5. EXISTING AND PLANNED MEASURES FOR THE LAKE BALATON ENVIRONMENTAL IMPROVEMENT

The government resolution 1068/1996, the present valid version of so-called the action program, integrates previous efforts for environmental improvement of Lake Balaton, and covers almost all fields related to this purpose. Therefore, existing and planned measures for Lake Balaton environmental improvement can be understood by reviewing the Action Program.

The Program consists of following items:

Items		Descriptions
1		Reduction of Internal and External Pollution Loads
	1.1	Development of sewerage system in tourist resort areas
	1.2	Development of sewerage system in the whole catchment area
	1.3	Kis-Balaton Phase II project
	1.4	Dredging
	1.5	Control of pollution loads from non-point sources
	1.6	Control of pollution loads agricultural activities
	1.7	Control of fishing activities
2		Shore protection
3		Balaton regional development plan
4		Solid waste management
5		Prioritization of proposed components
6		Financial institutional study
7		Establishment of the basis for evaluation and future revision
8		Middle term investment plan
9		Balaton National Park Foundation
10		Progress report
11		Funds for research activities
12		Involvement of local governments

5.1 INTERNAL AND EXTERNAL POLLUTION LOADS REDUCTION

(1) Sewerage System Development

The first sewerage systems in the catchment area of Lake Balaton were installed in Badacsony and Keszthely in the 1960's. Sewerage systems of the catchment area of Lake Balaton are classified into two (2) zones, lakeside sewerage system zone and other sewerage system zone. The lakeside sewerage system zone consists of seven (7) sewerage system regions as shown in *Figure 2.15*. Almost all lakeside resort areas except Balatonakali have already been covered by sewerage systems.

Wastewater treated in the region I, II, VI and VII is to be discharged to outside of the catchment area. Wastewater treated in the region IV is to be discharged to the Lower Kis-Balaton.

At present, 42 sewage treatment plants are in operation. Main features of the existing sewerage systems in the study area are summarized as below.

Zone	Present Capacity of Wastewater Treatment Plants (m^3/day)		
	Secondary Tr.	Secondary Tr.+ P removal	Total
Lakeside	52,100	34,500	86,600
Other Area	5,000	26,400	31,400
Total	57,100	60,900	118,000

A development plan of sewerage system up to 2010 in the Study Area has been prepared by KHVM. According to the plan, future sewerage systems are summarized as below.

Zone	Future Capacity of Wastewater Treatment Plants (m^3/day)		
	Secondary Tr.	Secondary Tr.+ P removal	Total
Lakeside	81,000	72,200	153,200
Other Area	-	46,500	46,500
Total	81,000	118,700	199,700

Total capacity of treatment plant is planned to be approximately 200.000 m^3/day in the year 2010, which means a total capacity will increase by 70%. Main sewage treatment plants are planned to be 31 plants. All treatment plants except region I, II, VI and VII are planned to have a phosphorus removal process.

(2) Kis-Balaton

Before the construction of the Siófok channel-gate in 1863, Kis-Balaton as well as the Lower Zala River Valley formed a lake just as the existing Keszthely Bay, and the water level fluctuated depending on the out-flow of the Zala River. Because of the remarkable degradation of the water quality of Lake Balaton, the utilization of the filtering function of Kis-Balaton was considered as a countermeasure with the aim of water quality improvement in the middle of 1960's. When ''Water Management and Development Program of Lake Balaton'' was instituted in 1971; the water management measures for the whole catchment area of Lake Balaton were indicated in its opening statement.

The Council of Ministers gave an agreement to the program for the water quality improvement system including the restoration of Lake Balaton in 1976. In mid-1970's, the national government started to consolidate the plan to realize the above-mentioned water quality improvement system. The through-flow system (proposed by NYUDU VIZIG) was adopted, which consists of two reservoirs and consequently has 120 days of retention time.

Outline of the Kis-Balaton is as follows.

a. Upper Reservoir (Lake Hídvégi)

Surface Area :	18km^2,
Max. Water Depth :	1.1m (average)
Operational High Water Level :	106.5m B.f.

b. Lower Reservoir (Lake Fenéki)

Surface Area :	more than 50km^2
Max. Water Depth:	1.1m (average)
Operational High Water Level :	105.7m B.f.

Upper Reservoir (Lake Hídvégi) started to operate in June 1985. Lower Reservoir (Lake Fenéki) is still under construction.

Recently, two engineering proposals were made to revise the original plan. The one is by the study of EU/PHARE and the other is the Revision Plan by Hungarian experts team.

The former one is related to the countermeasures against the problems of probability of the overtopping/breaking of both main and internal embankments and the breakdown of the water control structures.

The latter one has mainly proposed the following modifications.

- Ingói copse is managed in an independent way. It does not participate either in phosphorous retention or in flood protection functions for the reason of nature conservation.

- Sávoly and Vörs areas are not divided. Their primary function is phosphorus retention.

- Loading target prescribed for Lake Balaton cannot be realized by construction of the Lower Reservoir as a single measure. In order to meet the target conditions, external load must be reduced by an introduction of an effluent standard of 0.5mg(T-P)/l at the sewage treatment plant such as Zalaegerszeg or Keszthely, and 50 % of load reduction of non-point agricultural source.

(3) Dredging

In 1992, EU/PHARE granted a dredger to make it possible to remove the upper sediment layer without disturbing the consolidated harmless strata. The dredger (known as the "MASTER") launched in Siófok in 1992, which has a length of 30.6 m, a breadth of 6.34 m, a draft of 1.2 m on average and a maximum dredging depth of 5.5 m. It is operated by the Lake Balaton Local Branch Office of KDT VIZIG.

The areas already dredged were 54.4 ha (year 1992), 31.5 ha (1993), 10 ha (1994), 157.8 ha (1995), 182 ha (1996). The dredged area in 1997 are estimated to be 178 ha and about 180 ha a year in the near future. A total dredging area, as shown in *Figure 2.16*, is planned to be 2400 ha and the dredging layer is 0.2 m thick on average. Planned total dredging volume of the bottom sediment is 4,800,000 m^3. The dredging area has been planned on the basis of the map which shows highly polluted area with phosphorus. However, the dredging area ,especially its center area is to be reconsidered.

Thirteen disposal sites of the dredged bottom sediment are also shown in *Figure2.16*. The greater parts of the disposal sites are on the land of low productivity including wetlands and marshy areas. The dredged sediment is discharged into the disposal ponds that is mainly surrounded by man-made embankments.

(4) Runoff Control Facilities

Presently, there are 17 runoff control facilities installed in the catchment area. Fifteen (15) facilities are installed in canals or rivers, and the others are installed in the agricultural areas of Zánka and Balatonfenyves. Functions of the facilities are classified into the following six (6) categories.

- Sedimentation
- Screen
- Filtration by gravel
- Filtration / adsorption by grass (reed, cattail, etc.)
- Infiltration
- Oil separator

Outlines of the facilities in canal/river in the catchment area are shown in *Table2.16*. In general, these facilities have not been well maintained.

(5) Agricultural Pollution Loads Management

1) Management of livestock wastewater

Livestock breeding is strictly controlled in the Balaton catchment area from the view point of environmental protection. New animal farms are not allowed and measures against environmental pollution are enforced on the existing farms. These restrictions for environmental protection sharply reduced the number of livestock and stock breeders.

Small-scale stock breeders seem to have no treatment facilities for their wastewater. However dung is utilized for materials of compost and soil improvement and livestock wastewater does not seem to discharge into Lake Balaton.

2) Study on melioration and afforestation

Ministry of Agriculture (FM, currently FVM) commissioned a complex study of melioration and afforestation in the catchment area of Lake Balaton to Agrober Rt. The study has been completed in 1995.

3) Soil conservation monitoring system

Agrochemical Research Institute of Hungarian Academy of Science (MTA TAKI) has collected various soil data for the purpose of soil conservation.

4) Feasibility study on melioration and afforestation

FM (currently FVM) selected three areas for the feasibility study on melioration and afforestation for reducing pollution loads discharged to the lake. The feasibility study was planned to be conducted in this year, however, due to financial difficulty it has not been realized.

(6) Fishing Activity Management

A private fishing is only done by anglers with license. Commercial fishing is also controlled by FVM through the Balaton Fishing Incorporation.

5.2 SHORE PROTECTION AND REGULATION

(1) Conservation of Reed Belt

The national government (KDT VIZIG) have had a research activity in 1994-1996, in corporation with an university relating to the planting reeds on Lake Balaton. The contents of the research are composed of two parts. The first part is the confirmation of the existing situation about reed bushes in Lake Balaton. This research made it clear that reed bushes have been remarkably reduced. An acreage of the existing reed bushes was summed up about 87 ha by the research during 1984-1993. Another part is the experimental research related to the possibility of replanting reeds. The experiences and the results through the research show that a success of reed-planting basically depends on the effectiveness of protection against waves and icing.

(2) Shore Protection Structures

Shore protection structures were built primarily on the southern shore in order to prevent erosion , to protect the settlements and to assure the use of shores. Present situation of the shore protection works are given in *Table 2.17*.

Recently, the total length of shores where the shore regulation was completed and/or the rip-rap was implemented has come to 107.5 km (equivalent to 44 % of the whole shore length of Lake Balaton).

5.3 PREPARATION OF NEW REGIONAL DEVELOPMENT PLAN

From the second version of Balaton regional development plan (BRRT) approved in 1979, the BRRT has employed measures restricting and controlling land use and construction activities in the Balaton recreational area. Present BRRT (the third version BRRT), which was submitted to the government in 1985, reviews development of the Balaton recreational area over the past 30 years, and forms the framework of the regional plan giving high priority to lake water quality improvement.

The new BRRT (the fourth version) is now under preparation. Recently the VÁTI, the City Planning Institute of the Hungarian Society of Regional Development and Urbanization, has submitted a draft of the new BRRT to the Ministerial Council.

5.4 SOLID WASTE MANAGEMENT

So far in the Study Area a development of solid waste management systems have not significantly advanced.

5.5 OTHERS

Items from 5 to 12 cover non-structural measures which are necessary for and facilitate the implementation of above measures and provide a basis of further steps. While there have been considerable progress in structural measures in items 1 ~ 4, there is not a significant progress in the nonstructural measures.

Table 2.1 Tributaries and Sub-catchments

Recipient Basin	Name of River	Catchment Area (km^2)	Inflow (million m^3/yr)
I. Keszthely	Zala	2,637	460.4
	Esztergalyi-patak	23	2.5
	Direct catchment	38	10.5
	Sub-total	***2,698***	***473.3***
II. Szigliget	Tapolca-patak	45	13.0
	Kétöles-patak	40	0.8
	Nemesvitai-övárok	7	4.3
	Egervíz	361	11.2
	Nyugati-övcsatorna	241	80.2
	Keleti-Bozót-árok	309	42.1
	Direct catchment	776	215.5
	Sub-total	***1,779***	***367.0***
III. Szemes	Burnót-patak	83	7.6
	Örvényesi-Séd	26	4.4
	Tetves-patak	101	10.7
	Nagymetszés-patak	106	7.9
	Jamai-patak	50	3.0
	Kôröshegyi-Séd	34	3.7
	Direct catchment	163	60.9
	Sub-total	***620***	***98.3***
IV. Siófok	Arácsi-Séd	15	0.9
	Kéki-Séd	9	2.3
	Füzfôi-Séd	10	1.0
	Direct catchment	58	16.3
	Sub-total	***92***	***20.5***
Total		**5,188**	**959.1**

Source: Adapted from KDT-KÖFE Annual Report in 1996

Table 2.2 Number of Intense Rainfall Days

Station	Number of Days		Daily Rainfall (mm/d)	
	5 ~10 mm/d	≧10 mm/d	Maximum	Second largest
1995				
Zalaegerszeg	26	36	65.0	63.0
Veszprém	28	29	45.0	44.0
Siófok	20	32	66.9	61.0
Keszthely	16	32	78.1	49.5
1996				
Zalaegerszeg	NA	NA	NA	NA
Veszprém	26	29	78.0	77.1
Siófok	25	29	61.0	59.0
Keszthely	37	21	78.1	62.0

NA : Not applicable due to lacking data for several period

(Source : Adapted from OMSZ Data in 1995 and 1996)

Table 2.3 Peak Surface Run-off Coefficient

Name of River	Catchment Area (km^2)	Date (Y.M.D)	Maximum rainfall intensity (mm/hr)	Peak surface run-off coefficient	
				Urban	Total
Örvényesi séd	Total : 26	1995.6. 7	43.0	0.29	0.0001
	Urban : 0.54	1996.8.14	8.3	0.21	0.0040
		1996.9.23	5.5	0.22	0.0070
Tetves patak	Total : 101	1995.5.27	9.0	0.04	0.0010
	Urban : 2.4	1996.9.24	8.3	0.17	0.0030

(Source : Adapted from KDT-VIZIG Data)

Table 2.4 Major Economic Indices

	1990	1991	1992	1993	1994	1995	1996	Average 1991-96
Demand and output(% change to the previous year)								
Gross Domestic Product			-3.1	-0.6	2.9	1.5	0.8*	0.2
GDP price deflator			21.5	21.3	19.5	25.6	20.9*	21.6
			9.9	12.1	10.8	10.3	10*	10.6
Current account (Mil. US$)	127	267	324	-3,455	-3,911	-2,480	-1,677	
Exports	6,346	9,258	10,028	8,094	7,163	12,810	14,183	
Imports	5,998	9,069	10,076	11,340	11,248	15,252	16,828	
Trade balance	348	189	-48	-3,247	-3,635	-2,442	-2,645	
Excnage rate								
HUF/US$, end-period	61.4	75.6	84.0	100.7	110.7	135.9	160.7	
Nominaleffective rate(1990=100)	100.0	86.9	78.4	73.0	62.8	47.9	41.0	
Yen/$, end-period	134.4	125.2	124.8	111.9	99.7	103.4	106.0	
Interest rate (%)								
Lending rate	28.8	35.2	33.1	25.4	27.4	32.6	n.a.	
Deposit rate	24.7	30.4	24.4	15.7	20.3	26.1	n.a.	
% LIBOR	8.4	6.1	3.9	3.4	5.1	6.1	n.a.	

* estimated

Table 2.5 Short-term Economic Projections

Percentage changes (1991 prices)

	1995	1996	1997	1998
Exports of goods and services	13.4	13.0	11.1	11.0
Imports of goods and services	- 0.7	6.5	10.3	10.5
Foreign balance	4.9	2.2	0.1	- 0.1
GDP at constant prices	1.5	0.8	2.4	3.5
GDP price deflator	25.6	20.9	17.2	14.9
Unemployment rate	10.3	10.0	9.1	8.8
Short-term interest rate	31.3	23.8	19.5	18.5
Long-term Interest rate	31.3	23.8	19.5	18.5
General government budget balance, per cent of GDP	- 6.7	- 3.1	- 5.2	- 5.0

*Changes expressed as a percentage of GDP in the previous period.

(Source: OECD ECONOMIC SURVEYS - HUNGARY - 1997)

Table 2.6 Volume Indices of GDP and Its Sectoral Shares

Year	GDP	agriculture, hunting,fore-stry, fishing	mining,man-ufacturing, electricity	construction	trade,repair,hotels,resta-urants	transport,st-orage,comm-unication	other services
1980	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1985	109.1	116.4	112.2	93.4	107.6	108.1	119.7
1990	111.8	119.1	103.0	80.6	111.2	116.6	143.5
1991	98.5	109.5	84.7	68.5	102.0	103.3	140.1
1992	95.4	91.4	79.0	69.8	85.6	98.9	144.7
1993	94.8	84.2	81.4	66.0	82.3	93.6	151.4
1994	97.5	83.9	86.3	69.1	79.1	94.9	162.5
1995	99.0	86.4	92.6	67.0	75.4	107.4	151.5

(Source: HUNGARY: STRATEGY PLANS, INITIATIVES AND ACTIONS FOR SUSTAINABLE DEVELOPMENT -1997-)

Table 2.7 In-take Volume of Drinking Water from Lake Balaton

Waterworks			Volume of Taking Lake Water (m^3/month)												Total
No.	Name	Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	(m^3/year)
1	Balatonakarattya (Balatonkenes	SE	0	0	0	0	9,300	115,615	209,126	225,441	96,385	0	0	0	655,867
2	Balatonfoldvar	SE	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Balatonszeplak nagyfelszini	SE	444,927	411,473	451,438	445,570	569,656	591,667	637,569	606,435	482,897	494,122	441,924	404,616	5,982,294
4	Siofok regi	SE	0	0	0	0	0	0	37,484	75,534	0	0	0	0	113,018
5	Fonyod nagyfelszini	W	312,220	252,090	291,410	303,900	338,240	341,700	392,050	394,960	323,650	304,150	249,280	253,090	3,756,740
6	Fonyod DEVIG	W	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Balatonszarszo (Oszod) DEVIG	SE	0	0	0	0	31,440	151,590	245,340	202,530	31,465	0	0	0	662,365
8	Balatonszepezd felszini	W	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Revfulop felszini	W	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Balatonalmadi felszini	NE	47,014	34,104	33,907	48,467	71,263	116,018	79,433	76,037	13,229	0	29,333	34,150	582,955
11	Balatonalmadi KARY	NE	0	0	0	0	0	19,208	105,055	110,603	103,678	62,381	3,559	0	404,484
12	Balatonfured nagyfelszini	NE	68,819	81,732	83,838	82,594	119,373	136,418	155,027	126,886	73,859	99,508	94,263	88,156	1,210,473
13	Balatonfured KARY	NE	0	0	0	0	0	28,209	64,500	99,397	1,624	0	0	0	193,730
TOTAL			872,980	779,399	860,593	880,531	1,139,272	1,500,425	1,925,584	1,917,823	1,126,787	960,161	818,359	780,012	13,561,926

SE : The Regional Waterworks of South-Eastern Balaton
W : The Regional Waterworks of West Balaton
NE : The Regional Waterworks of North-Eastern Balaton

Source: Report on the works of water management and environmental protection in the catchment area of Lake Balaton in 1996, KDT VIZIG and KDT KOFE

Table 2.8 In-take Volume of Irrigation Water from Lake Balaton

Water Consumer		Volume of Taking Lake Water (m^3/month)												Total
No.	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	(m^3/year)
1	Balatonaliga watering bunc	0	0	0	8,000	22,000	54,000	54,000	54,000	11,000	4,000	0	0	207,000
2	Balatonfo watering bunch	0	0	0	0	0	0	0	0	0	0	0	0	0
	TOTAL	0	0	0	8,000	22,000	54,000	54,000	54,000	11,000	4,000	0	0	207,000

Source: Report on the works of water management and environmental protection in the catchment area of Lake Balaton in 1996, KDT VIZIG and KDT KOFE

Table 2.9 In-take Volume of Industrial Water from Lake Balaton

Water Consumer		Volume of Taking Lake Water (m^3/month)												Total
No.	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	(m^3/year)
1	DRV Siofok	1,652	1,248	1,382	2,115	3,025	7,552	5,138	5,190	2,363	3,020	1,398	1,960	36,043
2	NIKE Balatonfuzfo	524,705	524,705	524,706	622,000	622,000	622,006	536,226	536,226	536,228	505,850	505,850	505,850	6,566,352
3	Balatonfoldvar - Balatonlel	0	0	0	0	0	4,936	9,241	9,441	5,391	2,541	0	0	31,550
	TOTAL	526,357	525,953	526,088	624,115	625,025	634,494	550,605	550,857	543,982	511,411	507,248	507,810	6,633,945

Source: Report on the works of water management and environmental protection in the catchment area of Lake Balaton in 1996, KDT VIZIG and KDT KOFE

Table 2.10 Turnover of Public Accommodation of Balaton Region in 1995

Type of Accommodation	Turnover (million HUF)					
	International		Domestic		Total	
	along shore	*nearby lake*	*along shore*	*nearby lake*	*along shore*	*nearby lake*
Hotel total	2,198	1,266	669	214	2,867	1,480
Boarding-houses	96	20	69	7	165	27
Tourist hostels	12	1	21	1	33	2
Bungalows	454	5	112	3	566	8
Camping sites	587	71	54	3	641	74
Private rooms	387	15	72	5	459	20
Others	1,537	112	328	20	1865	132
Total	3,735	1,378	997	234	4,732	1,612

(Source: Yearbook of Tourism 1995; modified by JICA Study Team)

Table 2.11 Turnover of Public Accommodation by Selected Holiday Region in 1995

(percentage against previous year)

	Turnover (million HUF)		
	International	Domestic	Total
Budapest	21,104 (128.3)	1,141 (128.1)	22,245 (128.3)
Lake Balaton	3,735 (113.4)	997 (121.9)	4,732 (115.1)
Settlements nearby Lake Balaton	1,378 (154.1)	234 (110.0)	1,612 (145.6)
(Whole Region of Lake Balaton)	5,113 (122.1)	1,231 (119.4)	6,344 (121.6)
Danubebend	131 (117.3)	203 (133.1)	334 (126.4)
Lake Velencel	153 (119.5)	79 (146.1)	232 (127.4)
Mátra-Bükk	309 (110.4)	591 (122.6)	900 (118.1)
Sopron-Köszeghegyalja	1,205 (152.0)	497 (129.2)	1,701 (144.5)
Country Total	31,351(127.4)	6,429 (124.0)	37,780 (126.8)

(Source: Yearbook of Tourism 1995)

Table 2.12 Matrix of Relevant Organizations and Their Roles

Sector \ Level	State	County	Municipal	Others
Coordinating	Balaton Program (PMO)	County Development Council		Balaton Development Council
Environmental Protection (lake water)	KDT KÖFE, 2 NCDs, 3 ÁNTSZs			
Environmental Protection (lake shore and catchment area)	3 KÖFEs, 2 NCDs, 3 ÁNTSZs		towns/settlements along the lake	
Lake Water Management (water body)	KDT VIZIG			
Lake Water Management (transportation)	KDT VIZIG			
Lake Water Management (fishery)	FVM			Balaton Fishing Incorporation
Lake Water Management (tourism)	GM			
Lake Shore Management	KDT VIZIG			
River Management	3 VIZIGs			
Run-off Control (urban drainage)	3 VIZIGs		towns/settlements along the drainage	
Run-off Control (agricultural drainage)	FVM			Agricultural Cooperative Society, private
Land Use Management		Agricultural and Land Cultivation Office		Agricultural Cooperative Society
Tourism	GM			
Agricultural Management	FVM	Agricultural and Land Cultivation Office		Agricultural Cooperative Society, private
Sewerage System (state property)	KHVM			DRV Rt.
Sewerage System (municipal property)			towns/settlements (ownership)	DRV Rt., private (operation)
Septic Tank	a part of sewerage system			
Water Supply System	same as sewerage system			
Solid Wastes Management	GM, KFF, 3 KÖFEs,	counties	towns/settlements	private (operation)
Lake Dredging	KDT VIZIG			private
Lake Reclamation	3 VIZIGs			private
Environmentally-sound Structures	3 VIZIGs			
Forestry (afforestation, soil erosion control)	FVM			Cooperative Society, private

note: If their local authorities is listed, the ministry is not listed.

Table 2.13 Water Quality Requirements for River and Lake Categories

Items	Unit	Category					Analytical method	Remarks
		I	II	III	IV	V		
		Very good	Good	Acceptable	Polluted	Very polluted		
Group A: Organic Matter								
Dissolved Oxygen	mg/l	7	6	4	3	<3	MSZ ISO 5813	
(Saturation)	(%)	80-100	70-80	50-70	20-50	<20		
BOD	mg/l	4	6	10	15	>15	MSZ 12750-22	
COD_{Mn}	mg/l	5	8	15	20	>20	MSZ 12750-21	
COD_{Cr}	mg/l	12	22	40	60	>60	MSZ 12750-21	
TOC	mg/l	3	5	10	20	>20	under preparation	
Group B: Nitrogen/Phosphorous Matter								
NH_4-N	mg/l	0.2	0.5	1.0	2.0	>2.0	MSZ ISO 7150-1	
NO_2-N	mg/l	0.01	0.03	0.1	0.3	>0.3	MSZ 448-12	
NO_3-N	mg/l	1	5	10	25	>25	MSZ ISO 12750-18	
Organic-N	mg/l						MSZ ISO 12750-20	
Total P	μ/l	100	200	400	1000	>1000	MSZ 260-20	for stagnant water
Total P	μ/l	40	100	200	500	>500	MSZ 260-20	for flowing water
PO_4-P	μ/l	50	100	200	500	>500	MSZ ISO 12750-17	for stagnant water
PO_4-P	μ/l	20	50	100	250	>250	MSZ ISO 12750-17	for flowing water
Chlorophyll-a	μ/l	10	25	75	250	>250	MSZ ISO 10260	
Group C: Microbilogical Matter								
Coliform	No/ml	1	10	100	1000	>1000	MSZ ISO 9308-1	
Fecal Coliform	No/ml	0.2	1	10	100	>100	MSZ ISO 9308-2	
Fecal Streptococcus	No/ml	0.2	1	10	100	>100	MSZ 448-44;MSZ ISO 8199	
Salmonella	-	not detected		less than 1/3 of total tests	not applied		MSZ 448-44;MSZ ISO 6222	
* 37 Cdeg	-							
* 22 Cdeg	-							

(Source : MSZ 12749:1993-Hungarian Standards)

Table 2.14 Effluent Standards for Discharge from Sewage Treatment Plant

Substances	Items	Area categories					
		I	II	III	IV	V	VI
		Limit (10-3 kg/m³)					
Hazardous Substances	Dicromate Oxygen consumption	50	75	100	100	150	75
	organic solvent extract (oil-greese)	2	5	10	10	10	10
	organic solvent not mixing with water (10-3 m3/m3)	0.05	0.05	0.05	0.05	0.05	0.05
	pH						
	- under	6.5	6.5	5	6	5	6
	- above	8.5	9	9	9	10	9
	salt total						
	- nature originated	1000	1000	2000	1000	-	2000
	- technology originated	1000	1000	2000	1000	-	2000
	Natrium(%)	45	45	45	45	-	45
	Phenoles	0.1	0.1	3	3	3	3
	floating substances total	100	100	200	200	500	200
	tar	0.1	0.1	2	2	2	1
	Ammonia-ammonium-ion	2	5	30	10	30	10
	Fe total	10	10	20	20	20	20
	Mangan total	2	2	5	5	5	5
	ANA detergent	2	2	5	5	5	5
	Sulfids	0.01	0.01	2	2	5	2
	Active chlor	2	2	2	2	2	2
	Phluorids	2	2	10	5	10	10
	Phosphorus total	1.8	2	2	2	-	2
	nitrate	40	50	80	80	-	80
	Coliform number			10l/cm³			
Poisonous Substances	Cyanides easily absorbed	0.1	0.2	0.2	0.2	0.2	0.2
	Cyanid total	2	10	10	10	10	10
	Copper total	0.5	1	2	2	2	2
	Lead total	0.05	0.1	0.2	0.2	0.2	0.2
	Chrome total	0.2	0.5	1	1	1	1
	Chrome VI.	0.1	0.3	0.5	0.5	0.5	0.5
	Arsenic total	0.05	0.05	0.1	0.1	0.1	0.1
	Cadmium total	0.005	0.01	0.05	0.05	0.05	0.05
	Mercury total	0.001	0.005	0.01	0.01	0.01	0.01
	Nickel total	0.5	0.5	1	1	1	1
	Zink total	1	2	5	5	5	5
	Silver total	0.01	0.05	0.1	0.1	0.1	0.1
	Toxicity	LC 50% dilution requirement					

(Source : Government Decree 33/1993)

Table 2.15 Effluent Standards for Wastewater Discharge to Sewerage System

Substances	Items	Area categories					
		I	II	III	IV	V	VI
		Limit (10–3 kg/m^3)					
Hazardous Substances	Dichromate oxygen consumption	1000	1000	1200	1200	1500	1000
	organic solvent extract (oil–greese)	40	40	50	50	60	50
	Phenols	5	5	10	10	10	10
	Tar	1	2	5	5	5	5
	ANA detergent	20	20	50	50	80	50
	pH	under 6.5 above 10.0					
	Sulfide	1	1	1	1	1	1
	Sulfate	400	400	400	400	400	400
	(NH_3–NH_4)	100	100	150	150	150	150
	Active chlorine	10	10	30	30	50	30
	Salt total – with natural origin	1500	1500	2500	2500	3000	2500
	– with artificial origin	1500	1500	2500	2500	3000	2500
	Fluorides total	20	20	50	50	50	50
	Fe total	10	10	20	20	20	20
	10 substances capable of deposition	100	100	150	150	150	150
Poisonous substances	Cyanides easily absorbed	0.05	0.05	0.1	0.1	0.1	0.1
	Cyanide total	0.5	0.5	1	1	1	1
	Copper total	1	1	2	2	2	2
	Lead total	0.2	0.2	0.4	0.4	0.4	0.4
	Chrome total	0.5	0.5	1	1	1	1
	Chrome VI.	0.2	0.2	0.5	0.5	0.5	0.5
	Arsenic total	0.1	0.1	0.2	0.2	0.2	0.2
	Cadmium total	0.01	0.02	0.1	0.1	0.1	0.1
	Mercury total	0.005	0.01	0.05	0.05	0.05	0.05
	Nickel total	0.5	0.5	1	1	1	1
	Tin total	0.3	0.3	0.5	0.5	0.5	0.5
	Zinc total	2	5	10	10	10	10
	Silver total	0,1	0,1	0,2	0,2	0,2	0,2
	Organic solvent (10^{-3} m^3/m^3)	0,05	0,05	0,1	0,1	0,1	0,1
	Coal disulfide (10^{-3} m^3/m^3)	0,05	0,05	0,1	0,1	0,1	0,1
	Bensol (10^{-3} m^3/m^3)	0,05	0,05	0,1	0,1	0,1	0,1
	Toxicity	LC 50% dilution requirement					

(Source : Government Decree 34/1993)

Table 2.16 Run-off Control Facilities in the Study Area

Location						Catchment area			Operation / Maintenance		
No.	Area name	Drainage / River name	Outline	Function	Year of construction	Land Use	Area (sq.km)	Length of river (km)	KDT Vizig	City govern.	Water company
1	Balatonkenese	Árok	Deposit catcher 3 m(w) x 5 m(L) x1.5 m (D)	Sedimentation	1980	Residential area with sewerage system	not clear	1.5	-	B.kenese	-
2	Balatonkenese	Bakó street ditch	Deposit catcher (5 m(w) x 10 m(L))	Sedimentation/ Filtration	1997	Residential area with sewerage system	4.57	4.0	-	B.kenese	-
3	Balatonalmádi	Vörösbérényi Séd	Deposit catcher	Sedimentation	1982	Agricultural / Residential area	14.0	5.4	-	B.almadi (2.1 km)	Pápakörnyéki W.C. (3.3 km)
4	Balatonalmádi	Remete Árok	Deposit catcher (3 m(w) x 10 m(L))	Screen Sedimentation	1980	Residential area with sewerage system	16.8	2.5	-	-	Pápakörnyéki W.C.
5	Paloznak	Lovasi Séd	Filter field (6.35 ha)	Sedimentation/ Filtration by grass(reed, cattail)	1985	Agricultural / Residential area	21.0	7.7	-	-	Balaton highland W.C.
6	Balatonfüred	Kéki river	Deposit catcher / Filter field (10 m(w) x 15 m(L))	Sedimentation/ Filtration by grass(reed, cattail)	-	Agricultural / Residential area	11.8	4.0	-	B.füred	-
7	Örvényes	Örvényesi Séd	Deposit catcher / Filter field (Horseshoe - shaped 20 m (w) x 20 m(L))	Sedimentation/ Filtration by grass(reed, cattail)	1984	Agricultural / Residential area	19.9	8.4	KDT (0.8 km)	Örvényes (3.5 km)	Balaton highland W.C. (4.1 km)
8	Balatonrendes	Burnót patak	Deposit catcher (10 m (w) x 30 m(L))	Sedimentation	1995	Agricultural / Residential area	82.2	18.2	KDT	-	-
9	Szigliget – Balatonederics	Tapolca patak	Oil and deposit catcher 5 m (w) x 20 m(L)	Screen Sedimentation	1983 - 1987	Agricultural / Residential area	39.5	10.8	KDT (6.8 km)	Tapolca (4.0 km)	-
10	Szigliget – Balatonederics	Kélöles patak	Oil and deposit catcher 5 m (w) x 20 m(L)	Screen Sedimentation	1983 - 1987	Agricultural / Residential area	37.7	20.4	KDT (7.0 km)	Tapolca (0.6 km)	Balaton highland W.C. (12.8 km)
11	Szigliget – Balatonederics	Lesence patak	Reedy field (100 ha)	Sedimentation/ Filtration by grass(reed, cattail)	1987	Agricultural / Residential area	100.5	23.3	KDT (15.0 km)	-	Agricultural industry (8.3 km)
12	Szigliget – Balatonederics	Nemesvitai ditch	Reedy field (100 ha)	Sedimentation/ Filtration by grass(reed, cattail)	1987	Agricultural / Residential area	6.3	5.5	KDT (2.5 km)	-	Balaton highland W.C. (3.0 km)
13	Keszthely	Szent László árok	Infiltration Pond (5 m (w) x 100 m(L))	Sedimentation/ Infiltration	-	Agricultural / Residential area	not clear	not clear	not clear		
14	Fonyód	Keleti Bozót csatorna	Pond with Pump station	Sedimentation	-	Agricultural area	not clear	not clear	not clear		
15	Zamárdi – Siófok	Cinege patak	Fish pond (37.6 ha)	Sedimentation	-	Agricultural area	18.7	6.9	-	-	South Balaton Water comp.

Table 2.17 Present Situation of Shore Regulation/Protection Works in Lake Balaton

Distribution of regulated shores by county

unit: kilometer

County	Regulation Completed	Rip-rap	Total
Veszprém	27.1	12.8	39.9
Somogy	52.2	10.5	62.2
Zala	4.7	0.2	4.9
Total	84.0	23.5	107.5

Distribution of regulated shores by managing organization

unit: kilometer

Managing Organization	County			
	Veszprém	Somogy	Zala	Total
Water Sector	1.0	16.7	0.5	18.2
Council	10.6	8.9	3.2	22.7
Institution	22.0	21.7	1.2	44.9
Private	6.3	15.2	-	21.7
Total	39.9	62.5	4.9	107.5

Total length of the shore : 235 km

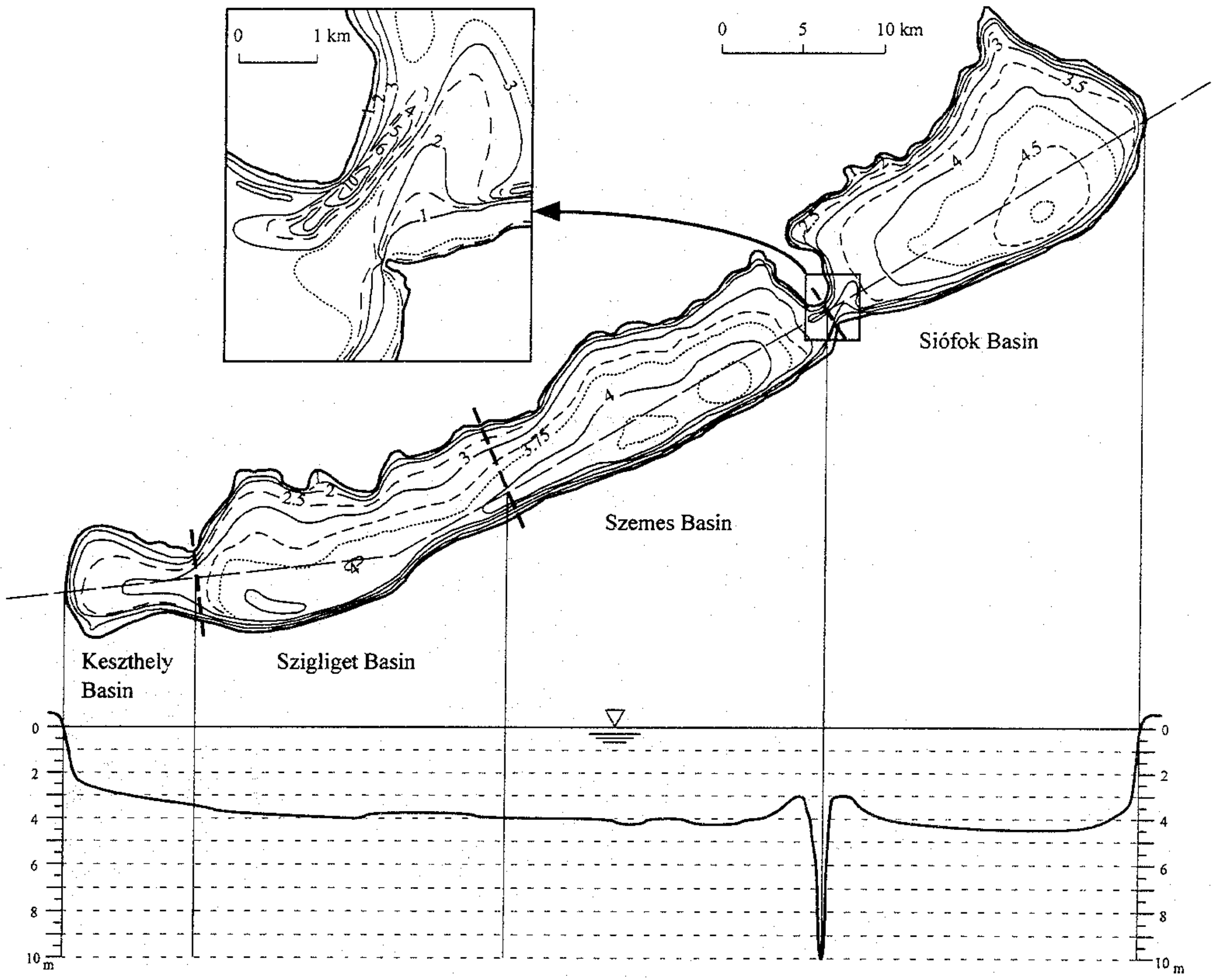


Figure 2.1 Shape of the Lake and Division of Sub-Basins

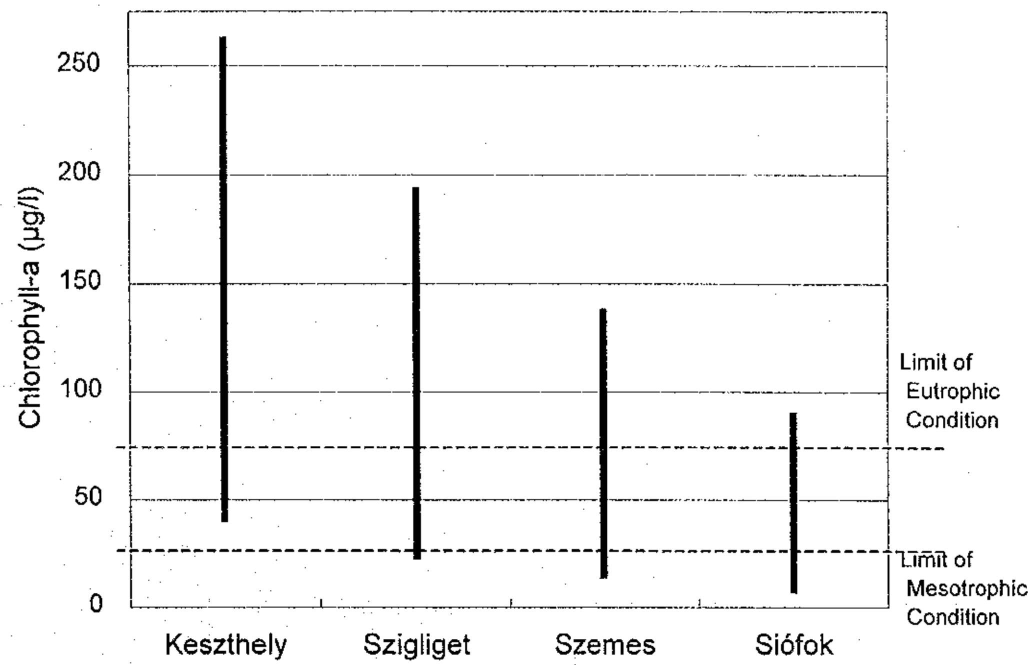


Figure 2.2 Trophic State of Each Basin

(Range of yearly maximum from 1982 to 1996, Data Source: KDT KÖFE)

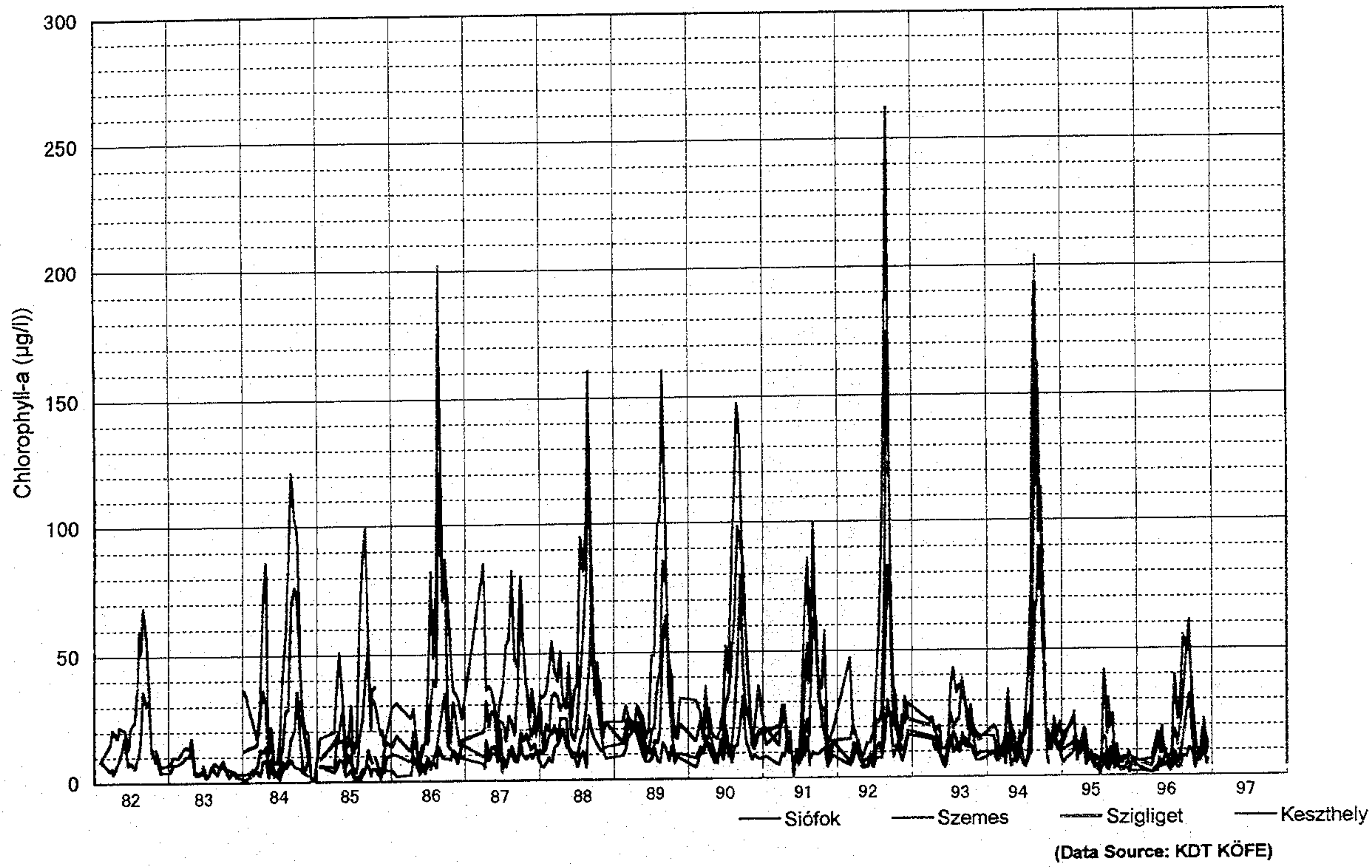


Figure 2.3 Chlorophyll-a Concentrations in Each Basin

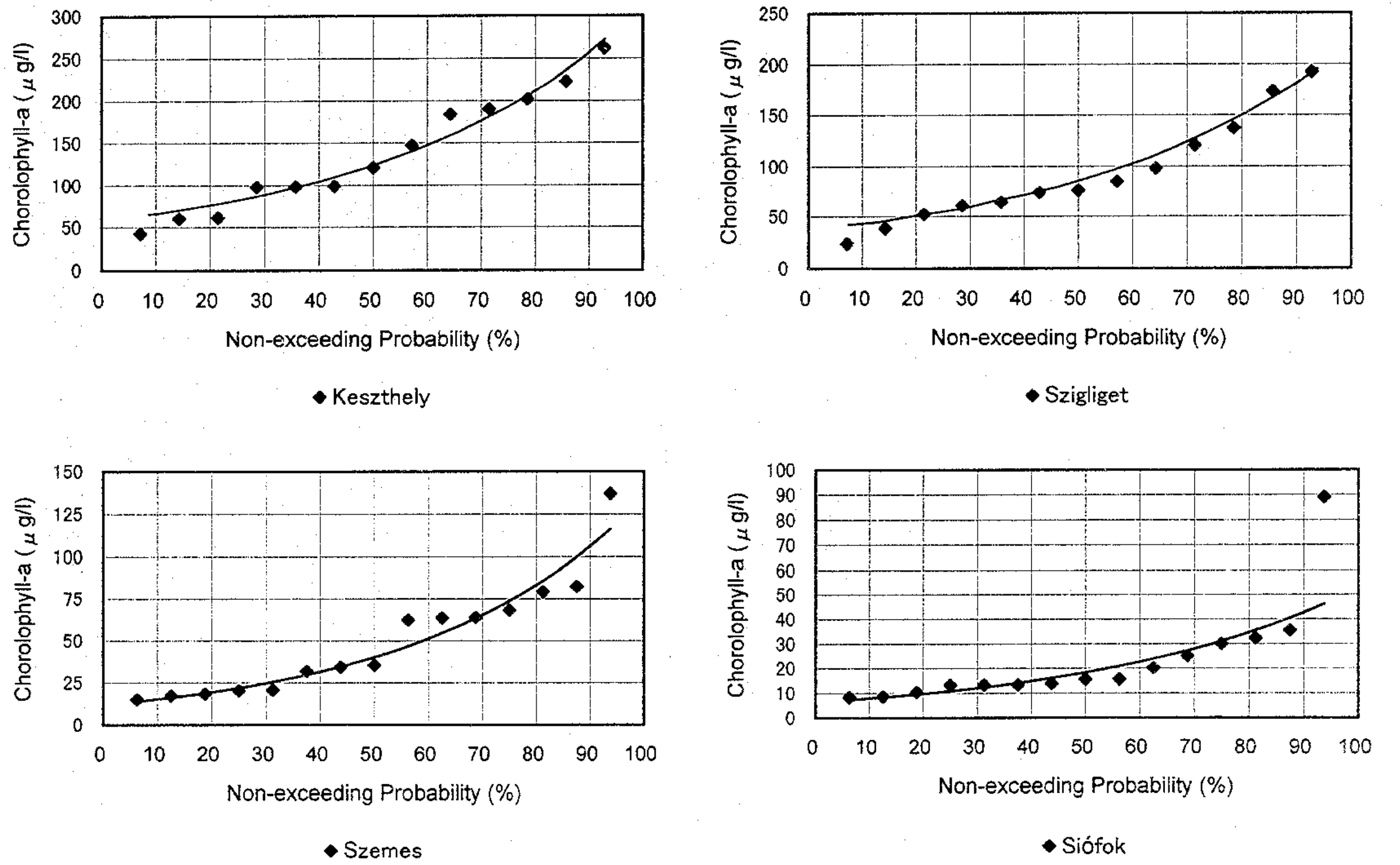


Figure 2.4 Non-exceeding Probability of Chlorophyll-a Concentration in Each Basin

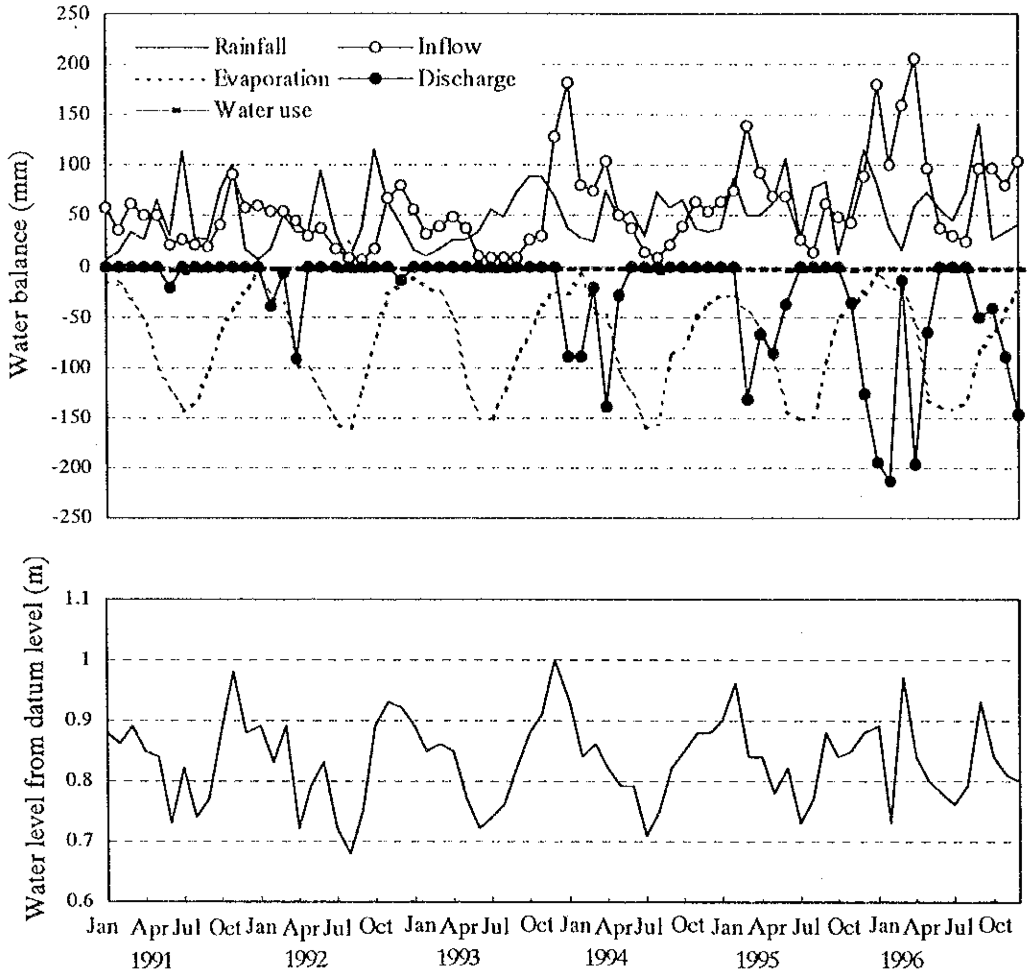


Figure 2.5 Water Balance and Water Level of Lake Balaton

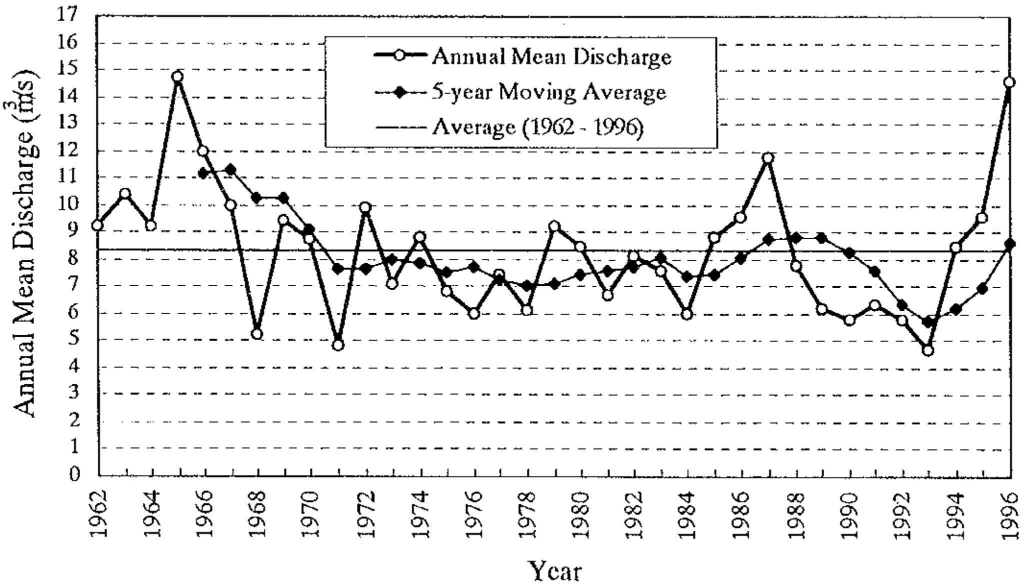


Figure 2.6 Annual Mean Discharge of Zala River

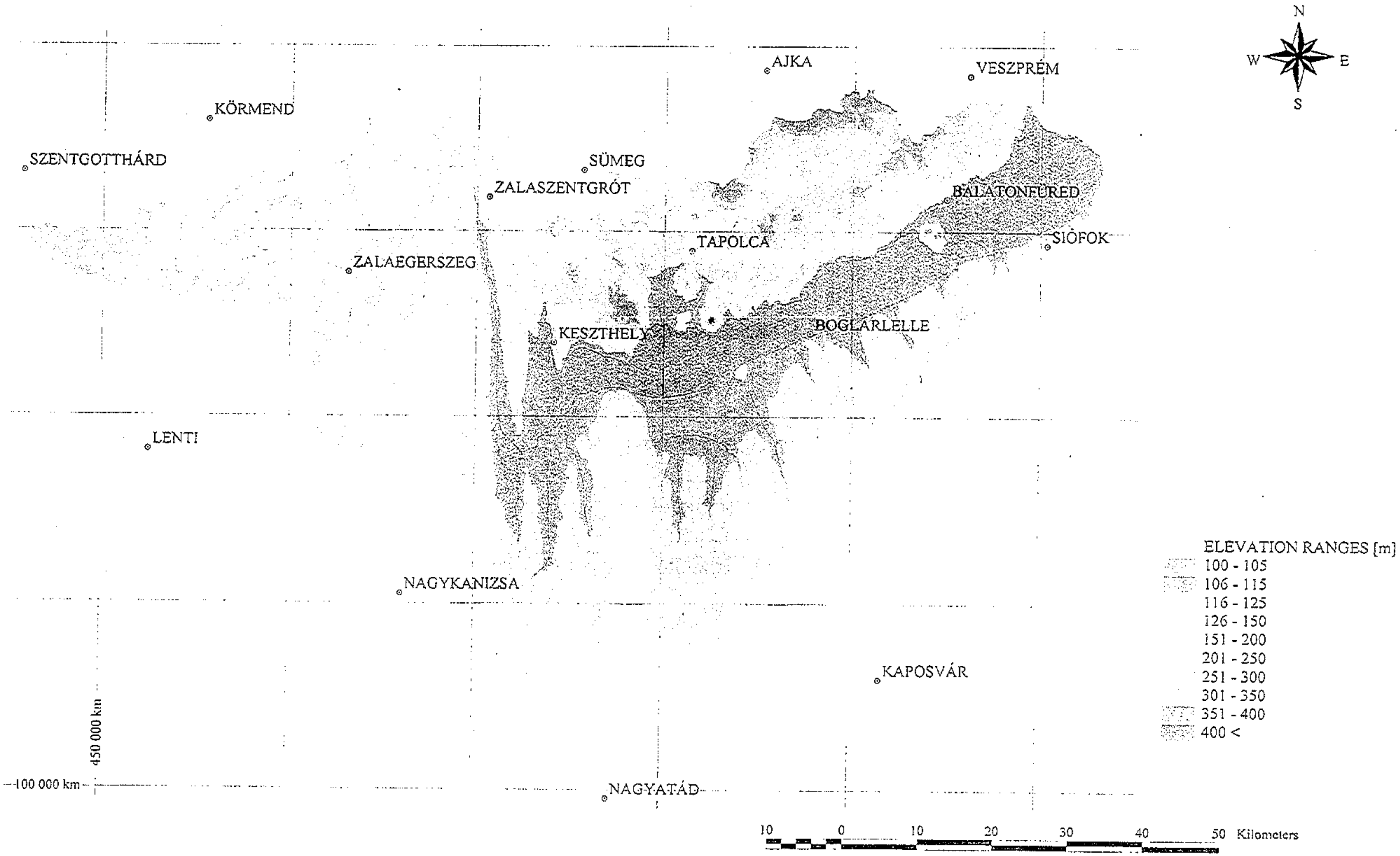


Figure 2.7 Topographic Map of the Catchment

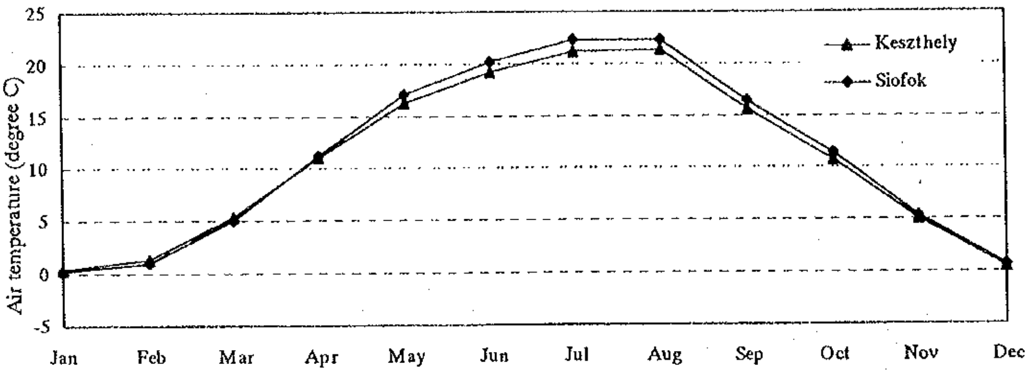


Figure 2.8 5-year Multi-annual Air Temperature (1992 - 1996)

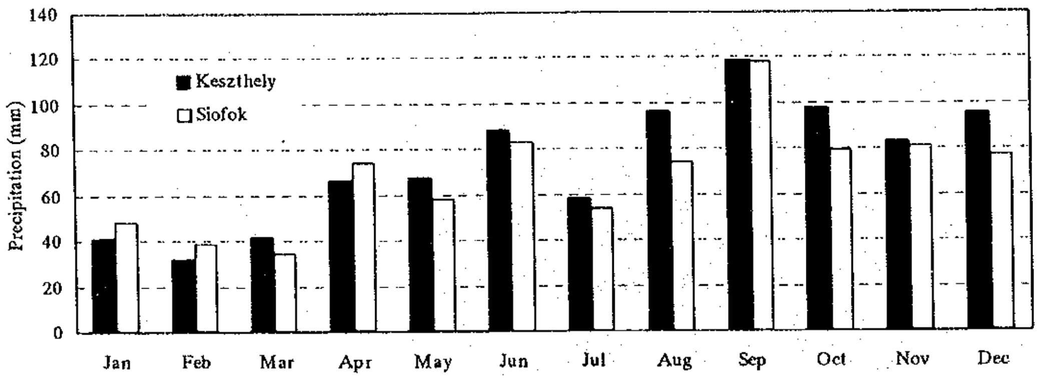


Figure 2.9 5-year Multi-annual Precipitation (1992 - 1996)

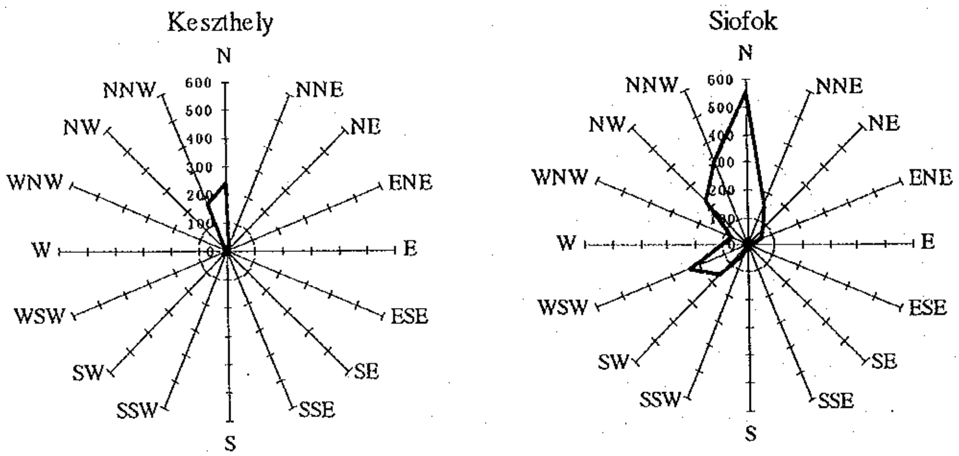
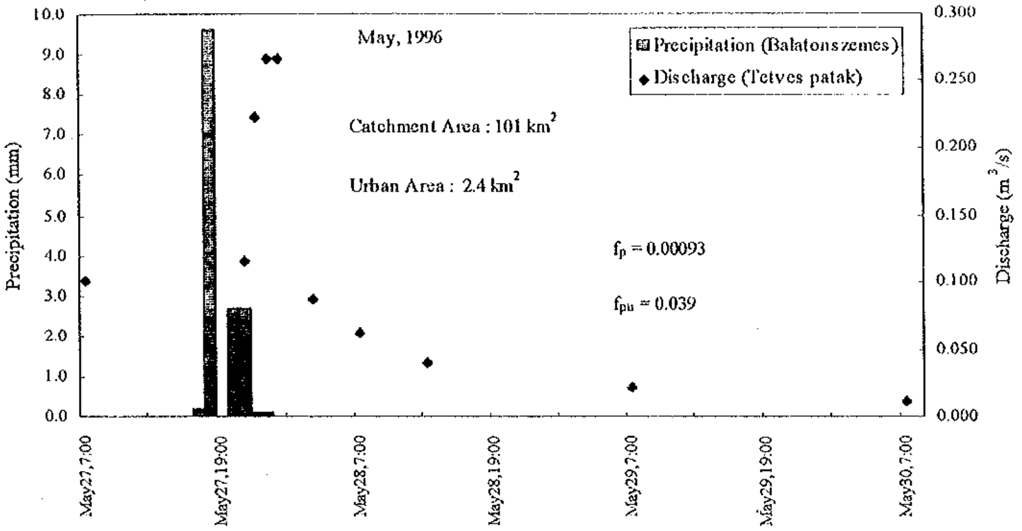
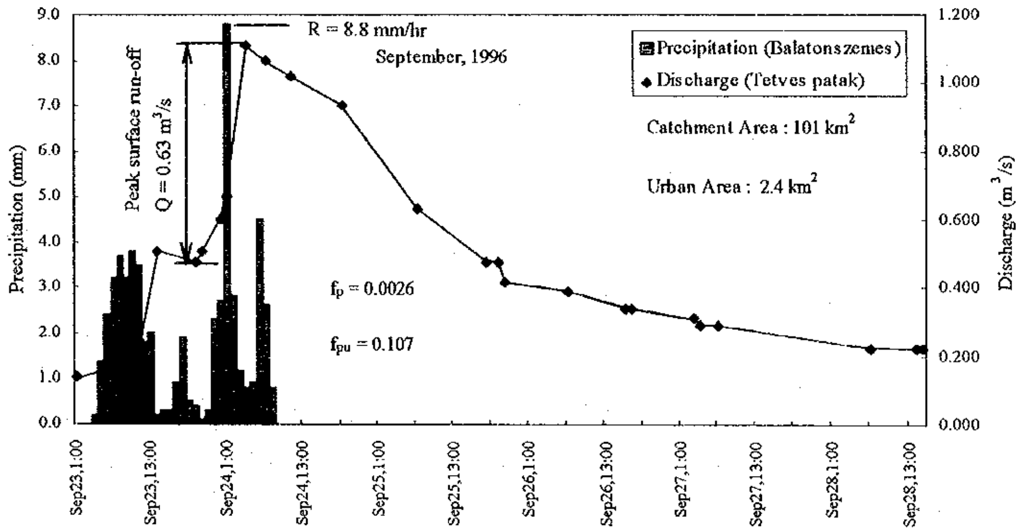


Figure 2.10 5-year Multi-annual Distribution of Wind Direction (1992 - 1996)





$$f_P = \frac{3.6 \times Q_P}{R \times A} = \frac{3.6 \times 0.63}{8.8 \times 101} = 0.0026$$

$$f_{PU} = \frac{3.6 \times Q_P}{R \times A} = \frac{3.6 \times 0.63}{8.8 \times 2.4} = 0.107$$

Figure 2.11 Relationship between Hourly Rainfall Intensity and Discharge in Tetves Patak

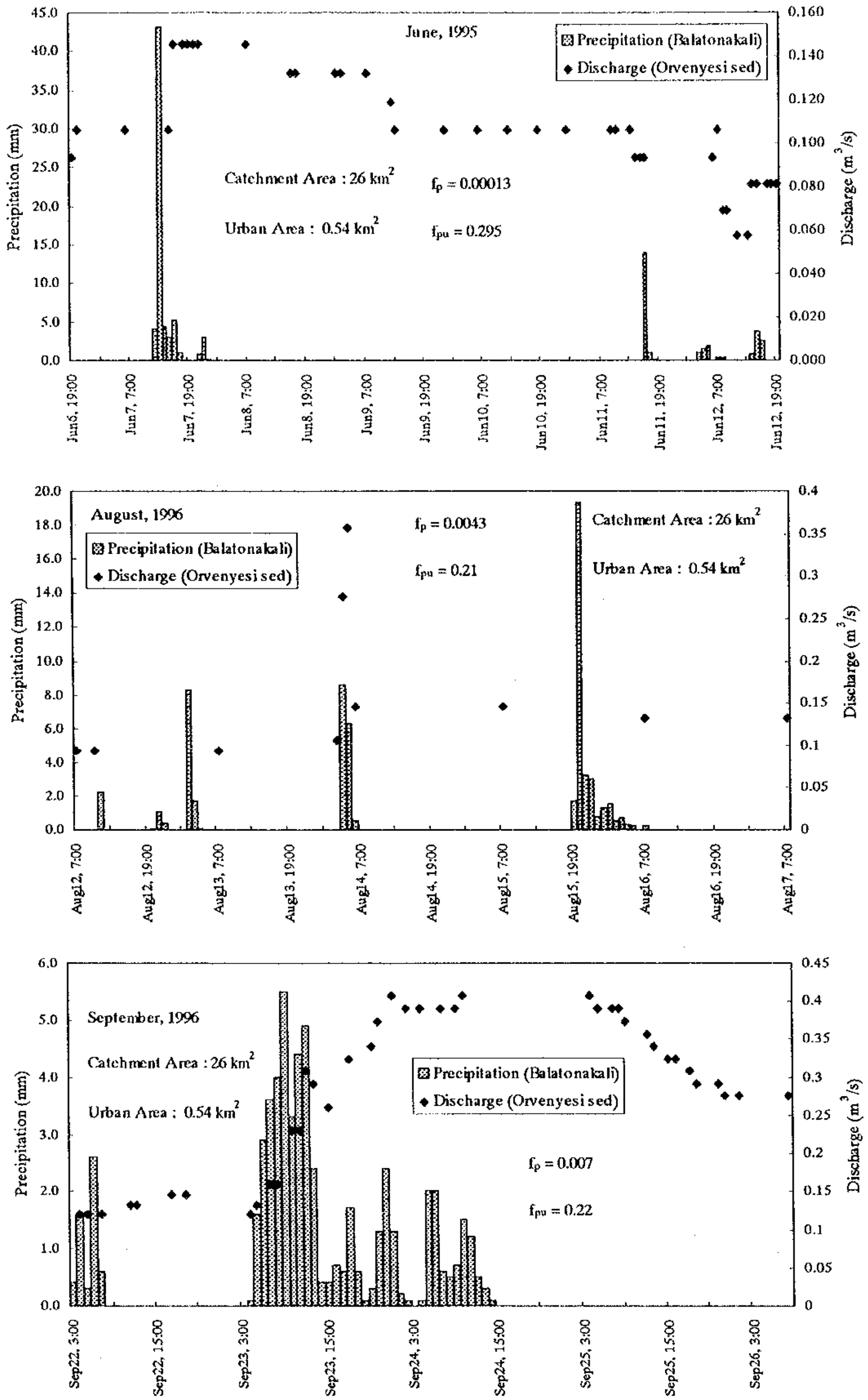


Figure 2.12 Relationship between Hourly Rainfall Intensity and Discharge in Örvényesi Séd

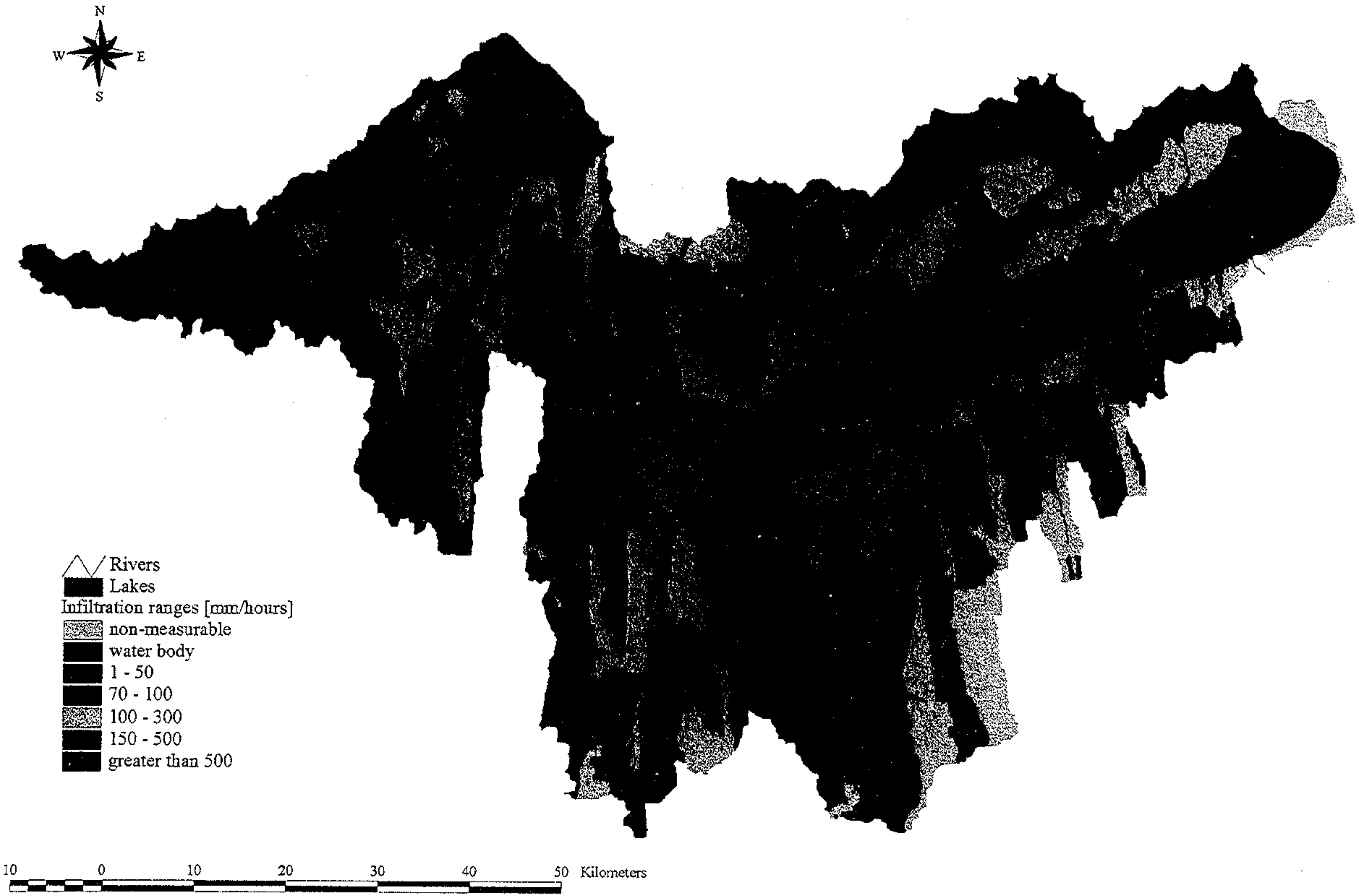


Figure 2.13 Distribution of Infiltration Capacity Source : Adapted from MTA-TAKI Data

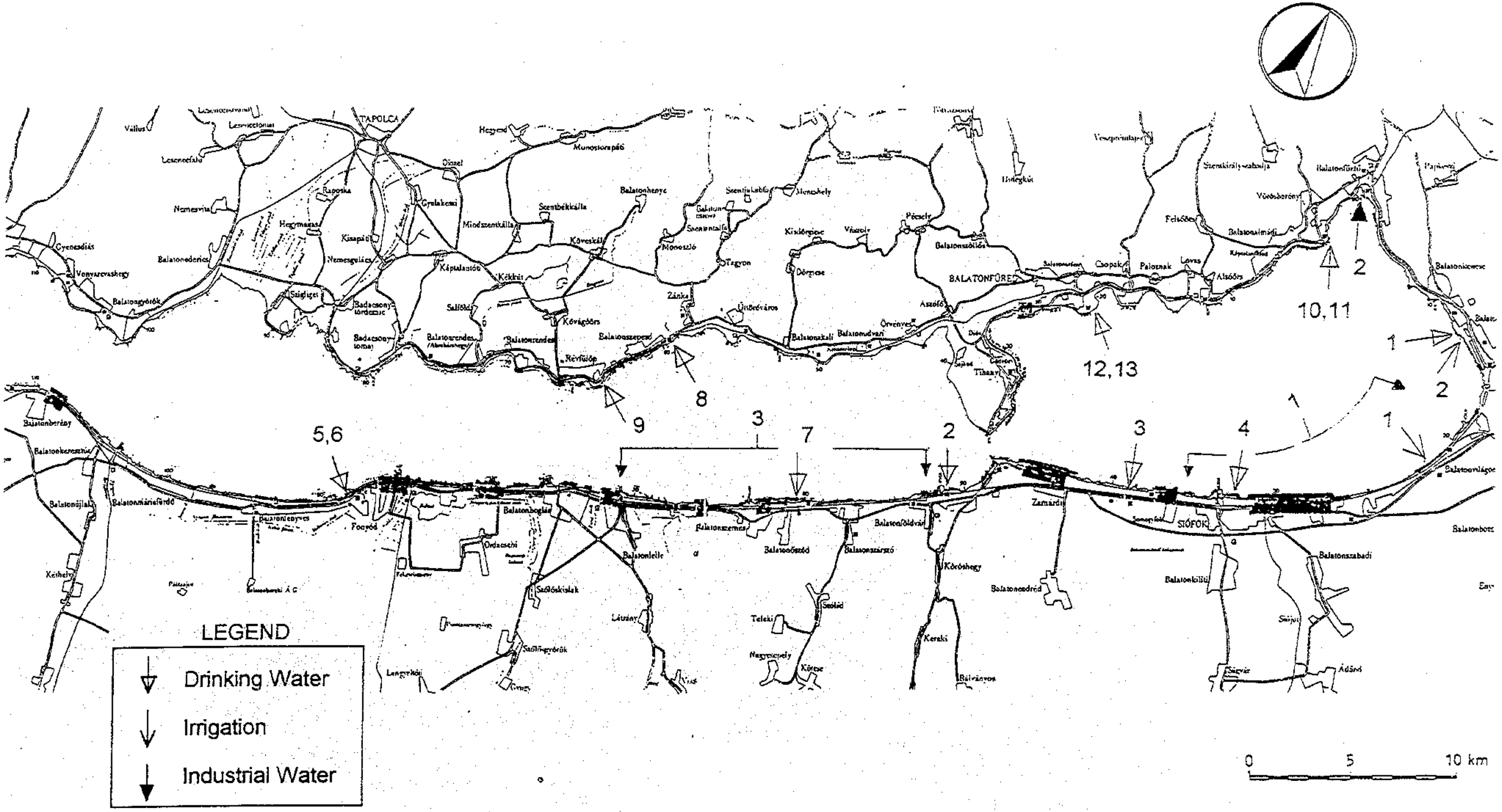


Figure 2.14 Location of In-take Facilities for Drinking / Irrigation/ Industrial Use

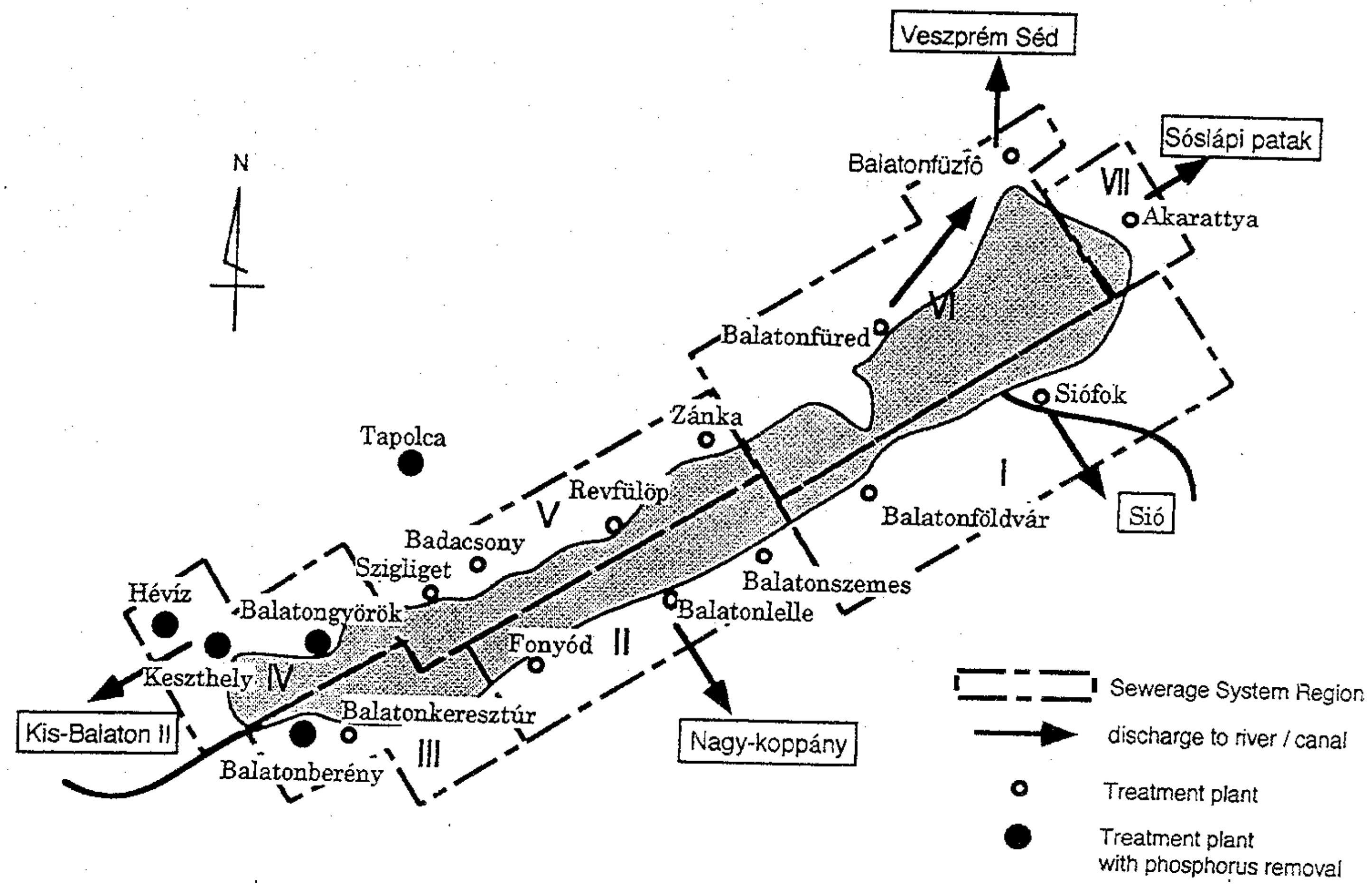


Figure 2.15 Sewerage System Region in the Lakeside Area

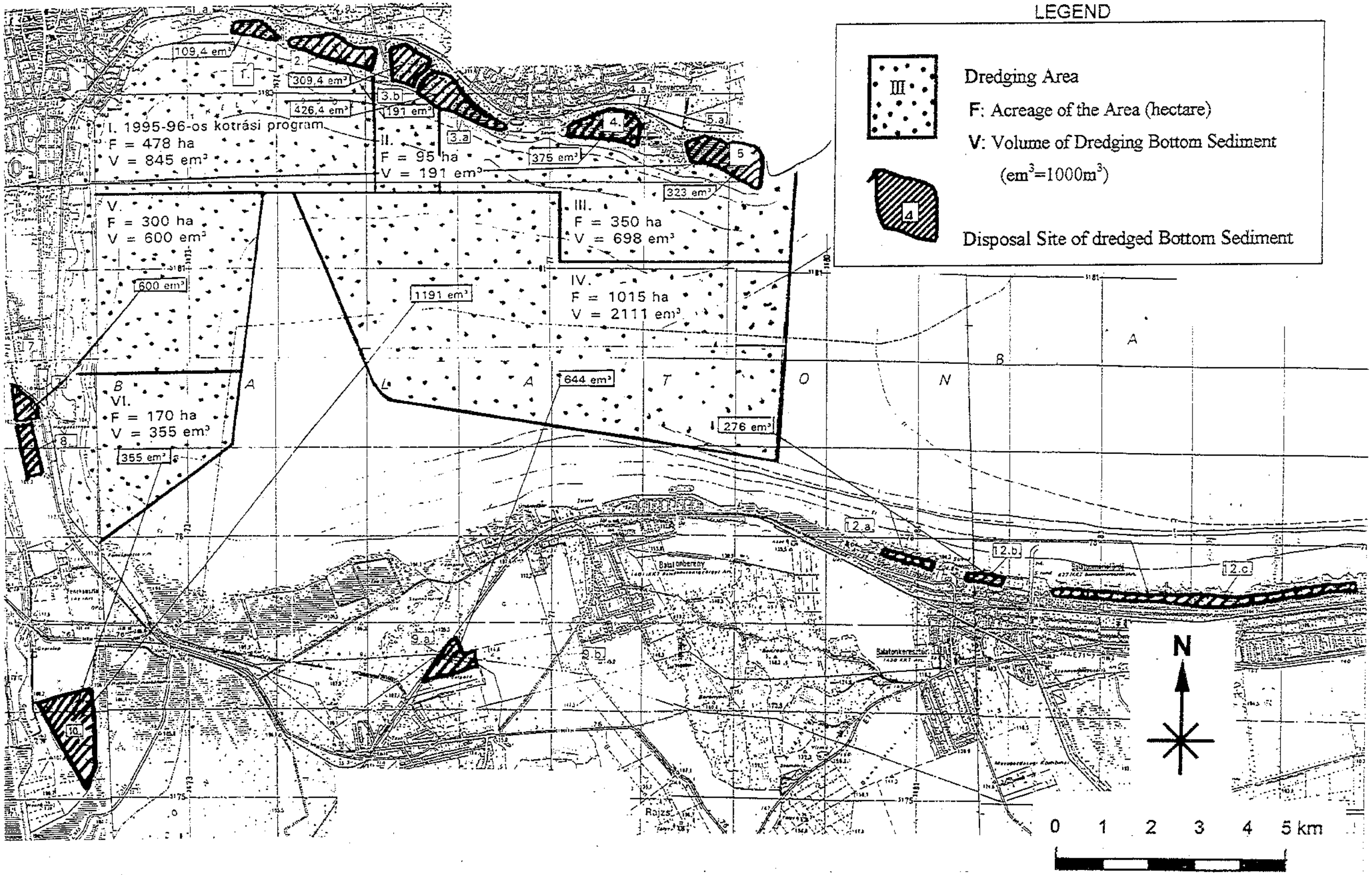


Figure 2.16 Planned Dredging Area and Disposal Sites of Dredged Bottom Sediment in Keszthely Bay

CHAPTER - 3

DEVELOPMENT OF DECISION MAKING TOOLS

CHAPTER - 3

DEVELOPMENT OF DECISION MAKING TOOLS

1. NEEDS OF DECISION MAKING TOOLS

The first step to formulate the Comprehensive Plan should be a prioritization of various measures proposed for environmental improvement of Lake Balaton. This prioritization requires an evaluation of those measures from the view point of improvement effect of lake water quality and cost effectiveness.

Decision making tools proposed in the Study aim to enable this evaluation. The evaluation needs an estimation of pollution loads discharged into the lake and a simulation of consequential lake water quality. For this purpose, the JICA Study Team developed following tools.

- PLDB : a pollution load database for the pollution loads estimation
- WQSM : a water quality simulation model for Lake Balaton

Moreover, the need of those tools can be justified from another aspect. Development and operation of those tools clarifies a deficient part of existing data and knowledge accumulation. This secondary benefit is important for making monitoring and research strategies.

2. POLLUTION LOAD DATABASE (PLDB)

2.1 PURPOSES OF PLDB

PLDB is required to be a tool for an estimation of pollution loads discharged into the lake (pollution loads discharge), and it has closely linked two functions; a database function for accumulation of relevant data, and a simulation function for estimation of pollution loads discharge.

The design of PLDB is determined by a method of pollution load analysis. The method specifies both which data should be accumulated, and which algorithm should be applied for the load estimation.

The method of pollution load analysis should enable to estimate future pollution loads discharge as well as present one, in order to evaluate improvement measures. For example, the simplest way of pollution load analysis, to measure flow and water quality of all kind of influent, is not a suitable method for simulation function of PLDB, because it can not reflect future conditions in the estimation of future pollution loads discharge.

At least, pollution load analysis applied for PLDB can estimate pollution loads generation in every sub-catchment, and runoff ratio of each sub-catchment which is defined as a ratio of the load reaching the lake to the load generated in the sub-catchment.

The calculated pollution loads discharge, a main output of PLDB, is one of input data of WQSM. Compatible data format between PLDB and WQSM is proposed to avoid a redundant data processing.

2.2 Methodology of Pollution Load Analysis

(1) Classification of Pollution Load Sources

Sources of pollution loads are generally as follows:

- domestic wastewater (black water from human metabolism, and gray water from household activities)
- industrial wastewater (discharge from factories and livestock farms)
- rural runoff (runoff rainwater containing fertilizers, herbicides and pesticides, eroded soil, etc.)
- urban runoff (runoff rain water containing roof and road depositions)
- atmospheric deposition

These sources can be classified into point sources and non-point (or defused) sources based on applicable estimation methods.

Point sources comprise effluents of sewage treatment plants, factories, and livestock farms. An estimation of point source pollution loads generation can be obtained by monitoring data of effluents.

On the other hand, an estimation of non-point source pollution loads generation demands dimensions and unit pollution loads generation by land use categories, and geological features. Moreover, a quantity of eroded soil and atmospheric deposition depends on intensity and duration of rainfall.

In the non-sewered areas domestic wastewater is treated by septic tanks, however, it is hard to believe that all of the gray water can be properly treated by septic tanks. Untreated gray water in the non-sewered area should be classified into non-point sources.

(2) Previous Researches and Studies

1) A series of studies on nutrient load estimation by VITUKI Rt.

Since the mid-1980s, VITUKI Rt. has conducted nutrient load estimates in almost every year. Total phosphorus (T-P) and total nitrogen (T-N) loads discharge are estimated based on the experimental data of the Lake Balaton Water Quality Monitoring System (the monitoring network).

Various estimation methods are tested, and regression analysis among the loads of various forms of phosphorus and nitrogen depend on the river flow, water temperature, and Julian day are carried out in the studies.

The latest report points out that following facts may cause serious underestimate of T-P and T-N loads discharge;

- low frequency of water sampling and river flow measurement,
- missing data, and
- lack of water quality and runoff data in direct catchment areas.

2) Pollution Load Map by KÖFEs (PLM)

As a part of the Action Program (the governmental resolution 1068/1996), KÖFEs conducted a study of the environmental condition in the Balaton catchment area in 1996. In this study, KÖFEs focused on an estimation of phosphorus load among other environment including atmospheric and noise pollution. The result of phosphorus load estimation were compiled as the pollution load map (PLM).

In PLM the whole catchment is divided into 24 sub-catchment areas based on administrative boundaries and the natural watershed. Land use categories such as municipal, agricultural, industrial, and services are defined, and these are further divided into sub-categories. The land use categories are used as the basis of non-point source T-P load generation. The Agrober study explained below is referred as a basis of T-P load generation from agricultural areas. Point source T-P load generation is estimated based on actual effluent data of sewage treatment plants and industries.

T-P load discharge is estimated taking runoff ratio (0.4 for lakeside areas and 0.25 for background areas) and T-P concentration in rain water (0.12 mg/l) into account.

3) Study of agricultural pollution load estimation by Agrober Rt.

As a part of the Action Program, FM commissioned a study, entitled a complex melioration and afforestation study of the Lake Balaton catchment area, to Agrober Rt. in 1995.

In this study, phosphorus load generation from agricultural areas is estimated based on soil loss and ammonia-lactate soluble phosphorus content of the soil by sub-watershed. Land use and slope of the area are taken into consideration.

4) Experimental program on urban runoff by NyDT and DDT KÖFEs

NyDT and DDT KÖFEs carried out experimental program on urban runoff in 1997.

NyDT KÖFE measured daily precipitation, river flow, and various water quality parameters at four small watersheds in Keszthely. This work provides valuable information on urban runoff. Nevertheless the river flow were not determined for the entire flood waves, a part of the data could be used to determine runoff rates and unit pollutant loads for T-P, T-N, and COD.

DDT KÖFE measured rain intensity, daily precipitation, and a number of water quality parameters in Fonyód. Because DDT KÖFE did not measure river flow, the runoff rates should have been assumed. The assumed values are slightly lower than in case of Keszthely. The estimated loads are lower than those for Keszthely. This can be attributed to the less urbanized area, and the existence of a park and forested area in the watershed.

(3) Applied Method of Pollution Load Analysis

In the Study Area, it is assumed that almost all of point source pollution loads reach Lake Balaton, because point source loads are discharged to tributaries of the lake or directly into the lake.

On the rationale, PLDB employs following equation to estimate pollution loads discharge.

Pollution Loads Discharge =
Point Source Loads + Runoff Ratio × Non-point Source Loads Generation

To represent a mechanism of generation and transportation of pollutants precisely, a runoff ratio must be a function of parameters at least including;

- area of catchment,
- rainfall intensity,
- distance between generated point and adjacent water course,
- slope, and
- soil filtration capacity.

Accumulation of these parameters in database is recommended for the future possibility of development such a function, however, at present it is almost impossible to apply that way, because development of such a function is subject to an enormous data accumulation and highly sophisticated researches.

In the Study, more realistic method is applied considering methods applied in previous studies and an availability of existing data and knowledge. The applied method consists of following steps.

i) Estimation of point source pollution loads.

ii) Estimation of non-point source pollution loads generation.

iii) Estimation of pollution loads discharge from the tributaries measured by KÖFEs and VIZIGs.

iv) Estimation of runoff ratio based on the results of *i)*, *ii)*, and *iii)*.

v) Estimation of pollution loads discharge from the whole catchment area using the results of *i)*, *ii)*, and *iv)*.

2.3 STRUCTURE OF PLDB

(1) Introduction

PLDB is designed to have following two functions;

- a database function for accumulation of relevant data, and
- a simulation function for estimation of pollution loads discharge based on the database.

An analysis of non-point source pollution loads requires spatial data like a land use map or a delineation map of sub-catchment areas as well as various tabulated data. To handle both spatial data and tabulated data simultaneously, a geographical information system (GIS) is introduced. The most important feature of GIS is an ability to link various kinds of data and map information in a way that data with spatial distribution can be quickly retrieved and analyzed.

PLDB is developed with the GIS software Arc/Info version 7.2.1 on a DEC Alpha Station 255 equipped with 128 MB RAM and 6 GB hard disk.

(2) Database Structure

1) Spatial data

Following base digital maps have been accumulated in PLDB.

- Basic topographic map (DTA 50 Digital Topographic Map Set, 1:50,000) from KDT-KÖFE
- Elevation contour map (1:100,000) from FÖMI
- Land cover map (Corine Land Cover Database, 1:100,000) from FÖMI

- Soil characteristics map (AGROTOPO, 1:100,000) from MTA TAKI

For selected model sub-catchment areas, following additional digital maps have been collected.

- Satellite images (LANDSAT TM and SPOT) from FÖMI

- Detailed soil map (detailed field records, 1:25,000) from MTA TAKI

In addition to above mentioned base digital maps, several maps were derived for the Study as follows.

- Administrative border map with latest land use inventory data (from FÖMI)

- Map of hydro-physical properties of soils (1:100,000) from MTA TAKI

- Erosion map (1:100,000) from MTA TAKI

2) Tabulated data

Following tabulated data have been accumulated in PLDB.

- National Land Use Inventory from FÖMI

- Population of sub-catchment acquired from PLM

- Information of point sources acquired from PLM

3) Derived digital maps by JICA Study Team

Various digital maps are derived by overlaying and analyzing collected spatial and tabulated data using GIS. Most important derived maps for the pollution load analysis are as follows.

a. Re-categorized land use map

Based on the Corine Land Cover Database, a re-categorized land use map is derived. New land use categories are determined as follows, in accordance with land use categories in pollution load analysis;

- urban area (residential and recreational area),
- arable land,
- pasture and meadow,
- forest,
- vineyard and orchard, and
- marshland and water bodies.

b. Meshed population data

Population of one (1) ha grids are calculated based on recent population data including tourists and the dimension of settlements.

Combination of this meshed population data and service ratio of sewerage system can be used as a basis of estimation of pollution loads generation from untreated gray water in non-sewered areas.

(3) User Interface for Pollution Loads Simulation

A user interface for pollution loads simulation was developed as a part of PLDB. The user interface applies customization with AML (Arc/Info Macro Language) and some commands of the GRID module so that the user can easily render an estimation of pollution loads generation by setting the unit pollution loads generation for each land use category, and an estimation of pollution loads discharge by setting the runoff ratio for each sub-catchment area.

The design of user interface is determined taking the future possibility of application of more detailed analysis into consideration.

2.4 POLLUTION LOAD ANALYSIS

(1) Estimation of Point Source Pollution Loads

PLM estimates pollution loads from sewage treatment plants by analyzing effluent quantity and quality.

In the Study Area, the contribution of other point sources are quite small. Most factories are connected to sewerage system. PLM estimates total phosphorus (T-P) loads from remaining factories are 94 kg/year in the northern catchment and 948 kg/year in Zala River catchment. Concerning livestock breeding, the JICA Study Team concluded that all of the manure is utilized for composting or soil improvement, and no wastewater is discharged to the lake.

Point source pollution loads are summarized in *Table 3.1*. It seems strange that in many case estimated T-N loads exceed COD loads. Especially the estimated values of T-N load of Tapolca STP both in 1994 and 1995 are more than twice of those of COD load. It might be caused by an overestimate of nitrogen concentration in the effluent.

(2) Estimation of Non-point Source Pollution Loads Generation

Analysis of non-point sources pollution loads generation is carried out on the 24 sub-catchment areas delineated according to PLM as shown in *Figure 3.1*.

The land use patterns are determined by overlaying the re-categorized land use map and the delineation map of sub-catchment as shown in *Table 3.2*. The re-categorized land use map is shown in *Figure 3.2*.

The unit pollution loads generation of each land use category is determined based on Japanese empirical value. The reason is that the values reported in Hungarian literature are quite small and in many cases an application of these values results in a contradiction that an estimated loads generation is smaller than estimated loads discharge. For reference, both Japanese and Hungarian values are summarized in *Table 3.3*.

Unit pollution loads generation of each land use category in the Study is determined as follows.

	COD_{Cr} (kg/ha/year)	T-N (kg/ha/year)	T-P (kg/ha/year)
Urban Area	282.0	19.7	2.70
Arable Land	20.6	29.6	0.79
Pasture and Meadow	31.8	16.6	0.55
Forest	43.0	3.6	0.30
Vineyard and Orchard	20.6	29.6	0.79

Pollution loads generation from untreated gray water in non-sewered areas is estimated by multiplying non-sewered population by the unit pollution loads generation of gray water.

Unit pollution loads generation of gray water is determined based on Japanese empirical values as follows.

COD_{Cr} : 0.65 g/capita/day, T-N : 0.25 g/capita/day, T-P : 0.25 g/capita/day.

Non-point source pollution loads generation is summarized in *Table 3.2*.

It is assumed that atmospheric deposition loads are included in the unit loads generation of each land use pattern. The amount of atmospheric deposition loads on the lake surface is calculated separately as an input of WQSM. Following unit pollution loads generation of atmospheric deposition is determined based on Hungarian values for T-N and T-P, and on Japanese empirical value for COD_{Cr} due to lack of Hungarian data.

COD_{Cr} : 113.8 kg/ha/year, T-N : 17.7 kg/ha/year, T-P : 1.06 kg/ha/year.

(3) Pollution Loads Discharge Estimated by Existing Monitoring Data

Most of tributaries of Lake Balaton are steep and short, and their mean flows are generally very low. These characteristics result in peaky fluctuation of flow volume. It is well known that concentration of pollutants in flash flood is so high that conveyed pollution loads by flash flood may be equivalent to the loads for several weeks of average condition. However, most of such flash flood remain non-sampled due to a low frequency of present water quality monitoring, once a two to four weeks.

In order to estimate the pollutant loads discharge including the effect of flash flood, continuous pollution loads discharge are estimated based on rating curve between the loads and river flow for each tributary. This method requires both water quality data and continuous water level data. Therefore 10 tributaries, included in the water quality monitoring network with continuous water level recorder, are selected. Selected 10 tributaries are Burnot patak, Eger víz, Tapolca patak, Kéki patak, Füzfôi séd, Örvénesyi séd, Nemesvitai övárok, Jamai patak, Tetves patak, and Zala River.

The water level data of KDT VIZIG are digitized taking into account the changes in the level, i.e. there are more frequent data when the fluctuation of the level is large. Then, river flow data are obtained by the digitized water level data and water level-flow calibration curves (H-Q curves).

The rating curve between the pollution loads discharge and river flow is searched in a parabolic form as follows, according to previous study by VITUKI.

$$L = k_1 + k_2Q + k_3Q^2$$

where L = pollution loads discharge; Q = river flow; k_1, k_2, k_3 = constants.

Constants of above expression have physical meaning, i.e. k_1 represents a natural background of load, k_2 represents point sources, and k_3 represents surface runoff.

Best fit rating curves of each tributary are determined for 1994 and 1995. Analyzed water quality parameters are T-P, T-N, and COD_{Cr}. Constants of the best fit functions as well as the correlation coefficients are summarized in *Table3.4*. As a sample, the best fitting rating curves of Jamai patak are shown in *Figure 3.3*. For most of the rivers and most of the water quality parameters, parabolic approximation gives satisfactory results except for Tapolca patak. A plausible reason of very poor correlation of Tapolca patak is a serious influence of the effluent of the Tapolca Sewage Treatment Plant.

Pollution loads discharge of each selected tributaries is summarized in *Table 3.5*.

(4) Estimation of Runoff Ratio

Runoff ratios of selected 10 tributaries are calculated as shown in *Table 3.5*, based on the following equation.

$$Runoff\ Ratio = \frac{(Pollution\ Loads\ Generation - Point\ Source\ Loads)}{Non\text{-}point\ Source\ Loads\ Generation}$$

It shows that some runoff ratios of Kéki patak and Nemesvitai övárok exceed 1.0, which is impossible. Also some of the ratios of Tetves patak and Zala River are nearly 1.0. The reasons might be following factors.

- Unit pollution loads generation is underestimated.

- The continuous water level recorder of Nemesvitai övárok is installed so close to Lake Balaton that the lake water level influences recorded water level and this results in overestimation of river flow.

- In case of Zala River, Kis-Balaton II was just inundated just before the objective years, and intensive release of COD and nutrients from decayed vegetation occurred.

The reason of negative values of Tapolca patak for T-N can be attribute to the aforementioned overestimate of T-N loads from the Tapolca STP.

After the removal of the values of Kéki patak, Nemesvitai övárok, Tetves patak, and Zala River as well as values of Tapolca patak for T-N, general tendency of runoff ratio is extracted as follows:

- Runoff ratio for COD is below 0.4.

- Runoff ratio for T-N is below 0.4 except Füzfôi séd in 1995.

- Runoff ratio for T-P is below 0.2 except Tapolca patak in 1995.

Considering the safer side for prevention of lake eutrophication, the runoff ratio for remaining tributaries are determined as follows:

0.4 for COD_{Cr}, 0.4 for T-N, 0.2 for T-P.

In the direct catchment area, no data is available for pollution loads discharge. Then, it is assumed that most generated pollution loads reach the Lake, runoff ratio of the direct catchment areas is set 0.8 uniformly for the three parameters.

(5) Estimation of Pollution Load Discharge

Pollution loads discharge for each sub-catchment area is obtained by multiplying the estimated pollution loads generation by the runoff ratio. The result is shown in *Table 3.6.*and their summay is shown in Table 3.7.

In case of COD, T-N, and T-P load, contribution of the Zala catchment is high, i.e. COD: 63-65 % , T-N: 33-34 %, and T-P: 43-44 %. In comparison between the point and non-point sources, the non-point source contribute to COD 97 %, T-N 81-83 % and T-P 81-82 % of the totals.

(6) Approaches to Improve Pollution Load Analysis

For the improvement of accuracy and reliability of the pollution load analysis, intense monitoring and research activities should be continued towards following goals:

- Reliable estimation of annual pollution loads discharge of each sub-catchment including flash flood events.

- Reliable estimation of unit pollution loads generation by land use category.

- Reliable estimation of runoff ratios.

For the first goal, JICA Study Team installed five water quality and water level monitoring stations on four water courses, i.e. Burnót patak (upstream and downstream), Kéki patak, Baricskadûlôi árok, and Tetves patak. Each station is equipped with a data logger which records water level and various water quality parameters with 5 minutes frequency, and an automatic sampler which starts by rain intensity signal. Continuous monitoring with these stations will greatly contribute to improve the accuracy of pollution loads estimation during flash flood events.

Based on reliable estimation of annual pollution loads discharge, unit pollution loads generation by land use categories can be analyzed. This analysis requires selection of model sub-catchment areas characterized by certain feature like land use, dimension, slope, or soil type. Then a series of multiple regression analyses should be tested to extract relation between unit pollution loads and various parameters of the sub-catchment.

For the last goal, the runoff ratios currently applied are based on the existing monitoring data during 1994 and 1995 and different ratios are used in each year. However, in the estimation of the future discharges, the runoff ratio is required to be common through the years. Reliable runoff ratio also could be given by the continuos monitoring and analysis of the data.

3. LAKE BALATON WATER QUALITY SIMULATION MODEL (WQSM)

3.1 CONCEPTUAL STRUCTURE OF WQSM

WQSM is developed as a fully two dimensional water quality model aiming to investigate the impact of various nutrient loads and to assess the effects of eutrophication abatement measures. The application of a two dimensional model is rationalized by a significant effect of pollution loads from the direct catchment areas on the lake water quality, along with the two-dimensionality of the wind-driven hydrodynamics in the lake.

WQSM consists of two sub-components, *i.e.* a two-dimensional hydrodynamics model (2-D HDSM) and a completely mixed algal dynamics model (0-D WQSM). The conceptual structure of WQSM is shown in *Figure 3.4*

The characteristics of the lake hydrodynamics have been studied using the 2-D HDSM, incorporating local wind fetch and ground roughness effects using multi-station wind data. 2-D HDSM has been calibrated and verified using multiple storm event data.

The structure of 0-D WQSM is shown in *Figure 3.5* Since the predominant specie in the lake, *Cylindrospermopis raciborskii*, is not limited by nitrogen, this sub-component is a phosphorus cycle model simulating following four variables: PO_4-P, algal-P, detrital-P, and algal dry weight biomass. In addition, a concentration of chlorophyll-a (*Chla*) can be obtained as a function of algal biomass. Extensive parameter calibration and sensitivity studies of biogeochemistry of the lake have been undertaken using this sub-model.

The mass transport sub-model is driven by unsteady flow field generated by 2-D HDSM. Upon satisfactory calibration and verification, all the sub-models have been integrated to form WQSM.

3.2 TWO-DIMENSIONAL HYDRODYNAMICS MODEL (2-D HDSM)

(1) Governing Equations

The governing equations for the hydrodynamics model consist of the unsteady nonlinear version of the depth-integrated shallow water equations, including convective acceleration, quadratic bottom friction, surface wind shear stress, and Corioli's effect. The wind stress incorporates the local fetch effect. The horizontal eddy viscosity terms are evaluated locally based on the Smagolinski's (1963) LES approach. The dependent variables are the x and y components of specific flow rates, and the surface elevation. The external forcing factors are the wind stresses and inflows and outflows. *Table 3.8* shows the set of governing equations for the hydrodynamics component.

(2) Numerical Method

The computational scheme employs the Finite Element Method for its convenience in variable and arbitrary local resolution refinement as well as in detailed boundary-fitting capability. In addition, the "mass lumping" technique is applied to achieve optimal computational efficiency by eliminating matrix operations. The spatial resolution is of order of 10 to 100 meter, utilizing 7199 triangular elements of variable size. The final FEM discretization of Lake Balaton is shown in *Figure 3.6*. The mesh was generated by a mesh generator based on a strategy for near-constant Courant Number and was adjusted manually for local refinements. The mean water depth contours are drawn directly from the nodal depths of the elements. Using a workstation equipped with a DEC Alpha 433 Mhz CPU, a real-time simulation for 4 days with a 20-second time step takes approximately 12 minutes.

(3) Calibration and Verification of the Hydrodynamics Model

The influence of the wind overwhelms the slow hydrologic through flow in formation of the flow pattern in Lake Balaton. The shallowness of the lake results in fast response to winds, generating currents orders of magnitude greater than those produced by the through flow.

Such processes have been fully incorporated into 2-D HDSM using recorded storm events and wind data. Although the present hydrodynamics model involves only two adjustable parameters: the wind drag and the bottom roughness coefficients, some difficulties were encountered in interpreting available wind data. Wind data around the lake are sparse, at only four stations: Keszthely, Siófok, Balatonakali, and Balatonszemes.

The former two stations operated by OMSZ provide hourly wind data with 1 m/s - 10° resolution, averaged over 10 minutes, while the latter two operated by KDT-VIZIG unfortunately provide only 1.6 m/s - 45° resolution, also averaged over 10 minutes. In addition, the hills along the northern shoreline of the lake are known to generate local effects by blocking and deflecting the prevailing winds from the NW quadrant, producing non-uniform wind field over the lake surface. Keszthely station, located approximately 1 km inland from the western bay shore, typically records significantly lighter winds than the other stations. During the in-lake field survey undertaken by JICA Study Team in 1997, there were occasions when the in-lake wind magnitude at the center of Keszthely Bay was measured at 4 m/s while the inland station, less than 4 km apart, recorded 0 m/s wind simultaneously.

Thus, using these raw wind data from the 4 stations to generate unsteady two-dimensional wind stress fields by spatial interpolation would not be a good representation of the reality. The Keszthely wind data unarguably need to be adjusted for the land to water roughness translation, as well as for the effect of wind fetch over the water surface since the prevailing wind is almost always from the NW quadrant. For this reason, the Keszthely wind data are adjusted based on the procedure outlined by Cook (1985) for roughness change and fetch effect in which local in-lake wind speed is a function of down-wind distance from shoreline. The concept of effective fetch (CERC, 1974) is also applied to determine the fetch length. Since, the Siófok station is located right on the southern coast, downwind of the prevailing wind, such adjustments are deemed unnecessary. The wind data at Balatonakali and Balatonszemes were not utilized in the present study for their low directional resolution. Therefore, even with the adjustments, the sparsity of wind data could be a considerable source of inaccuracies in modeling the lake hydrodynamics.

2-D HDSM has been calibrated using wind data and water-level record taken during the storm event of March 31 to April 3, 1994. The used wind data is shown in *Figure 3.7*. *Figures 3.8 to 3.10* show the calibrated results. Based on these results, the bottom roughness has been optimized at n=0.02, and the Wu's (1973) wind drag coefficient as a function of wind speed has been selected for subsequent computations.

Figures 3.11 and *3.12* show the calibrated calculation results of water level contours and flow fields during the corresponding storm event. As the direction of the strong winds coincide with the longitudinal axis of the lake, current vectors are nearly uniformly pointed to Siófok Bay except at the very end of the bay where a weak clockwise gyre is formed. Expectedly, the corresponding water level contours are nearly perpendicular to the longitudinal axis, showing typical wind setup phenomena.

Two more cases of the calibrated calculations for hindcasting the past storm events are shown in *Figures 3.13 and 3.14*. The first case represents the storm event recorded by Muszkálay (1966) during the period July 8 to 9, 1963, and the second case correspond to the events recorded by KDT-VIZIG during May 26 to 30, 1993. In the first case, only the Keszthely wind data were applied, in both the adjusted and unadjusted forms, as the Siófok data are not available. In the second case, the Keszthely wind data were adjusted according to the aforementioned manner, while the Siófok winds were unadjusted. The results of hindcasting are generally satisfactory, indicating that the calibration procedure has been successful, while in the first case the water levels at Keszthely are less satisfactorily reproduced, presumably resulting from the inadequacy in wind data, both in terms of the density of recording stations as well as the temporal resolution.

3.3 COMPLETELY-MIXED BIOGEOCHEMICAL MODEL (0-D WQSM)

(1) Previous Models

1) BEM Model

The BEM model is the earliest developed by the Hungarian Balaton Ecological Modelers Group (Kutas and Herodek, 1982). Emphasis of the model is placed on description of the phytoplankton biomass and the daily primary production.

Kutas and Herodek (1986) applied BEM to the four basins of Lake Balaton to reproduce *Chla* concentrations in 1976 and 1977. The composition of algal species during that time was more complex than that in the 1990s, so that four different types of algae were dealt with in the calculation. However, the hindcasts of the peak values of *Chla* during the summer in the Keszthely and the Szigliget basins were not satisfactory. The calculated maximum was lower in 1976 and was significantly higher in 1977 than measurements.

2) BALSECT Model

The BALSECT model (Balaton Sector Model) was developed at the International Institute for Applied System Analysis (IIASA) based on an earlier more general phosphorus and nitrogen cycle model. It concentrates on the analysis of phosphorus compound transformation in the lake (Leonov, 1980).

BALSECT consists of five state variables, of which dissolved organic-P and bacterial-P are difficult, if not impossible, to analyze and to establish rate-constants. In addition, data for directly measured phosphorus fractions, necessary for the model calibration, such as total dissolved phosphorus, particulate inorganic, and phytoplankton-P are not readily available for investigation.

Leonov (1985) applied BALSECT to simulate a relatively long-term phosphorus cycle in the four basins of Lake Balaton during 1976~1979.

Computed results are within a range comparable to the measured values; however, disparities in phase and annual maximums are substantial.

3) SIMBAL Model

The SIMBAL model (Simplified Balaton Model), the most extensively studied model of the existing phytoplankton dynamics models for Lake Balaton, consists of a set of models designed especially to investigate various hypotheses regarding the modes of phosphorus interaction between the water and the sediment (van Straten, 1980).

In the calculation, the lake was divided into four basins assuming a constant hydrological exchange rate between the neighboring basins. Comparison between the calculations and measurements were made for the four basins of the lake only during a year of 1977. In addition, the distribution of the nutrient loads over the months of the year was simply based on an assumption.

Luettich and Harleman (1986) introduced a variable cell-quota concept into SIMBAL to improve the model performance (see also Baker, 1982). The model was applied only for the period between June and December, 1977 for the Keszthely basin. The calculated *Chla* concentrations compare favorably with the measurements, while PO_4-P concentrations remained below 1 μg/l during the growth period with some increase later in the year, an intuitively reasonable outcome.

(2) General Framework of 0-D WQSM

Since the growth of heterocytic cyanobacteria such as *C. raciborskii* is not limited by nitrogen, 0-D WQSM is a phosphorus cycle model as found in the previous models. Despite the considerable uncertainties in the sediment-water interaction processes of phosphorus, such processes are included in the model taking into account the importance of them on the algal growth.

0-D WQSM consists of four variable components, *i.e.* orthophosphate (PO_4-P), phytoplankton-P, detrital-P, and algal dry-weight biomass. In addition, the suspended sediment concentration that relates to the P-sorption processes and the light transmission are dealt with as variables.

Bottom sediment layer is not included as an independent variable since the mobile bottom layer, representing at least decades of accumulation, is well mixed and has no memory. Instead, emphasis is placed on addressing the bulk diffusion process from the bottom sediment, as well as the effect of wind-induced sediment re-suspension both in terms of the phosphorus exchange with the water column and the light attenuation. Most of the model parameters used in the model are based on existing data specifically for Lake Balaton substantiated by field and laboratory studies conducted during the past decades.

Within a water column, phosphorous removal is primarily due to the uptake by phytoplankton, and contribution by biogenic lime co-precipitation or adsorption by suspended sediment is negligible (Herodek, 1986).

Since it is reported that *C. raciborskii* can store phosphorus adequate for two cell division (Shafik *et al.*, 1997), a variable cell-quota sub-model is incorporated addressing the phosphorus storage ability of blue-greens such as *C. raciborskii*.

The suspended sediment (SS) concentration is dynamically calculated simultaneously with the four independent variables. The rate of phosphorus desorption from the sediment is modeled as a function of SS concentration.

The conceptual structure of 0-D WQSM is referred to *Figure 3.5* and its governing equations are shown in *Table 3.9*.

(3) Phytoplankton Dynamics

The overall growth rate is formulated by multiplying the maximum growth rate by limiting functions of internal nutrient, temperature, and light.

1) Nutrient limitation

The growth limiting factor for nutrients is formulated as a function of the internal level of PO_4-P in the algal cell. The internal concentration is defined as a "cell quota," *i.e.*, ψ= (internal mass of phosphorus in cells) / (dry weight biomass of cells). The internal nutrient level depends on the relative magnitude of the nutrient uptake rate and the algal growth rate. The uptake rate is a function of both the internal and the external nutrient concentrations, while the growth rate depends primarily on the internal one. A Monod type equation is used to calculate the external uptake rate, and an equation of Droop (1973) is used as the internal nutrient limitation.

An experiment by Shafik *et al.* (1997) showed that ψ_{max} and ψ_{min} of *C. raciborskii* are 1.4% and 0.32%, respectively. The ψ_{max} value corresponds to the P-storage capacity sufficient for two subsequent cell divisions in the absence of external phosphorus source. These values were somewhat modified in the calibration process, and were settled at ψ_{max} =1.8 % and ψ_{min}=0.2%.

2) Temperature limitation

The optimum growth temperature for *C. raciborskii* has been chosen at 30 °C. The growth rates measured by Shafik *et al.* (1997) are normalized by the maximum growth rate. The obtained curve fits well to the temperature limiting function formulated by Lerman *et al.* (1975) by selecting the optimum, and the upper and lower limits at 30, 40, and 18 °C, respectively.

3) Light limitation

A laboratory experiment found that the growth of *C. racborskii* is not inhibited by strong light intensities, indicating that a saturation type of light limiting growth function is needed (KDT-KÖVIZIG, 1988). The Steele's light limiting equation is, therefore, modified to a non-inhibiting function as shown in *Table 3.10.* The function $f(I)$ is integrated over the depth for use in the 0-D and 2-D models. The magnitude of the integrated function, $\bar{f}(I)$, is quite sensitive to the light extinction coefficient K_e. Taking the average depth of 2 m in the Keszthely basin, and using K_e =1.0 and 3.0 m^{-1}, a commonly observed range, $\bar{f}(I)$ value with K_e =1.0 becomes more than twice that with the latter K_e. This exemplifies the model sensitivity to the extinction coefficient.

Taking into account that algal growth can also be limited by the light attenuation, resulting from the wind-induced sediment re-suspension in Lake Balaton, the extinction coefficient needs to be modeled as a function of SS concentration. Since SS concentration can be calculated by using physically straightforward manner, *i.e.* based on the bottom shear stress, the model employs to correlate extinction coefficients with SS concentrations directly.

To develop formulations to correlate the extinction coefficient to SS and *Chla* combined, vertical light quanta were measured at every 50 cm depth at several locations in the entire lake by JICA Study Team in June, July, and August 1997.

A local extinction coefficient, K_e, at each location was calculated based on Lambert-Beer's law. Correlation between the calculated and the measured value is high, with better than r=0.98. Relatively low *Chla* concentrations during the survey, less than 20 μg/l, enables to subtract *Chla*-induced extinction coefficient, $K_{e,Chla}$, from total coefficient, K_e, by using a simple relationship : $K_{e,Chla}$ [m^{-1}] = 0.02 *Chla* [μg/l] (Matsuoka, 1984) with $K_e = K_{e,Chla} + K_{e,SS}$. This procedure yields an equation of SS -induced extinction coefficient, $K_{e,SS}$.

Then an equation of $K_{e,Chla}$ for a wider range of *Chla* is derived based on data taken by KDT-KÖFE for *Chla,* SS and secchi depth during June and October from 1984 to 1996. Combining both the equations, the total extinction coefficient can be expressed as follows.

$$K_e\,[m^{-1}] = 0.2 + 0.059\ SS\ [mg/l] + 0.019\ Chla\ [\mu g/l]$$

The second factor for SS contribution is similar to that of Di Toro (1978) and the third factor for *Chla* is comparable to that of Matsuoka (1984).

(4) Suspended Sediment Modeling

Suspended sediment concentrations in the lake are calculated using the method by Luettich *et al.* (1990) as shown in *Table 3.11.* The stress by the mean current is disregarded by comparison to the stress by the wind-induced wave actions. Wave heights utilized for the suspended sediment sub-model are evaluated using the shallow-water modifications to the SMB method presented by CERC (1974) as shown also in *Table 3.11*.

The predicted wave heights as well as SS concentrations in Keszthely Bay are in good agreements with the measurements by Luettich *et al.* (1990), with a slight modification of the best fitting parameters from those used in the measurement. Although the minimum SS concentration of 15 mg/l was suggested by Luettich *et al.* (1990), measurements undertaken by JICA Study Team yielded a lower value at 5 μg/l. The latter value is used as the background concentration in the model.

(5) Internal Nutrient Loads Modeling

1) Sediment characteristics

The mixing layer thickness of the bottom sediment by wave-motion and currents is about 10 cm (Lijklema et al., 1983). Since annual maximum sediment deposition rate is about 3 mm (Lijklema, 1983; Herodek, 1989), time required for the deposition of the mixed layer can be estimated at least 33 years.

Another estimate yields an accumulation time of about 20 years for the 10 cm surface layer, by taking an average T-P contents in the sediment of 0.8 mg-P/g-dry sediment, with a dry sediment density of 2.6 g/cm^3, with 11 % dry sediment per unit volume, and with T-P load of 1.2 g/m^2/year.

Sediment core data support the estimate for the mixing layer thickness. Average phosphorus concentrations of 11 sediment cores taken along Lake Balaton in 1978 and 1995 show that T-P distributions are nearly uniform in the top 10-cm layer of the sediment cores (Dobolyi, 1995). The differences of T-P concentrations between the 0~5 and the 5~10 cm layers are less than 5 %. Even sediment core samples taken in the area 20~100 m offshore in the northern Keszthely Bay, where the bottom disturbance is expected to be minimal owing to the shortest fetch in the prevailing wind direction, exhibit small vertical variance in phosphorous concentration, average T-P concentrations in 0~10 cm and 10~20 cm layers differ only 8 % (BVK, Balaton Branch Office, 1992). Similarly, average of 23 samples taken in the same area shows only 5 % difference in the 0~10 and the 10~20 cm layers (KDT-VIZIG Report, 1994).

2) Diffusion process

More than 95% of total dissolved phosphorus released from intact sediment cores is in the form of PO_4-P (Istvánovics 1988). In the model, only PO_4-P release is considered in the diffusion process.

The phosphorus release from intact sediment cores taken at the center of the four basins were measured by JICA Study Team in August 1997. The results were 0.9~2.8 mg-P/m^2/day on the third day of incubation. The values are very similar to those measured by Istvánovics (1988), which varied seasonally between -0.5 and 2.8 $mg/m^2/day$ after 2~4 days of incubation, the latter maximum observed during the summer. Another set of experiments shows a higher release rate of 4 $mg\text{-}P/m^2/day$ corresponding to the maximum pH value of 9.2 during the summer (Istvánovics, 1988).

Another approach yields release rates of 0.2~10.0 $mg\text{-}P/m^2/day$, using a diffusion coefficient of 10^{-9} m^2/s with mixing-layer thickness of 2~20 cm, and an interstitial PO_4-P concentration in a range of 50~250 mg/m^3 (Lijklema *et al.* 1986).

A first order bulk-diffusion equation has been adopted in the current model as shown in *Table 3.9.* An equilibrium concentration of PO_4-P in the sediments is modeled using an interstitial PO_4-P level multiplied by a temperature correction factor corresponding to greater rate of phosphorus release during the summer season. The exchange rate has been chosen within the range found by Lijklema et al. (1986) taking into consideration that laboratory-measured rates tend to underestimate (Andersen, 1974; Ryding and Forsberg, 1977; Bostrom, 1982). The chosen release rate varies from 0.3 to 10 $mg\text{-}P/m^2/day$ in the range of 5~25°C water temperature, with the parameters listed in *Table 3.12.* There is a room for further study in the estimation of the release rates to narrow down the uncertainties in the laboratory values.

3) Sorption process

The rate of phosphorus adsorption by calcite-rich sediments in Lake Balaton is slow, taking 7 to 10 hours to attain equilibrium (Gelencser *et al.*, 1982, Istvánovics *et al.*, 1989). On the other hand, desorption process completes within 30 minutes. A threshold concentration, at which neither adsorption nor desorption takes place, determined from Langmuir isotherm is in the range of 10 to 18.1 μg/l (Istvánovics *et al.*, 1989). Since PO_4-P level in the lake water seldom exceeds 10 μg/l (Presing *et al.*, 1996), only the desorption process is considered in the model.

Phosphorus liberated from re-suspended sediments through the desorption process was calculated based on an experiment by Gelencser *et al.* (1982). In the experiment, increase in PO_4-P concentration was measured in triplicate with the same sediment samples using lake water, without addition of phosphorus but with SS concentrations in a range of 70 to 1300 mg/l, allowing a reaction time of 30 minutes. The result shows the desorption rate, defined as the PO_4-P increase per unit DM (dry material of SS), varies 5~15 μg-P/g-DM. However, the large scatter arising from uncertainties in the laboratory analysis does not allow to correlate the desorption rate to equilibrium SS concentration. The desorption rate in the model is, therefore, presumed as a constant at 10 μg-P/g-DM, the average value of the abovementioned experiment.