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NUTRIENT LOADING ESTIMATE FOR LAKE BALATON

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PREFACE

One of the principal projects of the Task on Environmental Quality Control and Management in IIASA's Resources and Environment Area is a case study of eutrophication management for Lake Balaton, Hungary. The case study is a collaborative project involving a number of scientists from several Hungarian institutions and IIASA (for details see WP-80-187).

As part of the case study, different lake ecological models and water quality management models are under development. The nutrient loads play a distinct role in both kinds of modeling. This is especially so if a comparison of the various approaches is also considered; certainly, the same loading figure must be employed. The objective of the present paper is to determine a nutrient load estimate for Lake Balaton which will then serve as a basis for all the modeling work.

ACKNOWLEDGMENT

The necessary condition for writing this report was to have an appropriate data base for different types of nutrient forms. Therefore, both the research and data collection by Hungarian colleagues working in this field are highly appreciated. G. Botond, E. Dobolyi and O. Joó deserve special mention. Many thanks are extended to O. Joó who placed the Zala River data at our disposal for the Case Study, which served as important background information for this load estimate. The useful support, advice, and criticism of other experts are equally appreciated.

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1. INTRODUCTION

Artificial eutrophication, a typical problem of today, is a result of the increase in the amount of plant nutrients entering water bodies. In turn, these water nutrients are closely related to the development of the surrounding region. Thus, the deterioration in water quality shows the conflict between the development of the infrastructure of the area in question and tolerance of the aquatic environment.

It follows from this argument that a well-grounded knowledge of the nutrients reaching the lake is of primary importance, independent of whether practice, lake research, or their combination is considered. This knowledge should involve different nutrient forms, and their respective spatial and temporal changes. The origin of nutrients, especially that of the available fractions, demands further exploration, a critical issue from the viewpoint of water quality management.

The objective in the present paper is to discuss the problem of nutrient loads in Lake Balaton (Figure 1) in the above context. The paper should also act as a background report on this field serving both for lake ecological and water quality management modeling, and other practical purposes. The paper is organized as follows.

Figure 1. Regular Sampling Points on the Tributaries of Lake Balaton

In Chapter 2, a classification of different nutrient forms, involving their dynamics, is given; following is a discussion on the amount and quality of available data. Next, an estimate on the yearly and monthly average nutrient loads based primarily on the raw data (five year long observation period) is presented and summarized in a form that can be easily used both for lake eutrophication modeling, where at present, four coupled lake segments are distinguished (van Straten and Somlyódy, 1980), and management modeling (Kovács et al., 1980; Bogárdi et al., 1981).

The objective of Chapter 3 is to analyze the credibility of the phosphorus estimates worked out. Different kinds of uncertainties are discussed (data scarcity, unidentified or unmonitored sources, etc.,) and an effort is made to refine the original loading figures, employing an evaluation of the sources of nutrients (erosion, fertilizer use, population, etc.,). Furthermore, a range around the mean load accounting for stochasticity and uncertainty is given. In the subsequent chapter, a brief survey is presented on nutrient related monitoring and modeling work in the light of this particular lake. Finally, conclusions are drawn on the present state of the nutrient loading problem and future research is recommended.

It is noted here that a preliminary study on the nutrient balance was previously elaborated (van Straten et al., 1979). With respect to other aspects of the case study, the reader is referred to van Straten and Somlyódy (1980).

2. ESTIMATE OF AVERAGE LOADS BASED ON AVAILABLE DATA

2.1 Classification

Plant nutrients entering the lake are either of point source or non-point source origin. Both of them can be divided into two groups, direct and indirect loading types, depending on how they reach the lake. This distinction will be used often in this report. For instance, a nutrient form of diffuse origin transported to the lake actually as a point source through one of the tributaries (and not directly as a line source along the shore), is called indirect non-point source. Similar differentiation is made between direct and indirect point sources, that is, sewage loads. In this regard, the following classification of nutrients entering Lake Balaton can be made:

- (a) Nutrients carried by tributaries, involving
  - (i) indirect sewage;
  - (ii) indirect non-point source loads.
- (b) Sewage loading
  - (i) direct;
  - (ii) indirect (which also belongs to category a(i));
  - (iii) a third group is formed by special sewage loads which are discharged to fishponds, marshland, etc., and occasionally drained directly or indirectly into the lake (since there is a temporal change in the direct vs. indirect character, the expression *mixed sewage load* will be used).
- (c) Direct non-point source loading
  - (i) urban stormwater runoff from towns and villages along the shoreline;
  - (ii) non-point sources from the direct vicinity (watershed) of the lake (rural area which does not belong to the sub-watersheds of permanent tributaries);
  - (iii) atmospheric pollution (wet and dry deposition);
  - (iv) groundwater infiltration.

Some of the load components listed above can hardly be specified in practice (sewage load from the non-sewered area in the vicinity of the lake; loads originating from animal farms and solid waste disposal sites; groundwater infiltration, etc.). For these, the term unidentified sources is used.

Subsequently, the question of availability for algae should be discussed briefly: a mass balance of the available nutrient forms is of primary importance if eutrophication is considered. Concerning phosphorus, for example, the orthophosphate-P deriving from a tributary load is completely available. Almost the same can be said about nutrients of sewage origin. Our knowledge of the availability of the (TP-(PO4-P)) forms is more limited (van Straten, 1979; Logan et al., 1979), i.e. the rest of the total phosphorus fraction. This depends basically on the composition of the particulate fraction, that is, which percentage is in organic form, and which compounds and binding forms are dominant. As a first estimate, 10 to 30% of the (TP-(PO4-P)) load could be available in the lake. Practically the same can be said about the atmospheric pollution (the availability of nutrients reaching the lake through wet deposition is slightly higher).

Some other likely insignificant load compounds, such as navigation effects and water sports, also fall into this category. It is noted that the structure of most of the sections--and chapters--follows the sequence of the classification.

2.2 Dynamics of the Load

The loading types listed show different temporal changes which basically depend on the use of certain materials associated with nutrient cycling (e.g. fertilizer, detergents) and on processes (excretion, change in vegetation cover and population, etc.) resulting in nutrients which may enter water bodies. These changes also depend on other processes which affect the transfer of nutrients to the lake (rainfall-runoff, air motion, groundwater flow, etc.). The dynamics are of importance for several reasons. To give only a few examples, they influence methods of proper monitoring of various nutrient forms, what the response of the lake to the input will be and how the management alternatives should be carried out.

(a) Nutrients carried by tributaries

If the sewage portion is related to a certain permanent population, this load is approximately constant through the year. Most of the indirect sewage is discharged to rivers; thus, the related load of the lake is actually influenced by various biological, chemical, and physical processes in these rivers. The indirect non-point source fraction is basically affected by the hydrologic cycle (rainfall-runoff-erosion, snow melting, infiltration, etc.) and is a subject of essential temporal changes. For example, Joó (1980) and Jolánkai (1977) showed that approximately 60-70% of the total phosphorus load is transported to the lake during floods, which occur less than 2-3 months a year.

The contribution of high flow periods to the dissolved load is less significant (Jolánkai, 1977); nevertheless an increase with growing discharge should be expected. The dynamics of tributaries of smaller sub-watersheds and larger average slopes are much faster than for rivers of medium size. Here, many stochastic peaks caused by individual storm events are superimposed on the seasonal variation.

(b) Sewage loading

The fluctuation in the direct sewage load (or more generally in the sewage load of the recreational area) is closely related to the seasonal changes in the population, that is, to tourism. Consequently, on average, a discharge 2-3 times higher than normal can be expected in the summer season. This is again perturbed by further variations, since the peak population may be 5-7 times more than the permanent one. In the direct region of the lake less than 20% of the population is connected to the public sewage system (this is 70% for the drinking water supply; Kovács et al., 1980). In some locations, a distortion in the dynamics may be caused by the presence of fishponds, reservoirs, etc. (see item (iii)) which are usually drained once a year, in the autumn.

(c) Direct non-point source loading

All the nutrient loads listed here are influenced by the hydrologic cycle just as with the tributary loads. The dynamics of urban runoff and non-point sources from the direct vicinity of the lake (e.g., the vineyards along the northern shoreline in this case) are especially fast. Atmospheric pollution is affected in addition to local hydrologic conditions by the long-range transport by air.

It follows from the explanation given previously, that the nutrient load of a lake depends on two essential factors: natural conditions and human activities. Of these, the latter can be controlled - an issue of basic importance if the management problem is considered.

The dynamics of nutrient loading processes are of importance for three reasons

- the proper observation and computation of the load itself. As a guideline, measurements would be needed; their sampling interval is not longer than the minimum time constant of interest and the length of the total experiment is approximately ten times longer than the largest time-constant (Beck,1981)--conditions which are rarely fulfilled. From such a data set, many kinds of temporal averaging can be performed (weeks, months, etc.).

- the required detail for the modeling of in-lake processes. An analysis by Somlyódy and Eloranta (1981) showed that for the lake eutrophication modeling, monthly average load data are satisfactorily accurate in this particular case. It is stressed that this finding is based on the study of the model.
- water quality management. Here even longer time scales can be used.

2.3 Data Availability, Quality and Load Estimates

(a) Nutrients carried by tributaries

The water quality network system involves 20 of the major water courses entering the lake (Figure 1). With a catchment area of 4522 km^2 it comprises 87% of the total watershed. The water quality sampling points are generally located in the vicinity of the mouth. The regular sampling usually occurs once a month when, among others, the streamflow Q, total phosphorus TP, orthophosphate-P PO4-P, total nitrogen TN, and nitrate-N NO3-N are measured. Data of this type were available for the present analysis for the five years between 1974 and 1979. In addition to the streamflow measurements carried out simultaneously with the sampling, more detailed information based on historical flow records were at our disposal for the ten largest tributaries, as follows (Figure 1): Zala, Lesence, Kétoles, Tapolca, Egerviz, Burnót, Örvényesi-séd, Nyugati-Övcsatorna, Tetves and Köröshegyi-séd (see Figure 1). These tributaries accounted for roughly 70% of the total yearly average water inflow of 17.9 m^3/s (Baranyi, 1975). The largest tributary of the lake, River Zala, to which around 50% of the total watershed belongs, yielded exceptional data from on-site observation; the West Trans-Danubian Water Authority initiated a more detailed data collection in the middle of 1975 (Joó, 1980). Thus, the record is 4½ years long, from which data for 1976-79 were utilized to reflect the annual cycle of hydrologic processes. Here daily sampling frequency was done for Q, SS, TP and TN; weekly sampling took place for complete chemical analysis (involving PO4-P, NO3-N, COD, BOD, etc.). In 1977, a second sampling section at Zalaapáti, approximately 25 km upstream from the mouth, was also established.

The fact that generally one observation per month was available for a relatively short period of time, a priori excluded the statistical evaluation for the whole lake and restricted the analysis solely to the calculation of yearly and monthly averages (the latter with less accuracy but still coinciding with the requirement of lake water quality modeling, see Section 2.2).

The monthly average loads were derived as the arithmetical mean of five observations for the subsequent years where no streamflow statistics were available. For the ten water courses listed above, the discharge was replaced by the monthly averaged value, except for the River Zala where the computation was based on the actually measured daily Q values (also for PO4-P and NO3-N). The yearly average loads valid for the five year period considered (four for the River Zala) were computed from the monthly averages.

The results derived thus for the loads of TP, PO4-P, TN and NO3-N are summarized in Tables 1 and 2, and Figures 2 and 3, respectively. Table 1 contains the yearly averages for each of the 20 tributaries. It is indicated to which sub-watersheds (Zala catchment, Southern and Northern watersheds, Figure 1 and van Straten et al., 1979) and basins (Figure 1 and van Straten and Somlyódy, 1980) the individual water courses belong. The table also includes the area and average slope of the sub-watersheds. The total P yield, (kd/d km^2) ranges in a realistic domain (Column 8) except for water courses Kétöles and Tapolca, where the karstic origin modifies the pattern. There is generally no close correlation between yield and average slope. In the next table, the sum of the monthly averages are presented for all the monitored rivers. For the sake of comparison, the Zala data are also given. As can be seen, this river accounts for approximately 52% of the total tributary load in TP and as far as temporal changes are concerned, similarities can be observed between the two data sets

Table 1. Yearly Average Loads for Tributaries (based on observations for 1975-79)

Sl. No.	Name of the River	Location Watershed/ Basin 1		Q m^3/s 2	TP kg/d 3	PO4-P kg/d 4	TN kg/d 5	NO3-N kg/d 6	Watershed area km^2 7	TP Yield kg/d km^2 8	Average slope %o 9
1.	Zala	Z	1	7.18	225.1	91.4	2509.5	902.3	2622.0	0.086	-
2.	Lesence	N	2	0.12	1.5	0.8	19.1	9.5	100.5	0.015	-
3.	Világos	N	2	0.11	0.9	0.3	23.5	14.4	53.1	0.017	1.9
4.	Kétöles	N	2	1.35	34.6	16.3	293.0	165.5	9.6	3.600	-
5.	Tapolca	N	2	0.94	30.0	21.9	301.8	246.2	39.5	0.760	5.6
6.	Egerviz	N	2	0.45	6.0	2.8	175.4	108.5	365.6	0.016	11.3
7.	Nyugati-Övcsat	S	2	1.58	69.2	27.3	307.9	124.2	604.5	0.115	1.5
8.	A-B-C-csatorna	S	3	0.25	10.5	1.8	85.1	24.5	-	-	-
9.	Keleti-Bozót	S	3	0.50	19.4	6.0	156.6	89.3	250.9	0.077	1.7
10.	Tetves-patak	S	3	0.21	9.4	1.3	66.3	41.4	94.1	0.100	4.3
11.	Jamai-patak	S	3	0.12	2.7	1.0	17.6	8.6	58.8	0.046	3.2
12.	Nagymetszés-pat.	S	3	0.15	5.8	1.1	42.9	26.1	87.8	0.066	2.7
13.	Burnót-patak	N	3	0.17	1.5	0.8	56.8	43.5	82.2	0.018	3.7
14.	Örvényesi-séd	N	3	0.09	0.8	0.4	51.8	40.8	19.9	0.040	20.0
15.	Köröshegyi-séd	S	3	0.11	6.6	2.5	69.3	38.4	36.8	0.179	-
16.	Csopaki-séd	N	4	0.01	1.1	0.9	8.2	5.2	14.2	0.078	31.0
17.	Vörösberényi-séd	N	4	0.02	1.8	0.2	26.1	25.1	10.8	0.167	33.6
18.	Füzfői-séd	N	4	0.18	1.4	0.7	124.9	52.8	4.9	0.286	1.7
19.	Lovasi-séd	N	4	0.07	0.6	0.3	26.1	20.7	49.0	0.012	23.1
20.	Endrédi-p	S	4	0.06	3.8	0.5	20.2	8.1	23.0	0.165	3.0
Total for Basin 1				7.18	225.1	91.4	2509.5	902.3	2622.0		
	2			4.55	141.2	69.4	1120.7	668.7	1172.8		
	3			1.60	56.6	14.9	546.4	312.6	630.5		
	4			0.34	8.7	2.6	205.5	111.9	96.9		
Total for the Zala watershed				7.18	225.1	91.4			2622.0	0.086	
	Southern			2.98	127.4	41.5	765.9	360.6	744.3	0.171	
	Northern			3.51	79.2	45.4	1106.7	732.6	1155.9	0.069	
Total for the Lake				13.67	431.7	178.3	4382.1	1995.5	4522.2		

Data Source: Jolánkai (1981), Joó (1980)

Table 2. Monthly Average Loads for Tributaries
(a) Total watershed (1975-79),
(b) River Zala (1976-79)

Month	Q m^3/s	TP kg/d	PO4-P kg/d	TN kg/d	NO3-N kg/d
I	17.56	508.7	191.2	5711.0	2784.9
II	20.01	550.5	206.2	7741.0	4003.5
III	20.42	349.6	177.6	5781.5	2341.0
IV	16.49	480.7	200.9	4901.2	2021.5
V	12.97	471.5	168.9	4249.0	1442.1
VI	11.21	524.1	218.5	3363.6	1429.3
VII	9.09	360.8	179.3	2999.6	1059.9
VIII	8.18	333.1	208.9	2550.8	1147.0
IX	7.75	305.4	99.6	1513.0	785.7
X	12.11	438.8	106.2	3473.8	2134.3
XI	12.39	384.0	188.5	4460.7	1879.5
XII	15.89	473.6	194.3	5839.5	2916.9
Total	13.67	431.7	178.3	4382.1	1995.5

Month	Q m^3/s	Q_{av} (1969-78)	TP kg/d	PO4-P kg/d	TN kg/d	NO3-N kg/d
I	8.71	9.99	277.3	73.6	3170.9	1143.1
II	13.65	11.33	342.9	136.8	5581.4	2332.8
III	9.46	9.91	181.8	98.9	2529.0	1037.7
IV	10.15	8.80	329.3	107.4	3309.1	1216.5
V	7.07	6.47	263.4	89.3	2370.0	739.6
VI	5.95	6.10	277.8	90.2	1995.0	663.6
VII	4.67	6.80	182.6	93.0	1565.6	349.5
VIII	3.39	4.60	136.0	69.6	1069.9	368.3
IX	3.10	3.96	123.0	71.9	873.3	267.9
X	4.43	6.30	156.3	91.2	1302.8	450.1
XI	6.47	5.70	213.7	97.5	2297.5	751.3
XII	9.14	8.20	223.5	77.2	3648.9	1506.8
Total:	7.18	7.35	225.1	91.4	2509.5	902.3

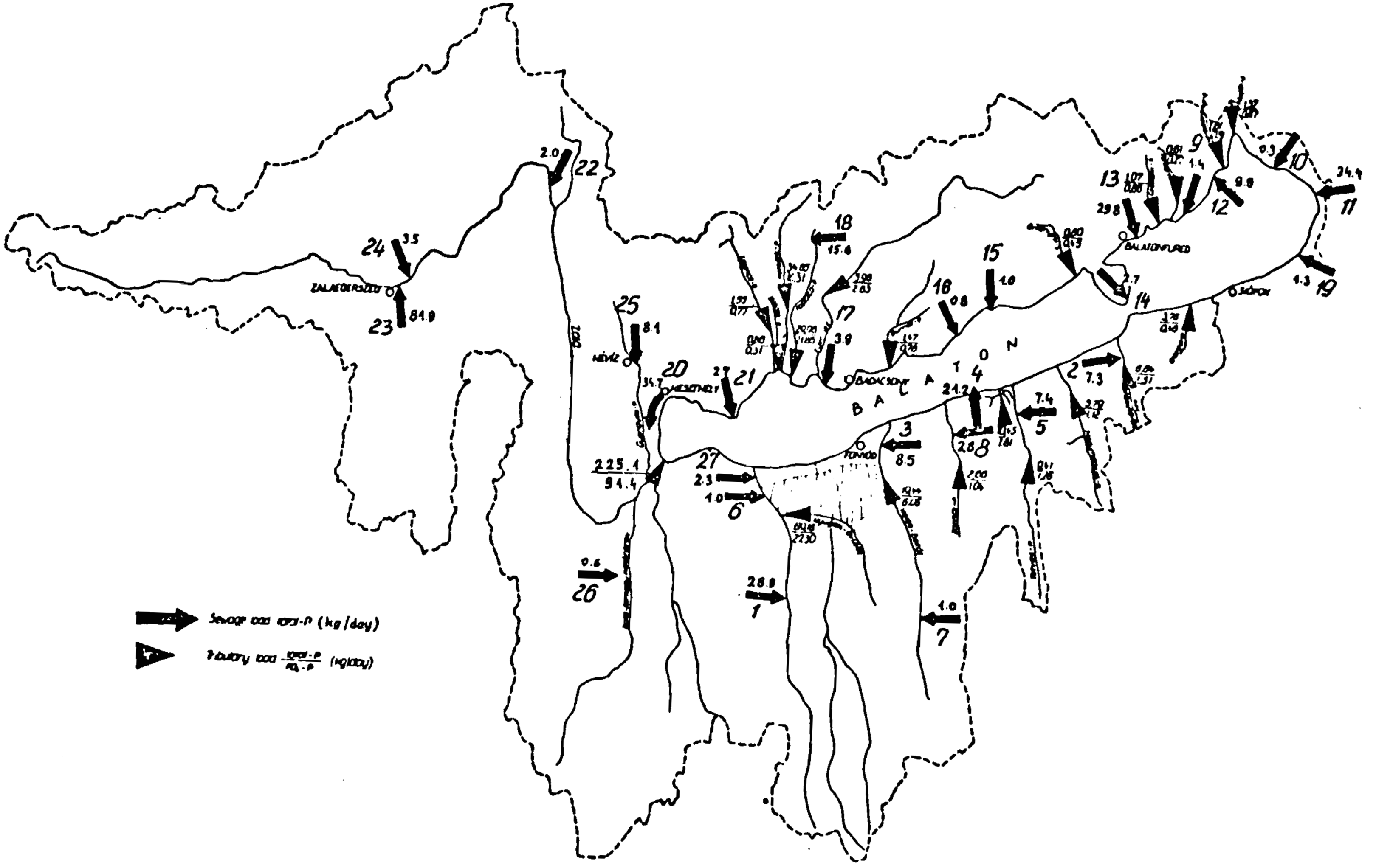


Figure 2. Yearly Average Tributary and Sewage Phosphorus Loads for the Lake Balaton region.

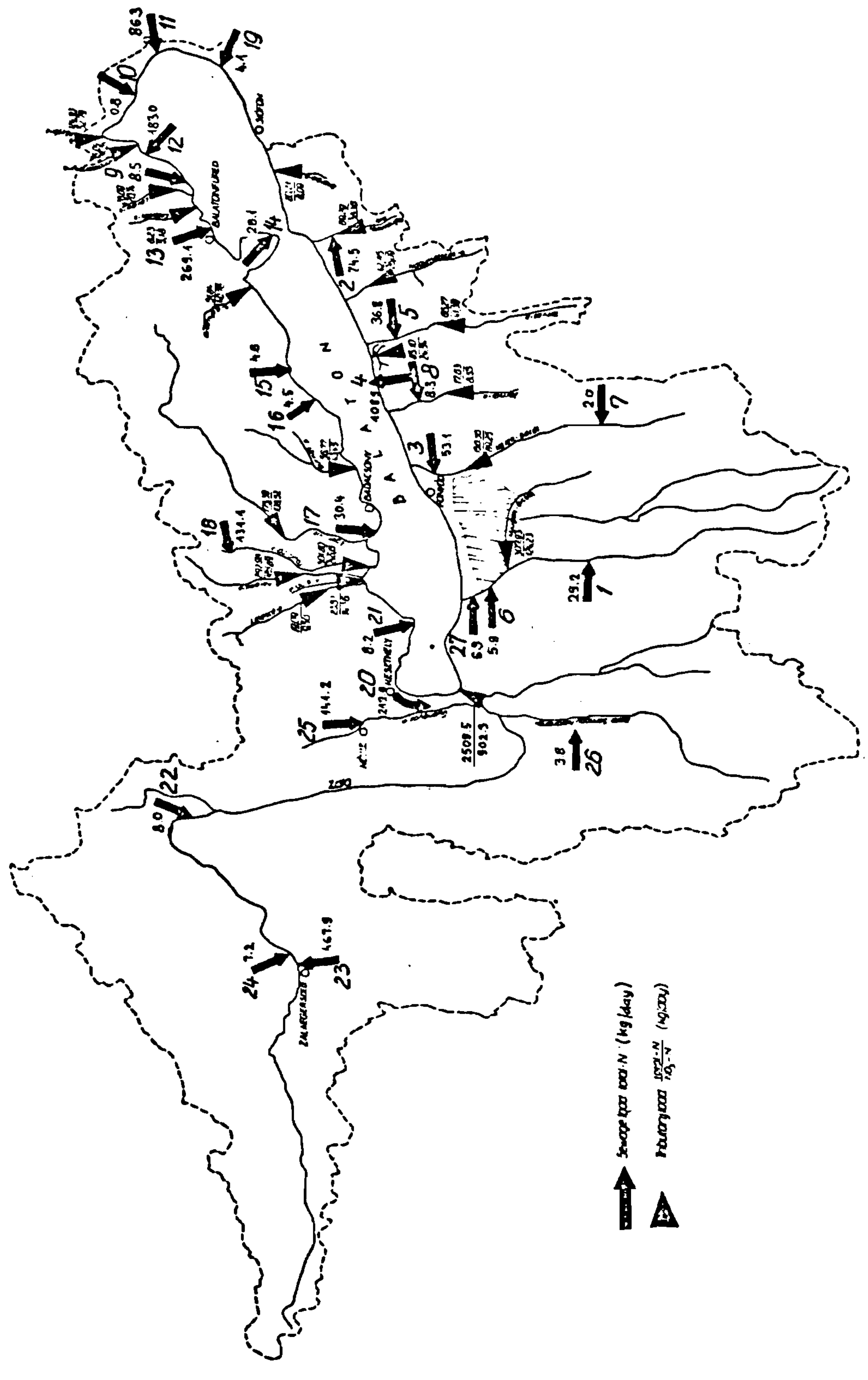


Figure 3. Yearly Average Tributary and Sewage Nitrogen Loads for the Lake Balaton Region.

(it is stressed that these similarities exist on a monthly basis). In the table (part b), the monthly average discharges for the period 1969-78 are also presented. From the comparison of the two columns for Q, it follows that, from the hydrological point of view, the period of water quality measurements corresponded approximately to average conditions. Therefore, the loading data can be considered as realistic averages. The total P load of the River Zala showed an increase during the period of observation (150.0, 215.5, 220.3 and 312.0 kg/d). However, except for 1978, this was associated with a simultaneous growth in the average discharge (6.0, 7.4, 6.1 and 9.2 m^3/s), thus suggesting that the hydrologic regime is responsible for the change, rather than the possible modifications in watershed activities. For systematical variations, the reader is referred to the trend analysis for 1970-79 for some of the smaller water courses by Jolánkai (1981).

The yearly averages are also given in the two figures. These illustrate well the spatial distribution of various plant nutrient loads. As can be seen from the summary of Table 1, loads are gradually decreasing in the W-E direction (from Basin 1 to Basin 4, Figure 1). The TP yield is highest for the Southern watershed (note that sewage loads are not separated; see Figures 2 and 3).

(b) Sewage loading

Here even less frequent data are available than for the tributaries: 2-6 measurements are made annually of the larger point sources indicated in Figures 2 and 3 with serial numbers 1 to 27. This data base is somewhat extended by the occasional studies on the most important treatment plants. Two slightly different data sets were available for this study: one published by Dobolyi (1981) for the recreational area, and the second based on Jolánkai's data collection for the whole watershed. The two data sources resulted in almost the same balance for total phosphorus for the recreational area, but with slight differences concerning the spatial distribution. Dobolyi's total nitrogen loads were systematically higher by about 40%.

In the frame of the present work, Dobolyi's load data were accepted and summarized in Table 3 and Figures 2 and 3. In the report referred to (Dobolyi, 1981), sewage loads for summer and winter seasons were distinguished; their duration is defined as 5 and 7 months respectively (summer period from May to the end of September). The weighted averages of these data, that is, the yearly mean loads, are given in the table and figures already mentioned. Here again the location of the sewage discharges is categorized in the second column according to: the three watersheds, four basins already mentioned, whether they are located on the recreational area or not, and whether the source is direct or indirect or mixed. In the table, the capacity of treatment plants (where it was known) is also given and the data source specified. With regard to the ratio of the summer load to the yearly average, not the original data, but the results of a regression analysis performed on them (Figure 4) were employed:

$$TP_{summer} \cong 1.43\ TP_{av}\ , \quad \text{and} \tag{1}$$

$$TN_{summer} \cong 1.35\ TN_{av}\ . \tag{2}$$

This means that the total phosphorus and nitrogen loads are approximately doubled compared to the off-season.

The summary of sewage loads for different catchments, regions and basins is presented in Table 4. The highest loads belong to the recreational area of Basin 4 (it is even higher if the discharge of Siófok, which is diverted from the region, is accounted for; Figure 1 and Table 3). The mixed sewage plays an essential role; its temporal pattern is discussed later.

Figure 2 presents an interesting finding for the River and watershed Zala, namely, approximately 50% of the monitored TP load at the mouth is of sewage origin. When one assumes some phosphorus transformations in the river, this agrees well with the observed PO4-P load at Fenékpuszta (see Appendix I).

Table 3. Yearly Average Sewage Loads

Serial No. of sewage discharges (Fig. 1)	Location	Q m^3/d	Q_c m^3/d	TP kg/d	TN kg/d
1.	S 2 NR ID	760	-	28.9	29.2
2.*	S 3 R ID	1600	1800	7.3	74.5
3.*	S 3 R M	740	720	8.5	53.1
4.*	S 3 R M	2500	2000	21.2	108.9
5.*	S 3 R M	610	1000	7.4	36.8
6.*	S 2 R ID	150	150	1.0	5.9
7.	S 3 NR ID	80	-	1.0	2.0
8.	S 3 R ID	480	-	2.8	8.3
9.*	N 4 R D	220	200	1.4	8.5
10.	N 4 R D	50	-	0.3	0.8
11.*	S 4 R D	1370	3600	34.4	86.3
12.*	N 4 R D	2290	1600	9.9	183.0
13.*	N 4 R D	5400	7800	29.8	269.1
14.*	N 4 R D	680	1100	2.7	28.1
15.*	N 3 R D	210	600	1.0	4.6
16.*	N 3 R D	140	1200	0.8	4.5
17.*	N 3 R D	540	600	3.9	30.4
18.*	N 2 R ID	2400	3600	15.6	131.1
19.	S 4 R D	110	-	1.3	4.1
20.*	Z 1 R M	5300	7500	34.7	212.6
21.*	N 2 R D	200	1200	2.7	8.2
22.	Z 1 NR ID	270	-	2.0	8.0
23.	Z 1 NR ID	15500	-	81.9	467.9
24.	Z 1 NR ID	330	-	3.5	7.2
25.*	Z 1 R ID	1900	2850	8.1	141.2
26.	Z 1 NR ID	450	-	0.6	3.8
27.*	S 2 R ID	160	260	2.3	6.9
Total:		44400		315.1	1924.9

Notes: * Data source: Dobolyi (1981); Q_c = capacity of treatment plants (Dobolyi, 1981); Z,S and N watersheds; 1...4 Basins; R recreational area, NR non-recreational area; D direct, ID indirect and M mixed sewage, respectively.

The load of Siófok (TP ≅ 125 kg/d) is excluded from the table since its sewage is diverted from the watershed.

Table 4. Yearly average sewage load summary

	Q m^3/s	TP kg/d	TN kg/d
Zala watershed	23750	130.8	840.7
Southern watershed	8560	116.1	416.0
Northern watershed	12130	68.2	668.2
Basin 1	23750	130.8	840.7
2	3670	50.5	181.3
3	6900	53.9	323.1
4	10120	79.9	579.8
Total:	444000	315.1	1924.9
Recreational area	27050	197.2	1406.8
Basin 1	7200	42.8	353.8
2	2910	21.6	152.1
3	6820	52.9	321.1
4	10120	79.9	579.9
Direct sewage	11210	88.3	627.6
Basin 1	-	-	-
2	200	2.7	8.2
3	890	5.7	39.5
4	10120	79.9	579.9
Mixed sewage	9150	71.8	411.3
Basin 1	5300	34.7	212.6
2	-	-	-
3	3850	37.1	198.7
4	-	-	-

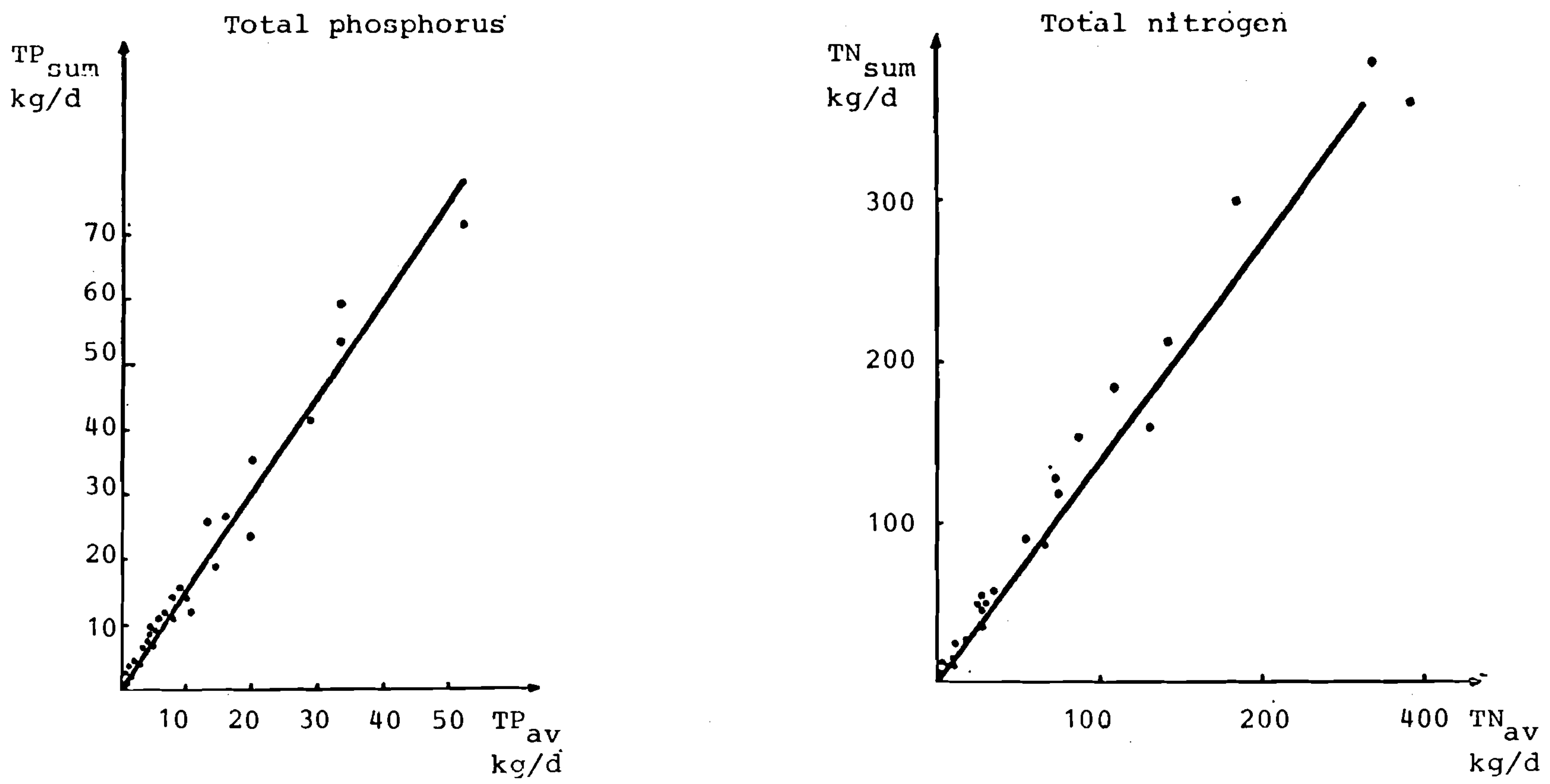


Figure 4. Relation between Yearly Average and Summer Sewage Loads, Lake Balaton

(c) Direct non-point source loading

The effect of direct urban runoff from the villages surrounding the lake can be significant according to literature estimates (Melannen and Laukkanen, 1980). Until 1980, no information was available for the Lake Balaton region, at which time, measurements on a pilot area of 70 hectars at Keszthely (Figure 1) were initiated at VITUKI (Botond, 1981). Observations during three storms were performed, which clearly showed that the total amount of nutrient forms were washed out during the first 1-2 hours of the precipitation. The flux for TP exceeded the value 4 g/s which, when related to unit surface area, is in good agreement with the data in the literature (Melannen and Laukannen, 1980). Next, the measurement results were extended for yearly averages and larger settlements based on a simple analysis of rainfall data and the area of villages, respectively. Finally a total balance was provided for the basins and entire lake (Table 5).

Certainly, one may question the appropriateness of involving this estimate here for two reasons: it was established on rather scarce data, and it could be added to Chapter 3, which considers the confidence of the loads. However, to achieve a complete loading figure which covers more or less all the nutrient forms, the inclusion of runoff data (of low quality) was decided on. The calculation of the previous loadings (e.g., for tributaries) already required some assumptions and this will be the case with the load type (ii) and atmospheric pollution as well. In addition, the urban runoff estimate cannot be refined later and even its accuracy can hardly be studied.

Load type (ii) involves the contribution of non-point sources from the direct vicinity of the lake which is not covered by the sub-watersheds of tributaries and accounts for 13% of the total watershed area. The structure of this immediate watershed is quite heterogenous, since it consists of urbanized areas, motoring roads, vineyards where the erosion is of primary importance, and other agricultural fields. Without going into detail, since the data will not allow it, it was decided to derive area yields based on the tributary loads (after removing the sewage discharges) and then calculate the various loads. The results are summarized for the basins and total lake in Table 6.

The influence of atmospheric pollution (precipitation and dry outfall on the water surface) is also significant and was studied in a joint program of VITUKI and the Central Institute of Atmospheric Physics (Dobolyi and Horváth, 1978; Mészáros et al. 1980; Dobolyi, 1981). Samples were taken each month for a year period in 1976-77 at six locations around the lake. These were followed by some later studies in subsequent years. The data obtained were averaged and then extrapolated for the whole lake. The first estimate of nitrogen loads based on data for 1976-77 was essentially reduced (Dobolyi, 1981). Here the modified results are employed. A summary is given in Table 7. Wet deposition was found to be more important than the dry deposition; this may explain the high ratio of PO4-P. It should also be mentioned that, because of the location of sampling stations, the data presented should result in an overestimate of the atmospheric load. Data for item (iv) were not available; its possible contribution (which seems to be insignificant) is discussed later.

2.4 Summary of Average Load Calculations

The summary of all the loading components discussed is given on a yearly basis in Table 8. The global figure can be obtained in several ways, e.g. with or without separating the sewage loads from the monitored tributary loads (where it is required). In this case, the second way was selected since the river data express the actual load independent of its origin and processes taking place in rivers. In addition, it was felt that this information is more accurate. Consequently, in the summary tributary, direct and mixed sewage loads are distinguished. Their sum together with the other sources gives the total load. When the management of the system is considered, the use of the original data is naturally suggested, together with the locations of individual sewage discharges and tributaries.

Table 5. Estimated Loads from Urban Runoff
Data source: Botond (1981)

	TP kg/d	PO4-P kg/d	TN kg/d	NO3-N kg/d
Total	160.5	18.5	323.2	93.2
Basin 1	12.8	1.5	25.9	7.5
2	35.4	4.1	71.1	20.5
3	38.5	4.4	77.6	22.4
4	73.8	8.5	148.6	42.8

Table 6. Estimated Loads for Direct Non-Point Sources in the Vicinity of the Lake

	TP kg/d	PO4-P kg/d	TN kg/d	NO3-N kg/d
Total	49.0	7.5	549.0	278.0
Basin 1	7.0	1.0	86.0	44.0
2	13.0	2.0	142.0	72.0
3	20.0	3.3	225.0	113.0
4	9.0	1.2	96.0	49.0

Table 7. Estimated Loads from Atmospheric Pollution
Data source: Dobolyi (1981)

	TP kg/d	PO4-P kg/d	TN kg/d	NO3-N kg/d
Total	171.1	105.0	1655.0	293.0
Basin 1	10.3	6.3	99.3	17.6
2	41.1	25.2	397.3	70.3
3	53.0	32.5	513.0	90.8
4	66.7	41.0	645.4	114.3

Table 8. Total Yearly Average Load summary

	TP kg/d	PO4-P kg/d	Available P kg/d	TN kg/d	NO3-N kg/d	Volume million m^3
Tributaries	431.7	178.3	229.0	4382.1	1995.3	
Direct sewage	88.3	-	88.3	627.6	-	
Mixed sewage	71.8	-	71.8	411.3	-	
Urban runoff	160.5	18.5	46.9	323.2	93.2	
Atmospheric pollution	171.1	105.0	105.0	1655.0	293.0	
Direct non-point sources (ii)	49.0	7.5	15.8	549.0	278.0	
Total:	972.4	309.3	556.8	7948.2	2659.5	
Zala watershed	272.8	92.9	156.6	2748.0	909.8	
Southern watershed	354.7	109.0	182.3	2358.4	753.4	
Northern watershed	344.9	107.4	217.9	2841.8	996.3	
Basin 1	289.9	100.2	165.0	2933.3	971.4	82 (4.3%)
2	233.4	100.7	126.2	1739.3	831.5	413 (21.8%)
3	210.9	55.1	116.3	1600.3	538.8	600 (42.3%)
4	238.2	53.3	149.2	1675.3	317.8	802 (42.3%)

The total phosphorus and nitrogen estimates are the same as given by Joó (1980) and lie in the range of the preliminary guess of van Straten et al. (1979) (see Table 12). The available P load was calculated by assuming 20% availability for phosphorus fractions of (TP-(PO4-P)). As can be seen from the table, approximately half of the TP load (around 500 kg/d) is available for algae in the lake, 35% of which is originating from the sewage load of the recreational area. The table also involves the usual summary for the three main watersheds and four basins. The pattern of the total load shows a similar longitudinal gradient as that of the tributary load discussed before. This is even more apparent when volume related values are considered, e.g., the volume of Basin 1 is only 4.3% of the total lake (Table 8). Consequently, the relative TP load represents a striking distribution, 11.9:1.9:1.2:1.0 for the four basins, a clear indication of the differences of the trophic state of the lake segments Keszthely, Szigliget, Szemes and Siófok, respectively.

As the temporal changes are concerned with tributaries and sewage, the reader is referred to Table 2, and Equations (1) and (2), respectively. Further discussions are provided together with an explanation of the uncertainties of the present estimate in the next chapter. The chapter is restricted to phosphorus because it plays the limiting role on spatial and temporal averages in the eutrophication process. The analysis for nitrogen can be performed in a similar fashion.

3. CONFIDENCE OF THE PHOSPHORUS LOAD ESTIMATE

3.1 Correction of the Different Loading Types

(a) Nutrients carried by tributaries

1^{o} Order of magnitude analysis

Apart from the problem of indirect sewage, to be discussed in the next section, this question involves the problem of determining indirect non-point source loading. Had the loading rates at the mouth section been determined on the basis of measurements with proper sampling frequency (Section 2.2), no problem of uncertainty would arise, at least for the load reaching the lake.

This does not apply, however, to the load's origin in the watershed. For the determination of nutrient loading rates given in the foregoing chapter, only scarce data are available, which may lead to crucial uncertainties since the floods remain unobserved. Their duration ranges from some hours to 1-2 days for the smaller tributaries, but during these events, the largest portion of TP and TN nutrients is carried, as stressed previously.

Concerning the quality of data (Chapter 2), basically three groups should be distinguished:

- River Zala, components TP and TN, for which the load can be considered accurate;
- River Zala, components PO4-P and NO3-N. The load can not be calculated precisely because of infrequent observations;
- All the other tributaries - for which even less frequent data exists; therefore, the load is corrupted by a higher error. For two of these water courses (Figure 1), event based measurements were performed which can be used to judge the contribution of floods to the load (Jolánkai, 1981).

To begin the discussion with the third group, it should be mentioned that only a part of these rivers is truly important when uncertainties are considered--those rivers for which the slope is relatively high (see Table 1). It is rainfall-runoff processes which play the primary role in inducing the nutrient load. The rivers of serial number 6, 9-14, and 18-20 in Table 1 belong to this category (the rest are similar to the River Zala in behavior, or influenced by other factors such as the presence of marshlands, the origin of karstic water, or sewage discharges along the river; they are, furthermore, characterized by slower dynamics). The catchment area of these rivers is less than 20% of the total, while the streamflow and TP load are, on the basis of monthly observations, 15 and 12%, respectively. Thus, the estimate given in Chapter 2 should be considered reasonably accurate even if the error for these particular rivers is unrealistically high.

For illustration, the load versus discharge data is given in Figures 5-7 for the Keleti Bozot (based on the regular sampling network) and Örvényesi-séd. In both Figures 6 and 7, the results of regular observations and event based measurements are involved. From the latter, the difference is apparent in the behavior of various storms, such as summer storms, autumn floods, and a more or less steady summer rainfall. The data for the last event coincide quite well with that of the regular sampling network (suggesting that the rapid processes will remain unobserved in the frame of conventional sampling). The measurements also show clearly that the increase in the PO4-P load is less extensive than in the TP. Only a few such event based measurements are available and they do not allow a statistical extension for a longer period (e.g. a year), unless for example, rainfall or streamflow data series are known. A simple conclusion, however, can be drawn from Figures 6 and 7: when it is surmised that conditions corresponding to large autumn floods taking place through the whole year (or in other words, that the corresponding relationship is valid for the whole year), the load is at maximum doubled when compared to the estimate from the regular monitoring network data (the average slope of this sub-watershed is one of the highest in the Lake Balaton region, see Table 1). This would result in an error of 10-15% in the lake's total estimate.

In order to compare the well-monitored Zala River to the others, the annual total P yield was illustrated as a function of runoff in Figure 8, together with four typical water courses belonging to the Southern and Northern watersheds, respectively (Table 1 serial numbers in 6, 9-14 and 19). As can be observed, the Northern creeks form a separate domain of smaller yield, which has the same magnitude for the River Zala and Southern tributaries. It is believed, on the basis of Figure 8 and the watershed areas of Table 1, that the load of the lake is approximately double in comparison to that of the River Zala. This surmise is well supported in Table 1, even though the River Zala data involve the contribution of floods, and the other rivers do not necessarily. With reference to the tributaries conventionally monitored, one can conclude that first, the load estimate of the previous chapter represents a realistic magnitude, and second, there are

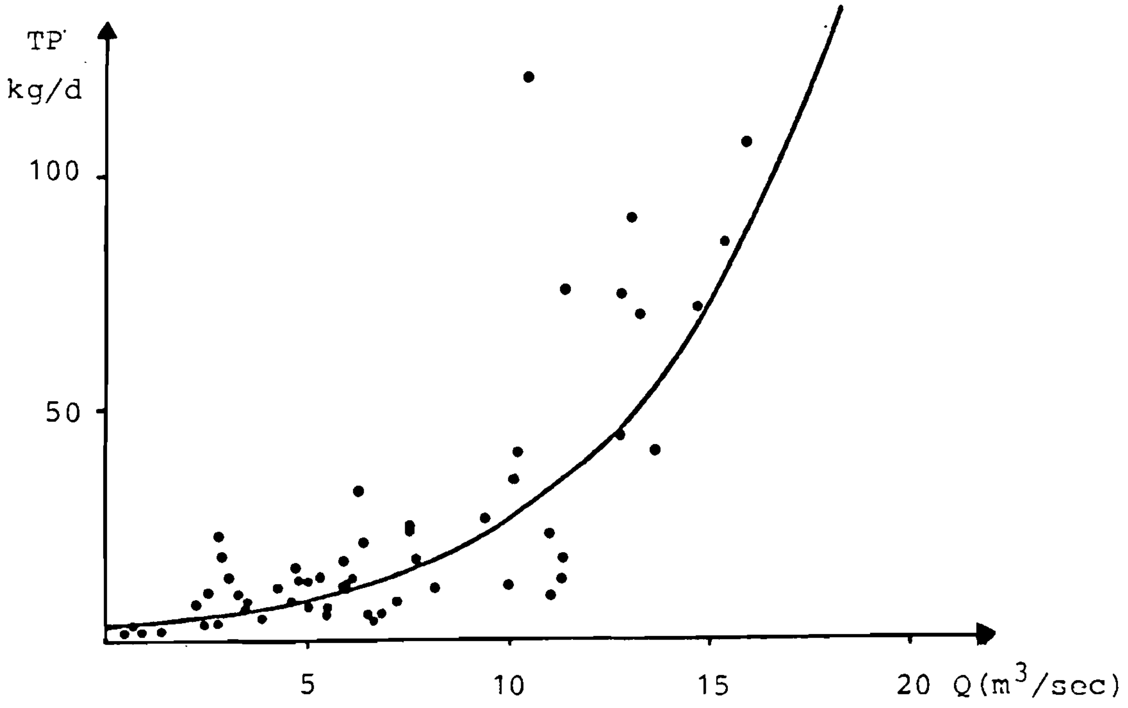


Figure 5. Relation between TP Load and Discharge based on Regular Sampling - Keleti Bozót

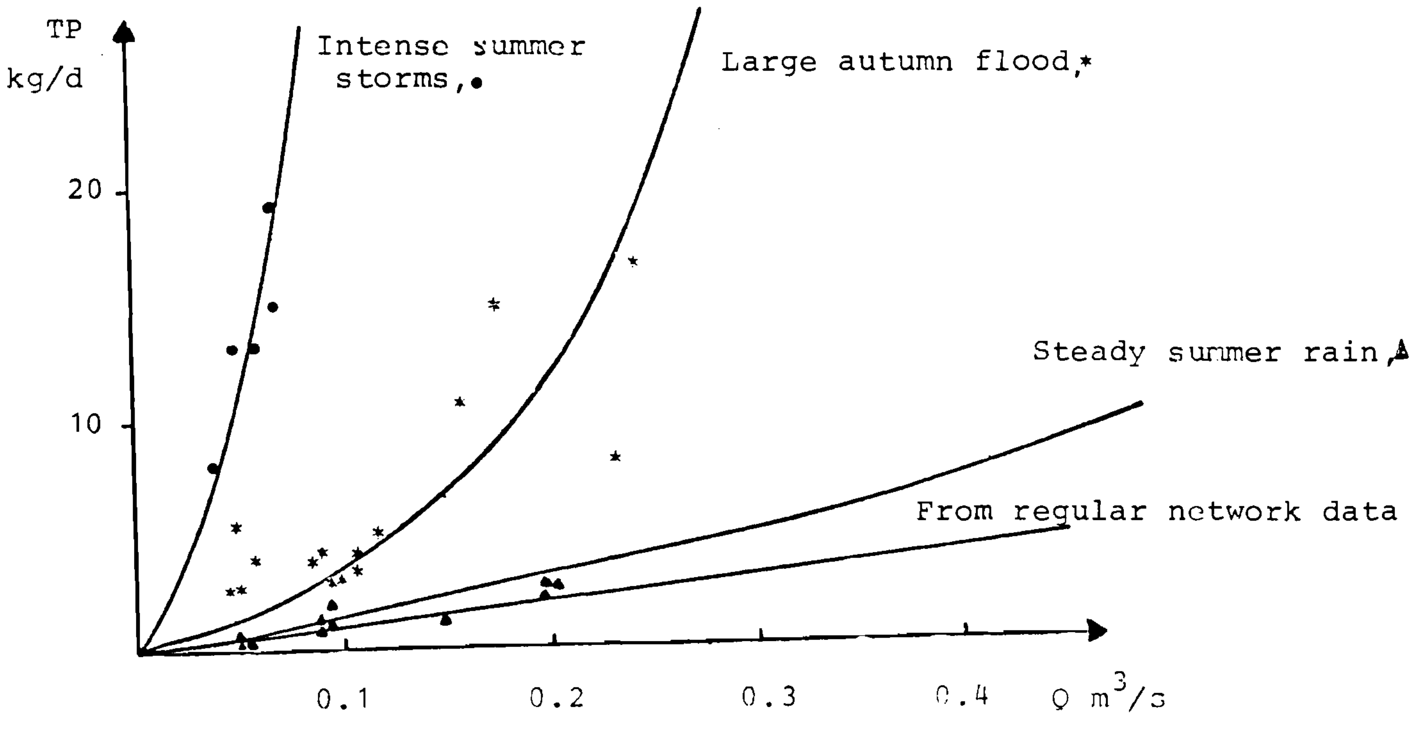


Figure 6. Relation between TP load and discharge based on regular sampling and flood measurements, Örvényesi-séd

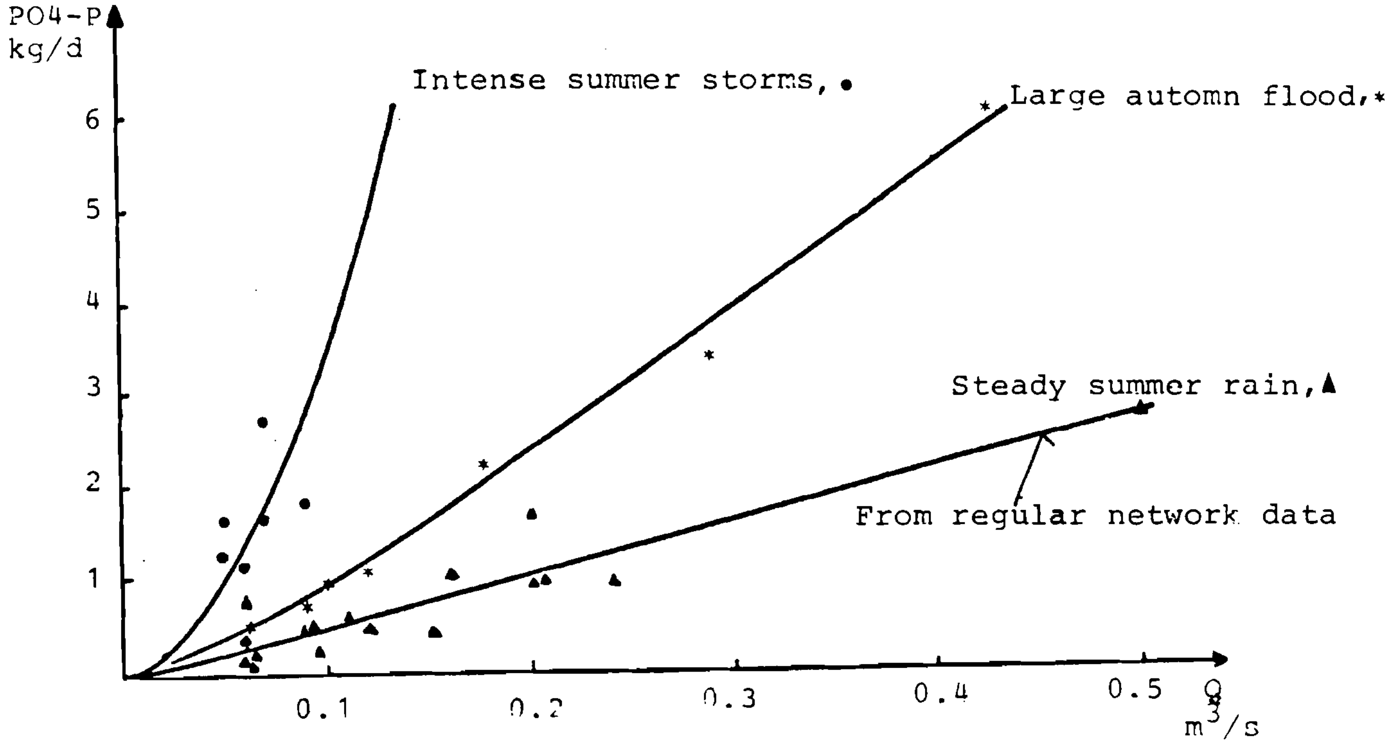


Figure 7. Relation between TP load and discharge based on regular sampling and flood measurements, Örvényesi-séd

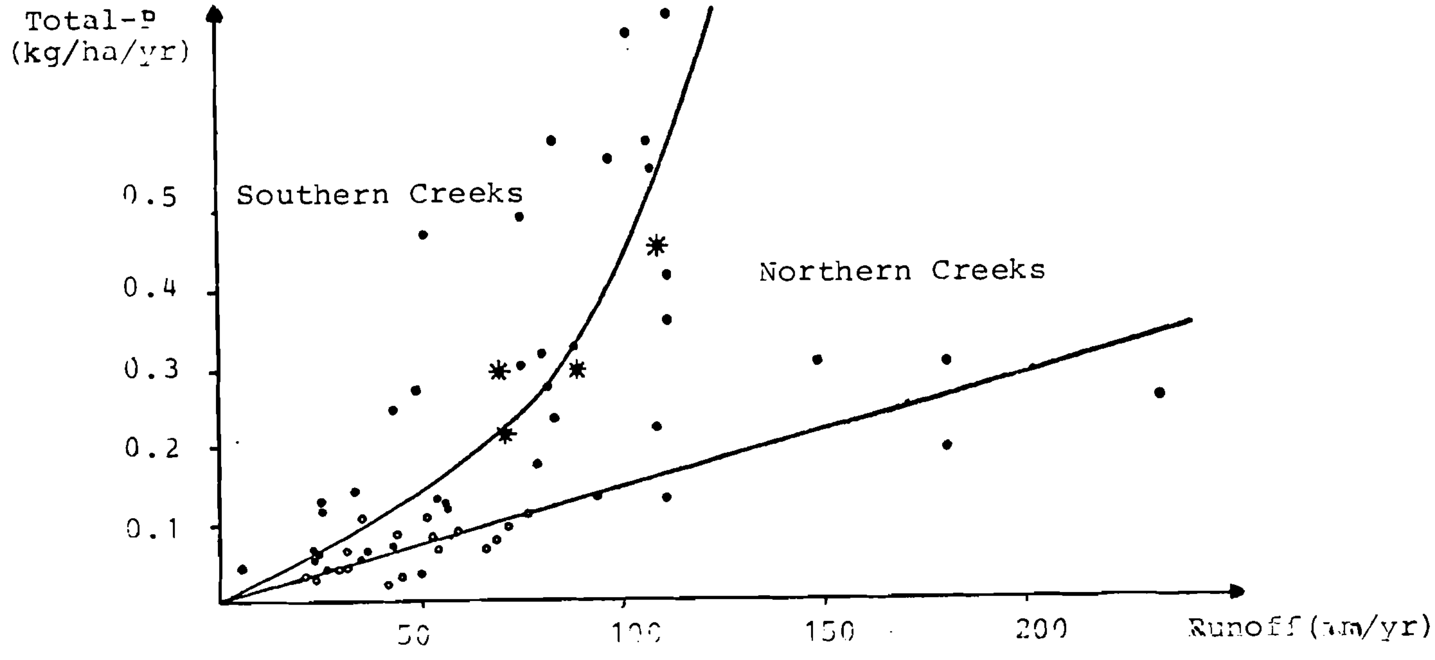


Figure 8. Relation between the annual TP yield and runoff for the three main watersheds

*Zala watershed

similarities when compared to the Zala watershed on a yearly basis (Figure 8). Thus, keeping in mind the details of the Zala observations, an analysis can be performed, the objective of which is to test the accuracy of loading calculations from scarce data (in other words, the contribution of unobserved events). Then the results can be used to correct the PO4-P load for the River Zala, and finally a correction can be done by extrapolation for the total watershed.

2^o Uncertainty Analysis on the River Zala Data

This study was performed by Somlyódy and Eloranta (1981) for total phosphorus and orthophosphate-P. The idea is as follows: assume a situation when the detail of available streamflow and concentration data will allow the derivation of the "exact" load for the river cross section for a given period (e.g., a month or year). Next, one can suppose that from this data set, only infrequent observations with some regularities (e.g., one piece of data monthly) are known. These infrequent data can be sampled randomly from the original data base and the load calculated. The procedure then will be repeated several times in a Monte Carlo fashion and finally a statistical analysis in the resulting load data series can be performed (for a similar study with a different objective, see Dolan et al., 1981). As a result, the average value, range, distribution, variance, etc., can be derived and compared to the exact (known) value. From this comparison, the error related to infrequent sampling (that is a measure of information loss) will be given. This technique will indicate whether a sampling strategy is appropriate or should be modified, an important issue from the viewpoint of establishing the monitoring network .

This kind of analysis was carried out for TP and PO4-P, and for monthly and yearly averages, respectively. The details can be found in Somlyódy and Eloranta (1981), and in a condensed form in Appendix I. In summary, the following can be stated:

- The standard and maximum errors for the yearly average TP load are ± 13 and ± 21%, respectively, if biweekly measurements were assumed.

- The standard error of the PO4-P load is less than ± 10% for one monthly measurement. This is valid, however, in comparison to the load computed from weekly data, though not to the exact value (this is unknown).
- The error of the monthly averages is higher and fluctuates depending on the streamflow rate. The mean and extreme values, as well as the domain of ± standard deviation and a typical distribution is given in Figure 9.
- Given the prior ranges, and the fact that the unobserved floods cause a systematic error, it is realistic to increase all the yearly average loading types as follows:
    - o The PO4-P load of the Zala River by 13% (taken from the analysis of TP data for the biweekly observations).
    - o Both the TP and PO4-P loads for all the other tributaries by 20% (which is perhaps higher for TP and smaller for PO4-P). The correction will be performed on the tributary load, which, it should be stressed, also involves the contribution of indirect sewage.

3^o Influence of the Hydrologic Regime

In Somlyódy and Eloranta's analysis (1981) (also see Appendix I), it was found that the monthly average TP load correlated satisfactorily with the corresponding streamflow rate. Accepting the monthly average streamflows from Table 1 and deriving their statistics from Baranyi (1979), confidence levels of 90% can be established for the TP load (Figure 10). For the purpose of comparison, the extreme values for the period 1976-79 are also presented in Figure 10 and an event of low probability in July, 1975, is likewise indicated.

Contrasted with the high fluctuation in the monthly averages, the uncertainty in the yearly average is substantially smaller. The reason stems from the virtually linear dependence of the load on the streamflow (see Appendix I) and the much smaller variation in the yearly average Q than the monthly. Judging from the streamflow observations for 1969-78, a change in the ± 25% range can be expected and extended to the whole watershed (this is again probably smaller for PO4-P).

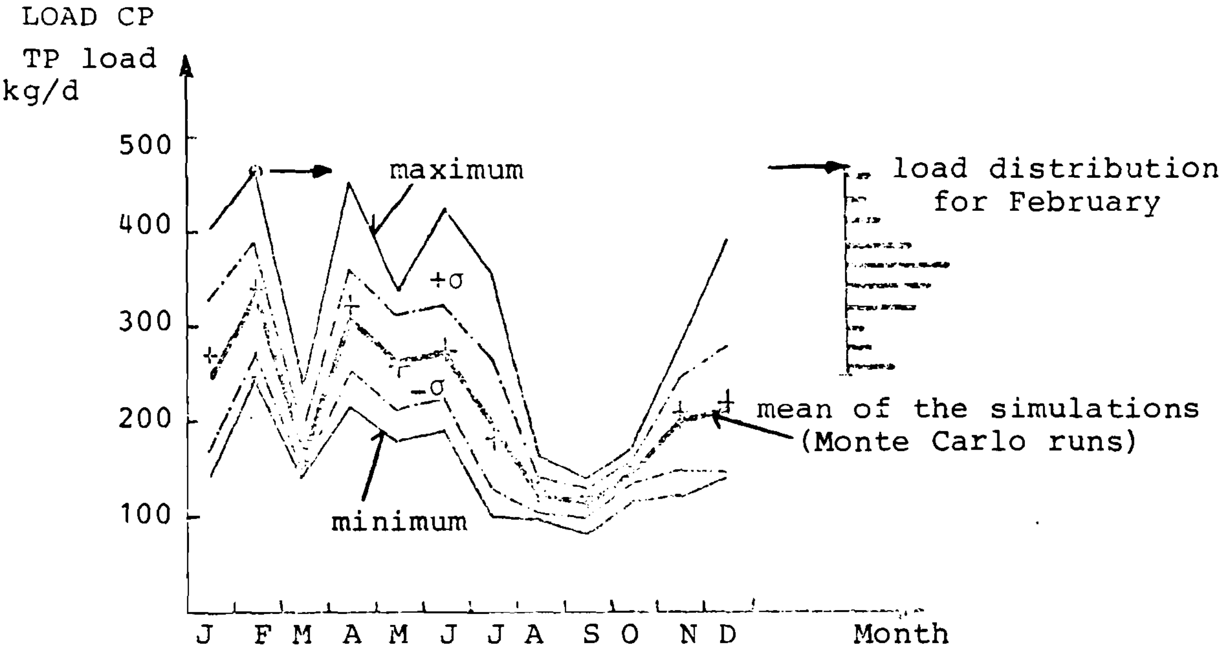


Figure 9. Monthly average TP load: uncertainty caused by scarce observations (River Zala, 1976-79), + "exact" values

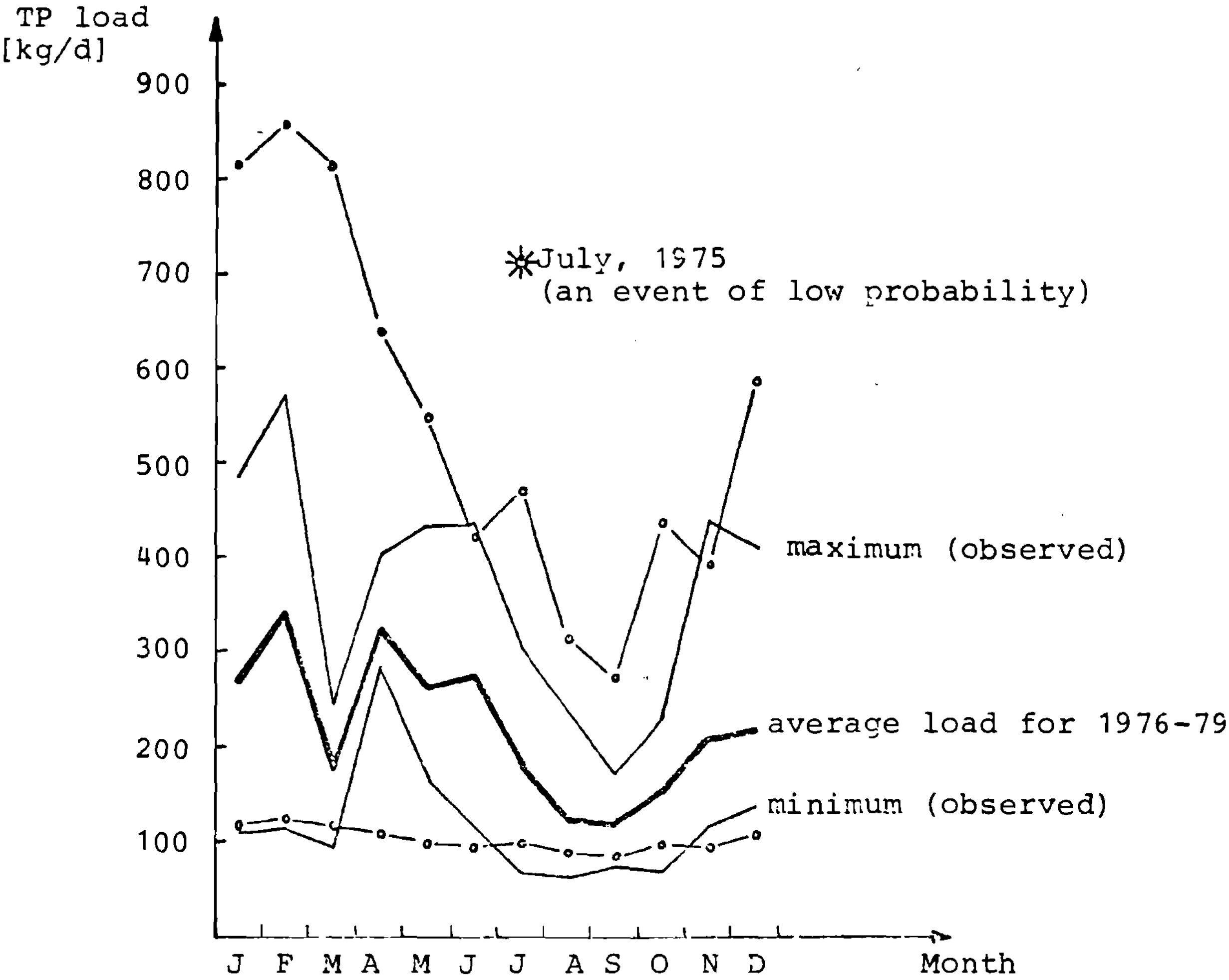


Figure 10. Influence of the hydrologic regime on the monthly average load, River Zala
o 90% confidence level

4. Summary for Tributary Loads

Based on the previous arguments, the corrected loads are as follows:

$$L_{TP} = 473 \pm 118 \text{ kg/d}$$

$$L_{PO4-P} = 208 \pm 53 \text{ kg/d}$$

$$L_{Available} = 261 \pm 65 \text{ kg/d}$$

Concerning the temporal changes, the extension of the dynamics of the River Zala can be accepted on a monthly basis for the whole watershed.

b. Sewage Loading

1° Order of Magnitude Analysis

Because of the data's character and infrequent sewage load measurements, it is hard to judge the accuracy of the estimate given from the data before. Hopefully, the averaging smoothed out the random errors and the scarcity of data did not cause serious problems, particularly since the dynamics are not so essential as in the previous case, meaning that the estimate can be considered realistic.

There is, however, an opportunity to check the reliability of the data through the regional population. In the recreational area (the rest of the total watershed will not be considered here since its influence is expressed through the river data) domestic sewage is dominant. This situation is closely connected to the number of inhabitants and its fluctuation due to tourism in summer periods. In a strict sense, this analysis belongs to the source evaluation (see later), but the sewage aspects which may lead to a refinement of the original estimate are discussed here.

The data published by Dobolyi (1981) served as a basis for analysis. Information for 19 villages in the direct region of the lake was collected on the number of inhabitants, water supply, water consumption, sewage discharge and loads, and the level of sewerage development. Most of the information was available for winter and summer seasons separately.

Because of the uncertainty of the existing observations, a regression analysis was first performed on the corresponding discharges (m^3/d) and load data and these (they showed, by the way, a correlation coefficient of approximately 0.95) equations resulted:

$$L_{TP} \cong 0.0064\ Q\ [kg/d] \qquad (3)$$

$$L_{TN} \cong 0.0338\ Q\ [kg/d]\ . \qquad (4)$$

Siófok (Figure 1) and another village were excluded from the analysis. In the latter case, the origin of the wastewater was not exclusively domestic. According to Equation (3), an average phosphorus concentration of 6.4 mg/ℓ corresponds, a realistic value (apart from one plant, there is only biological treatment), which simultaneously shows the effectiveness of the tertiary treatment planned for the future (1/6 - 1/10 reduction can be achieved). Expressions (3) and (4) are approximately valid for the whole watershed, including Zalaegerszeg. A fundamentally higher concentration of 15 mg/ℓ corresponds to Siofok; this would modify the average value of the recreational area to 8.5 mg/ℓ. It is worthwhile mentioning that the efficiency of most of the existing treatment plants of secondary level should also be improved and the capacity increased. Thus the problem of removing the phosphorus from the sewage cannot be separated from that of the biological treatment. In the framework of sewage management, this fact should be taken into consideration (for details see Kovács et al. 1980, and for sewage data, Dobolyi, 1981).

From the sewage discharge data, 200 l/d/capita is the resulting off-season average, which agrees with the literature. Furthermore, knowing the total permanent population (58250 and 124650 if Siófok is included) and Equation (3), a TP load of 126 and 205 kg/d, respectively, will ensue. This coincides well with the measured off-season load (see Table 3 and Equation (1)) - 141 and 232 kg/d.

The distributions along the four basins are also similar, e.g., 0.19:0.27:0.13:0.41 for the permanent population, and 0.22: 0.14:0.13:0.59 for the sewage discharge (Basins, 1,2, 3 and 4. Siófok is included). The difference is essential only for the Szigliget Bay. Thus, all things considered, the estimate for the winter season is justified from the aspect of source evaluation. The analysis suggests that the system of treatment plants and sewerage is not overloaded and the total amount of produced wastewater is flowing through this system.

It is worth mentioning that the simple proportionality expressed by Equations (3) and (4) is a very useful tool for performing preliminary calculations on the sewage problem in the Lake Balaton area.

2^o Fluctuation and Correction of the Direct Sewage Load

Following the argument of the previous section, the correctness of the summer sewage load estimate can also be checked through the population count. Compared to the permanent population, there is a 3.7 times increase in the summer period, to which 468 and 758 kg/d TP load belongs (without and with Siófok) - 60% of this is reflected by the sewage data. The rest is collected in septic tanks which ultimately causes uncertainties concerning the fate of sewage gathered. This fact is taken into consideration by an increase of the load. It is assumed (rather arbitrarily) that 1/4 of the missing portion, or 15% of the original summer load estimate belongs to this unidentified category. This modification, principally, concerns all the sewage loads; however, the indirect sewage is expressed through the tributary load (Section 3.1a) and is believed to be monitored properly. The recipient of the mixed load is not the lake, but another water body in the main season. Thus, only the direct load will be modified, including the region of Siófok. Consequently, 40 kg/d will be added to the summer direct load (in the yearly average, this means 16.7 kg/d) and distributed among Basins 1...4 according to 0.15:0.20:0.20:0.45. These global ratios were found on the basis of population, water use, and sewage discharged.

One more correction will be made in the sewage category which will not influence the yearly average value. The data discussed until now were valid in an average for the summer period assumed to be 5 months long. Certainly in July and August, during the peak tourist period, a further increase should occur. In fact, Dobolyi's measurement in 1979 showed a nearly three times growth compared to the off-season. This ratio is in harmony with the total capacity of the treatment plant under overloaded conditions. Thus, the ratio 1:2:3 is realistic for the winter, summer, and peak seasons, respectively. If the 40 kg/d TP load is also distributed for the summer and peak periods in the same way and the yearly average increased by the corresponding 16.7 kg/d value, the temporal pattern given in Table 9 appears.

3° Variation of the Mixed Sewage Load

Table 3 involves four discharges for this category (Nr 3-5 and 20). Among these, the major portion of the sewage of Keszthely is diverted to the marshland nearby and drained to the River Zala. Accordingly, it is monitored at the river mouth and will be omitted from the sewage load table.

The recipients of wastewater Nr 3-5 are fishponds closed via the lake in the summer season and drained between the middle of September and November. There is correspondingly no load during summer in these locations, but there is an increased loading in autumn. Based on available information, it appears that some nutrient removals take place in the ponds, the efficiency of which can be estimated up to 50%. Assuming that the ponds in question are recipients of the sewage for five months with the above removal rate, the total amount of phosphorus drained into the lake is approximately 900, 2300, and 800 kgs, respectively. To derive a daily load, the duration of the release period should be known. For simplicity, a month is suggested (it is noted, however, that this period is generally shorter). Assuming also that this month is October, the time pattern of Table 10 results for the three mixed sewage loads. The above removal in fishponds reduces the yearly load by 11 kg/d.

Concerning the sewage load in general, it is felt that the estimate for the yearly average and winter time is satisfactorily accurate, but more uncertainties exist for summer conditions.

c. Direct Non-point Source Loading

As mentioned in Section 2.3, the load estimate for urban runoff cannot be corrected, since only limited information is available. Concerning the second type of loads in this group,

Table 9. Monthly Variation of the Direct Sewage Load related to the Yearly Average, L = 105 kg/d

Month, i	Load, L_i/L
I - IV	0.60
V - VI	1.32
VII - VIII	1.97
IX	1.32
X - XII	0.60

Table 10. Monthly Variation of the Mixed Sewage Load related to the Yearly Average Value, L = 26.1 kg/d for Nr. 3-5 (see Table 3)

Month, i	Load, L_i/L
I - IV	1.01
V - IX	0
X	5.94
XI - XII	1.01

the non-point sources from the direct vicinity of the lake, the figure given in Chapter 2 is presumably underestimated. If, for example, it is assumed that in a year at least one event of 30 mm rainfall occurs, the probability of which is higher than 90%, and the runoff coefficient is virtually 0.1, with concentrations corresponding to observations for such events, an additional load of 30.0 and 3.0 kg/d can be derived for TP and PO4-P, respectively. These values will be used for correction.

Contrasted to the previous load type, the PO4-P load originating from atmospheric pollution is believed to be overestimated because of the location of sampling stations (Section 2.3). Therefore, a reduction is done by maintaining the original TP load, but calculating the PO4-P load to 40% (68.4 kg/d).

In relation to the groundwater infiltration, the following can be stated. From the viewpoint of water balance, the influence of infiltration and subsurface springs is believed to be negligible (approximately 1%, Baranyi, 1979). According to simplified calculations (Major, 1980, pers. communication), groundwater inflow may take place at the western end of the lakes. Its magnitude is 1000 m^3/d, which means that even if the concentration is unrealistically high, the load still remains negligible. It is stressed, however, that a more precise answer would need regular observations.

Finally, the assumption about the time pattern of loading types discussed here should be mentioned. To express the influence of the hydrologic regime, it is supposed that the loads from urban runoff and direct diffuse sources have a similar temporal variation on a monthly basis compared to the load of the Zala River (this similarity is assumed also for the range of the yearly average estimate around the mean value). The atmospheric pollution is considered constant through the year.

3.2 The New Phosphorus Loading Figure

The new estimate for phosphorus is summarized in Table 11, the structure of which follows that of Table 8, except that the

Table 11. The New Phosphorus Loading Figure for Lake Balaton

	TP kg/d	PO4-P kg/d	Available P kg/d	Temporal Changes
Tributaries	473.0	208.0	261.0	f(t), see Table 2.6
Zala watershed	225.1	103.7	128.0	
Southern watershed	152.9	49.8	70.4	
Northern watershed	95.0	54.5	62.6	
Basin 1	225.1	103.7	128.0	
" 2	169.5	83.3	100.5	
" 3	67.9	17.5	27.9	
" 4	10.5	3.1	4.6	
Direct sewage	105.0	-	105.0	Table 9
Basin 1	2.5		2.5	
" 2	6.0		6.0	
" 3	9.0		9.0	
" 4	87.5		87.5	
Mixed sewage	26.1	-	26.1	Table 10
Basin 1	-		-	
" 2	-		-	
" 3	26.1		26.1	
" 4	-		-	
Urban runoff	160.5	18.5	46.9	f(t)
Atmospheric pollution	171.1	68.4	88.9	constant
Direct non-point sources (ii)	79.0	10.5	24.2	f(t)
Total	1014.7		552.1	
Basin 1	262.0		143.0	from Tables 2b, 9 and 10
" 2	273.0		144.6	
" 3	226.7		111.9	
" 4	253.0		152.6	

corrected tributary, direct sewage, and mixed sewage loads are also given separately for the four basins. The same can be easily performed for the direct non-point sources and the atmospheric pollution from Tables 6 and 7.

As shown, the loading estimate remains very close to the original. The corrections for the temporal changes are, however, more substantive, the last column referring to the corresponding tables in this respect.

According to the final estimate, the contribution of sewage (direct, indirect, and mixed) to the load reaching the lake is 32%, that of the atmospheric pollution is 17%, and 24% is derived from direct diffuse sources (urban and rural), while the rest, 27%, is associated with indirect non-point sources (fertilizer loss, liquid manure; Section 3.2). The contribution of the sewage load of the recreational area to the total available load is approximately 35%. Accordingly, the management of sewage associated nutrients may have an effective influence on the lake's water quality (see Kovács et al., 1980).

Since the major portion of the load is influenced by hydrologic conditions, stochastic effects will influence the actual yearly load. It is estimated that this range, which also involves the role of different kinds of uncertainties, is not larger than ± 25%.

3.3 Phosphorus Load from Source Evaluation

This approach was used in the frame of van Straten et al.'s analysis (1979). The goal is to follow the phosphorus cycle as it is linked with the various activities and processes in the region. In this manner, two approximations can be derived for the same load type, one from the aspect of monitored characteristics as was done generally in this report, and the second from the view of watershed activities. The two estimates can then be contrasted, which in some cases allows for the refinement of the calculation as demonstrated for the sewage load in the previous section. However, the second method generally gives ranges which are too broad and cannot actually be utilized quantitatively. For this reason, this approach is not discussed in detail and the original estimate of van Straten et al. (1979) is adapted and provided in Table 12.

Table 12. Phosphorus Load Estimate from Source Evaluation (after van Straten et al, 1979)

	TP kg/d	Fraction available	Available-P kg/d
Fertilizer losses, erosion, run-off	250-800	0.2	50-160
Liquid manure	50-200	1.0	50-200
Industry	30-50	1.0	30-50
Direct sewage	150-200	1.0	150-200
Indirect sewage	80-160	0.9	70-140
Precipitation	140-190	0.6	80-110
Total	700-1600		430-860

The table provides a reasonable range compared to the estimate of the previous section. Some comments on the individual sources are as follows. Many uncertainties and contradictions exist in relation to fertilizer loss and erosion. For example, a recent report of the planning bureau VIZITERV estimated the load associated with the natural phosphorus content of the eroded soil to be 1000 kg/d ; however this fraction is virtually unavailable. The available load from fertilizer loss was approximated at 30-150 kg/d. Here the basic questions are: which portion of the eroded soil and leached fertilizer will reach the waterbody and which fraction is available? The uncertainty is further increased by the fact that a small change in the fertilizer loss may cause a large variation in the load of the lake.

The amount of liquid manure basically depends on the technology applied on animal farms. According to a recent estimate (Máté, pers. communication), its minimum value is around 100 kg/d, while the upper limit may be 300 kg/d. The sum of the estimated fertilizer loss and the liquid manure gives a value close to the indirect non-point source load estimated previously. The direct sewage is slightly higher (see the previous section) than the value given in the table, and the same is valid for the indirect sewage.

4. OUTLOOK TO MODELING AND MONITORING

4.1 Modeling

In this section, diffuse sources will be discussed because for point sources, a solid data base rather than modeling activity is necessary. Similarly, in Haith's classification (1980) descriptive and management models can be distinguished. In the first case, the determination of the load reaching the lake under given conditions is of interest. This can be done either by following each step of the transport of chemicals in the watershed or in a more simplified way by using, e.g., regression equations, if a sufficient amount of data are available for the mouth section of rivers. In the second case, the objective is to study the transport under changed conditions or more generally, to determine those changes in watershed activities which will result in an economically optimal loading reduction. The latter formulation leads to an optimization problem. This will not be reviewed here.

Three model types are reviewed:

1^{o} Chemical Transport Models

Water cycling and transport of eroded soil are traced in the watershed together with the associated dissolved and particulate nutrient forms. The models may differ according to their structure (whether they serve descriptive and/or planning purposes), number of parameters, how hydrologic effects are included, data utilization, etc. For a summary see Haith (1980) and Shvytov (1980), for the application of a simple model for the Tetves sub-watershed (Figure 1) for this problem, see Bogárdi and Duckstein (1978).

Some of these models (e.g., CREAMS, Knisel 1980; Morgan, 1980) tend to describe the subprocesses in extensive detail in an attempt to achieve a general applicability. This leads to an immense increase in the number of parameters and a heterogeneous model structure from the mathematical point of view. This in turn generally excludes a priori the performance of several useful steps in the course of model development such as identification, sensitivity analysis, etc. In practice then, the situation is like that pointed out by Haith (1980)--that calibration and validation cannot be avoided, in contradiction to the original aim. These latter steps are, however, rendered more difficult because of the high data need which is available at best in a field, not a watershed level.

Some of the models have a more simplified structure, e.g., based on the Wischmeier equations for calculating the volume of runoff and the amount of eroded soil (Bogárdi and Bolla, 1980). With these two factors, the dissolved and particulate nutrient loads can be calculated if the concentrations are known: parameters which have to be calibrated on the basis of in situ measurements. The difficulty of transition from the field level to the regional still exists.

Referring to the Zala watershed (~2500 km^2) for which detailed observations are available for two stations covering 60 and 100% of the total catchment area, respectively, it is hard to imagine at present how to overcome this difficulty. In principle, 50-300 more or less uniform sub-regions should have been distinguished for which the information required is not available and the way to link them is not properly known. There are also doubts whether this modeling strategy is appropriate or not, since the basic parameters (the dissolved and particulate P concentrations) have to be found for all the fields on the basis of measurements which do not exist. From the observations for the two cross sections, only a limited number of parameters can be estimated, suggesting the use of some lumped model.

A further difficulty is caused by the fact that the dominant role of rainfall-runoff events in the load cannot be justified, especially not for the available fractions. Thus, the first step would be to separate the influence of diffuse and point sources, which together with the modeling of non-point source loads would need detailed measurements of the lake's total watershed and its rivers.

2° Regression Models

When using this classical approach, a relationship between the load and streamflow is generally sought (see Section 2.3a, Dolan et al.,1981; Verhoff et al. 1980), which in some cases can then be extended by involving the simplest watershed parameters (such as area, Verhoff et al., 1980; and/or slope). The applicability of this technique depends very much on the character of the watershed considered. Generally, it can be satisfactorily employed for nitrogen while the experiences for phosphorus are less promising, especially for the available fractions. In most of the cases, so many factors influence the behavior of the nutrient load that the appropriate operation of a regression equation cannot be expected. For example, when analyzing the Zala data, it turned out that the total period consists of many smaller intervals for which the sewage discharge, snow melting, rainfall-runoff-erosion or drainage from other water systems (see Appendix 5 and Figure 11) occur virtually alone. Thus, for each of these periods, different load versus streamflow relationships may exist often with unsatisfactory accuracy, since the conventional regression equations do not take into account the dynamic properties of the system.

3° Time Series Analysis

The dynamics of the system can be incorporated into the model with the help of a time series analysis. The distinction among periods of different character cannot necessarily be avoided. The other problem still exists--how to connect the parameters of the time series equation(s) to the watershed characteristics, that is, how to use the model for management purposes.

Naturally, the type of analysis of 2° and 3° depends basically on the time scale necessitated. For example, the regression analysis for the River Zala on a daily basis did not work well. Nevertheless, it was quite satisfactory when monthly averages were used (Appendix I), the time period being in harmony with the objective of the present study.

To summarize, it is stressed that the type of model primarily depends on the features of the particular watershed and its pollution conditions; no general modeling method exists at the moment. Consequently, in the model development, the knowledge from measurements must play a decisive role. At present, a limited activity with the aim of establishing aggregated models is suggested.

4.2 Monitoring

There is no intention of providing an overview here. Rather, the present problem will be discussed in the light of the two previous chapters. The measurements can be taken according to the two different approaches mentioned previously for estimating the load:

- to monitor the load which enters the lake,
- to follow the nutrient cycle in the watershed.

The two methods are complementary in character and correspond to the descriptive and planning model types.

Related to the first issue, the development of the proper sampling strategy is of major importance. It is obvious, for example, that more frequent sewage measurements would be needed for the summer season. From the analysis of the Zala River data (Appendix I), it appeared that the weekly PO_4-P observations afford hardly any more information than the monthly. Thus, a drastic increase in the sampling frequency would be necessary (or if it cannot be realized, a reduction is proposed). A compromise solution would also prove satisfactory, e.g., lower the frequency of the TP measurements but involve periods (high flow conditions) when the most important fraction, the orthophosphate P, is also monitored with appropriate frequency.

In order to cover the tributary load of the whole watershed, similar regular observations would be required for some of the smaller water courses. These can be selected on the basis of watershed parameters (Table 1) and the characteristics of nutrient sources (Figures 2 and 3).

Further, more emphasis should be given to monitoring the direct vicinity of the lake (urban and rural areas involving, for instance, vineyards along the northern shore of the lake) and unidentified sources such as groundwater infiltration, septic tanks, and animal farms. The latter two belong partly to the second category of measurements indicated at the beginning of this section. In this group, only the importance of experiments related to fertilizer loss and the resulting availability of nutrients is stressed.

5. SUMMARY AND CONCLUSIONS

1^{o} On the basis of data for 19 tributaries (Tables 1 and 2), 27 sewage discharges (Tables 3 and 4), atmospheric pollution, event based observations for urban runoff, and estimates for diffuse sources in the direct vicinity of the lake, a loading figure was given in Chapter 2 for TP, PO4-P, TN and NO3-N. According to the balance, approximately 1000 kg/d TP and 8000 kg/d TN reach the water body (Table 8), i.e., their ratio is 1:8.

2^{o} The estimate serves for studying both the in-lake processes and problems of water quality management. Accordingly, data were given for the various sewage discharges and tributaries separately, and also in aggregated form for different regions, sub-watersheds, and lake segments. The volume related load is more than ten times higher at the western end of the lake compared to the eastern end, thus explaining the corresponding pronounced water quality gradient and the presence of different trophic levels in the lake.

3° In Chapter 3, the credibility of the phosphorus load estimate was analyzed. An order of magnitude analysis was performed separately for the tributary and sewage loads, as well as for the total estimate. For these purposes, the following steps and information were used: the intercomparison of the characteristics of sub-watersheds, event based measurements and the subsequent extrapolation of the Zala River data for tributary load; population, sewage and water use data and their dynamics for sewage, and finally, a source evaluation from the viewpoint of phosphorus cycling on the watershed. The results justified the credibility of the loading figure.

4° The original estimate was corrected in several respects. To involve the influence of floods which are often unobserved in the smaller tributaries, an uncertainty analysis was performed on the Zala River data. In harmony with the results, an increase of 20% was applied to all the water course loads. The sewage load was found accurate for the winter season, but a correction was made for the summer season (assumed to be five months long). At that time, the load is approximately doubled. A further peak was given for July and August--the ratio is 1:2:3 for the three intervals (Table 10). The operation of fishponds influencing the load on the southern part of the lake was involved (Table 11). Slight modifications were also done on other loading types. The final figure (Table 12) agrees well with the original estimate and it too includes the temporal changes on a monthly basis. Approximately 50% of the TP load is available for algae in the lake. The yearly average load may vary in a ± 25% range due to stochastic effects and uncertainties.

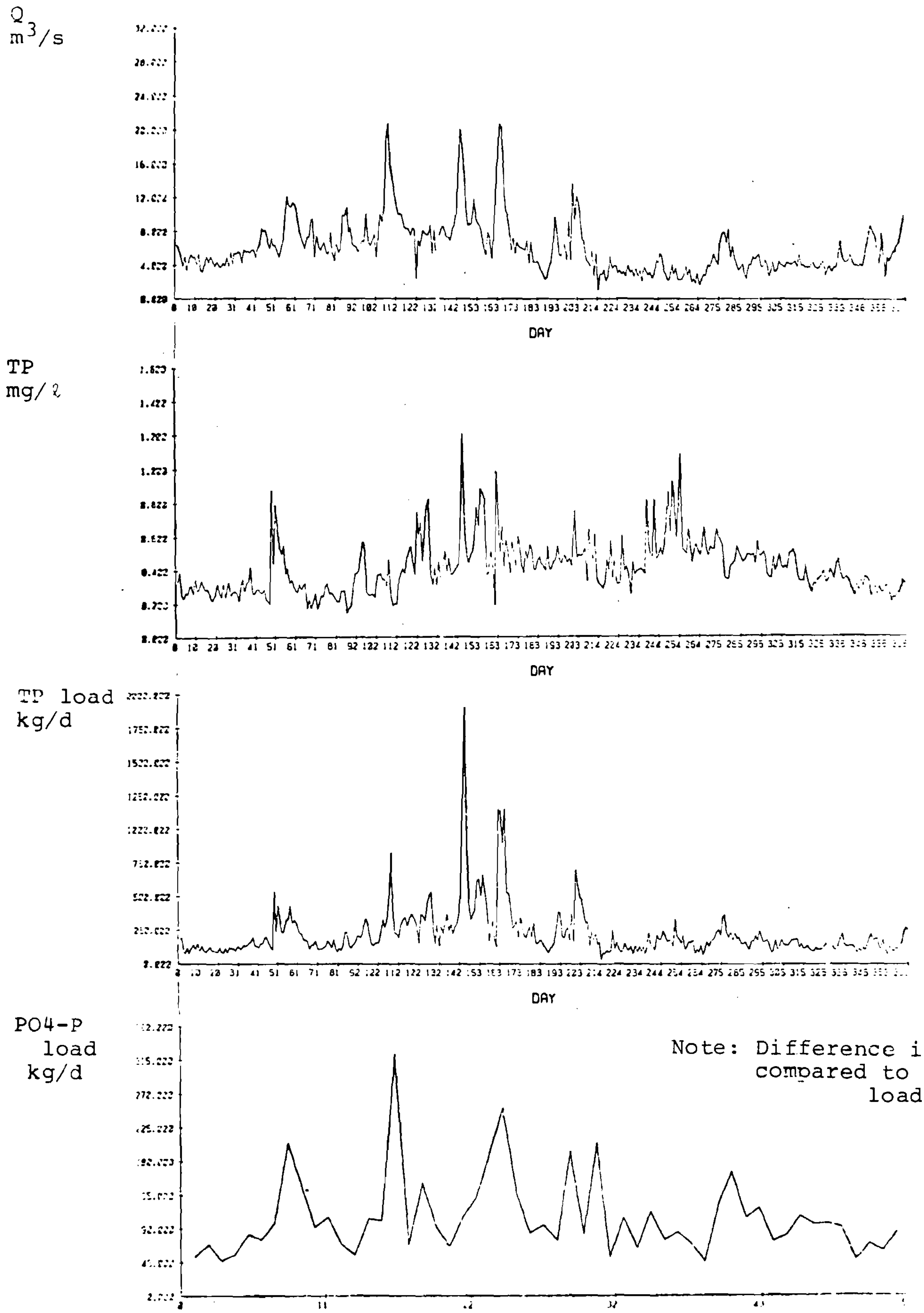
5° The contribution of sewage to the load reaching the lake is 32% (two-thirds of which stems from the recreational area), 17% is from atmospheric pollution, and 24% is derived from direct diffuse sources (urban and rural), while 27% is associated with indirect non-point sources. The sewage load of the recreational area represents 36% of the total available load and accordingly, its management would have an effective influence on the lake's water quality.

6° In Chapter 4, the problem of modeling and monitoring was discussed in the light of the present problem. The importance of measurements was stressed as a basis for nutrient modeling both for descriptive and management purposes. Suggestions were made concerning the monitoring strategy and other experiments.

APPENDIX I: ANALYSIS OF THE ZALA RIVER DATA

A study was performed by Somlyódy and Eloranta (1981), the objective of which was to test how a detailed lake model (see van Straten and Somlyódy, 1980, in connection to the three model versions under development) should or could be used in a simplified way in a management framework. The section relating to nutrient loading analysis on the River Zala is summarized here.

To provide an impression of the behavior of the river and the data availability, the records for 1978 (Joó, 1980) are given in Figure 11. As can be observed, there is only one event in the year when a flood induces a pronounced increase in the TP concentration. However, there are two periods (around days 50-60 and 235-265, respectively) when the presence of other mechanisms is suspected (such as snow melting and drainage from marshland, respectively). The similarity is higher between Q and TP loads, since the latter involves the streamflow as well. The dynamics of the PO4-P load are partly lost because of the infrequent measurements, although to some extent, it follows the pattern of Q. However, the absence of a peak around the day Nr. 142 is especially apparent. A further impression can be gained about the behavior of orthophosphate-P from Figure 12, which illustrates the (PO4-P)/TP ratio (1978, two stations) as a function of the streamflow rate. Although the points are scattered, they



Note: Difference in scale compared to the TP load

Figure 11. Records for the Zala River, 1978, Fenékpuszta involving streamflow, TP concentration, TP load (all daily) and PO4-P load (weekly)
Data source: O. Joó

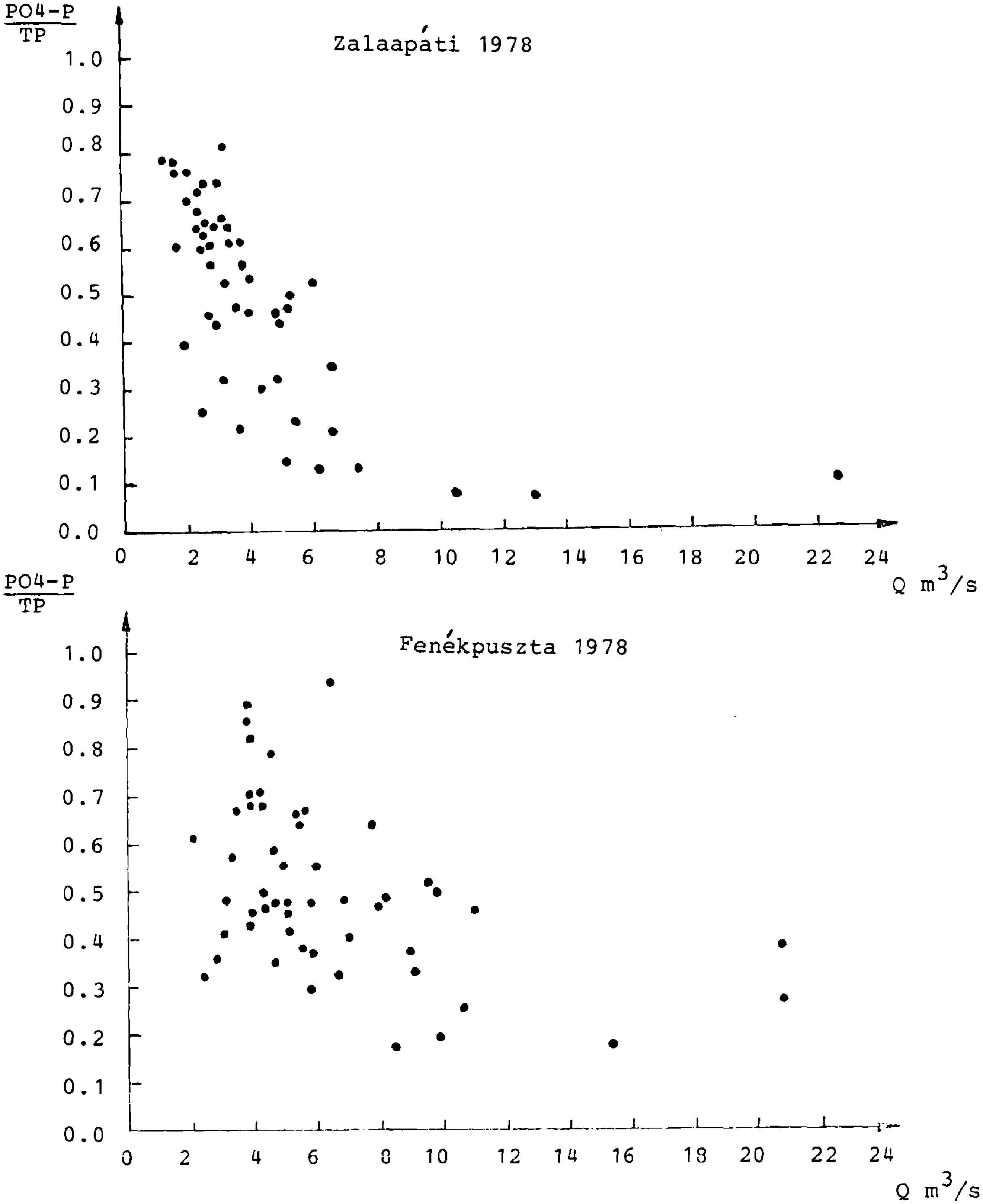


Figure 12. The ratio of TP and PO4-P as a function of the streamflow rate for two sections of the River Zala

clearly show a declining tendency with increasing Q. This fact can be explained in the light of Figure 2: at low flow conditions, the contribution of sewage discharge is dominant, but the increase in the discharge does not cause such an increment in the PO4-P concentration as in TP (that is, the influence of rainfall-runoff processes on PO4-P is smaller, see Section 2.3.b).

In this chapter two different analyses will be performed using the regular phosphorus and discharge observations of the Zala River. The first analysis is related to the uncertainty caused by data scarcity, that is, the role of unobserved flood events, while the second concerns the stochastic influence of the hydrologic regime.

1° Uncertainty caused by Data Scarcity

Consider first the daily streamflow and TP measurements from which the monthly or yearly average load can be calculated with satisfactory accuracy and called an "exact" value. Next, one can assume that from this data set only infrequent data with some regularities are known (n measurements for m periods of length ΔT for a total period of $T = k\Delta t$, $k = 1,2,3...$, e.g., biweekly data for a year: $n = 2$, $m = 12$, $\Delta T = 1$ month). The loading for the averaging period i.e. a year, $\bar{L}_1$, can then be computed as, for example, the arithmetical mean of all the c_jQ_j products. The sampling on the original data basis may take place randomly in a Monte Carlo fashion ($1 \leq i \leq N$, when N is a sufficiently large number), thus resulting in the loads $\bar{L}_i$. Next, the statistical analysis of the data series $\bar{L}_i$ can be performed. Such an analysis will indicate how reliable the load estimate is if it is derived not from 365 but 12 or 24 observations only, which a priori exclude some of the essential mechanisms contributing to the load (floods, sudden releases, etc.).

The idea is similar to Dolan et al. (1981); although the objectives differ in their study, the most accurate method for calculating the yearly average load from scarce data was sought. For some of the methods tested, the missing data were replaced by a concentration versus flow relationship, a procedure which does not operate well here on a daily data basis (see later).

For the yearly averages, 200 runs were performed, randomly selecting two monthly measurements from the data set of 1977. As an average of all the runs, 212.1 kg/d was arrived at, which almost agrees with the exact value of 215.5 kg/d (no bias was in the computation). The minimum and maximum values were 170.9 and 262.6 kg/d respectively, with standard deviation of 28.2 kg/d (the empirical distribution was different from the Gaussian). Accordingly, the maximum error is ± 21%, while the standard error is ± 13% (both parameters may be higher if only one monthly data is sampled).

The possible range of the monthly average loads was also tested. In this case, the measurements of the corresponding four months for 1976-79 were sampled randomly from uniform distribution for both the first and second half of each month. A hundred simulations were performed for all the months. The results, including mean and extreme values, as well as the range of $\bar{L} \pm \sigma$ (where σ is the standard deviation), are summarized in Figure 9. Here the exact values are also given for comparison. As shown, some slight bias exists (which is probably related to the insufficient amount of runs) but still, its influence is negligible. For illustrative purposes, a typical distribution is also given (for February). One can conclude that on average, the calculation of the monthly mean load for the River Zala from a data set of four years has 20% standard errors, if the presence of two monthly data is assumed (the maximum error is ± 39%). This error is larger for months of higher discharge (compare Figure 9 and Table 2b).

Next, a similar analysis was done for the orthophosphate load. An essential difference exists in comparison to the previous case, namely that, at best, four or five data per month are available. Consequently, the load called exact cannot be derived. Therefore, the objective of the analysis could be nothing more than to obtain information on resulting uncertainties, if the load is calculated from even less frequent observations--the case for the other tributaries. Because of the scarcity of the measurements, 3 data per 90 days were randomly selected, which corresponds to the assumption of twelve yearly observations. The domain gained from the Monte Carlo simulation is obviously narrower than before. All the values were found in the mean ± 10 kg/d range, while the standard error was less than 10%. This feature suggests a change in the strategy of the water quality sampling: from 52 yearly measurements hardly any more useful information can be collected than from 12. Thus, an increase (or if it is not realistic from other aspects, a decrease) in frequency is proposed. Another possibility is to reduce the regular sampling, but involve daily measurements for the critical periods (high flow conditions).

The same procedure was also performed for the monthly loads. The number of runs was limited to 50 to avoid the inclusion of the same combination several times, due to the limited amount of data (another possibility would be to derive all the combinations). This fact slightly increased the bias in the results.

The standard error for this situation was on average ± 16%, while the maximum error was ± 23%, both again being smaller than the error for total phosphorus. It is felt that the error for PO4-P would be smaller even if as detailed information were available as for TP (daily measurements). As an upper limit, the error characteristics of TP can be accepted.

Since a lack of flood observations causes a systematical error in the determination of the load, an increase of the estimated value based on scarce data is realistic in possession of the above ranges (Section 3.1).

2^o Influence of the Hydrologic Regime on the Load

Several regression analyses were performed with the aim of obtaining a relationship between TP load and the streamflow rate (not necessarily in a conventional way, but involving dynamic properties if needed). Different averaging periods were considered and a satisfactory relation of approximately 85% correlation was found on the monthly basis, which is also acceptable from the standpoint of lake water quality modeling (see before). The relationship is expressed as follows:

$$L_{TP} = 71.1 + 11.4\ Q^{1.3} \quad [\mathrm{kg/d}], \qquad (5)$$

where Q is in m^3/s. With this equation, it is possible to derive an estimate related to the stochasticity derived from the changes in hydrologic conditions. The procedure is as follows.

The monthly average discharges for the period 1969-78 given in Table 2 and the probability distributions of Q for the upstream station Zalaapáti (Figure 1) published by Baranyi (1979), were considered first. Then the latter were normalized by the monthly mean Q values for each month and a single log-normal distribution fitted. For the sake of the present loading study, it was assumed that this distribution remains the same for the mouth section and confidence values of 90% were established. Finally, the lower and upper bounds were derived from Equation (5).

The results are presented in Figure 10 where the mean, minimum, and maximum values of the observation period 1976-79 are also given. It can be seen that the lower limit agrees quite well with the minimum loads, but the upper one is essentially higher than the observed maximum. It should be mentioned, however, that events of lower probability may result in extraordinarily high loads. For instance, in July 1975, an extreme flood was observed: in this month, the total P load exceeded 700 kg/d, a value nearly four times larger than the means of 1976-79.

In closing, a final important point is stressed. All these stochastic changes influence the monthly average values to a much greater extent than the yearly average loads, since the fluctuation in the yearly average streamflow is substantively smaller than that of the monthly. During the period 1969-78, Q varied between 5.1 and 9.1 m^3/s, having a mean of 7.4 m^3/s. Equation (5) is nearly linear in Q and can be replaced satisfactorily by the relation

$$L_{TP} = 50 + 27.5\ Q \quad , \qquad (6)$$

which means that the stochasticity is reflected in L_{TP} as it is in the streamflow rate. From Equation (6), the corresponding mean of the yearly average load is 253.3 kg/d, which is in good agreement with Table 2 (four year long observation period) its range is ± 25%.

The results of these two analyses discussed in this Appendix are used in Section 3.1a to correct the phosphorus load estimate of the Zala River. This is followed by an extrapolative modification for all the other tributaries of the lake.

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