no quantitative data from those points were available. This reduced the reliability of the results in the downstream stretches of the Nitra.

In the estimation of the deoxygenation parameter values separately to the different stretches, the large fluctuation in the parameter values was surprising. One could assume that this fluctuation was caused by the lack of data on the dischargers and tributaries. Nevertheless, assumably more evident was that either there were unknown reactions influencing the BOD, or errors in the measured values were remarkable. Possibly the analysis of dissolved oxygen would have brought new information to this case. Yet, the estimation of the reaeration parameter is highly dependent on the estimation of the deoxygenation parameter. With data of the present quality and quantity the uncertainties of such analysis is likely to grow too large to faciliatate any reasonable results. Dissolved oxygen concentration has a closer relation to the utility value of water and therefore, it would be more justified to concentrate on oxygen deficits. Also the significance of the loads could be examined with mass balance analyses of nutrients, which would demand data on the nutrient concentrations and loads.

The results presented in Figures 3.4.7. and 3.4.8. gave an illustration how the quality of water could change after a discharge is removed. The change of the BOD mass can be regarded as significant, when it is bigger than the corresponding coefficient of variance in Figure 3.4.3. The relative impacts of the dischargers depend highly on the used deoxygenation parameter value. The dischargers, which influenced more than the values of the coefficients of variance in Figure 3.4.3. to the BOD mass in different measurement points are presented in Table 4.1. The dischargers with a smaller influence were left out.

Table 4.1. The most important dischargers in the twelve stretches of the Nitra based on BOD mass analysis. The coefficient of variation c_v is a quotient between the standard deviation and the mean of the simulated BOD mass using deoxygenation parameter $\mathbf{k_1}$ = 0.2, see Figure 3.4.3. Only the dischargers with influence higher than the corresponding c_v values were taken into account. The names of the dischargers are presented in Appendix 3.

Mes. point	C_v [%]	Discharger in river stretch	Decrease in BOD [%]	Discharger in river stretch	Decrease in BOD [%]
2	11.4	-		-	
6	7.7	-		-	
7	6.3	Z5 in 6-7	7.2	Z6 in 6-7	7.1
8	11.2	-		-	
10	10.0	Z1 in 8-10	31.5	-	
11	11.1	Z1 in 8-10	28.9	Z1 in 10-11	15.0
14	7.9	Z1 in 8-10	15.4	Z1 in 10-11	8.0
15	13.8	Z1 in 8-10	16.2	Z3 in 14-15	37.0
16	12.4	-		Z3 in 14-15	10.2
17	18.5	Z4 in 16-17	20.1	-	
25	17.1	Z2 in 17-25	22.3	-	
26	14.7	Z2 in 17-25	18.3	-	

Based on Figures 3.4.5. to 3.4.7., the stretches between measurement points 2-6, 6-7, 11-14 and 15-16 seemed to have the greatest influence with longest duration to the BOD mass along the river. Also the stretch between points 7-8 was interesting, because water seemed to purify remarkably in that stretch. Therefore, these stretches seemed to be most crucial ones for more accurate data collection.

Biochemical oxygen demand is not necessarily a relevant analysis for describing water quality in cases like this. The BOD measures the gross consumption of oxygen in a bottle in a laboratory conditions within five or seven days. In the Nitra the travel times within the stretches ranged between a few hours to a few days. The processes causing oxygen consumption within the first few hours after discharge, and their rates can be totally different from the dominant processes within the incubation of five or seven days.

This analysis was designed to facilitate the expansion to the direction of decision theory. One could use approaches such as value of information, value of control, risk attitude and utility theory in the inclusion of socio-economic dimension to the study (Varis et al, 1992).

5. CONCLUDING REMARKS

1. In practice, modeling approaches should be available and easily applicable for management even if data are scarce. The approach presented is not free of problems, but it has potential for further applications and development. It can be extended to the direction of socio-economic decision analysis.

2. The present scarce data on the Nitra leaves much room for speculations. The data in cases like this should be more coherent. The quality of the discharge data should correspond to the river water quality data.

3. The relative impact of each stretch and individual discharge was analyzed along the river. The results in terms of proportional importances of discharges were not very sensitive to the parameter values used. In addition, the accumulation of the prior uncertainties to the estimated parameters and the mass flows was studied. The study indicated locations, where the BOD equation gave unrealistic results. The reasons to it need special notice in future studies.

4. In addition to substantial organic material pollution, there are also several other water quality problems in the basin of the Nitra. They call for further investigation. The various water quality aspects should be integrated in the river basin management.

5. REFERENCES

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APPENDIX 1: Data of river water and discharges

BOD 5 of dischargers in 1990 [t/year]

Part	Z 1	Z 2	Z 3	Z 4	Z 5	Z 6	Z 7	Z 8	Z 9	Z 10
1--2	6.9									
2--6	34	0.7	0.8	0.3						
6--7	3.7	3.3	9.8	0.4	158.8	155.7	0.6	49.9	2.7	2.1
7--8										
8--10	630.8	17.5								
10--11	292									
11--14	0.1	3.7								
14--15	0.3	3.1	1176	48.5	3.7	6.5				
15--16	2.8	2	0.1	0						
16--17	0.1	45.5	0.1	1509.1	5.1	277.1	13.9	0.2	61.9	
17--25	3.2	1214.4	0.4							
25--26	18.4									

Distances of Z in and dischargers to nearest mes.point [km]

Part	Z in	Z 1	Z 2	Z 3	Z 4	Z 5	Z 6	Z 7	Z 8	Z 9	Z 10	tribut
1--2	16	2										
2--6	16.5	10.7	8.3	2	10.6							4.4
6--7	8.7	14.7	13	10.3	9.8	8.2	7.2	5.9	5.1	5	2.2	
7--8	8.1											
8--10	10.2	10.1	5.7									6.7
10--11	3.9	3.4										
11--14	3.4	3.1	2.7									3.5
14--15	7.1	5	18.9	6.4	4.4	4	1.3					
15--16	25.5	15.3	8.1	7.1	6.6							
16--17	17.8	17.8	17.7	15.7	15.5	12.95	12.7	6.6	6.5	4.7		
17--25	33.3	10.4	10.6	0.5								12.7
25--26	8	2.3										

Temperatures in river in 1990 [C]

Mes.point	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	3	4	7	11	10	11	13	7	9	5	2
2	0	3	4	8	10.5	11	15	17.5	9	10.5	6.5	3
6	2	3.5	4	10	11	11	17	21	12	12.5	6.5	1
7	4	8.5	6	15	14.5	15	21	24.5	15	14	9	3.5
8	3	8	7	14	15.5	15	21	24	14	12	8.5	3
10	2	7	7	14	15	15	21	24	14	12	8.5	3
11	2	7	7.5	13	15	15.5	21	24	14	11.5	8	3
14	2	7	6.5	13	15	15	21	24	14	12	9	3
15	5	4	7	7	15	12	17	19	12	15	4	1
16	3	4	11	9	19	17	20	24	14	16	5	1
17	3	4	10	10	19	17	20	25	13	17	6	1.5
25	3.5	4	8.5	9	18	17	20	24	13	16	6	1
26	3.5	4	8.5	9.5	18	17	19	24	13	17	6	1

BOD 5 in river in 1990 [mg/l]

Mes.point	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	2.3999	1.2999	1	1.5	1	1.5999	1.3999	1.7999	2	1.1999	3.7999	2.0999
2	4	1.8999	2.5999	2.7999	1.7999	3.0999	2.0999	3	2.5999	3.3999	6	2.6999
6	11.3999	7.5	7.0999	7.1999	4.8999	5.5999	6.3999	8.3999	8.1999	8.7999	6.7999	9.1999
7	30	20.5	8.1999	16	13	13.5	11	20	20.7999	13.5999	11.5999	10.3999
8	16	16.3999	6.8999	7	5.2999	6.6999	7	8	7	15.3999	6	7.1999
10	14	12.5999	7.6999	7.2999	6.1999	6.2999	5.3999	7	3.5999	10	8.3999	13.3999
11	14	7	9.6999	8.1999	5.5999	4.1999	6.7999	7	5.3999	12	20	7.3999
14	16.5999	9.3999	8.7999	11.5	7.3999	6.0999	14.1999	35	8.1999	11.5999	35	7.7999
15	13.7999	7.5999	7	8	2.6999	5.7999	5.1999	14	11	6.5999	15.3999	16.7999
16	9.5999	4.6999	10.3999	6.7999	5.5999	11.6999	10.1999	30	12	14	17.5999	16
17	9.6999	9	5.5999	9	8.0999	8.8999	18.1999	12	29.1999	11.3999	13	19
25	6.1999	6.6999	9.8999	20	8.2999	10	12.5999	5.5	7.5	5.3999	40.5	17.7999
26	6.1999	5.2999	12.3999	21	10	15	13.5999	5.2999	5.1999	7.5999	31.1999	19.1999

River flows in 1990 [m3/s]

Mes.point	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0739	0.0749	0.1389	0.1099	0.3409	0.2489	0.0869	0.0599	0.0619	0.0689	0.2129	0.2629
2	0.4429	0.8549	2.7229	1.1539	4.3189	2.3169	0.5519	0.4569	0.4539	0.4479	3.2089	3.5279
6	2.6549	2.7369	5.3439	3.6129	7.2079	4.5849	1.9279	1.4739	2.4899	2.0539	5.3329	6.0379
7	3.1499	3.2469	6.3389	4.2859	8.5499	5.4389	2.2869	1.7489	2.9539	2.4359	6.3259	7.1629
8	3.6509	3.7629	7.3469	4.9669	9.9089	6.3039	2.6509	2.0269	3.4239	2.8229	7.3319	8.3019
10	4.1589	4.2569	8.0519	6.4269	12.1699	7.3849	3.7379	3.1099	3.1129	4.5229	8.5539	12.5399
11	4.1799	4.2779	8.0919	6.4589	12.2299	7.4219	3.7569	3.125	3.1279	4.5449	8.5969	12.6019
14	4.8589	5.1789	10.1009	7.2919	16.3389	8.9909	6.6539	3.6129	3.5589	5.0939	10.1009	17.9679
15	5.8799	5.7099	16.4499	20.5199	11.4599	13.2999	6.4409	4.0489	4.9479	6.2349	6.9739	17.8299
16	6.7269	6.5319	18.8189	23.4749	13.1099	15.2149	7.3689	4.6319	5.6609	7.1329	7.9779	20.3979
17	6.8029	6.6059	19.0329	23.7419	13.2589	15.3879	7.4519	4.6849	5.7249	7.2139	8.0689	20.6289
25	7.4479	7.6749	20.3899	19.6099	14.0899	16.0899	8.8199	5.2629	4.8339	6.7239	6.6989	16.8999
26	7.4849	7.7129	20.4919	19.7079	14.1599	16.1699	8.8639	5.2889	4.8579	6.7579	6.7319	16.9849

BOD 5 and river flows of tributaries regarded as dischargers in 1990

Mes.point	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BOD												
5	20	13.5999	15	12	18	20	11	21	14	12.3999	8.7999	12.3999
9	2.8999	2	2.2999	3.6999	2.7999	4.5	4.1999	0	0	3	0	0
12	10.7999?	4.1999	2.3999	2.5	7.1999	4.2999	2.2999	3.7999	2.8999	7	9	5.2999
13	10.5999	6.7999	5.5999	6.5	4.7999	6.7999	4	12	6.5999	7.5	16.7999	3
22	9.0999	4.6999	4.5999	11.5	6.1999	5.3999	4	8.1999	5.1999	4.2999	11.5999	9
Flow												
5	0.7549	0.8869	2.0559	0.8709	2.2069	0.8419	0.8659	0.7439	0.6309	0.9079	1.5989	1.9299
9	0.3609	0.4379	0.9319	0.8529	3.0089	1.2549	0.8139	0	0	0.6869	0	0
12	0.3119?	0.3099	0.7059	0.4249	1.0519	0.5559	0.3449	0.3099	0.2569	0.3609	0.6769	1.0119
13	0.9059	1.0989	2.0749	1.3619	2.4469	1.4449	0.8999	0.5609	0.6579	1.2649	2.1079	2.5709

Parameters for calculating velocities

mes point	a	b
2	0.304384	2.4
6	0.257453	2.4
7	0.259305	2.43
8	0.332643	2.7
10	0.261925	2.48
11	0.132065	1.55
14	0.243388	2.4
15	0.177673	2.09
16	0.021741	1.3
17	0.028514	1.4
25	0.149745	2.4
26	0.149807	2.4

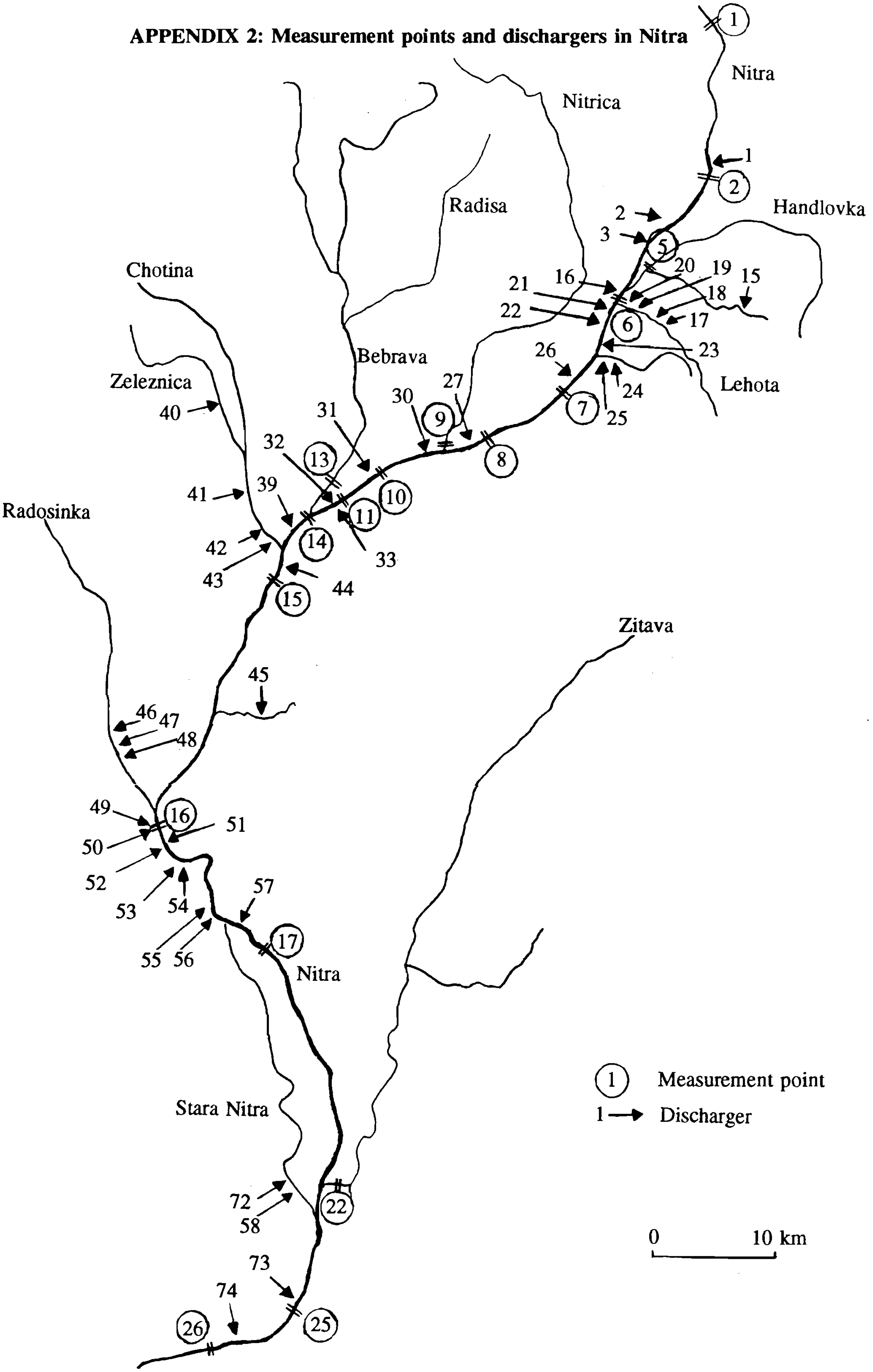
Dissolved oxygen [mg/l]

Mes.point	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	14.1999	14.8999	12.7999	12.3999	11.5999	14.0999	10	10.1999	11.0999	12	13.7999	11.5
2	14.5	17	13.1999	14.6999	12.0999	13.3999	10.0999	8.5	11	11.0999	13.5999	13.3999
6	10.1999	11	12.7999	9.2999	11.1999	11.8999	7	4.3999	7.2999	8.7999	13.1999	13.5999
7	9	12.0999	10.6999	8.5999	13.2999	9.1999	5.6999	8.0999	7.6999	3.5	12.0999	13.6999
8	9.8999	11.3999	12	11.1999	11.2999	10.8999	10	8.3999	7.2999	4.8999	12	13.7999
10	8.6999	9.6999	10.8999	11.5999	10.5	9.7999	9.5	8.2999	8.3999	6	11.5	13.5
11	12	9.1999	12	11.1999	8.5999	9.8999	7.8999	4.8999	7.3999	1.2999	9.1999	11.5
14	12	12.6999	12.7999	12.8999	10.7999	11	7.5999	0	7.6999	4.7999	9.6999	12.2999
15	8	8.7999	11.5	13	7.8999	7.1999	1.1999	0.5	5.3999	5.5	5.5999	12.1999
16	11.3999	12.3999	10.3999	11.3999	8.3999	6	7.5	8.3999	3.6999	8.2999	9.5	12.5999
17	12.6999	10.7999	11.6999	12	8.8999	5.5	6.1999	4.1999	1.6999	5.3999	5.0999	12.1999
25	12.0999	12.3999	11.6999	11	9.1999	7.7999	7.2999	8.0999	8.1999	9.6999	0.6999	13
26	11.3999	11.2999	12.7999	9.8999	10.2999	7.2999	5.6999	5	5.7999	8.2999	1.0999	12

Oxygen saturation level [%]

Mes.point	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	96	109	96	101	104	123	87	97	90	102	105	83
2	99	125	100	123	107	117	98	87	94	98	108	98
6	74	82	96	82	100	107	72	49	66	81	105	95
7	67	102	84	84	128	90	64	95	76	33	103	100
8	73	95	97	106	112	107	110	100	70	45	98	100
10	62	79	89	110	103	97	105	97	81	55	104	99
11	84	74	99	104	84	98	88	57	70	12	75	83
14	84	102	102	120	106	107	84	0	74	44	83	90
15	62	66	93	105	77	65	12	5	50	53	45	85
16	82	93	93	98	89	66	82	100	35	82	70	88
17	92	82	102	105	94	56	67	50	16	55	40	85
25	90	93	100	94	95	80	80	95	77	96	5	90
26	84	85	107	85	107	74	80	58	54	84	8	83

APPENDIX 2: Measurement points and dischargers in Nitra



APPENDIX 3: Names of dischargers

Number	River part	Codenum.	Name	River	Slovak.code
1	1--2	Z1	TATRA NABYTOK N.P. PRAVENEC	NITRA-1	V3905PVA
2	2--6	Z1	OUNZ BOJNICE	DUBNICKA-1	V3970PVA
3		Z2	ZAV.POLIKLINIKA BOJNICE	NITRA-1	V3970SVA
15		Z3	ZAV.BANA CIGEL PRIEVIDZA	CIGLIANKA	V4080QVB
16		Z4	VOJ.OPR.ZAVOD NOVAKY	TREBIANSKA	V4140PVA
17	6--7	Z1	ULB BANA LEHOTA	LEHOTA	V4125PVA
18		Z2	STVAK KANAL VAK LEHOTA	LEHOTA	V4130DVA
19		Z3	ZAV.BANA NOVAKY	LEHOTA	V4140SVD
20		Z4	260.0ULB BANA MLADEZE	LEHOTA	V4125PVB
21		Z5	STVAK KANAL VAK NOVAKY	NITRA-1	V4140DVA
22		Z6	CHZWP N.P. NOVAKY	NITRA-1	V4140RVB
23		Z7	CHZWP N.P. NOVAKY	NITRA-1	V4140RVA
24		Z8	LSH Z. POROBETON Z.KOSTOLANY	LELOVSKY P.	V4145RVA
25		Z9	ZAV. VOZ Z.KOSTOLANY	LELOVSKY P.	V4145SVA
26		Z10	ENO ELEKTR. Z.KOSTOLANY	NITRA-1	V4145PVA
27	8--10	Z1	OUNZ PARTIZANSKE	NITRA-1	V4235PVA
30		Z2	ZSVAK KANAL.VAK PARTIZANSKE	NITRA-1	V4235DVA
31	10--11	Z1	SL.SKROBARNE ZAVOD CHYNORANY	NITRA-1	V4830PVA
32	11--14	Z1	ZAV.VU 3992 BOSANY	NITRA-1	V4425QVA
33		Z2	KOZELUZNE N.P. BOSANY	NITRA-1	V4425PVA
39	14--15	Z1	SLOV.SLADOVNE ZAVOD TOPOLCANY	NITRA-1	V4950PVA
40		Z2	ZAV.OSCR AUTOKEMP. DUCHONKA	ZELEZNICA	V4905PVA
41		Z3	ZTZ ZAVOD TOVARNIKY	CHOTINA	V4935PVA
42		Z4	ELEKTROKARBON TOPOLCANY	CHOTINA	V4950SVA
43		Z5	OUNZ S.NEM.TOPOLCANY	CHOTINA	V4950RVA
44		Z6	ZSVAK KANAL.VAK TOPOLCANY	NITRA-1	V4950DVA
45	15--16	Z1	PREV.HORNE LEFANTOVCE	RYBNICKY P.-1	V5100PVA
46		Z2	ELEKTROPORCELAN CAB	RADOSINKA	V5290PVA
47		Z3	ZAV.AGROCHEM.PODNIK CAB	RADOSINKA	V5290RVA
48		Z4	POZ. STAVBY ZAV. CAB	RADOSINKA	V5290QVA
49	16--17	Z1	ZHZ ZAVOD LUZIANKY	NITRA-1	V5380PVA
50		Z2	VINARSKE ZAV. ZAVOD LUZIANKY	NITRA-1	V5380QVA
51		Z3	ZAV.OPR.POLN.STROJOV NITRA-MLYNARCE	NITRA-1	V5387PVA
52		Z4	AZBESTOCEM. ZAV. ZAVOD MLYNARCE	NITRA-1	V5415PVA
53		Z5	CUKROVAR NITRA	NITRA-1	V5415RVA
54		Z6	ZAV.PS STAVOMONTAZE NITRA	NITRA-1	V5415VVA
55		Z7	MRAZIARNE ZAVOD NITRA	NITRA-1	V5430PVA
56		Z8	BIOVETA NITRA	NITRA-1	V5415SVA
57		Z9	ZSVAK KANAL.VAK NITRA	NITRA-1	V5415DVA
58	17-25	Z1	ZSVAK KANAL.VAK SURANY	STARA NITRA	V5985DVA
72		Z2	CUKROVAR SURANY	STARA NITRA	V598DPVA
73		Z3	ZAV.OSCR TERM.KUP. NOVE ZAMKY	NITRA-1	V5995RVA
74	25--26	Z1	ZSVAK KANAL.VAK N.ZAMKY	NITRA-1	V5995DVA