(6) Input Data

The input data for 0-D WQSM include; daily loads from Zala River, direct runoff, and atmospheric deposition; hourly wind; water-temperature measured once a day at 7:00 am; daily total solar radiation; and daily water level.

The loads from Zala River, direct runoff, and atmospheric deposition are considered as the external loads to Keszthely Bay. Daily measurement data for PO_4-P, T-P, and *Chla* are available for Zala River. Annual T-P load by the direct runoff estimated by PLDB is converted into daily load in proportion to the precipitation in the area. Contribution of PO_4-P in T-P is determined by measurements conducted by JICA Study Team. Atmospheric deposition data are assembled by using measurements for PO_4-P and T-P (Hidrological Kozlony, 1973) and daily precipitation (OMSZ).

The physical data except solar radiation, *i.e.* wind data, water temperature data, and water level data are linearly interpolated at every time step. The daily total solar radiation is distributed assuming a sinusoidal function each day from sunrise to sunset.

The data set of the year 1994 is utilized for calibration of 0-D WQSM, since the year was an anomaly in view of the extent of algal bloom, which spread to the entire lake basin and the maximum *Chla* reached 210 μg/l in the Keszthely basin. In addition, the Zala River load in 1994 is more representative of the current load condition than that in the earlier years prior to the completion of Kis-Balaton II.

The data set of the following year, 1995, is also utilized to test the multi-year reproducibility of the calibrated model. The year 1995 was noted for low productivity in the lake despite the steady trend in nutrients load condition.

(7) Calibration of 0-D WQSM

The equations of the four dependent variables shown in *Table 3.9* were solved using 4th-order Runge-Kutta method with a time step of 0.005 hour. The short time step was required to obtain stable solutions at very low PO_4-P levels. Start-time of the calculation was chosen just after the spring diatom-bloom when measured records are available. The initial conditions were taken as average values of *Chla* and T-P measured at the center and two locations near the west coast of Keszthely Bay. The calculation was terminated when the summer algal-bloom ceased. Simulated results were compared with measurements taken by KDT-KÖFE at three locations in Keszthely Bay indicated in *Figure 3.15*.

The calibration process was focused on matching the measured and calculated *Chla* due to the difficulty of using T-P and PO_4-P for the following reasons:

- PO_4-P analysis, for low levels of PO_4-P concentrations as in the lake, by KDT-KÖFE is unreliable (Herodek, 1986). Concentrations of PO_4-P of the lake water analyzed by KDT-KÖFE in 1994 ranged 0~108 μg/l with an average of 20 μg/l, while those analyzed by Présing, Herodek, Vörös, and Kóbor (1996) were within 0~ 4 μg/l.

- Major fraction of SS is formed by $CaCO_3$ and T-P (Tóth *et al.*, 1975), and large fluctuations of T-P concentration in the lake water have been observed. However, no data are available for the phosphorous release from SS other than in the form of PO_4-P. Therefore, T-P was excluded from the calibration process.

Alhough the model employs the parameters supported by existing data taken from field and laboratory studies for Lake Balaton, there still remain some uncertainties in those studies as well as in the model itself. Thus, the relevancy of model parameter were verified through extensive sensitivity analyses by changing the parameters within realistic range. Selected model parameter values are listed in *Table 3.12* with references.

Figure 3.16 shows calculated *Chla* in 1994 using the standard parameter values. In the figure, the measured *Chla* values were taken from the database at KDT-KÖFE except those at the center of Keszthely Bay in 1994 which were taken from Présing *et al.* (1996), whose data conform to the measurements taken by KDT-KÖFE except the peak value. The calculated *Chla* transition in 1994 reproduces the timing and the maximum peak as well as the overall trend very favorably. The PO_4-P level during the bloom stays at less than 1 μg/l, in agreement with the measurements by Présing *et al.* (1986).

A hindcast of *Chla* in 1995 was also performed using the same parameter values. The result is shown in *Figure 3.17*. The figure shows that the hindcast prominently replicates the much lower levels of *Chla*, 50 μg/l at the maximum, as compared to 1994. The lower water temperature is the most probable reason of the much lower productivity (Tóth and Padisák 1986; Padisák and Istvánovics, 1996). When the water temperature of 1995 is replaced by that of 1994, the maximum *Chla* approaches close to the 1994 level as shown in *Figure 3.17*, underlining the critical role of water temperature in the explosive algal bloom.

3.4 TWO DIMENSIONAL WATER QUALITY MODEL (WQSM)

(1) General Framework

A two-dimensional mass transport model has been developed, and 0-D WQSM has been incorporated into the mass transport model to form the two-dimensional water quality model (WQSM).

The mass transport equation of WQSM is a simultaneous set of multiple vertically integrated two-dimensional convective-dispersion equations, representing each of the modeling constituents in a water column including the reaction and source/sink terms as shown in *Table 3.13*. In the equation, R_i represents the combined biogeochemical reactions and internal source/sink terms arising from 0-D WQSM. The convective terms are driven by the two-dimensional flow fields generated by 2-D HDSM. The dispersion terms are evaluated as local parameters using the Smagorinsky's LES concept.

(2) Numerical Method of WQSM

The computational method for WQSM also utilizes the finite element method that is compatible with 2-D HDSM and shares the same mesh. The time-integration method utilizes a special implicit scheme to eliminate matrix operations as with the case for 2-D HDSM. The approach can achieve optimal computational efficiency with a significantly larger time step than in the usual explicit schemes.

(3) Parameter Adjustments

The property of the sediments differs between eastern and western basins. Although the sediment in Keszthely Bay is finer than those in the Szemes and Siófok basins, the former has about 3 to 4 times greater settling velocity than the latter (Somlyódy and Koncsos, 1991). In the 2-D computations, therefore, calibration of SS-related parameters in the eastern basins is also required as undertaken for Keszthely Bay. Measured SS data in the Siófok basin have been used for the calibration process in which the best-fit values for settling velocity and critical wave height are 0.018 cm/s and 14.3 cm, respectively, while those for Keszthely Bay are 0.022 cm/s and 0.0 cm. The differences are distributed in proportion to the square root of the normalized distance from Keszthely along the major axis of the lake.

Phosphorus diffusion rate in the Siófok basin is lower than that in Keszthely Bay, reflecting a difference in the mobilizable phosphorus contents in the sediments in the two areas (Istvánovics, 1988). The maximum diffusion rates of 0.3 in the Siófok basin and 2.8 mg-P/m^2/day in the Keszthely basin were measured by Istvánovics in 1980, while those measured by JICA Study Team in August 1997 are 0.9, 2.2, 2.9, and 2.1 mg-P/m^2/day on the third day of incubation, in the Siófok, the Szemes, the Szigliget, and the Keszthely basins, respectively. Although the variance among the data is rather large, the equilibrium concentrations are varied from a basin to a basin in proportion to the values measured by JICA Study Team.

(4) Input Database for WQSM

WQSM requires following data.

- Initial values of *Chla*, PO_4-P, T-P and SS in each of the four basins
- Daily loads from major tributaries
- Distributed direct runoff from 19 sub-regions
- Atmospheric deposition loads

- Hourly wind at the Keszthely and the Siófok stations
- Daily water-temperature at four stations in each basin
- Daily total solar radiation at the Keszthely station
- Daily precipitation at the Balatonakali and the Balatonszemes stations

Initial values of *Chla*, PO_4-P, T-P and SS in each of the four basins are determined by using measured values at station in the basin, and by distributing uniformly within a basin. Selected stations of measurement are 04FB03 in the Siófok basin, 04FB08 in the Szemes basin, 04FB17 in the Szigliget basin, and 04FB16 in the Keszthely basin, as shown in *Figure 3.15.*

Data of external loads from major tributaries, direct runoff, and atmospheric deposition are prepared by PLDB. Remaining physical data as well as water quality data are compiled together as an input database (IPDB).

Since the water temperature varies among the basins, higher toward the west as shown in *Figure 3.18,* measured water temperatures at the four stations are linearly interpolated along the major axis of the lake.

The input data, except the solar radiation, are linearly interpolated in time at every time step as in the case of 0-D WQSM calculations. The daily total solar radiation is distributed sinusoidally from sunrise to sunset in the manner as used in 0-D WQSM. The wind magnitudes and directions recorded at the Siófok weather station in 1994 and 1995 are shown in *Figures 3.19* and *3.20.*

(5) Verification of WQSM

Figure 3.21 shows computed SS distributions in the lake under two distinct wind events on July 4 and August 26 in 1994. In the former case, high concentrations of SS prevail in the southern region of Keszthely Bay corresponding to the northerly winds of about 5 m/s for 5 hours measured at the Keszthely station. In the latter case, the persistent easterly strong wind blow of 10~14 m/s for 12 hours at the Siófok station resulted in very high concentrations, about 180 mg/l, in the Siófok and the Szemes basins.

Figures 3.22 and *3.23* show the computed *Chla* distributions in 1994 and 1995 when *Chla* levels reached the maximum during the respective year. As seen in both the figures, the maximum *Chla* concentrations occurred in the Keszthely basin, while the minimum spread over the Siófok basin.

Figures 3.24 and *3.25* are comparisons of the computed and the measured time-series of *Chla* values for 1994 and 1995 at the four stations of measurement. The computed time-series of *Chla* for both 1994 and 1995 compare favorably with the measurements at all the locations, capturing the overall trends effectively in the respective year. Nonetheless, in 1994, *Chla* levels at the Szigliget station are considerably lower than the measurements, and in 1995, the computed values are somewhat higher than the measurements in all the basins. Also, in 1994, there are significant phase lags between the computed and measured *Chla* except for the Keszthely basin. Whereas the peaks of computed *Chla* in the four basins occur simultaneously corresponding to the water temperature peaks, the measured *Chla* trails behind the temperature trend, notably eastward to the Siófok basin.

The most probable cause of this phase lags is attributed to the possibility that the water temperature data do not represent the reality. The measuring points are sparse and measurements are infrequent, only once a day at 7:00 am, when the water temperature is expected to be near its daily minimum. A diurnal temperature variation in shallow water bodies can easily exceed few Celsius degrees in a summer climate. Actual diurnal variation of vertical water temperature profile, observed by JICA Study Team at the center of Keszthely Bay on September 3, 1997, show that the surface water temperature varied from 22.5°C to 25.9°C, while that at the depth of 2.5 m stayed constant at 21.1°C. The sparse and infrequent water temperature records measured at an unspecified depth only once a day, cannot represent the transition of daily maxima in the upper water both in terms of their extents and phase lags.

In spite of this phase rag problem, WQSM has been confirmed to be able to hindcast *Chla* concentrations in 1994 and 1995, the two contrasting years in terms of algal productivity. WQSM is, therefore, believed to be qualified for prediction of *Chla* to a variety of weather and nutrient-load conditions.

4. CONCLUDING REMARKS

Whereas there are some uncertainties in both pollution load analysis and biogeochemical process of the lake, mainly due to an insufficiency of available data, JICA Study Team has managed to develop a set of decision making tools successfully.

The combination of PLDB and WQSM can demonstrate the attained lake water quality by various measures taken for the lake environmental improvement. This makes it possible to evaluate the effect and cost effectiveness of those measures.

Table 3.1 Point Source Pollution Loads in 1994 and 1995

PLM Code	Sub-Catchment	Name of Point Source	Point Source Pollution Loads in 1994			Point Source Pollution Loads in 1995		
			T-P load (kg/year)	T-N load (kg/year)	COD load (ton/year)	T-P load (kg/year)	T-N load (kg/year)	COD load (ton/year)
E-4	Tavi sed	Diana Camping STP.	4	118	0.1	7	318	0.2
E-5	direct	Holiday Camping STP., ZankaGyermekudul STP.	81	3,688	3.3	73	3,426	1.8
E-6	direct	Revfulop STP.	146	7,366	7.0	97	9,889	2.8
E-8	direct	Badacsonytomaj StP.,Badacsony STP.	168	4,256	8.6	211	8,555	7.1
E-9	Tapolca patak	Tapolca varos STP.	2,769	127,398	46.8	1,954	87,096	36.8
Northern Catchment Area TOTAL			3,168	142,826	65.7	2,342	109,284	48.7
D-7	Nyugati ovcsatorna	Balatonnujlak STP., Marcali STP., Baltonbereny STP.	1,406	32,581	63.4	1,240	39,158	63.8
Southern Catchment Area TOTAL			1,406	32,581	63.4	1,240	39,158	63.8
Zala	direct	Balatongyorok STP.	590	33,120	12.7	316	21,629	8.8
	Zala river	Keszthely STP., Heviz STP., Zalakalos STP., Zalaszentgrot STP., Zalaegerszeg STP., Zalaapati STP., Zalakomar STP., Sarmellek STP.	13,297	315,085	407.9	16,071	329,893	423.8
Zala Catchment Area TOTAL			13,887	348,205	420.5	16,387	351,522	432.6
Total Catchment Area			18,461	523,612	549.6	19,969	499,964	545.1

Note1 : STP=Sewage Treatment Plant
Note2 : The unit of COD loads is in "ton/yr", while those of TP and TN loads are in "kg/yr".

Table 3.2 Land Use Pattern and Non-point Source Pollution Loads Generation

PLM code	Sub-catchment	Pollution Loads from Each Land Use Pattern																				Pollution Loads from Untreated Gray Water			Total Non-point Source Pollution Loads Generation		
		Urban				Arable land				Pasture & Meadow				Forest				Vineyard & Orchard									
		Area (ha)	TP (kg/yr)	TN (kg/yr)	COD (ton/yr)	Area (ha)	TP (kg/yr)	TN (kg/yr)	COD (ton/yr)	Area (ha)	TP (kg/yr)	TN (kg/yr)	COD (ton/yr)	Area (ha)	TP (kg/yr)	TN (kg/yr)	COD (ton/yr)	Area (ha)	TP (kg/yr)	TN (kg/yr)	COD (ton/yr)	TP (kg/yr)	TN (kg/yr)	COD (ton/yr)	TP (kg/yr)	TN (kg/yr)	COD (ton/yr)
E-1	direct	1,049	2,832	20,665	295.8	1,224	967	36,230	25.2	47	26	780	1.5	0	0	0	0.0	428	338	12,669	8.8	0	0	0.0	4,163	70,344	331.3
	Cinege patak	4	11	79	1.1	772	610	22,851	15.9	0	0	0	0.0	322	97	1,159	13.8	196	155	5,802	4.0	0	0	0.0	873	29,891	34.8
E-2	direct	877	2,368	17,277	247.3	1,168	923	34,573	24.1	0	0	0	0.0	250	75	900	10.8	65	51	1,924	1.3	0	0	0.0	3,417	54,674	283.5
	Fuzfoi sed	271	732	5,339	76.4	51	40	1,510	1.1	30	17	498	1.0	521	156	1,876	22.4	19	15	562	0.4	0	0	0.0	960	9,785	101.3
E-3	direct	693	1,871	13,652	195.4	291	230	8,614	6.0	124	68	2,058	3.9	614	184	2,210	26.4	877	693	25,959	18.1	45	267	6.0	3,091	52,760	255.8
	Vorosberenyi sed	309	834	6,087	87.1	1,091	862	32,294	22.5	408	224	6,773	13.0	677	203	2,437	29.1	348	275	10,301	7.2	329	1,972	42.0	2,727	59,864	200.9
	Lovasi sed	39	105	768	11.0	748	591	22,141	15.4	187	103	3,104	5.9	1,168	350	4,205	50.2	454	359	13,438	9.4	255	1,532	33.0	1,763	45,188	124.9
E-4	direct	873	2,357	17,198	246.2	817	645	24,183	16.8	197	108	3,270	6.3	676	203	2,434	29.1	486	384	14,386	10.0	0	0	0.0	3,697	61,471	308.4
	Csopaki sed	7	19	138	2.0	201	159	5,950	4.1	84	46	1,394	2.7	832	250	2,995	35.8	0	0	0	0.0	0	0	0.0	474	10,477	44.6
	Aracsi sed	30	81	591	8.5	192	152	5,683	4.0	28	15	465	0.9	1,224	367	4,406	52.6	10	8	296	0.2	0	0	0.0	623	11,441	66.2
	Keki patak	107	289	2,108	30.2	124	98	3,670	2.6	44	24	730	1.4	562	169	2,023	24.2	11	9	326	0.2	0	0	0.0	589	8,857	58.6
	Szolosi sed	85	230	1,675	24.0	814	643	24,094	16.8	119	65	1,975	3.8	953	286	3,431	41.0	274	216	8,110	5.6	153	918	20.0	1,593	40,203	111.2
	Tavi sed	17	46	335	4.8	295	233	8,732	6.1	153	84	2,540	4.9	553	166	1,991	23.8	59	47	1,746	1.2	51	303	6.0	627	15,647	46.8
E-5	direct	210	567	4,137	59.2	1,067	843	31,583	22.0	395	217	6,557	12.6	2,329	699	8,384	100.1	949	750	28,090	19.5	66	395	8.0	3,142	79,146	221.4
	Orvenesyi sed	54	146	1,064	15.2	722	570	21,371	14.9	177	97	2,938	5.6	1,087	326	3,913	46.7	529	418	15,658	10.9	153	919	20.0	1,710	45,863	113.3
E-6	direct	196	529	3,861	55.3	125	99	3,700	2.6	119	65	1,975	3.8	900	270	3,240	38.7	762	602	22,555	15.7	88	530	11.0	1,653	35,861	127.1
	Csorszai patak	60	162	1,182	16.9	358	283	10,597	7.4	464	255	7,702	14.8	609	183	2,192	26.2	639	505	18,914	13.2	161	966	21.0	1,549	41,553	99.5
	Horogi sed	19	51	374	5.4	124	98	3,670	2.6	157	86	2,606	5.0	202	61	727	8.7	317	250	9,383	6.5	0	0	0.0	546	16,760	28.2
E-7	direct	0	0	0	0.0	0	0	0	0.0	0	0	0	0.0	0	0	0	0.0	18	14	533	0.4	0	0	0.0	14	533	0.4
	Burnot patak	273	737	5,378	77.0	2,437	1,925	72,135	50.2	2,041	1,123	33,881	64.9	2,652	796	9,547	114.0	834	659	24,686	17.2	378	2,267	48.0	5,618	147,894	371.3
E-8	direct	88	238	1,734	24.8	88	70	2,605	1.8	147	81	2,440	4.7	556	167	2,002	23.9	1,056	834	31,258	21.8	0	0	0.0	1,390	40,039	77.0
	Eger viz	867	2,341	17,080	244.5	12,065	9,531	357,124	248.5	6,791	3,735	112,731	216.0	14,846	4,454	53,446	638.4	1,517	1,198	44,903	31.3	1,813	10,877	232.0	23,072	596,161	1,610.7
E-9	direct	41	111	808	11.6	128	101	3,789	2.6	212	117	3,519	6.7	109	33	392	4.7	13	10	385	0.3	0	0	0.0	372	8,893	25.9
	Tapolca patak	449	1,212	8,845	126.6	1,357	1,072	40,167	28.0	1,595	877	26,477	50.7	660	198	2,376	28.4	440	348	13,024	9.1	275	1,651	35.0	3,982	92,540	277.8
E-10	direct	58	157	1,143	16.4	346	273	10,242	7.1	237	130	3,934	7.5	266	80	958	11.4	0	0	0	0.0	223	1,337	29.0	863	17,614	71.4
	Ketoles patak	107	289	2,108	30.2	776	613	22,970	16.0	1,165	641	19,339	37.0	1,878	563	6,761	80.8	40	32	1,184	0.8	0	0	0.0	2,138	52,362	164.8
	Vilagos patak	15	41	296	4.2	386	305	11,426	8.0	901	496	14,957	28.7	775	233	2,790	33.3	0	0	0	0.0	0	0	0.0	1,075	29,469	74.2
	Lesence patak	270	729	5,319	76.1	1,542	1,218	45,643	31.8	854	470	14,176	27.2	5,934	1,780	21,362	255.2	113	89	3,345	2.3	528	3,167	68.0	4,814	93,012	460.6
	Nemesvitai Ovarok	34	92	670	9.6	429	339	12,698	8.8	157	86	2,606	5.0	93	28	335	4.0	0	0	0	0.0	74	445	9.0	619	16,754	36.4
Northern Catchment area TOTAL		*7,102*	*19,177*	*139,911*	*2,002.8*	*29,738*	*23,493*	*880,245*	*612.9*	*16,833*	*9,256*	*279,425*	*535.5*	*41,248*	*12,377*	*148,492*	*1,773.7*	*10,454*	*8,259*	*309,437*	*215.4*	*4,592*	*27,546*	*588.0*	*77,154*	*1,785,056*	*5,728.3*
D-1	direct	469	1,266	9,239	132.3	618	488	18,293	12.7	421	232	6,989	13.4	648	194	2,333	27.9	103	81	3,049	2.1	0	0	0.0	2,261	39,903	188.4
	Endredi patak	124	335	2,443	35.0	1,635	1,292	48,396	33.7	212	117	3,519	6.7	978	293	3,521	42.1	0	0	0	0.0	259	1,555	33.0	2,296	59,434	150.5
D-2	direct	171	462	3,369	48.2	3	2	89	0.1	8	4	133	0.3	0	0	0	0.0	0	0	0	0.0	0	0	0.0	468	3,591	48.6
	Koroshegyi sed	288	778	5,674	81.2	1,353	1,069	40,049	27.9	503	277	8,350	16.0	1,226	368	4,414	52.7	31	24	918	0.6	103	620	13.0	2,619	60,025	191.4
D-3	direct	695	1,877	13,692	196.0	845	668	25,012	17.4	20	11	332	0.6	750	225	2,700	32.3	211	167	6,246	4.3	57	339	7.0	3,005	48,321	257.6
	Nagymetszes patak	552	1,490	10,874	155.7	6,478	5,118	191,749	133.4	754	415	12,516	24.0	2,262	679	8,143	97.3	457	361	13,527	9.4	400	2,399	51.0	8,463	239,208	470.8
D-4	direct	301	813	5,930	84.9	94	74	2,782	1.9	143	79	2,374	4.5	0	0	0	0.0	33	26	977	0.7	0	0	0.0	992	12,063	92.0
	Tetves patak	242	653	4,767	68.2	4,294	3,392	127,102	88.5	798	439	13,247	25.4	3,920	1,176	14,112	168.6	727	574	21,519	15.0	466	2,794	60.0	6,700	183,541	425.7
	A-B-C csatorna	44	119	867	12.4	208	164	6,157	4.3	299	164	4,963	9.5	129	39	464	5.5	381	301	11,278	7.8	9	55	1.0	796	23,784	40.5
D-5	direct	287	775	5,654	80.9	0	0	0	0.0	15	8	249	0.5	0	0	0	0.0	0	0	0	0.0	0	0	0.0	783	5,903	81.4
	Forro arok	72	194	1,418	20.3	355	280	10,508	7.3	112	62	1,859	3.6	41	12	148	1.8	200	158	5,920	4.1	0	0	0.0	706	19,853	37.1
	Jamai patak	358	967	7,053	101.0	2,611	2,063	77,286	53.8	159	87	2,639	5.1	806	242	2,902	34.7	701	554	20,750	14.4	389	2,331	50.0	4,302	112,961	259.0
D-6	direct	265	716	5,221	74.7	0	0	0	0.0	12	7	199	0.4	16	5	58	0.7	0	0	0	0.0	0	0	0.0	728	5,478	75.8
	Kelet- Nyugti Focsatorna	130	351	2,561	36.7	2,188	1,729	64,765	45.1	365	201	6,059	11.6	0	0	0	0.0	540	427	15,984	11.1	196	1,176	25.0	2,904	90,545	129.5
	Keleti bozot	1,278	3,451	25,177	360.4	18,028	14,242	533,629	371.4	1,060	583	17,596	33.7	4,840	1,452	17,424	208.1	272	215	8,051	5.6	2,607	15,644	334.0	22,550	617,521	1,313.2
D-7	direct	1,047	2,827	20,626	295.3	1,205	952	35,668	24.8	215	118	3,569	6.8	397	119	1,429	17.1	47	37	1,391	1.0	152	927	20.0	4,205	63,610	365.0
	Nyugati ovcsatorna	2,500	6,750	49,250	704.8	36,379	28,739	1,076,818	750.0	6,457	3,552	107,186	205.2	20,082	6,025	72,296	862.7	687	543	20,335	14.5	2,692	16,150	345.0	48,301	1,342,035	2,882.2
Southern Catchment Area TOTAL		*8,823*	*23,824*	*173,815*	*2,488.0*	*76,294*	*60,272*	*,258,303*	*1,572.3*	*11,553*	*6,356*	*191,779*	*367.3*	*36,095*	*10,829*	*129,944*	*1,551.5*	*4,390*	*3,468*	*129,945*	*90.6*	*7,330*	*43,990*	*939.0*	*112,079*	*2,927,776*	*7,008.7*
Zala	direct	1,093	2,951	21,532	308.2	974	769	28,830	20.1	224	123	3,718	7.1	2,291	687	8,248	98.5	80	63	2,368	1.6	24	142	3.0	4,617	64,838	438.5
	Zala river	10,549	28,482	207,815	2,974.8	128,699	101,672	3,809,490	2,651.2	25,054	13,780	415,896	796.7	78,327	23,498	281,977	3,368.1	2,374	1,875	70,270	48.9	18,692	111,611	2,381.0	187,999	4,897,059	12,220.7
Zala Catchment Area TOTAL		*11,642*	*31,433*	*229,347*	*3,283.0*	*129,673*	*102,441*	*,838,320*	*2,671.3*	*25,278*	*13,903*	*419,614*	*803.8*	*80,618*	*24,185*	*290,225*	*3,466.6*	*2,454*	*1,938*	*72,638*	*50.5*	*18,716*	*111,753*	*2,384.0*	*192,616*	*4,961,897*	*12,659.2*
Total Catchment Area		*27,567*	*74,434*	*543,073*	*7,773.8*	*235,705*	*186,206*	*,976,868*	*4,856.5*	*53,664*	*29,515*	*890,818*	*1,706.6*	*157,961*	*47,391*	*568,661*	*6,791.8*	*17,298*	*13,665*	*512,020*	*356.5*	*30,638*	*183,289*	*3,911.0*	*381,849*	*9,674,729*	*25,396.2*

Note : The unit of COD load is in "ton/yr", while those of TP and TN loads are in "kg/yr".

Table 3.3 Empirical Values of Unit Pollution Loads Generation

			T-P	T-N	COD	Source
Human life (g/day/capita)		Japan	1.2	12	28*	①
		Hungary(1)	2	12	100	②
		Hungary(2)	3.0			③
Land use (kg/ha/year)	City, Town	Japan	2.7	19.7	141*	①
		Hungary(1)	1.89	9.45		④
		Hungary(2)	1.1～5.6	6.0～10		⑤
		Hungary(3)	2.91～4.83	52.6～66.2	208～610	⑧
		Hungary(4)	0.53～1.54	2.0～9.7	9.4～73.9	⑨
	Arable land	Japan	0.79	29.6	10.3*	①
		Hungary(1)	1.68	5.37		④
		Hungary(2)	0.7～8.2	0.7～53		⑤
	Pasture	Japan**	0.55	16.6	15.9*	①
		Hungary(1)	1.22	3.92		④
		Hungary(2)	0.3～1.5	1.1～5.3		⑤
	Forest	Japan	0.3	3.6	21.5*	①
		Hungary(1)	0.05	0.16		④
		Hungary(2)	0.02～1.0	1.4～33		⑤
	Vineyard	Japan	0.79	29.6	10.3*	①
		Hungary(1)	2.57	8.22		④
		Hungary(2)	0.8～20	0.1～260		⑤
Atmospheric deposition (kg/ha/year)		Japan	0.55	11.5	56.9*	①
		Hungary(1)	1.056	17.64		⑥
		Hungary(2)	0.14～1.56	10～31		④
Amount of fertilizer use (kg/ha/year)	Arable land	Hungary	15.0			⑦
	Vineyard	Hungary	24.4			⑦
	Green	Hungary	14.3			⑦
	Garden	Hungary	29			⑦

* : Value as COD_{Mn}, and $COD_{Cr} = 2.0COD_{Mn}$

** : Pasture = (Forest + Arable land) / 2

① Common values by the Manual for the planning of the sewer system in Japan

② Estimated by the influent water quality of some sewage treatment plans around the Lake Balaton, in this study

③ Estimated by VITUKI (Report 1985)

④ Estimated by VITUKI (Report 1996)

⑤ Range of literatures investigated by VITUKI (Report 1996)

⑥ Hidorological Kozlony, 1973, in Hungary

⑦ Pollution Land Map (PLM), by KDT KOFE (1997)

⑧ Identification of Pollution Land on Kesthely Resion Runoff, by Szombathely KOFE (1997)

⑨ Study of Urban Runoff, by Pecs KUFE (1997)

Table 3.4 Constants of the Best Fit Function and the Correlation Coefficients

Name of Tributaries	TP				TN				COD			
	K_1	K_2	K_3	R^2	K_1	K_2	K_3	R^2	K_1	K_2	K_3	R^2
Burnot p.	8.518	-25.396	239.790	0.913	0.000	4.454	2.526	0.942	0.243	15.362	8.080	0.960
Eger viz	6.736	35.610	211.230	0.659	0.010	4.449	7.157	0.911	0.000	27.854	6.775	0.945
Tapolca p.	57.920	203.330	0.000	0.136	0.000	7.986	0.000	0.478	0.000	12.158	17.643	0.455
Keki p.	0.695	59.862	1616.700	0.751	0.024	5.572	76.958	0.943	0.088	-0.790	202.690	0.963
Fuzfoi sed	0.200	148.412	1437.244	0.532	0.010	2.785	54.754	0.329	0.083	6.545	337.530	0.925
Orvenyesi sed*	-	-	-	-	0.028	7.029	0.000	0.789	-	-	-	-
Nemesvitai a.	8.477	-139.700	975.610	0.956	0.010	1.717	5.348	0.985	0.000	61.621	-36.171	0.950
Jamai p.	0.311	69.592	66.149	0.685	0.004	0.970	4.459	0.875	0.253	11.352	25.740	0.838
Tetves p.	20.000	-411.150	2209.200	0.985	0.000	4.193	4.117	0.970	1.800	-25.383	117.301	0.993
Zala	0.411	0.099	0.000	0.603	5.384	1.556	0.068	0.808	47.535	32.395	0.000	0.918

*) For Orvenyesi sed, the best fit functions are as fillows :

TP : $L = 197.98Q - 4026.9Q^2 + 25654Q^3$, $R^2 = 0.941$

COD : $L = 27.654Q + 616.83Q^2 + 4338.4Q^3$, $R^2 = 0.976$

Legend:

$L = K_1 + K_2Q + K_3Q^2$ L = load (g/s) Q = discharge (m^3/s) R^2 = correlation coefficient

Table 3.5 Pollution Loads Discharge and Runoff Ratio of Selected Tributaries

PLM Code	Sub-catchment	A. Pollution Loads Discharge						B. Point Source Loads						C. Non-point Source			D. Runoff Ratio (= (A-B) / C)					
		1994			1995			1994			1995			Pollution Loads Generation			1994			1995		
		TP (kg/yr)	TN (kg/yr)	COD (ton/yr)	TP (kg/yr)	TN (kg/yr)	COD (ton/yr)	TP (kg/yr)	TN (kg/yr)	COD (ton/yr)	TP (kg/yr)	TN (kg/yr)	COD (ton/yr)	TP (kg/yr)	TN (kg/yr)	COD (ton/yr)	TP	TN	COD	TP	TN	COD
E-2	Fuzfoi sed	126	2,508	11.6	144	4,376	20.1	0	0	0.0	0	0	0.0	960	9,785	101.3	0.13	0.26	0.11	0.15	0.45	0.20
E-4	Keki patak	263	13,368	21.4	203	19,938	35.5	0	0	0.0	0	0	0.0	589	8,857	58.6	0.45	1.51	0.37	0.34	2.25	0.61
E-5	Orvenesyi sed	106	12,038	14.0	172	14,069	28.1	0	0	0.0	0	0	0.0	1,710	45,863	113.3	0.06	0.26	0.12	0.10	0.31	0.25
E-7	Burnot patak	725	31,970	116.4	667	34,772	126.1	0	0	0.0	0	0	0.0	5,618	147,894	371.3	0.13	0.22	0.31	0.12	0.24	0.34
E-8	Eger viz	753	34,825	144.8	734	35,885	155.0	0	0	0.0	0	0	0.0	23,072	596,161	1,610.7	0.03	0.06	0.09	0.03	0.06	0.10
E-9	Tapolca patak	3,254	56,136	116.3	3,546	67,431	145.5	2,769	127,398	46.8	1,954	87,096	36.8	3,982	92,540	277.8	0.12	-0.77	0.25	0.40	-0.21	0.39
E-10	Nemesvitai Ovarok	575	7,714	563.2	826	6,182	240.7	0	0	0.0	0	0	0.0	619	16,754	36.4	0.93	0.46	15.47	1.33	0.37	6.61
D-4	Tetves patak	1,640	22,979	91.9	3,669	45,146	352.8	0	0	0.0	0	0	0.0	6,700	183,541	425.7	0.24	0.13	0.22	0.55	0.25	0.83
D-5	Jamai patak	195	3,728	42.1	220	4,415	51.6	0	0	0.0	0	0	0.0	4,302	112,961	259.0	0.05	0.03	0.16	0.05	0.04	0.20
Zala	Zala river	39,299	856,599	10,113.1	42,811	912,017	11,261.1	13,297	315,085	407.9	16,071	329,893	423.8	187,999	4,897,059	12,220.7	0.14	0.11	0.79	0.14	0.12	0.89

Note: The Unit of COD load is in "ton/yr", while those of TP and TN loads are in "kg/yr".

Table 3.6 Pollution Load Discharge of the Whole Catchment Area

PLM code	Sub-catchment	Catchment Area(ha)	Point Source Loads						Non-point Source Loads Generation			Runoff Ratio						Estimated Pollution Loads Discharge					
			1994			1995						1994			1995			1994			1995		
			TP load (kg/yr)	TN load (kg/yr)	COD load (ton/yr)	TP load (kg/yr)	TN load (kg/yr)	COD load (ton/yr)	TP load (kg/yr)	TN load (kg/yr)	COD load (ton/yr)	TP	TN	COD	TP	TN	COD	TP load (kg/yr)	TN load (kg/yr)	COD load (ton/yr)	TP load (kg/yr)	TN load (kg/yr)	COD load (ton/yr)
E-1	direct	2,782	0	0	0.0	0	0	0.0	4,163	70,344	331.3	0.800	0.800	0.800	0.800	0.800	0.800	3,330	56,275	265.0	3,330	56,275	265.0
	Cinege patak	1,432	0	0	0.0	0	0	0.0	873	29,891	34.8	0.200	0.400	0.400	0.200	0.400	0.400	175	11,956	13.9	175	11,956	13.9
E-2	direct	2,403	0	0	0.0	0	0	0.0	3,417	54,674	283.5	0.800	0.800	0.800	0.800	0.800	0.800	2,734	43,739	226.8	2,734	43,739	226.8
	Fuzfoi sed	947	0	0	0.0	0	0	0.0	960	9,785	101.3	0.131	0.256	0.115	0.150	0.447	0.198	126	2,508	11.6	144	4,376	20.1
E-3	direct	2,828	0	0	0.0	0	0	0.0	3,091	52,760	255.8	0.800	0.800	0.800	0.800	0.800	0.800	2,473	42,208	204.6	2,473	42,208	204.6
	Vorosberenyi sed	2,833	0	0	0.0	0	0	0.0	2,727	59,864	200.9	0.200	0.400	0.400	0.200	0.400	0.400	545	23,946	80.4	545	23,946	80.4
	Lovasi sed	2,596	0	0	0.0	0	0	0.0	1,763	45,188	124.9	0.200	0.400	0.400	0.200	0.400	0.400	353	18,075	50.0	353	18,075	50.0
E-4	direct	3,281	0	0	0.0	0	0	0.0	3,697	61,471	308.4	0.800	0.800	0.800	0.800	0.800	0.800	2,958	49,177	246.7	2,958	49,177	246.7
	Csopaki sed	1,124	0	0	0.0	0	0	0.0	474	10,477	44.6	0.200	0.400	0.400	0.200	0.400	0.400	95	4,191	17.8	95	4,191	17.8
	Aracsi sed	1,485	0	0	0.0	0	0	0.0	623	11,441	66.2	0.200	0.400	0.400	0.200	0.400	0.400	125	4,576	26.5	125	4,576	26.5
	Keki patak	848	0	0	0.0	0	0	0.0	589	8,857	58.6	0.447	1.509	0.365	0.345	2.251	0.606	263	13,368	21.4	203	19,938	35.5
	Szolosi sed	2,248	0	0	0.0	0	0	0.0	1,593	40,203	111.2	0.200	0.400	0.400	0.200	0.400	0.400	319	16,081	44.5	319	16,081	44.5
	Tavi sed	1,086	4	118	0.1	7	318	0.2	627	15,647	46.8	0.200	0.400	0.400	0.200	0.400	0.400	129	6,377	18.8	133	6,577	18.9
E-5	direct	5,129	81	3,688	3.3	73	3,426	1.8	3,142	79,146	221.4	0.800	0.800	0.800	0.800	0.800	0.800	2,595	67,005	180.4	2,587	66,743	178.9
	Orvenesyi sed	2,569	0	0	0.0	0	0	0.0	1,710	45,863	113.3	0.062	0.262	0.124	0.101	0.307	0.248	106	12,038	14.0	172	14,069	28.1
E-6	direct	2,159	146	7,366	7.0	97	9,889	2.8	1,653	35,861	127.1	0.800	0.800	0.800	0.800	0.800	0.800	1,469	36,055	108.6	1,419	38,578	104.5
	Csorszai patak	2,129	0	0	0.0	0	0	0.0	1,549	41,553	99.5	0.200	0.400	0.400	0.200	0.400	0.400	310	16,621	39.8	310	16,621	39.8
	Horogi sed	819	0	0	0.0	0	0	0.0	546	16,760	28.2	0.200	0.400	0.400	0.200	0.400	0.400	109	6,704	11.3	109	6,704	11.3
E-7	direct	22	0	0	0.0	0	0	0.0	14	533	0.4	0.800	0.800	0.800	0.800	0.800	0.800	11	426	0.3	11	426	0.3
	Burnot patak	8,262	0	0	0.0	0	0	0.0	5,618	147,894	371.3	0.129	0.216	0.313	0.119	0.235	0.340	725	31,970	116.4	667	34,772	126.1
E-8	direct	2,155	168	4,256	8.6	211	8,555	7.1	1,390	40,039	77.0	0.800	0.800	0.800	0.800	0.800	0.800	1,280	36,287	70.2	1,323	40,586	68.7
	Eger viz	36,122	0	0	0.0	0	0	0.0	23,072	596,161	1,610.7	0.033	0.058	0.090	0.032	0.060	0.096	753	34,825	144.8	734	35,885	155.0
E-9	direct	517	0	0	0.0	0	0	0.0	372	8,893	25.9	0.800	0.800	0.800	0.800	0.800	0.800	298	7,114	20.7	298	7,114	20.7
	Tapolca patak	4,493	2,769	127,398	46.8	1,954	87,096	36.8	3,982	92,540	277.8	0.122	-0.770	0.250	0.400	-0.213	0.391	3,254	56,136	116.3	3,546	67,431	145.5
E-10	direct	991	0	0	0.0	0	0	0.0	863	17,614	71.4	0.800	0.800	0.800	0.800	0.800	0.800	690	14,091	57.1	690	14,091	57.1
	Ketoles patak	3,961	0	0	0.0	0	0	0.0	2,138	52,362	164.8	0.200	0.400	0.400	0.200	0.400	0.400	428	20,945	65.9	428	20,945	65.9
	Vilagos patak	2,077	0	0	0.0	0	0	0.0	1,075	29,469	74.2	0.200	0.400	0.400	0.200	0.400	0.400	215	11,788	29.7	215	11,788	29.7
	Lesence patak	8,714	0	0	0.0	0	0	0.0	4,814	93,012	460.6	0.200	0.400	0.400	0.200	0.400	0.400	963	37,205	184.2	963	37,205	184.2
	Nemesvitai Ovarok	713	0	0	0.0	0	0	0.0	619	16,754	36.4	0.929	0.460	15.473	1.334	0.369	6.613	575	7,714	563.2	826	6,182	240.7
Northern Catchment area TOTAL		*106,725*	*3,168*	*142,826*	*65.7*	*2,342*	*109,284*	*48.7*	*77,154*	*1,785,056*	*5,728.3*	*0.314*	*0.306*	*0.504*	*0.331*	*0.342*	*0.464*	*27,406*	*689,401*	*2,950.9*	*27,885*	*720,255*	*2,707.2*
D-1	direct	2,288	0	0	0.0	0	0	0.0	2,261	39,903	188.4	0.800	0.800	0.800	0.800	0.800	0.800	1,809	31,922	150.7	1,809	31,922	150.7
	Endredi patak	3,028	0	0	0.0	0	0	0.0	2,296	59,434	150.5	0.200	0.400	0.400	0.200	0.400	0.400	459	23,774	60.2	459	23,774	60.2
D-2	direct	190	0	0	0.0	0	0	0.0	468	3,591	48.6	0.800	0.800	0.800	0.800	0.800	0.800	374	2,873	38.9	374	2,873	38.9
	Koroshegyi sed	3,425	0	0	0.0	0	0	0.0	2,619	60,025	191.4	0.200	0.400	0.400	0.200	0.400	0.400	524	24,010	76.6	524	24,010	76.6
D-3	direct	2,544	0	0	0.0	0	0	0.0	3,005	48,321	257.6	0.800	0.800	0.800	0.800	0.800	0.800	2,404	38,657	206.1	2,404	38,657	206.1
	Nagymetszes patak	10,620	0	0	0.0	0	0	0.0	8,463	239,208	470.8	0.200	0.400	0.400	0.200	0.400	0.400	1,693	95,683	188.3	1,693	95,683	188.3
D-4	direct	586	0	0	0.0	0	0	0.0	992	12,063	92.0	0.800	0.800	0.800	0.800	0.800	0.800	794	9,650	73.6	794	9,650	73.6
	Tetves patak	10,104	0	0	0.0	0	0	0.0	6,700	183,541	425.7	0.245	0.125	0.216	0.548	0.246	0.829	1,640	22,979	91.9	3,669	45,146	352.8
	A-B-C csatorna	1,432	0	0	0.0	0	0	0.0	796	23,784	40.5	0.200	0.400	0.400	0.200	0.400	0.400	159	9,514	16.2	159	9,514	16.2
D-5	direct	323	0	0	0.0	0	0	0.0	783	5,903	81.4	0.800	0.800	0.800	0.800	0.800	0.800	626	4,722	65.1	626	4,722	65.1
	Forro arok	780	0	0	0.0	0	0	0.0	706	19,853	37.1	0.200	0.400	0.400	0.200	0.400	0.400	141	7,941	14.8	141	7,941	14.8
	Jamai patak	4,974	0	0	0.0	0	0	0.0	4,302	112,961	259.0	0.045	0.033	0.163	0.051	0.039	0.199	195	3,728	42.1	220	4,415	51.6
D-6	direct	366	0	0	0.0	0	0	0.0	728	5,478	75.8	0.800	0.800	0.800	0.800	0.800	0.800	582	4,382	60.6	582	4,382	60.6
	Kelet- Nyugti Focsatorna	3,727	0	0	0.0	0	0	0.0	2,904	90,545	129.5	0.200	0.400	0.400	0.200	0.400	0.400	581	36,218	51.8	581	36,218	51.8
	Keleti bozot	27,192	0	0	0.0	0	0	0.0	22,550	617,521	1,313.2	0.200	0.400	0.400	0.200	0.400	0.400	4,510	247,008	525.3	4,510	247,008	525.3
D-7	direct	3,365	0	0	0.0	0	0	0.0	4,205	63,610	365.0	0.800	0.800	0.800	0.800	0.800	0.800	3,364	50,888	292.0	3,364	50,888	292.0
	Nyugati ovcsatorna	68,395	1,406	32,581	63.4	1,240	39,158	63.8	48,301	1,342,035	2,882.2	0.200	0.400	0.400	0.200	0.400	0.400	11,066	569,395	1,216.3	10,900	575,972	1,216.7
Southern Catchment Area TOTAL		*143,339*	*1,406*	*32,581*	*63.4*	*1,240*	*39,158*	*63.8*	*112,079*	*2,927,776*	*7,008.7*	*0.263*	*0.393*	*0.443*	*0.282*	*0.401*	*0.482*	*30,921*	*1,183,344*	*3,170.5*	*32,809*	*1,212,775*	*3,441.3*
Zala	direct	4,970	590	33,120	12.7	316	21,629	8.8	4,617	64,838	438.5	0.800	0.800	0.800	0.800	0.800	0.800	4,284	84,990	363.5	4,010	73,499	359.6
	Zala river	263,727	13,297	315,085	407.9	16,071	329,893	423.8	187,999	4,897,059	12,220.7	0.138	0.111	0.794	0.142	0.119	0.887	39,299	856,599	10,113.1	42,811	912,017	11,261.1
Zala Catchment Area TOTAL		*268,697*	*13,887*	*348,205*	*420.5*	*16,387*	*351,522*	*432.6*	*192,616*	*4,961,897*	*12,659.2*	*0.154*	*0.120*	*0.794*	*0.158*	*0.128*	*0.884*	*43,583*	*941,589*	*10,476.6*	*46,821*	*985,516*	*11,620.7*
Total Catchment Area		*518,761*	*18,460*	*523,612*	*549.7*	*19,968*	*499,964*	*545.1*	*381,849*	*9,674,729*	*25,396.2*	*0.219*	*0.237*	*0.632*	*0.229*	*0.250*	*0.678*	*101,910*	*2,814,334*	*16,598.0*	*107,515*	*2,918,546*	*17,769.2*

Note : The unit of COD load is in "ton/yr", while those of TP and TN loads are in "kg/yr".

Table 3.7 Summary of Pollution Load Discharge Calculations

1994

	Point Source Load			Non-point Source Load			Total Load		
	TP	TN	COD$_{Cr}$	TP	TN	COD$_{Cr}$	TP	TN	COD$_{Cr}$
	(kg/yr)	(kg/yr)	(ton/yr)	(kg/yr)	(kg/yr)	(ton/yr)	(kg/yr)	(kg/yr)	(ton/yr)
Northern Catchment Area	3,168 (3%)	142,826 (5%)	66 (0%)	24,238 (24%)	546,575 (19%)	2,885 (17%)	27,406 (27%)	689,401 (24%)	2,951 (18%)
Southern Catchment Area	1,406 (1%)	32,581 (1%)	63 (0%)	29,516 (0%)	1,150,763 (41%)	3,107 (19%)	30,921 (30%)	1,183,344 (42%)	3,171 (19%)
Zala Catchment Area	13,887 (14%)	348,205 (12%)	421 (3%)	29,696 (29%)	593,384 (21%)	10,056 (61%)	43,583 (43%)	941,589 (33%)	10,477 (63%)
Total Catchment Area	18,460 (18%)	523,612 (19%)	550 (3%)	83,450 (82%)	2,290,722 (81%)	16,048 (97%)	101,910 (100%)	2,814,334 (100%)	16,598 (100%)

1995

	Point Source Load			Non-point Source Load			Total Load		
	TP	TN	COD$_{Cr}$	TP	TN	COD$_{Cr}$	TP	TN	COD$_{Cr}$
	(kg/yr)	(kg/yr)	(ton/yr)	(kg/yr)	(kg/yr)	(ton/yr)	(kg/yr)	(kg/yr)	(ton/yr)
Northern Catchment Area	2,342 (2%)	109,284 (4%)	49 (0%)	25,543 (24%)	610,971 (21%)	2,658 (15%)	27,885 (26%)	720,255 (25%)	2,707 (15%)
Southern Catchment Area	1,240 (1%)	39,158 (1%)	64 (0%)	31,569 (29%)	1,173,617 (40%)	3,378 (19%)	32,809 (31%)	1,212,775 (42%)	3,441 (19%)
Zala Catchment Area	16,387 (15%)	351,522 (12%)	433 (2%)	30,434 (28%)	633,994 (22%)	11,188 (63%)	46,821 (44%)	985,516 (34%)	11,621 (65%)
Total Catchment Area	19,968 (19%)	499,964 (17%)	545 (3%)	87,547 (81%)	2,418,582 (83%)	17,224 (97%)	107,515 (100%)	2,918,546 (100%)	17,769 (100%)

Table 3.8 Two Dimensional Hydrodynamics Equations

$$\frac{\partial H}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=0 \cdots\cdots\cdots\cdots (1)$$

$$\frac{\partial q_x}{\partial t}+\frac{\partial}{\partial x}\left(\frac{q_x^2}{H}\right)+\frac{\partial}{\partial y}\left(\frac{q_x q_y}{H}\right)$$

$$= -\frac{\partial N_p}{\partial x}+\frac{1}{\rho}\left(\frac{\partial N_{xx}}{\partial x}+\frac{\partial N_{yx}}{\partial y}\right)+fq_y+\frac{1}{\rho}\left(\tau_{sx}-\tau_{bx}\right)+g\eta\frac{\partial h}{\partial x} \cdots\cdots (2)$$

$$\frac{\partial q_y}{\partial t}+\frac{\partial}{\partial x}\left(\frac{q_x q_y}{H}\right)+\frac{\partial}{\partial y}\left(\frac{q_y^2}{H}\right)$$

$$= -\frac{\partial N_p}{\partial y}+\frac{1}{\rho}\left(\frac{\partial N_{yy}}{\partial y}+\frac{\partial N_{xy}}{\partial x}\right)-fq_x+\frac{1}{\rho}\left(\tau_{sy}-\tau_{by}\right)+g\eta\frac{\partial h}{\partial y} \cdots\cdots (3)$$

$$N_{ij}=\left\langle \tau_{ij}+\rho u_i' u_j' \right\rangle \equiv \int_h^\eta \left(\tau_{ij}+\rho u_i' u_j'\right)dz \cong \rho\varepsilon_{ij}\left(\frac{\partial q_i}{\partial x_j}+\frac{\partial q_j}{\partial x_i}\right) \quad ;(i,j=x,y) \cdots (4)$$

$$N_p = g\eta h+\frac{1}{2}g\eta^2 \cdots\cdots\cdots (5)$$

$$\tau_{sx}=\rho_{air}C_D U^2 cos\theta_w \cdots\cdots\cdots (6) \qquad \tau_{sy}=\rho_{air}C_D U^2 sin\theta_w \cdots\cdots (7)$$

$$\tau_{bx}=\frac{C_f \rho q_x\sqrt{q_x^2+q_y^2}}{H^2} \cdots\cdots\cdots (8) \qquad \tau_{by}=\frac{C_f \rho q_y\sqrt{q_x^2+q_y^2}}{H^2} \cdots\cdots (9)$$

where q_i =mass flux per unit width; h =depth; η =surface elevation; $H=h+\eta$; f=Corioli's parameter; g =gravitational acceleration; ε =eddy viscosity; ρ_{air} =air density; τ_s =wind stress; τ_b =bottom shear stress; U =wind speed at 10 m above the water surface; C_D =drag coefficient (Wu, 1973); θ_W =angle between the wind direction and the x axis; friction coefficient $C_f=n^2gH^{-1/3}$; n =Manning's roughness coefficient.

Table 3.9 0-D WQSM Equations

Dissolved inorganic phosphorus: P_1 [mg-P/m^3]

$$\frac{dP_1}{dt} = -k_f P_1 - k_u \frac{P_1 B}{P_{1k}+P_1}\frac{\psi_{max}-\psi}{\psi_{max}-\psi_{min}} + k_m \theta_m{}^{T_w-20} P_3 + (1-f_{op}) d_p \theta_p{}^{T_w-20} P_2 + Sop(SS) + c_{ex}(P_{eq}\theta_m{}^{T_w-20} - P_1) + L_1$$

Algal phosphorus: P_2 [mg-P/m^3]

$$\frac{dP_2}{dt} = -k_f P_2 + k_u \frac{P_1 B}{P_{1k}+P_1}\frac{\psi_{max}-\psi}{\psi_{max}-\psi_{min}} - d_p \theta_p{}^{T_w-20} P_2 - \frac{v_{s4}}{h} P_2 + L_2$$

Algal biomass: B [mg dry-wt/m^3]

$$\frac{dB}{dt} = -k_f B + \mu_{\max} f(\psi) f(I) f(T) B - d_p \theta_p{}^{T_w-20} B - \frac{v_{s4}}{h} B + L_B$$

Detrital phosphorus: P_3 [mg-P/m^3]

$$\frac{dP_3}{dt} = -k_f P_3 + f_{op} d_p \theta_p{}^{T_w-20} P_2 - k_m \theta_m{}^{T_w-20} P_3 - \frac{v_{s3}}{h}(1-r) P_3 + L_3$$

$Chla$ [mg/m^3]

$$Chla = B/(\frac{\alpha I_{opt}}{\mu_{\max} e} c_{b/c})$$

where

k_f: flushing rate

k_u: maximum uptake rate

P_{1k}: half-saturation constant for uptake

ψ: cell quota, $\psi = P_2/B$

ψ_{max}, ψ_{min}: maximum and minimum cell qotas

d_p: mortality rate

θ_p: temperature factor for mortality

v_{s3}: settling rate of detritus

v_{s4}: settling rate of algae

h: depth

L_i: external loads

μ_{max}: maximum specific growth rate

$f(\psi)$: cell quota growth limiting factor,

α: initial slope of P-I curve

I_{opt}: optimum light intensity

$$f(T) = \exp[-2.3 \left(\frac{T-T_{opt}}{T_x-T_{opt}}\right)^2]$$

$$T_x = T_{min} \quad for \quad T \le T_{opt}$$
$$= T_{max} \quad for \quad T > T_{opt}$$

c_{ex}: exchange coefficient of the sediment phosphorus release

P_{eq}: equilibrium concentration of the sediment phosphorus release

$c_{b/c}$: ratio of algal biomass to carbon

$f(\psi) = 1 - \psi_{min}/\psi$

$f(T)$: temperature limiting factor

T_{min}: minimum temperature for algal growth

T_{max}: maximum temperature for algal growth

T_{opt}: optimal temperature for algal growth

$f(I)$: light limiting factor (see *Table* 5.3)

k_m: mineralization rate

θ_m: temperature factor for mineralization

$Sop(SS)$:sorption as a function of suspended sediments

f_{op}: fraction of organic phosphorus in TP contained in dead phytoplankton

γ: fraction of detritus that is dissolved

Table 3.10 Modified Steele's Light Limiting Function for Non-light Inhibition

Conventional Steele's light limiting function is modified to non-inhibiting function as follows.

$$f(I) = \begin{cases} 1 & \text{for } \mathrm{I} \geq \mathrm{I_s} \quad \text{-----------------(1)} \\ \dfrac{I}{I_s}\exp(1-\dfrac{I}{I_s}) & \text{for } \mathrm{I} < \mathrm{I_s} \quad \text{-----------------(2)} \end{cases}$$

where I = light intensity in the water column: $I = I_0 e^{-K_e z}$, z = distance from the water surface, I_s = saturation light intensity, I_0=surface light intensity, K_e = extinction coefficient.

At the depth, where light intensity reaches a saturation light intensity, $I = I_s \quad at \quad h_s \quad \rightarrow \quad I_s = I_0 e^{-K_e h_s}$.

The depth of a saturation light intensity can be induced as,

$$h_s = -\frac{1}{k_e}\ln\frac{I_s}{I_0}$$

Integrating equation (2) over $z = h_s \sim h$ and taking its average, equations (1), (2) can be converted as,

$$\overline{f}_1(I) = 1 \qquad \text{for } z = 0 \sim h_s \qquad \text{---- (3)}$$

$$\overline{f}_2(I) = \frac{e}{k_e(h-h_s)}\left\{\exp(-ae^{-k_e h}) - \exp(-ae^{-k_e h_s})\right\} \qquad \text{for } z = h_s \sim h \qquad \text{---- (4)}$$

where $a = \dfrac{I_0}{I_s}$

For all the depth, equations (3) and (4) are combined as,

$$\overline{f}(I) = \frac{1}{h}\left\{h_s + (h-h_s)\overline{f}_2(I)\right\} \qquad \text{---- (5)}$$

Table 3.11 Suspended Sediment Model Equations (Luettich *et al.*, 1990)

$$\tilde{c} = c_e + c_{bak} + (\tilde{c}_i - c_e - c_{bak}) \exp[-\frac{\beta}{h}(t - t_i)]$$

where

$\tilde{c}$: depth-averaged suspended sediment concentration, $\tilde{c} \equiv \int_{-h}^{0} \bar{c}\, dz$

$\tilde{c}_i$: initial condition of $\tilde{c}$ at $t = t_i$

c_e: equilibrium suspended sediment concentration, $c_e = K[\frac{H - H_C}{H_{ref}}]^n$

H, H_{ref}, H_C: wave height, reference wave height, and critical wave height
n: model parameter
β: settling velocity
c_{bak}: non-settling background suspended sediment concentration
K: model parameter (mg/l)

Wave height equations (CERC, 1974),

$$\frac{gH}{U_{10}^2} = 0.283 \tanh[\alpha] \tanh[\frac{\gamma}{\tanh \alpha}]$$

$$\alpha = 0.53\,(gh / U_{10}^2)^{0.75}$$

$$\gamma = 0.125\,(gF / U_{10}^2)^{0.42}$$

where
g = gravitational acceleration
U_{10}= wind speed at 10m above the water surface
F = effective fetch

Table 3.12 Parameter Values for Completely-mixed Biogeochemical Model Calculations

Descriptions	symbol in equations	terms in graphs	unit	standard value	Reference
maximum cell quota	q_{max}	*psi_max*	ND	0.018	Shafik *et al.*, 1987
minimum cell quota	q_{min}	*psi_min*	ND	0.002	Shafik *et al.*, 1987
maximum P uptake rate	k_u	*p_up_max*	1/day	1.5	Shafik *et al.*, 1987
half-saturation constant for P uptake	P_{1k}	*half _sat*	mg/m^3	18.0	Shafik *et al.*, 1987
mineralization rate	k_{m0}	*R_mineral*	1/day	0.04	Tezuka,1989
temperature correction factor for mineralization	θ_m	*T_mineral*	ND	1.18	Tezuka,1989
death rate	d_{p0}	*R_mortal*	1/day	0.092	Bowie *et al.*, 1985
temperature correction factor for death	θ_p	*T_mortal*	ND	1.04	Bowie *et al.*, 1985
maximum specific growth rate	μ_{max}	*Growth_max*	1/day	1.8	Shafik *et al.*, 1987
surfase area of Keszthely bay	A	-	km^2	38	Herodek *et al.*, 1988
settling rate of algal biomass	v_{s3}	*Ws-bmass*	m/d	0.01	Sommer,1984
settling rate of detritus	v_{s4}	*Ws-det*	m/d	0.05	Sommer,1984
fraction of organic-P in dead algal-P	f_{op}	*Fop*	ND	0.7	Tezuka,1989
fraction of detritus that is dissolved	r	*gamma*	ND	0.1	Tezuka,1989
initial slope of P-I curve	α	*alpha*	mg C/mg Chla/ly	2.6	Balaton Limnol.Res.Inst., 1996
biomass carbon ratio	C_{bc}	*P/C ratio*	mg d.w./mg C	0.02	IBP,1971
equilibrium concentration of PO_4-P in the sediment	P_eq	*P_eq*	mg P/m^3	30	Istvanovics *et al.*, 1989
exchange coefficient of sediment P-release	C_ex	*C_ex*	1/day	0.15	
P-desorption rate	$\Delta C/ss$	*P_release*	mg P/g DM	0.008	Gelencser *et al.*, 1982
			ND=no unit		

Table 3.13 Two Dimensional Mass Transport Equations

$$\frac{\partial C_i}{\partial t} + \frac{\partial\left(\left(q_x/H\right)C_i\right)}{\partial x} + \frac{\partial\left(\left(q_y/H\right)C_i\right)}{\partial y} = -\frac{\partial M_x}{\partial x} - \frac{\partial M_y}{\partial y} \pm R_i \quad ; i = 1, 4 \cdots\cdots (1)$$

$$C_i = \int_{-h}^{\eta} c_i dz = \bar{c}_i H \cdots\cdots (2)$$

$$M_x = -E_{xx} H \frac{\partial \bar{c}_i}{\partial x} - E_{xy} H \frac{\partial \bar{c}_i}{\partial y} \cdots (3)$$

$$M_y = -E_{yx} H \frac{\partial \bar{c}_i}{\partial x} - E_{yy} H \frac{\partial \bar{c}_i}{\partial y} \cdots (4)$$

where

C_i =consituent concentration per unit area

$\bar{c}_i$ =depth average concentration

$H = h + \eta$; h = depth, η = surface elevaton

R_i=internal reactive source/sink;

E_{xx}, E_{xy} =longitudinal and lateral dispersion coefficient.

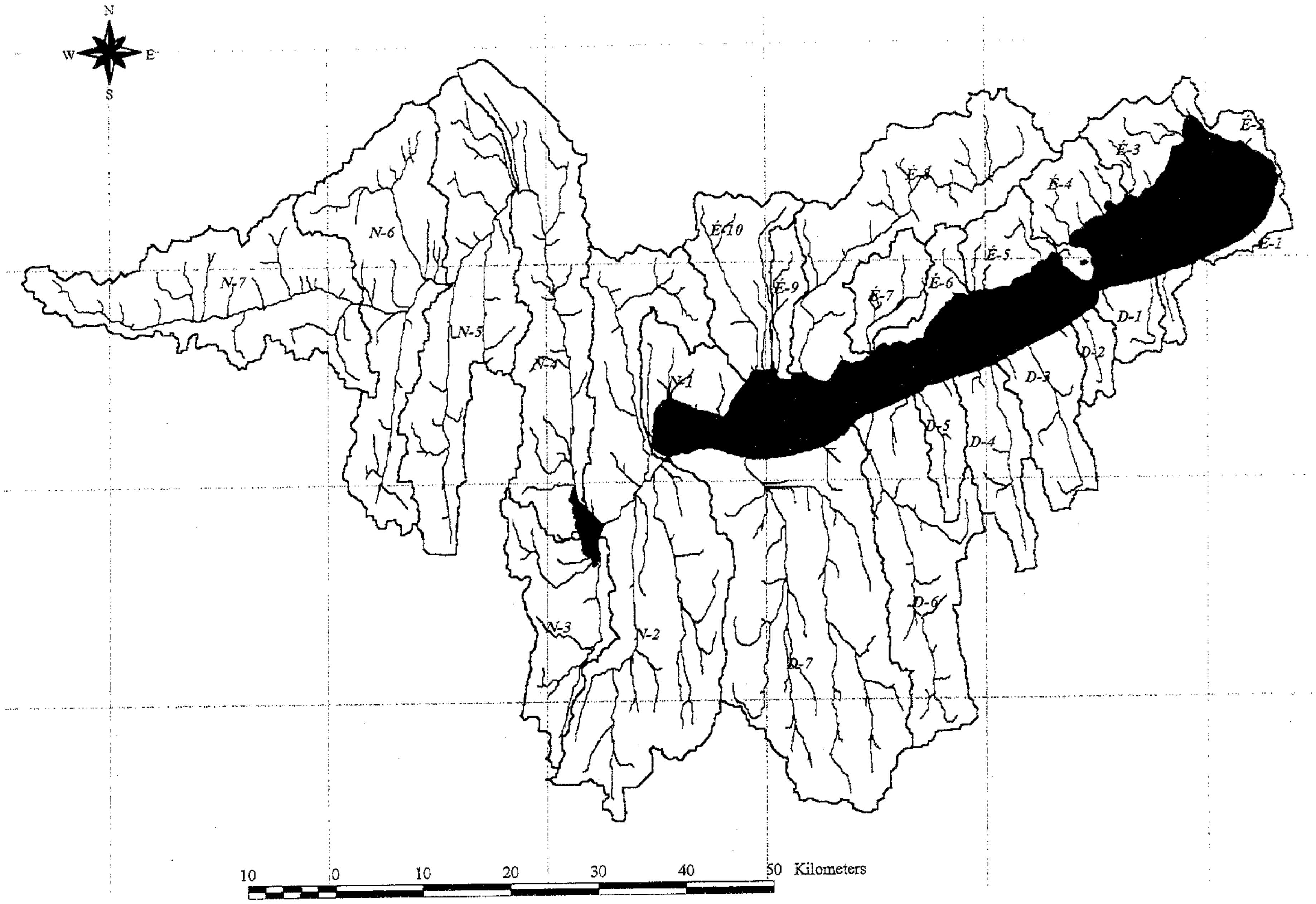


Figure 3.1 Sub-catchment Areas in Lake Balaton Basin

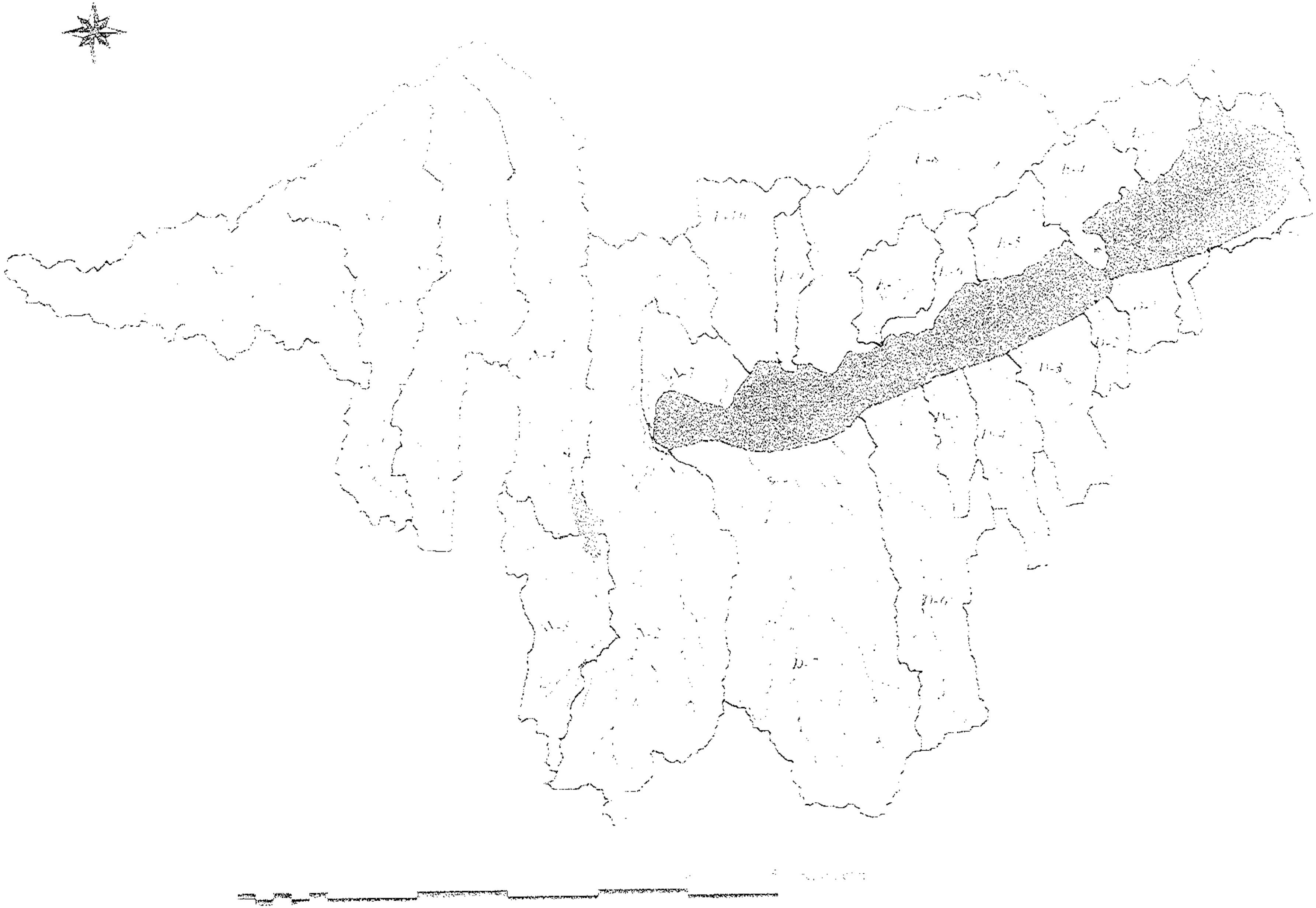


Figure 3.1 Sub-catchment Areas in Lake Balaton Basin

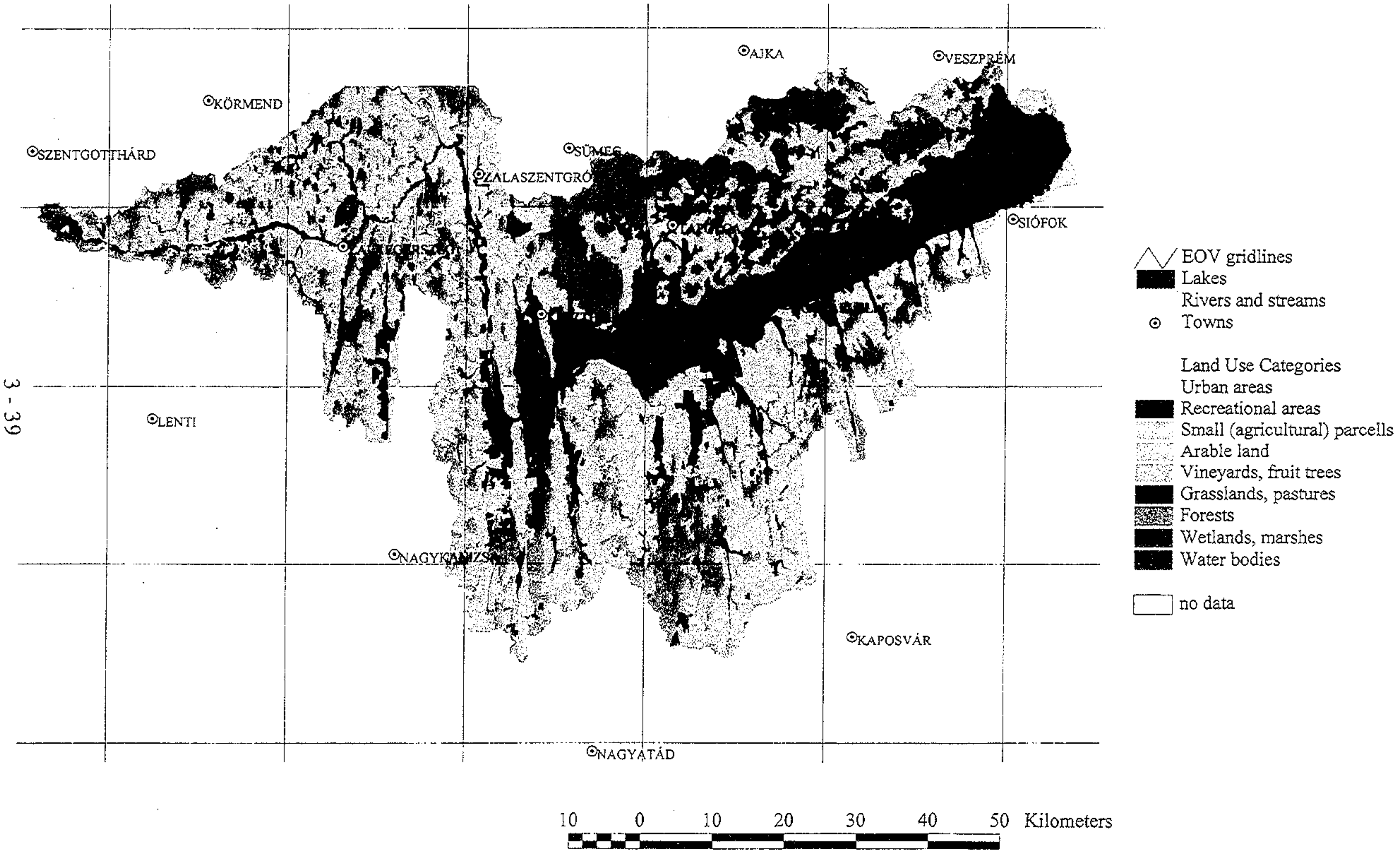
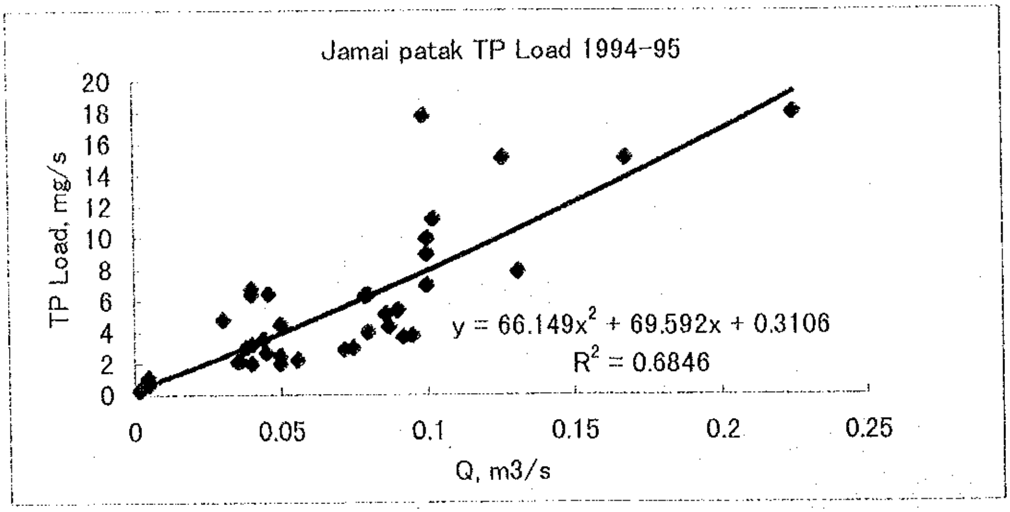
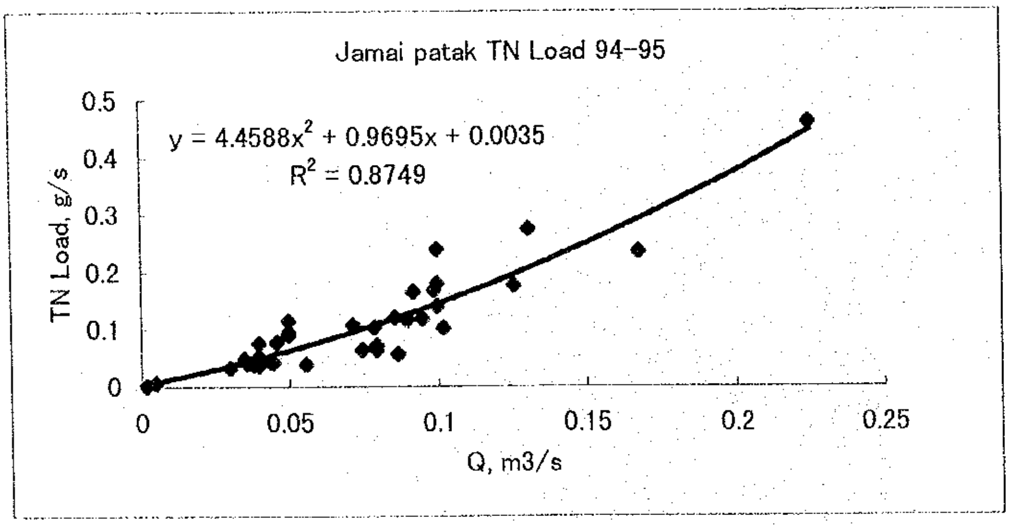


Figure 3.2 Re-classified Land Cover Map

Figure 3.2 Re-classified Land Cover Map





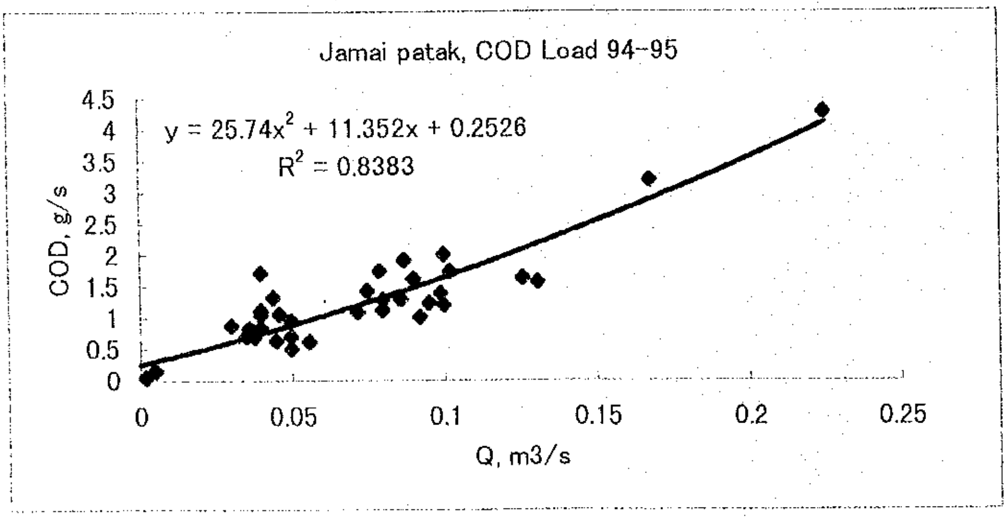


Figure 3.3 Best Fit Curve for Load-Discharge Correlations (Jamai)

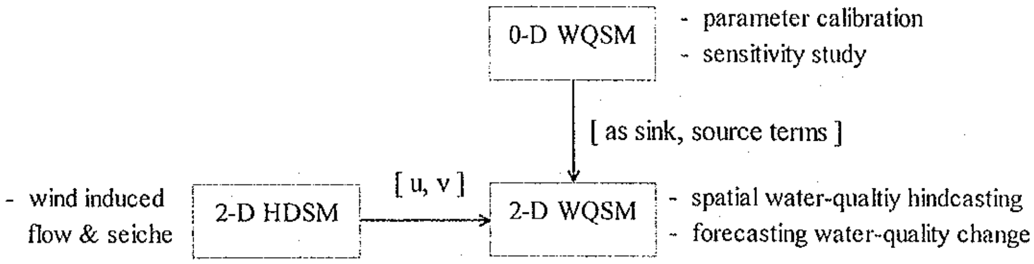


Figure 3.4 Conceptual Structure of WQSM

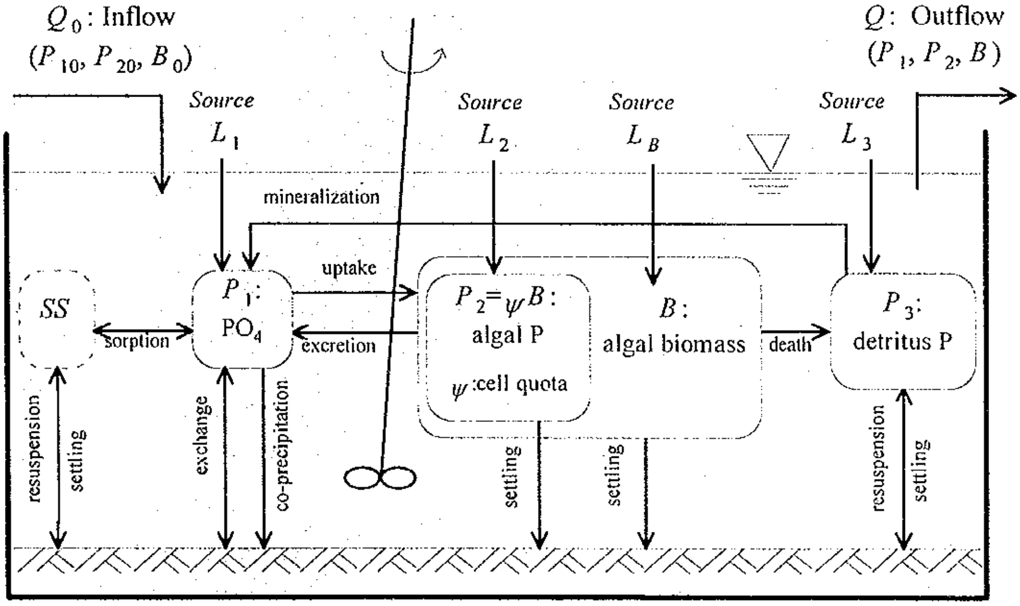


Figure 3.5 Conceptual Structure of 0-D WQSM

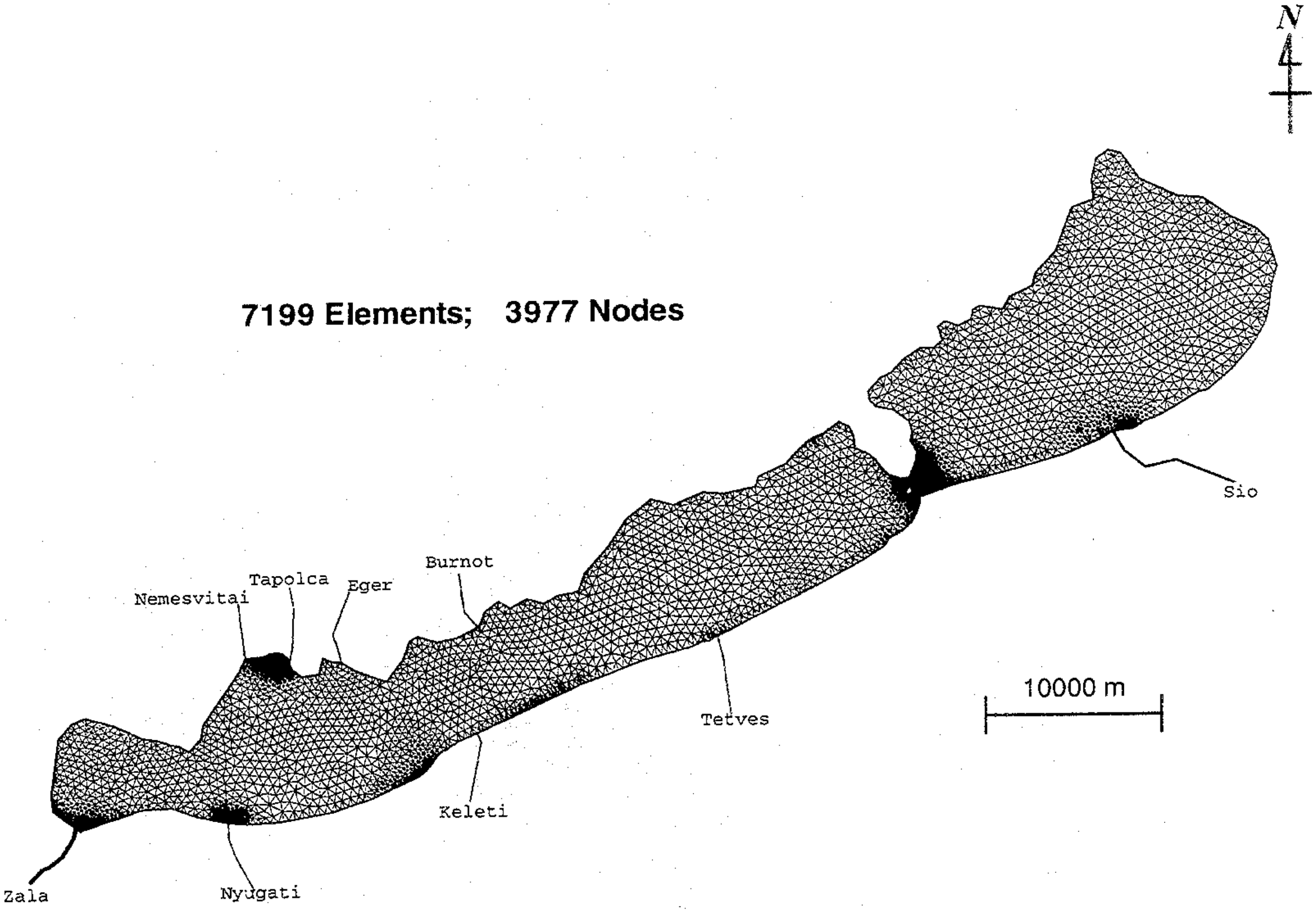
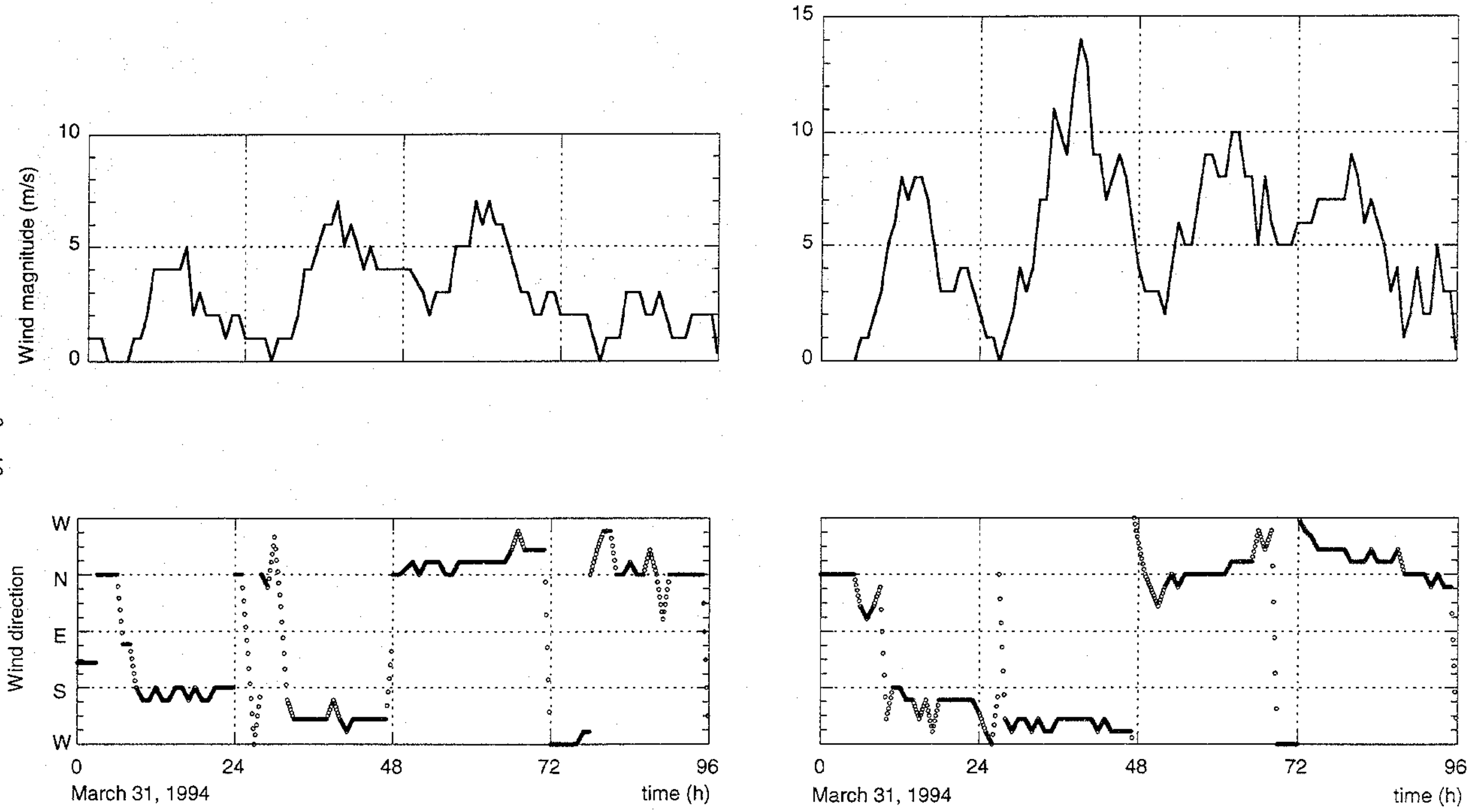


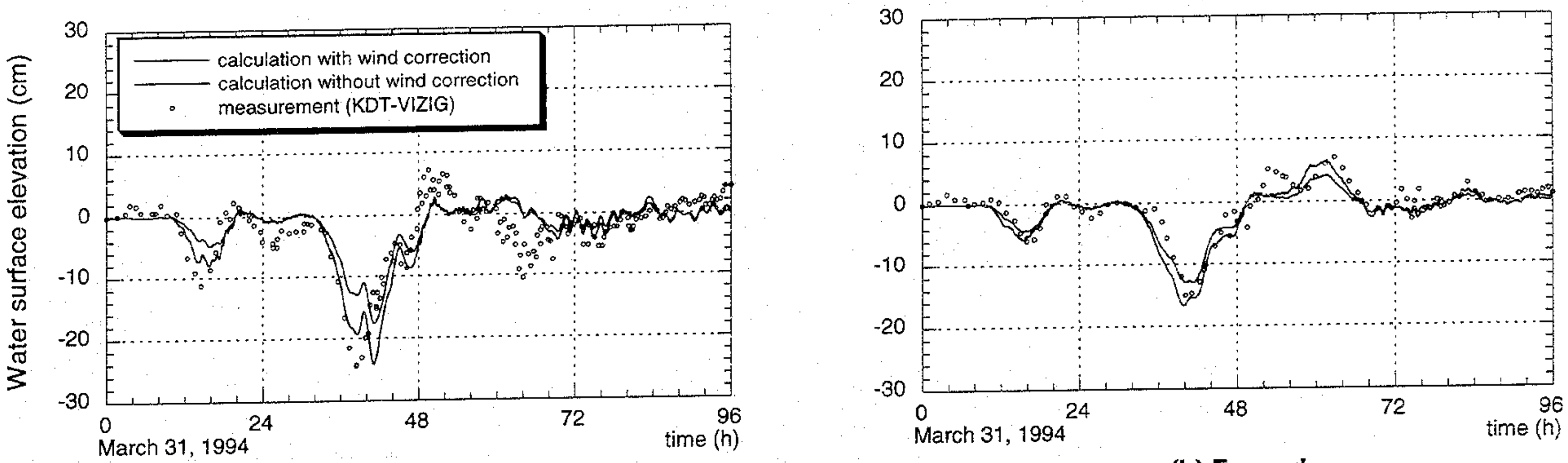
Figure 3.6 Finite Element Mesh for Lake Balaton



(a) Kestzthely

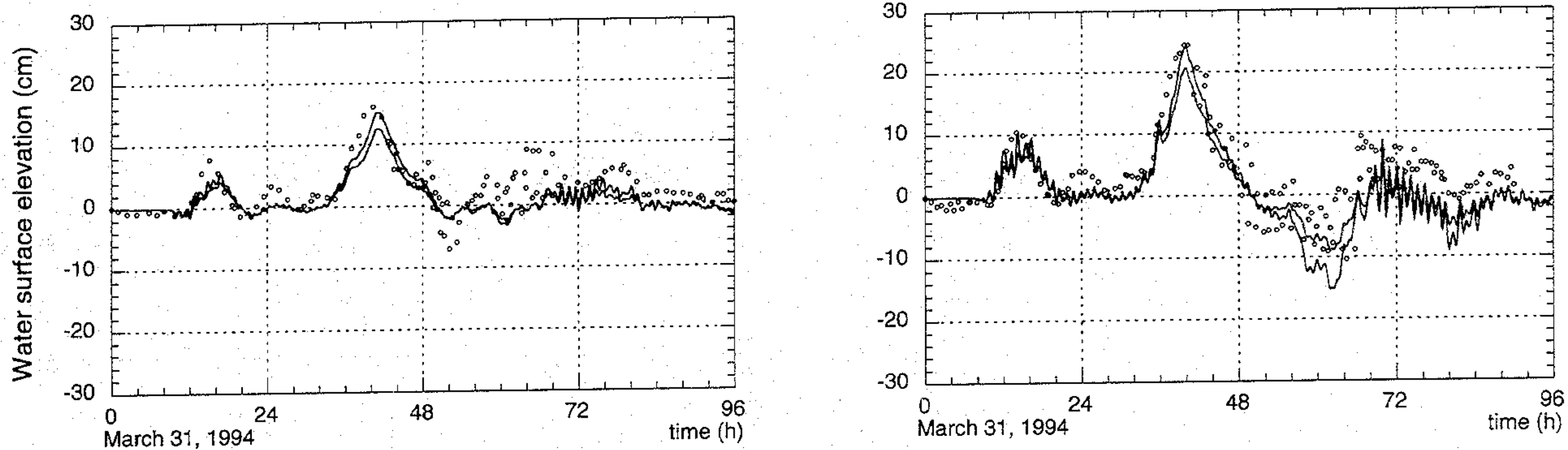
(b) Siofok

Figure 3.7 Wind Speed and Direction during Storm Event, 31 March - 3 April, 1994 (OMSZ)



(a) Keszthely

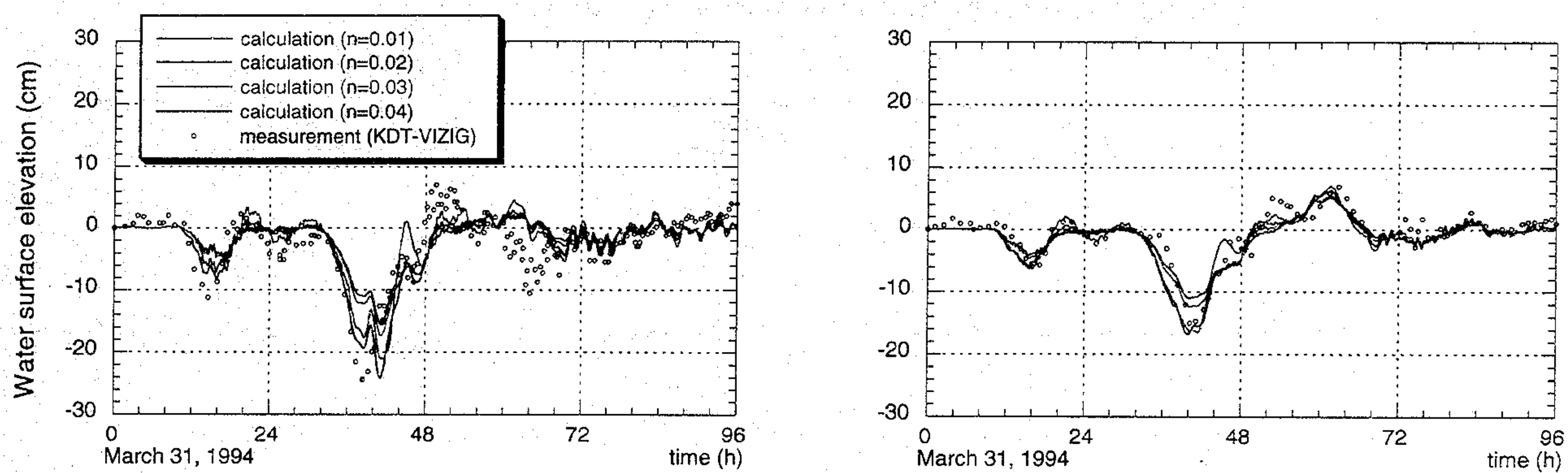
(b) Fonyod



(c) Siofok

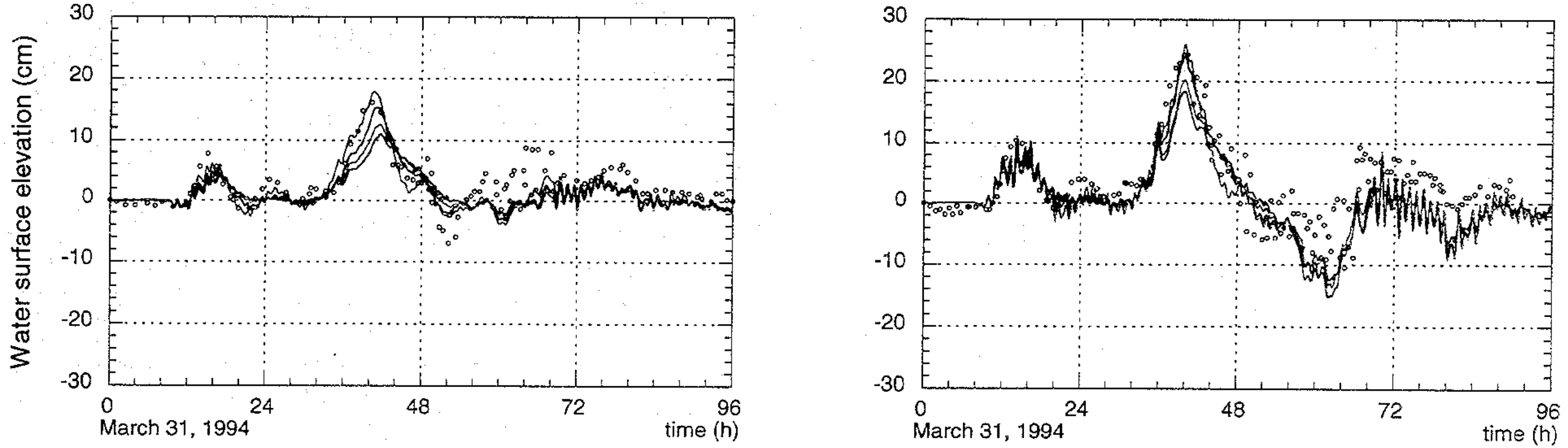
(d) Balatonfuzfo

Figure 3.8 Sensitivity of Predicted Seiche to Wind Speed Correction



(a) Keszthely

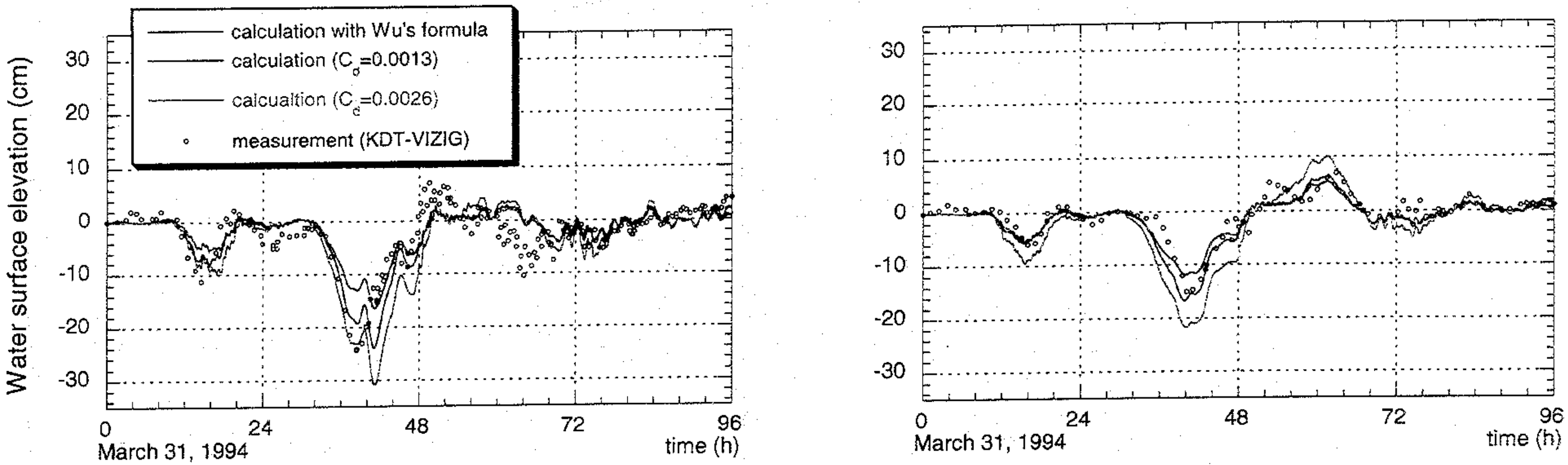
(b) Fonyod



(c) Siofok

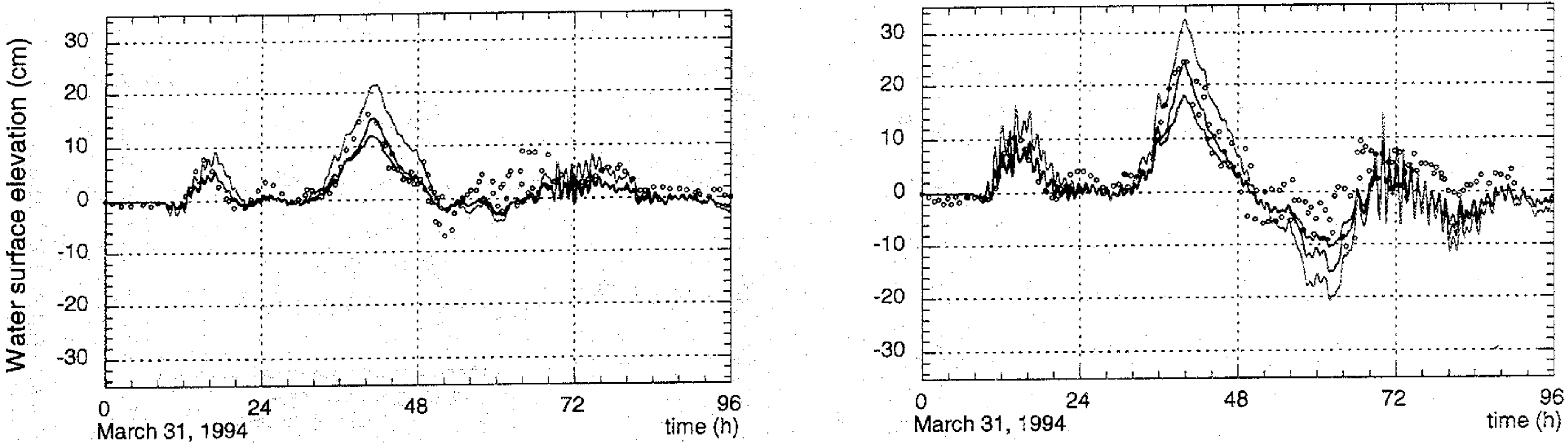
(d) Balatonfuzfo

Figure 3.9 Sensitivity of Predicted Seiche to Manning's Roughness Coefficient



(a) Keszthely

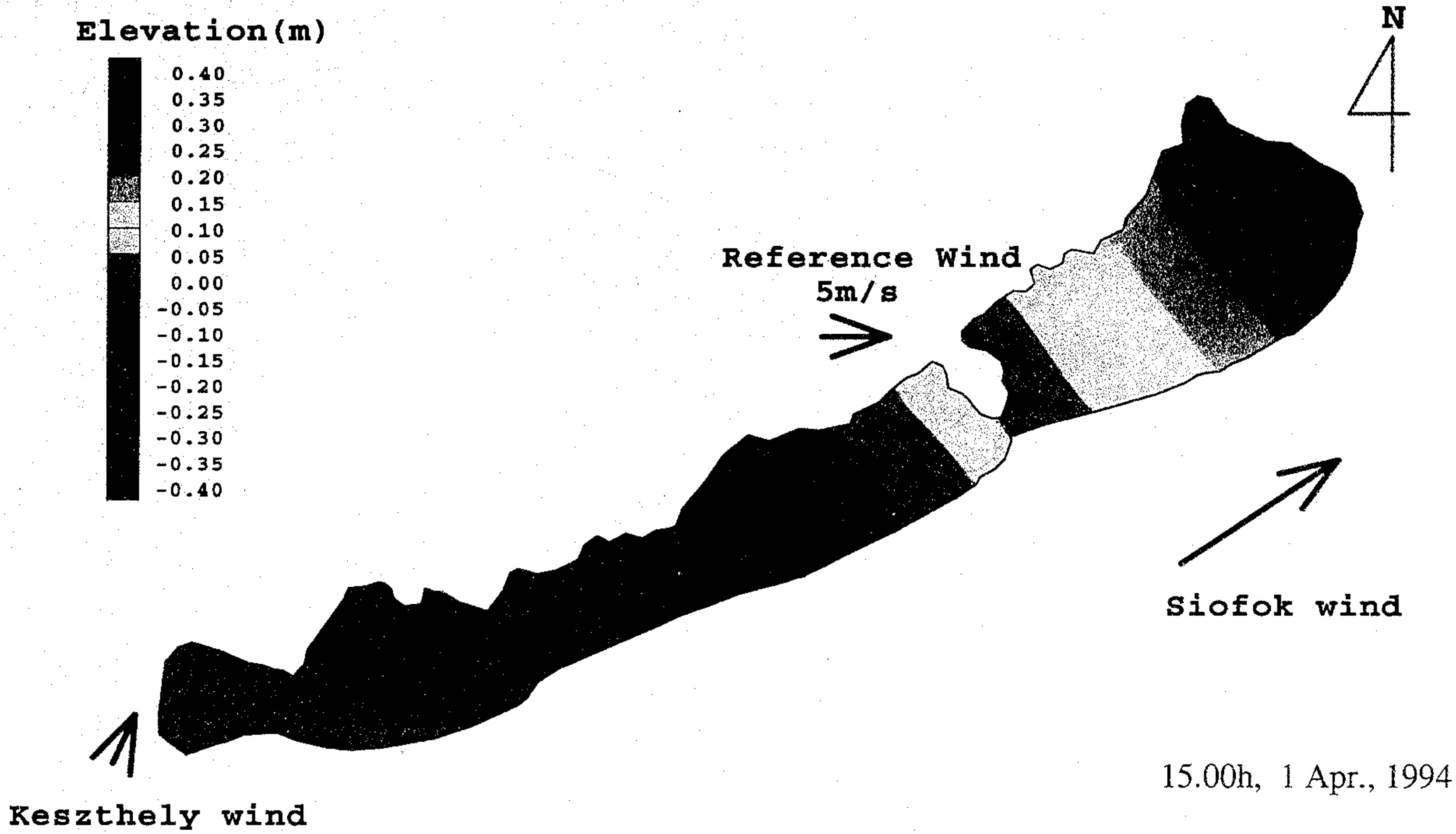
(b) Fonyod



(c) Siofok

(d) Balatonfuzfo

Figure 3.10 Sensitivity of Predicted Seiche to Wind Shear Drag Coefficient



15.00h, 1 Apr., 1994

Figure 3.11 Water Surface Elevation during Storm Event, 31 March-3 April, 1994

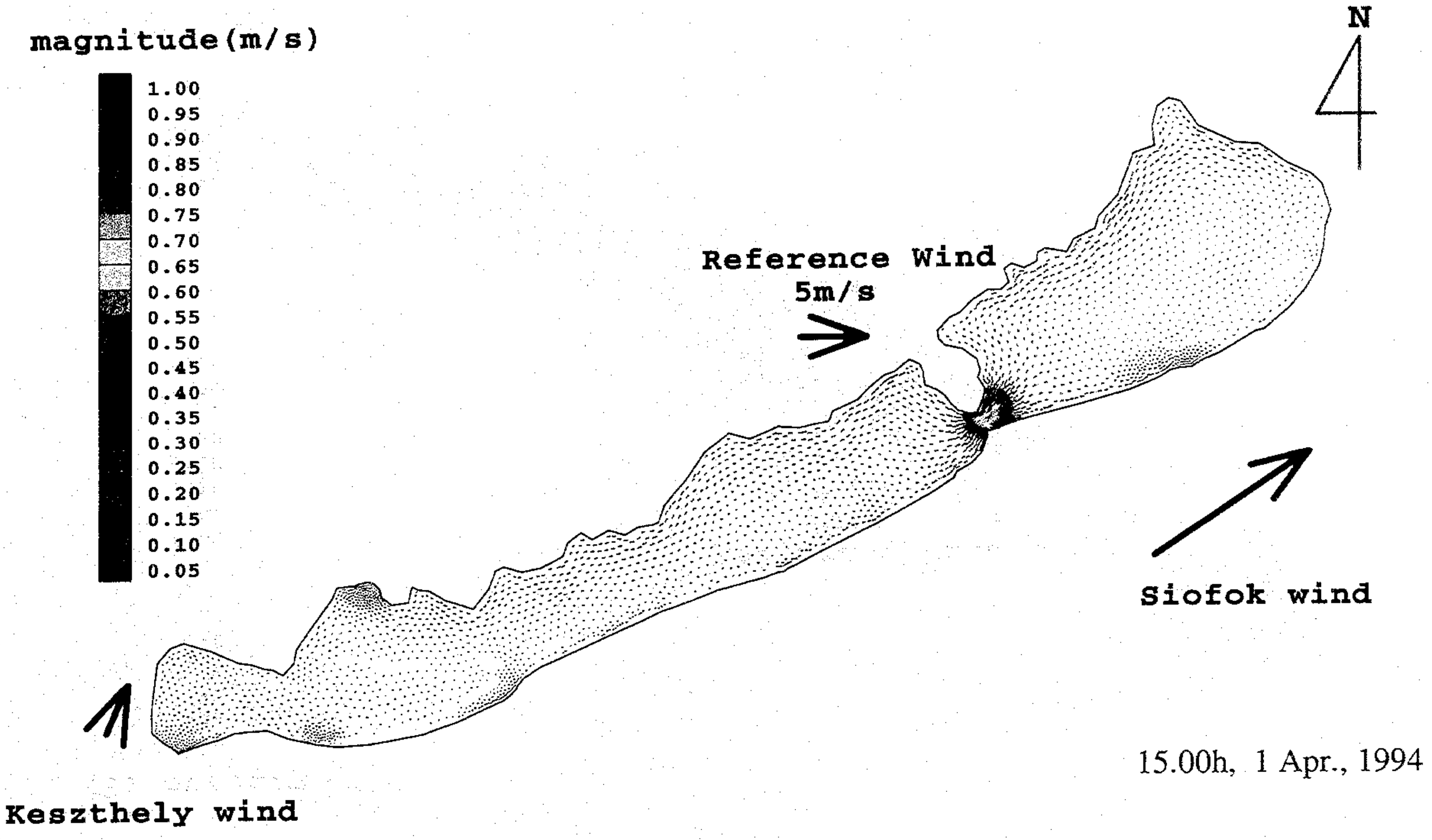
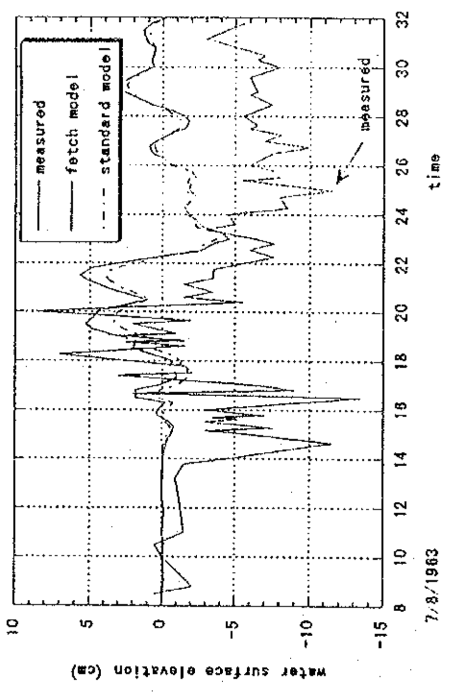
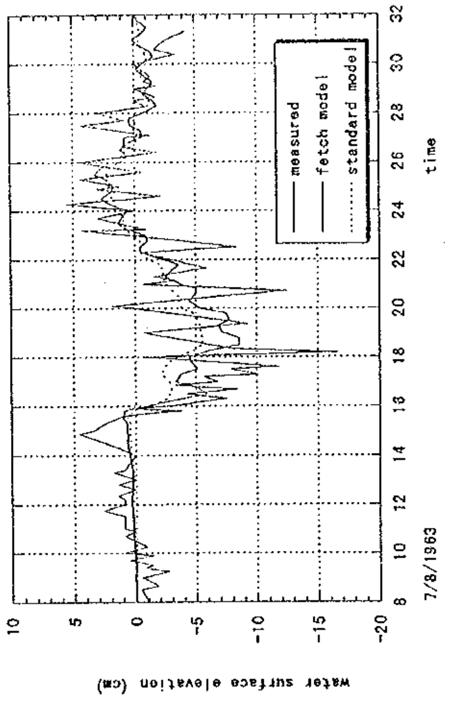


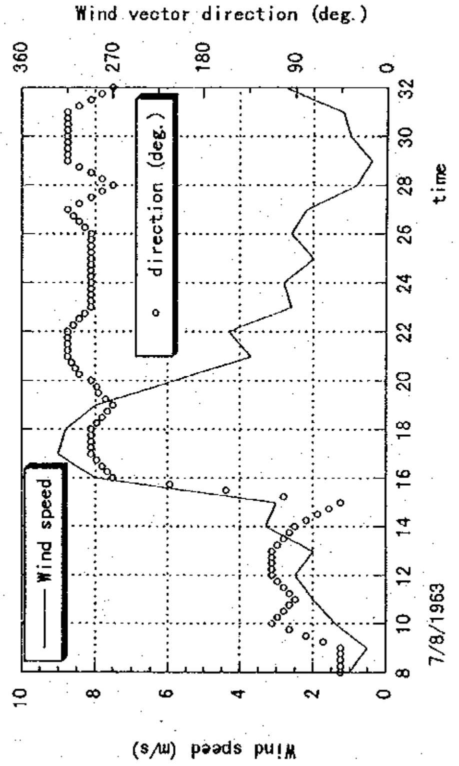
Figure 3.12 Flow Field during Storm Event, 31 March-3 April, 1994



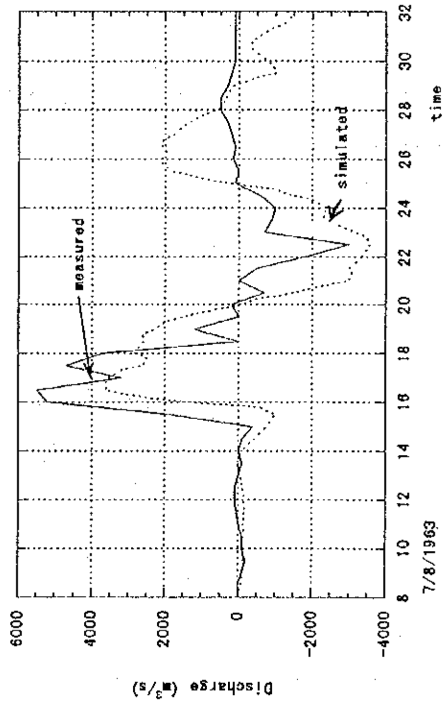
(a) Water surface elevation at Keszthely



(b) Water surface elevation at Balatonkenese

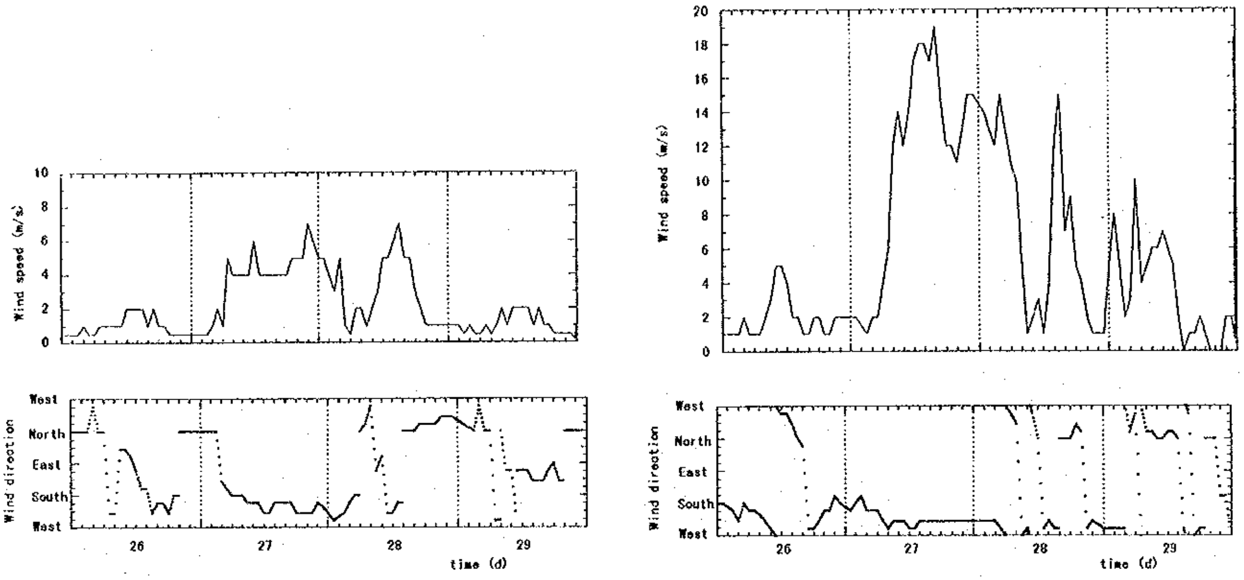


(c) Wind speed and direction



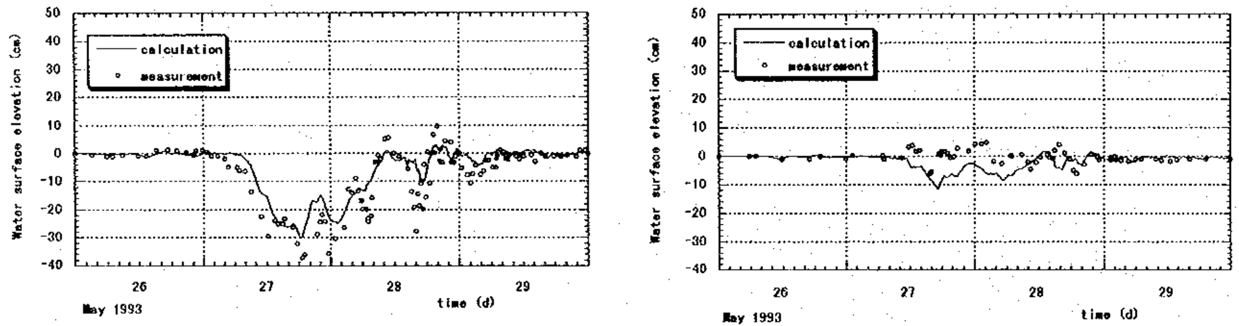
(d) Discharge at Tihany strait

Figure 3.13 Water Surface Elevation and Discharge Time-series during Storm Event, 8-9 July, 1963 (measured data from Muszkálay)



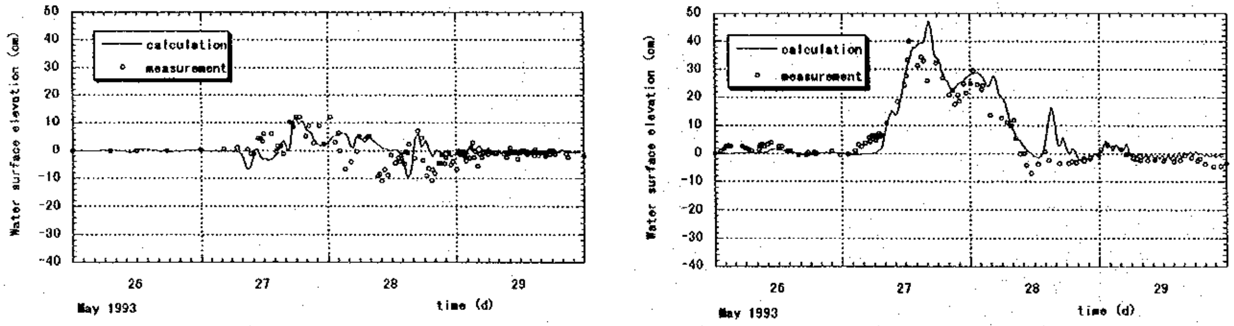
Wind data measured at Keszthely

Wind data measured at Siofok



(a) Keszthely

(b) Balatonakali



(c) Tihany

(d) Balatonaliga

Figure 3.14 Time-series of Water Surface Elevation during Storm Event, 26-30 May, 1993 (measured data from KDT-KÖFE)

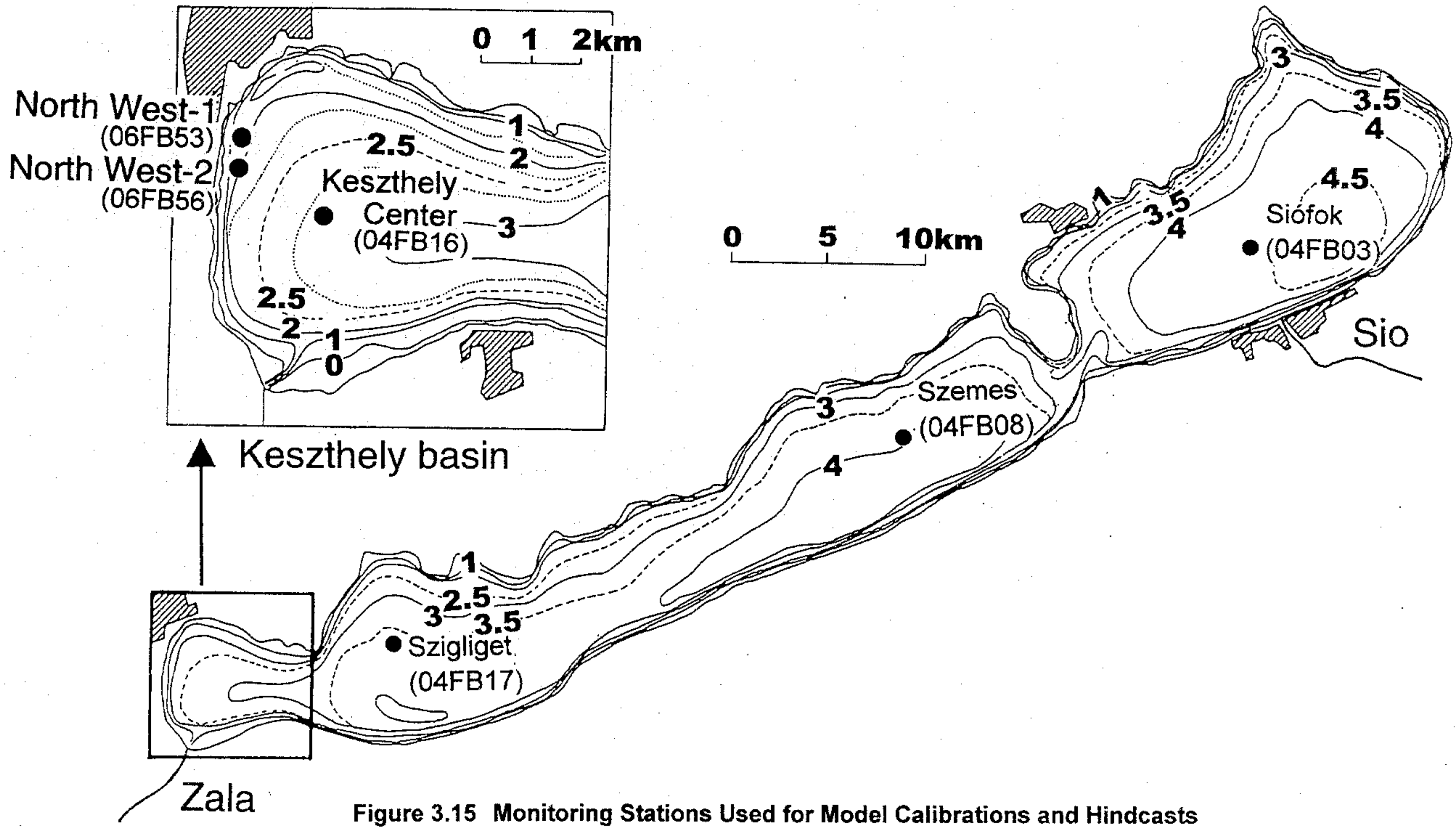


Figure 3.15 Monitoring Stations Used for Model Calibrations and Hindcasts

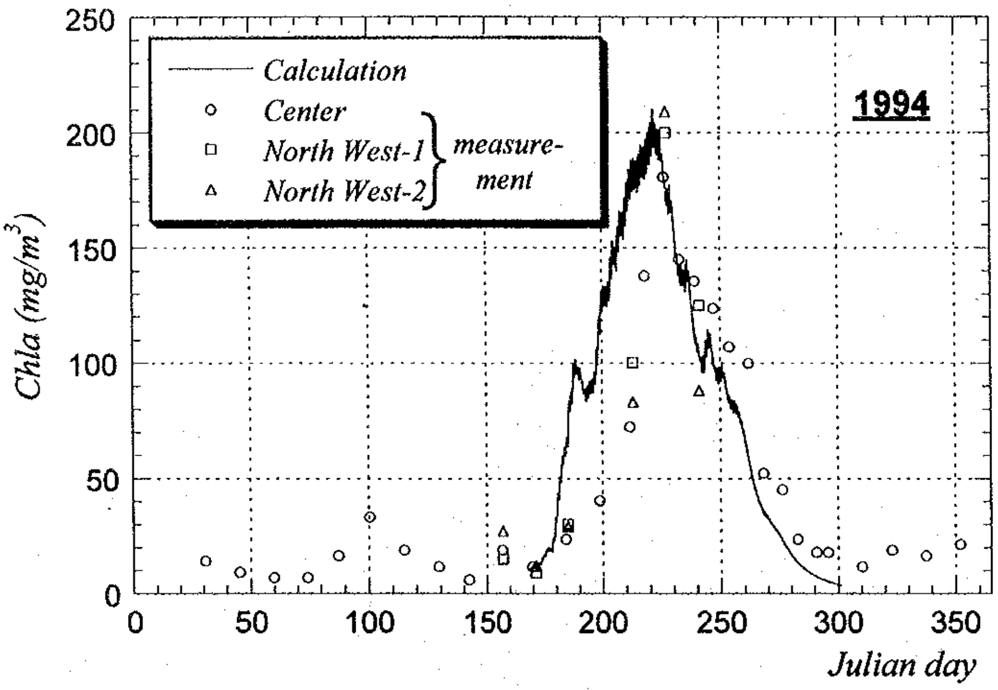


Figure 3.16 Chlorophyll-a Hindcast Compared with Measurements (Présing and KDT-KÖFE) in 1994

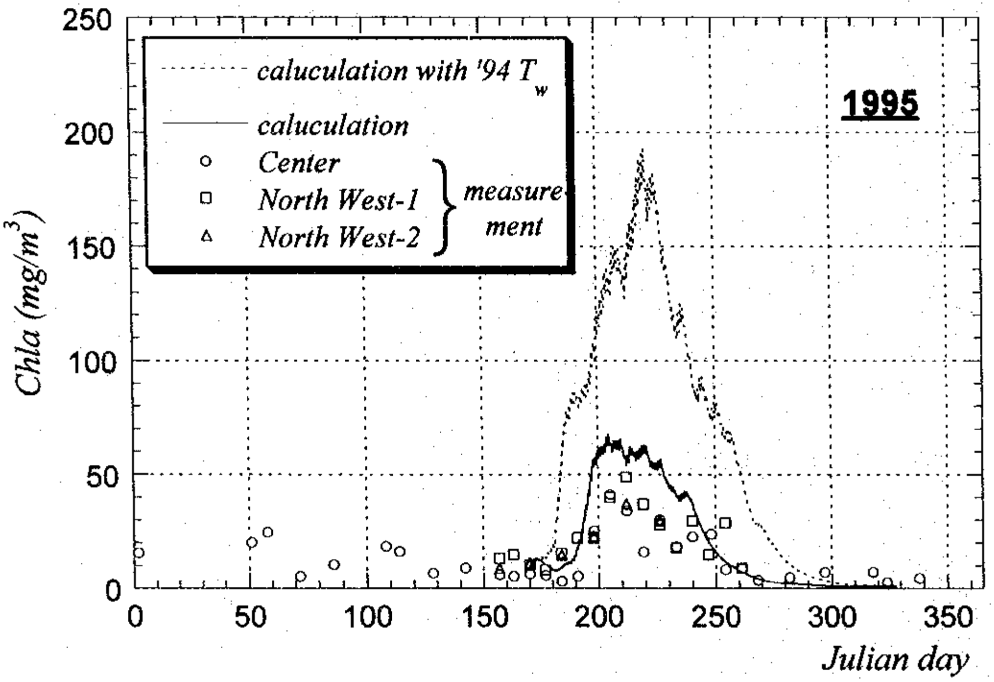
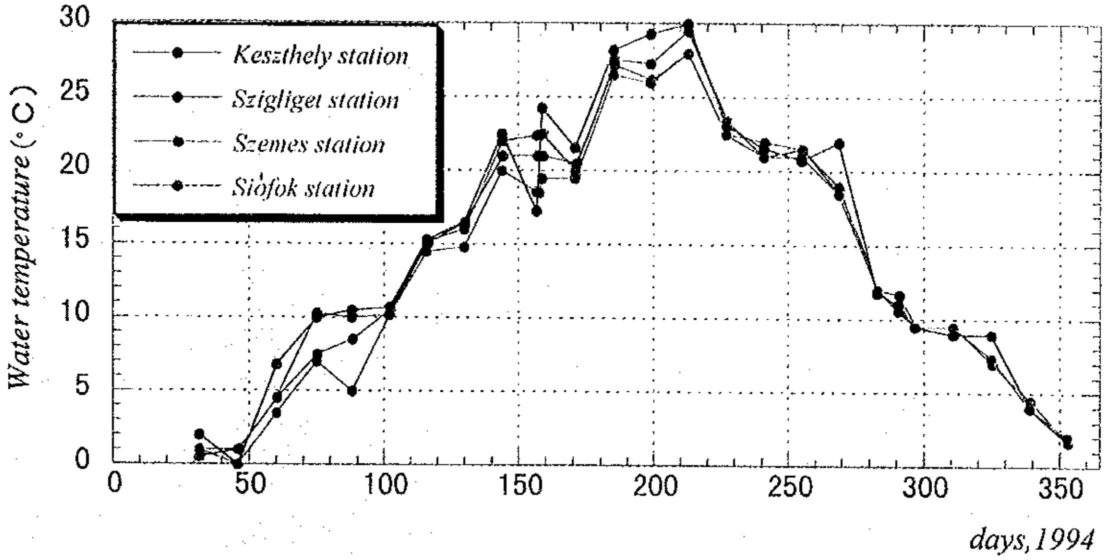


Figure 3.17 Chlorophyll-a Hindcast Compared with Measurements (KDT-KÖFE) in 1995



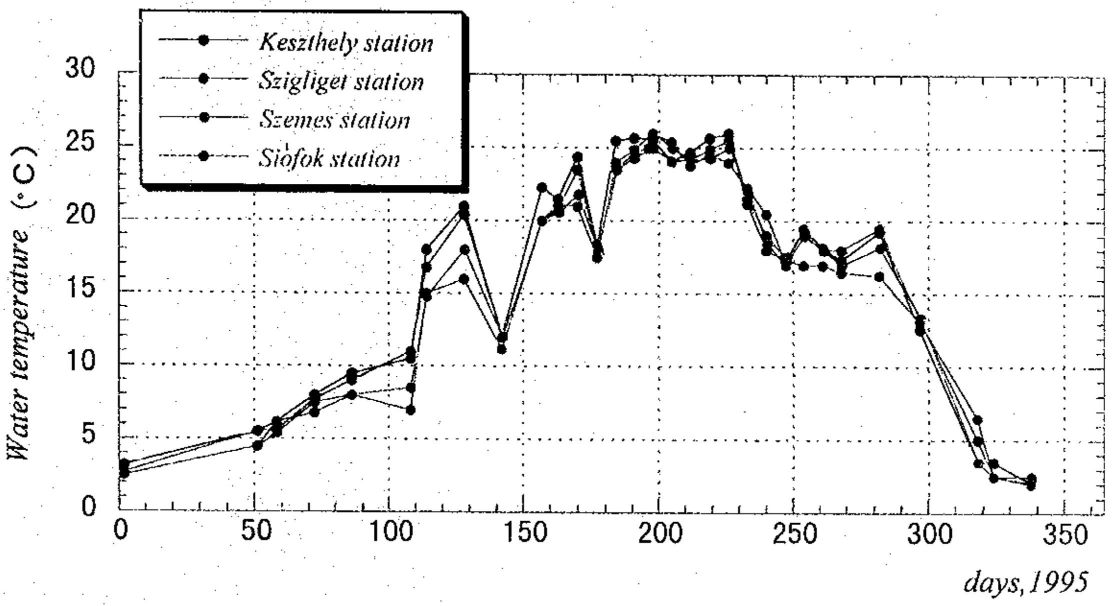


Figure 3.18 Water Temperatures in Each Basin of Lake Balaton (KDT-VIZIG)

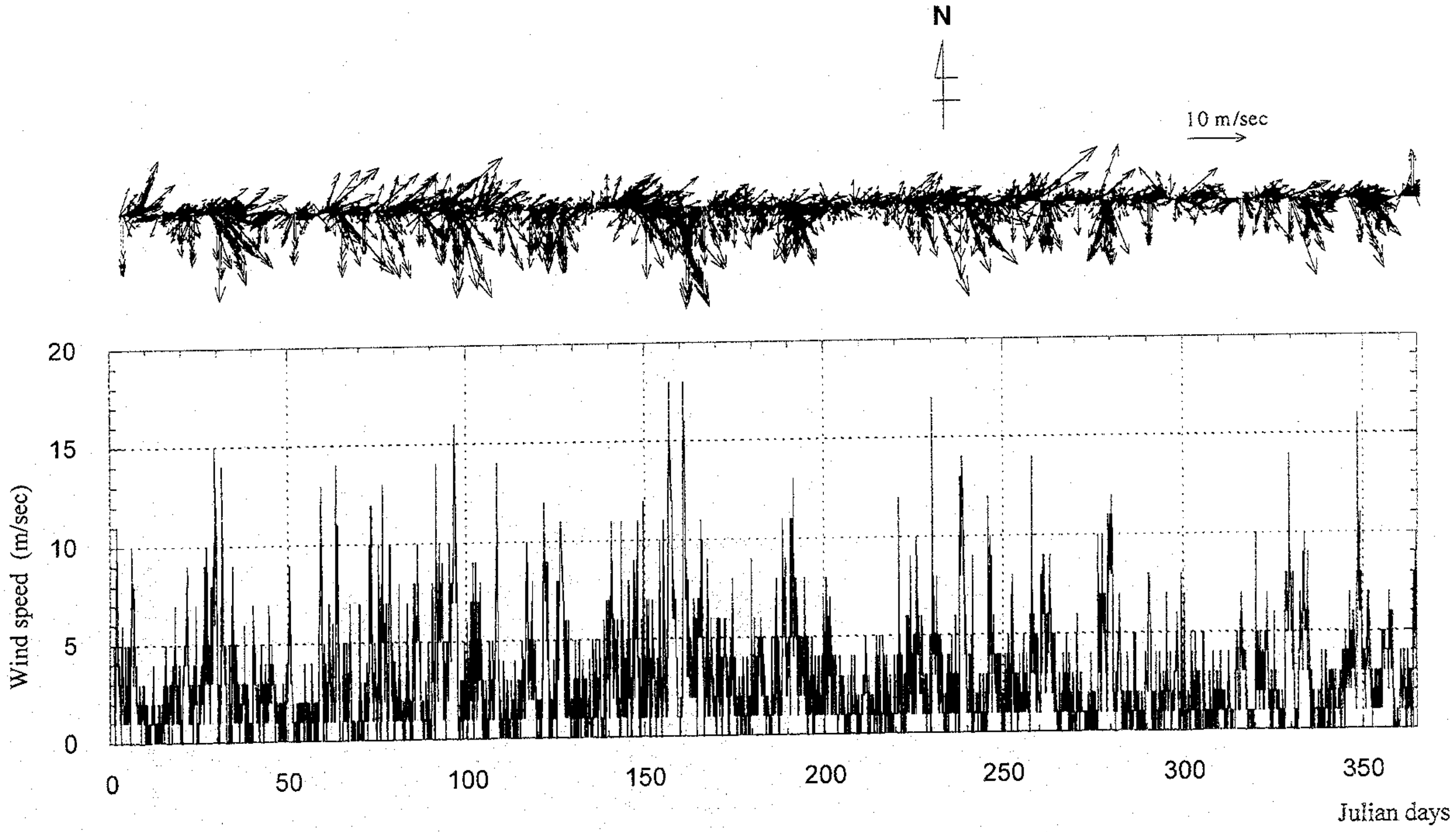


Figure 3.19 Wind-vector and Wind-speed at the Siófok Weather Station, 1994 (OMSZ)

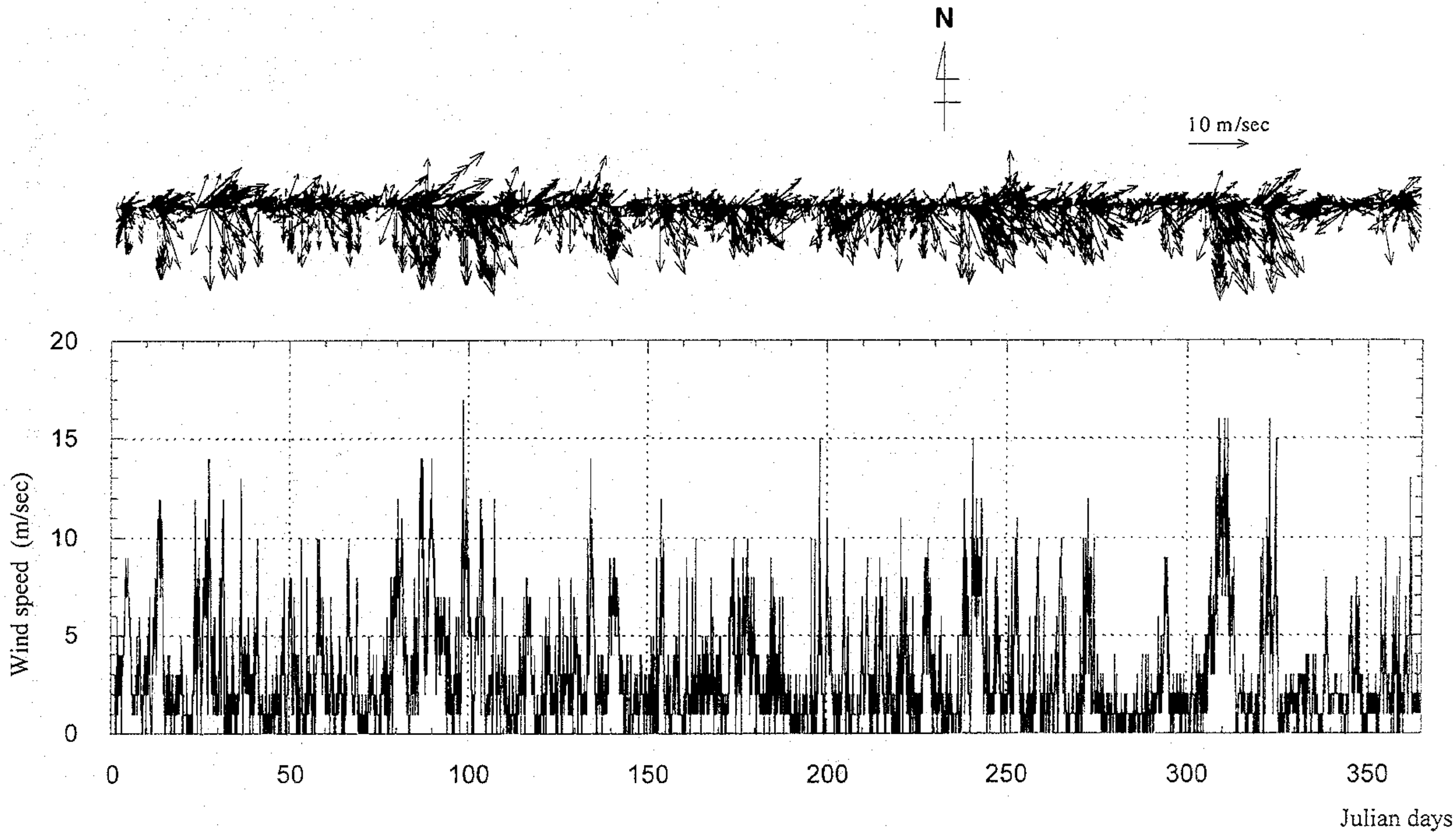


Figure 3.20 Wind-vector and Wind-speed at the Siófok Weather Station, 1995 (OMSZ)

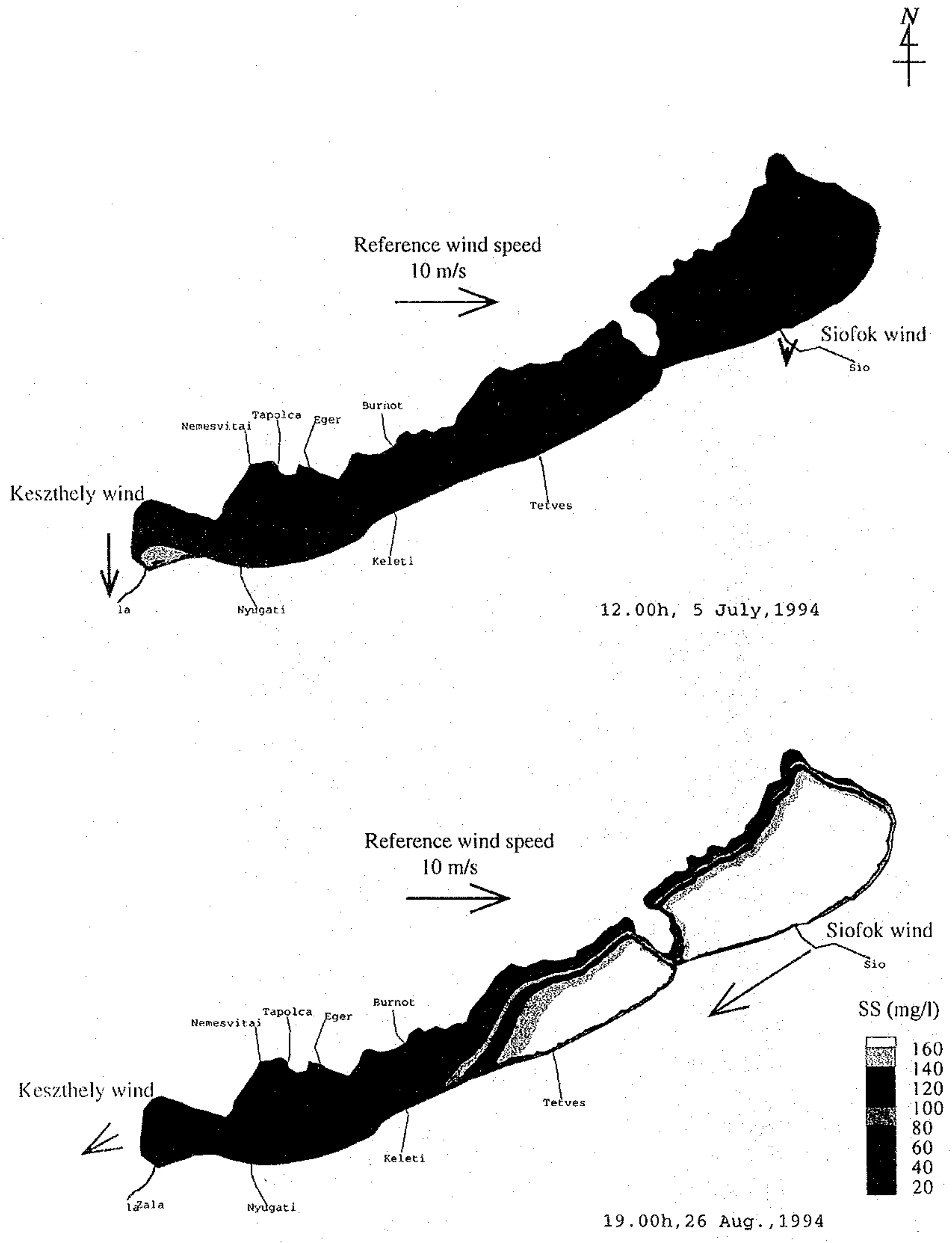
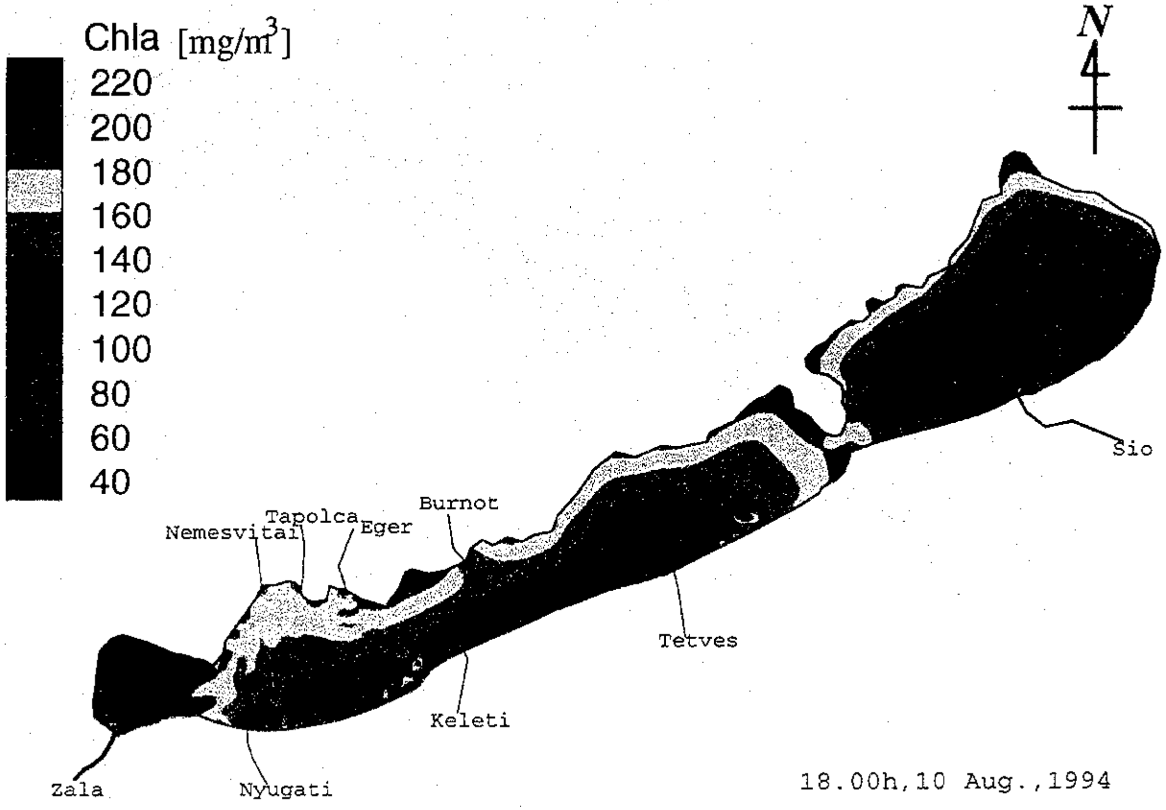
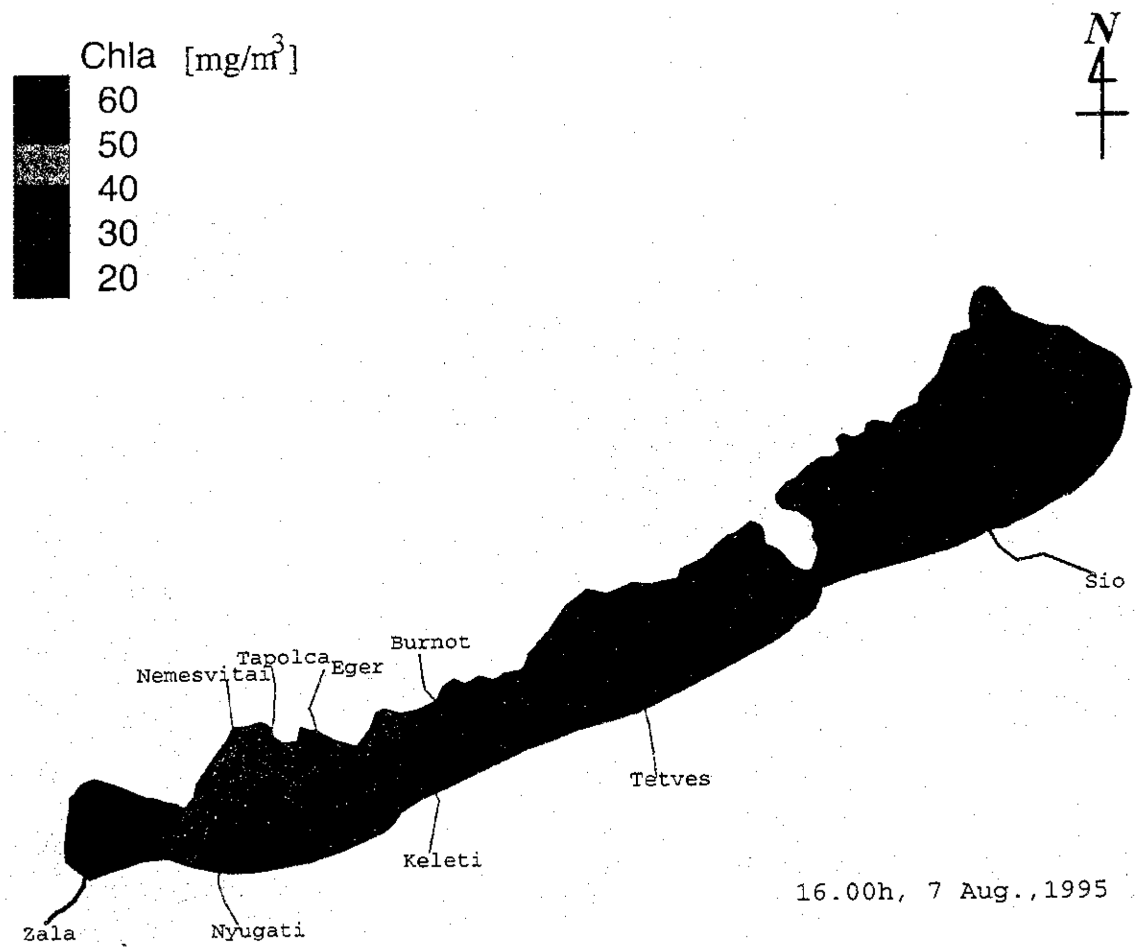


Figure 3.21 Suspended Sediment Distribution Calculated by WQSM



18.00h,10 Aug.,1994

Figure 3.22 *Chla* Distribution at the Time of Peak Bloom in Keszthely Bay in 1994



16.00h, 7 Aug.,1995

Figure 3.23 *Chla* Distribution at the Time of Peak Bloom in Keszthely Bay in 1995

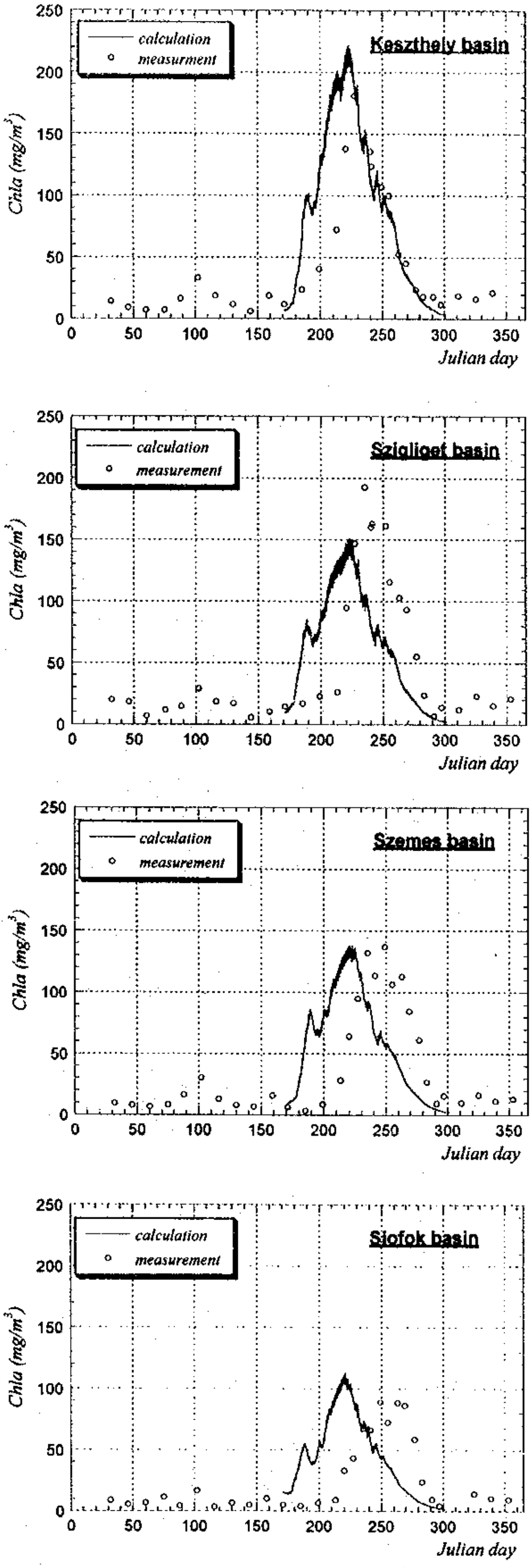


Figure 3.24 **Computed, by WQSM, and Measured (KDT-KÖFE) Time-series of *Chla* in 1994**

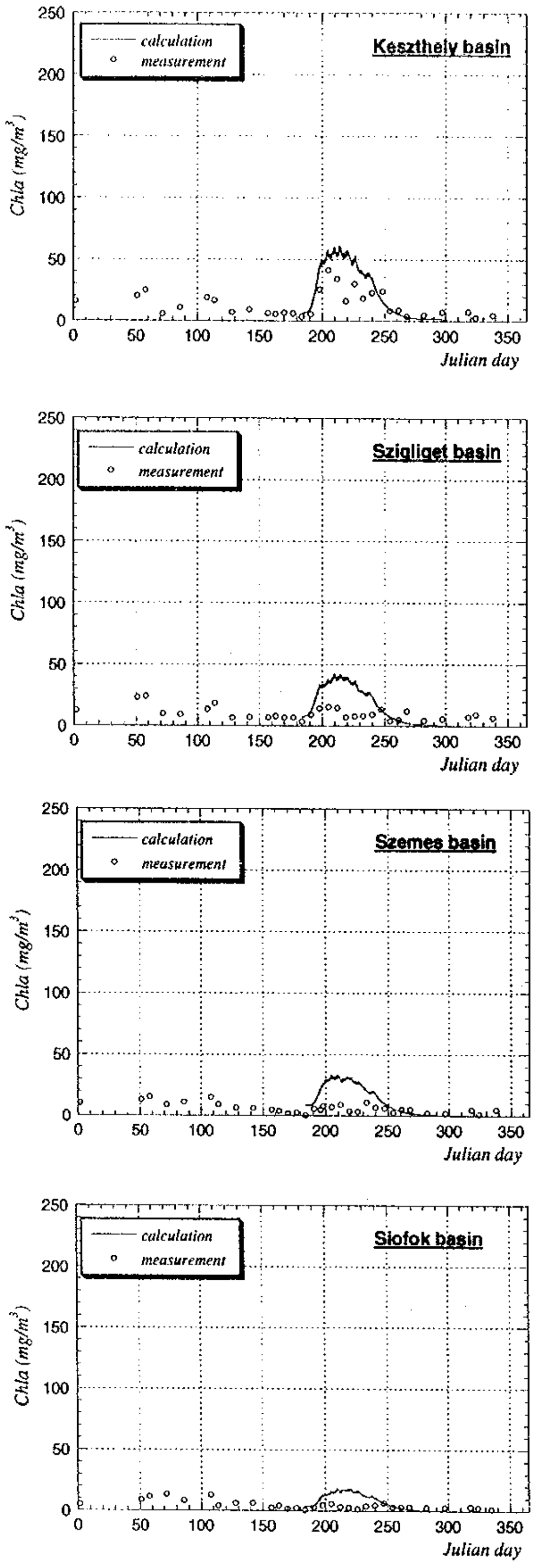


Figure 3.25 Computed, by WQSM, and Measured (KDT-KÖFE) Time-series of *Chla* in 1995

CHAPTER - 4

STUDY OF THE COMPREHENSIVE PLAN

CHAPTER - 4

STUDY OF THE COMPREHENSIVE PLAN

1. FRAMEWORK OF THE COMPREHENSIVE PLAN

1.1 TARGETS

(1) Target Year

A significant improvement of lake water quality would not be achieved within a short time period even if any control measures are realized, in other words, there would be time lag between pollution load reduction and lake water quality improvement.

On the other hand, a target year in the too far future would make it difficult to predict future conditions that compose the background of the plan. Uncertain future conditions would make the Comprehensive Plan unreliable.

The Government of Hungary compiled almost all kinds of necessary improvement measures for lake environment for the period from 1994 until 2010 in the "Action Plan for the Environmental Protection of Lake Balaton" (Resolution No.1049/1994). "Water Management Development Program for Lake Balaton (1995-2000)" (Governmental resolution No.2100/1995) has also set up the target year at the year 2010. The Comprehensive Plan considered in the Study should respect these plans.

Taking the above into account, the target year is set up as 2010.

(2) Targets for Water Quality Improvement

Target is determined following the existing plan "Water Management Development Program for Lake Balaton from 1995 to 2000" (Governmental resolution No.2100/1995). Target water qualities are converted into trophic categories as shown below, based on the classification of OECD.

Target Area (Sub-basin)	Water Quality (Trophic Category)	
	Recent Situation	Target
Keszthely	"Hypertrophic" or "Eutrophic"	"Eutrophic"
Szigliget	"Hypertrophic" or "Eutrophic"	slightly "Eutrophic"
Szemes	"Eutrophic"	"Mesotrophic"
Siófok	"Eutrophic" or "Mesotrophic"	"Mesotrophic"

The target is not necessarily possible water quality levels to be realized by possible technology, but desirable levels to be recovered within a decade. Therefore, it might be revised at the final stage of the Study when feasibility of environmental improvement measures are concluded.

In general, targets of water quality improvement are set up so as to secure existing and/or expected water uses of targeted water bodies. There are five significant water uses in Balaton, *i.e.* water supply, irrigation, industrial water, fishery, and tourism. It might be possible to determine the targets by referring to water quality standards for each water use. However, in case of Lake Balaton, problems are caused by the aesthetic or sensitive deterioration of the lake water quality, which is strongly related to the eutrophication conditions of the lake, rather than by the hygienic or chemical deterioration. Thus, it is more practical to set up the targets by trophic conditions than by various water quality items.

1.2 FUTURE CONDITIONS

The future conditions adopted in the Comprehensive Plan are assumed to be same as the present. Following three facts may be keywords in the prediction of the Hungarian future conditions:

- Hungary is a country well developed and industrialized in past.
- Hungarian economy is in the transitional state since the adaptation of market economy.
- Hungary will join the European Union (EU) in the near future.

The first fact suggests stability in changes of population and industrial structure. In European countries including Hungary, where industrialization has gradually taken place with experiencing various trials and errors in its process, it is considered that the industrial structure has reached to a stable state. It would hardly occur that population in agricultural industry rapidly shifts to manufacturing industry, causing eruption of urban population and rapid change of land use pattern, which are common causes of environmental concerns in developing countries.

On the other hand, the second factor may indicate a potential increase of its economy. It is said that the production levels decreased by 30% just after the corruption of the socialism system, by losing its markets in eastern European countries and the former Soviet Union. Although recovery of the production level has not been significant, it is a matter of fact that potential demands exist there. Hungarian production level could be affected by recovery of the former markets. However, it would be difficult to predict its timing and degree.

Joining EU may cause substantial quantitative and qualitative structural changes in Hungarian economy, which are expected to help growth of its economy as it was so in Greek and Portuguese. However, it is difficult to draw up its transitional or final state quantitatively at present, too.

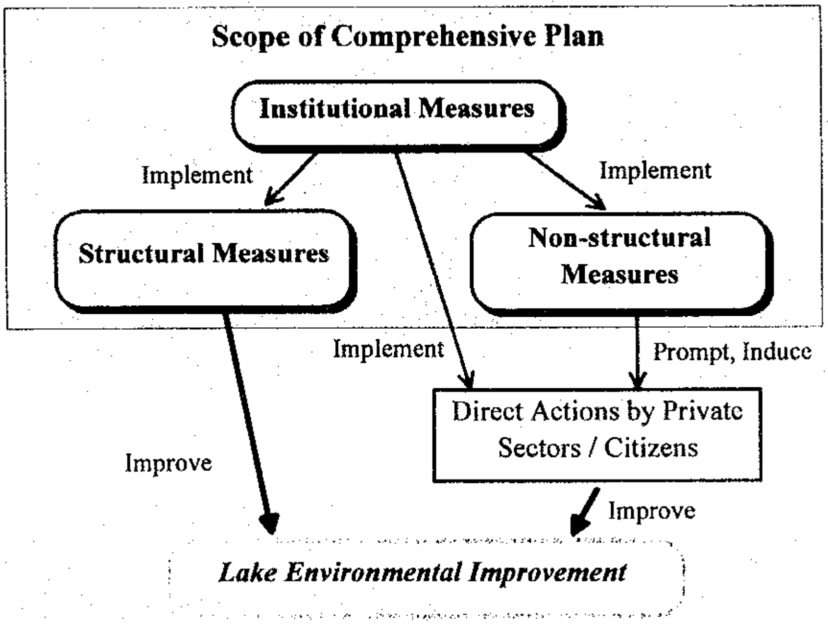
As such, future trend of Hungarian economy would be understood as a combination of a stable trend, which is a result of historical industrialization and development, and external factors, which probably increase its economy. Although the external factors could not be neglected, they are too uncertain to determine future conditions for a framework of a master plan or comprehensive plan, where quantitative expression is required. Therefore, it is judged to be more realistic to fix the present conditions towards the target year than to newly forecast future conditions based on uncertain factors.

2. CONCEPTS OF THE COMPREHENSIVE PLAN

From the viewpoint of governmental side, possible efforts to improve the Lake environment are composed of following three components:

- Structural measures
- Non-structural measures
- Institutional measures

The concept is illustrated below.



In the Study, a structural measure is defined as the measure taken by the governmental side to physically improve Lake Balaton environment.

A non-structural measure is defined as the measure aiming to motivate citizens or private sector to take some actions directly improving water quality (hereinafter referred to as "direct actions"). For example, when the government enacts water quality standards for industrial wastewater discharge for the reduction of industrial pollution loads, the purpose can be achieved by some direct actions of the manufacturer such as installation of wastewater treatment facility or revision of production process for reducing discharged loads. Water quality standards themselves only can prompt or induce such direct actions.

Institutional measures are required to provide an institutional framework which makes implementation of the abovementioned measures possible.

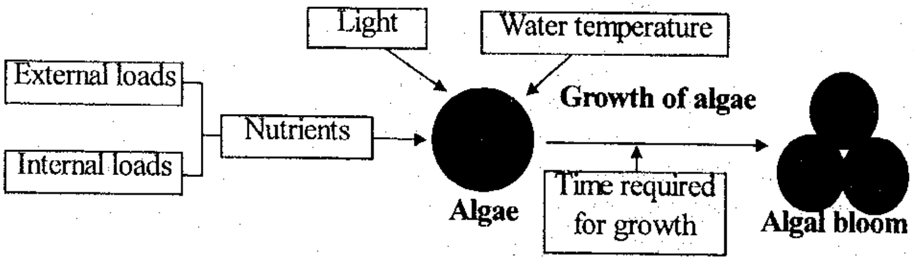
The fact that a prevention or mitigation of the eutrophication problems of large shallow lakes is extremely difficult has been accepted worldwide. Lake Balaton is not an exceptional case and there is no panacea to improve water quality of the lake. Tackling with this difficult problem necessitates step-by step and hardworking efforts of not only central government but also local governments and even individual citizens. Thus, non-structural and institutional measures should be studied in the Comprehensive Plan as well as structural measures, even though their effects can not be estimated quantitatively.

Furthermore, most environmental improvement projects are implemented as public works because beneficiaries of such projects are hardly specified, resulting in extreme difficulty to recover the project cost from beneficiaries. Whether environmental improvement projects are realized or not depends on the state or local governments' policies, which are to be affected by citizens' or taxpayers' will. Therefore, all of three components should be studied to make the Comprehensive Plan more realistic.

3. STRUCTURAL MEASURES

3.1 GENERAL

Deterioration of Lake Balaton environment is caused by excess growth of algae, which was resulted in along with progress of the eutrophication process of the lake. Major factors that affect the algal growth is schematically illustrated in a figure below.



The growth of algae can be controlled if one of these factors can be controlled. There are various methods, which are actually in operation or proposed, aiming to control the above growth factors, as summarized in *Table 4.1* and *Table 4.2*. *Table 4.1* presents methods other than the nutrient reduction together with applicability to Lake Balaton, while *Table 4.2* presents methods to reduce nutrient loads to the lake.

(1) Methods Other Than the Nutrient Reduction

As shown in *Table 4.1*, those methods mainly related to lake's physical conditions are of site specific and are applicable only in a limited scale. The size of Lake Balaton, even it is divided into sub-basins, apparently exceeds an applicable scale. In addition, some of them will damage the water uses and injure the beauty of the Lake. Thus, it is judged that those methods can be excluded from further study.

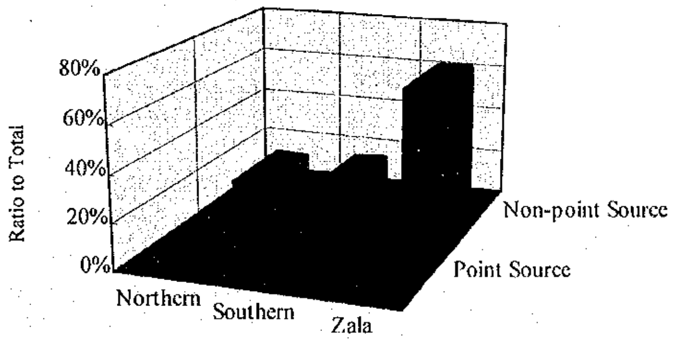
(2) Methods for Nutrient Reduction

Table 4.2 presents methods for nutrient reduction. As discussed in the previous section, it is widely accepted that phosphorous is the limiting factor of algal growth in Lake Balaton. Thus, the nutrient control means the phosphorous control in the following parts of this report. The table also indicates present status of application of each method in the Lake Balaton catchment. The sources are classified into internal sources and external sources, and the external sources are further divided into point sources and non-point sources. Existing measures applied to the lake cover all nutrient sources.

1) External load

According to results of the pollution load analysis in the Study, non-point pollution loads are dominant as shown in the figure below, counting about 80 % of total external pollution loads. This means that further point source loads reduction would not have a significant water quality improvement effect, and the reduction of non-point source load should have a higher priority in the Comprehensive Plan.

Pollution Loads (TP) by Catchments and Sources



Several measures have been already installed in the catchment as shown in *Table 4.2*, however, implementation of those measures is considered as trials and their effects have not been confirmed, except the Kis-Balaton project. In general, effective methods to control non-point source loads have not been technically established, although there are various trials in the world. The

Comprehensive Plan should include development of measures for non-point source reduction.

2) Internal load

The water quality of Lake Balaton has not shown significant improvement, while external loads have been substantially reduced by development of sewerage system with phosphorous removal and effluent diversion. This fact suggests considerable contribution of the internal load to the lake water quality.

3) Comparison between external and internal loads reduction measures

Table 4.3 shows the values of annual maximum chlorophyll-a concentration by sub-basin of the lake. These values for following cases have been predicted, using WQSM developed in the Study.

Hindcast:	A base case. Actual values of chlorophyll-a concentration in 1994 and 1995.
Case A1:	Phosphorous loads of all rivers flowing to the lake are reduced by 30 percent.
Case A2:	Phosphorous loads of all direct runoff such as urban drainage channels are reduced by 30 percent.
Case B1:	Phosphorous loads of bottom sediment of all sub-basins are reduced by 40 percent.
Case B2:	Phosphorous load of bottom sediment of the Keszthely basin is reduced by 40 percent.

Spatial distribution of annual maximum chlorophyll-a concentration for these cases are shown in *Figures 4.1 ~ 4.5*.

The results show the following predictions:

- Load reduction measures for bottom sediment of all sub-basins would reduce chlorophyll-a concentration (annual maximum) of the lake by 9~17 percent.
- Measures for bottom sediment of the Keszthely basin would reduce chlorophyll-a concentration of the basin by 10~11 percent, however would contribute very little to chlorophyll-a reduction of other three sub-basins.
- External load reduction measures for all rivers or direct run-off flowing to the lake would reduce chlorophyll-a concentration (annual maximum) of the lake by at most 3 percent.
- Quick effect would be expected from internal load reduction rather than external load reduction.

These predictions may suggest that internal load reduction measures should be taken with the highest priority to realize quick effect something like a surgical operation. Such a quick effect may not be expected from external load reduction. The effect of external load reduction may be slow but steady like preventive medicine, since external loads are sources of internal loads.

Based on these facts, both internal and external load reduction measures are studied and included in the Comprehensive Plan. This general approach can be justified from the viewpoints of continuation of the present policies and coordination of existing projects and plans.

3.2 MEASURES FOR EXTERNAL LOADS REDUCTION

(1) Measures for Non-point Source Loads Reduction

Non-point source loads can be reduced by reduction of runoff into a lake directly or indirectly through rivers/drainage channels, or purification of river water discharging to a lake, or combination of both.

In rural areas, soil erosion control works consisting of sedimentation and infiltration of storm water are applicable measures for non-point source loads reduction. Infiltration of storm water can not only reduce peak flood discharge but also feed a river base flow. Therefore, the erosion control works will improve overall water environment, if harmful materials such as chemicals and heavy metals are not contained in soils.

Urban storm runoff occurs within a short time like a few hours after a storm rainfall, and carries accumulated sediments as well as solid wastes and unnatural pollutants. As a result, storm water from urban area is highly polluted. Taking this fact into account, water flows from urban areas should be treated as much as possible, if collection of the water flows is not difficult.

Following measures for reduction of non-point source loads are evaluated in this study.

- River water purification to cope with the loads from its whole watershed
- Soil erosion control of rural areas in upper catchment areas
- Urban runoff control in direct catchment areas which have no typical rivers

Figure 4.6 shows a classification of measures for non-point source loads reduction based on location. It is remarkable that these measures have already been practiced in Hungary since 1980's. For example, river water purification facilities have been constructed for several rivers such as Lesence patak, Lovasi séd, Örvényesi séd, etc., the retention facility in Zánka is a soil erosion control system in an agricultural area, and the infiltration system at the mouth of Szent László árok is one of the measures for pollution loads from urban area. However, the effects on pollution loads reduction of those facilities have not been examined due to lack of periodical monitoring, or the scale of the facilities were not necessarily designed with reasonable engineering grounds.

1) River water purification

There are various methods to remove phosphorous from natural water bodies. Among them, the followings are selected as generally possible methods for river water purification.

- Settling reservoir method
- Coagulation sedimentation method
- Anaerobic-aerobic activated sludge method
- Mixture of coagulation and activated sludge method
- Soil infiltration method
- Crystallization for phosphorous removal method
- Vegetation purification method

Applicability of above methods to Lake Balaton has been evaluated as shown in *Table 4.4*. Evaluation criteria include availability of land, topographic conditions, hydrological/hydraulic conditions of rivers, natural conditions around the lake, construction/maintenance costs, environmental acceptability, phosphorous removal efficiency, easiness of operation and maintenance, and examples to follow. Finally, following three methods have been selected as applicable ones taking local characteristics of Lake Balaton into account.

a. Settling reservoir method

This method requires a large area for the site, but land for the site can be easily found in the middle reach of river. Maintenance cost is low, though construction cost is relatively high. System of the facility is simple and maintenance is easy. There are some examples in the middle reaches of rivers around Lake Balaton.

b. Vegetation purification method

Comparing to the settling pond method, this method requires smaller area of site, construction cost is lower, removal efficiency is almost same, and maintenance cost is higher. Land for the site would be acquired along the river or around the river mouth where reed bushes are grown. This is advantageous to ecosystem and natural scenic view, which means that this method is environmentally friendly. There are some examples in the lower reaches of rivers around Lake Balaton.

c. Coagulation sedimentation method

This method has been practiced in sewage or industrial wastewater treatment. Comparing to the above-mentioned two methods, phosphorous removal efficiency is higher, land for site is smaller, construction and maintenance costs are higher, and operation and maintenance is not easier due to machinery system. This method uses chemicals as coagulants, which may be not environmentally friendly. This method would be advantageous when land area for the site is limited.

2) Soil erosion control of rural areas in upper catchment areas

Assuming that the soil particles larger than 0.02 mm are settled, 55 % of the sediments can be reduced by sedimentation, judging from the soil particle distribution in the Study Area.

The volume of sediments caused by surface runoff would be reduced as follows :

$$Sr = 0.55 * Ar * Ep / \Sigma(Ai * Epi)$$

where, Sr : reduction of sediments
Ar : total catchment area covered by Erosion Control Facilities
Ep : average potential erosion volume
Ai : area of certain land use i
Epi : potential erosion volume of certain land use i

The proposed erosion control areas are selected as shown in *Figure 4.7* based on following conditions;

- soil erosion potential analyzed by MTA-TAKI is more than 1 ton/ha/year,
- infiltration capacity is less than 150 mm/hour, and
- excluding forest areas.

Total area covered by the facilities is 6,362 ha, however, this area is something like a soil erosion potential area determined on the basis of the existing analysis by MTA-TAKI. It should be noted that actual erosion would greatly be depend on the local conditions, and it would be necessary to conduct a survey to confirm the areas actually eroded.

3) Urban run-off control in direct catchment areas

In direct catchment areas many small drainage channels and small creeks directly flow into the lake. The most important things are how to intercept these waters and how to transport them to the purification facilities. Coagulation sedimentation method would be applicable to water purification due to the limitation of land acquisition in urban area.

Pipelines are installed paralleling the lake shoreline to intercept waters from many small drains or creeks and lead them to the treatment facilities.

(2) Measures for Point Source Loads Reduction

In the catchment area of Lake Balaton, pollution loads of point sources are considerably controlled and treated. Therefore only the followings are considered as remaining measures for point source loads.

- Further development of sewerage systems
- Upgrading/improvement of sewage treatment level

1) Further development of sewerage systems

Permanent population (395,900) and seasonal population (673,600) discharge wastewater in the whole catchment area of Lake Balaton. About 40% of them are provided with public sewerage systems (off-site systems) and about 50% of them are provided with public utility substitutions (on-site systems).

According to the existing sewerage development program based on the governmental resolutions No.2100/1995 and No.1068/1996, public sewerage systems are to be provided for about 920,000 persons equivalent to 86 % of total population in the whole catchment area, which means that present service level will be doubled by the year 2010. It is expected that sewerage coverage ratio will significantly increase in the southern catchment area. On the other hand, the full-scale program need a great amount of investment, approximately 53,000 million HUF estimated by the existing program in 1996.

The program should be accelerated to follow the planned schedule as much as possible from the hygienic point of view. The benefit would be more significant in villages or cities where groundwater is used for drinking water and polluted by untreated or badly treated sewage. However it may not be expected that the program will contribute so much to reduction of phosphorous loads flowing into Lake Balaton in the whole catchment area. Phosphorous load is reduced by a natural-purification effect during flowing down on/in the ground, and the efficiency of sewage treatment system can not exceed that of the natural-purification where the load is discharged far from the lake.

2) Upgrading/improvement of sewage treatment level

The governmental resolution No.2100/1995 prescribes 95% nutrient removal in case of treated water being led directly to the lake and 80% nutrient removal in case of being led indirectly to the lake.

For determination of water quality of effluent from sewage treatment plants in the area, the program has targeted limit values of T-P 0.5 mg/l ~0.7 mg/l in the lakeside areas and cities of the catchment area and 1.8 mg/l in other settlements of the catchment area.

According to the data in recent years (1994~1996), effluents from Zalaegerszeg STP (sewage treatment plant), Keszthely STP, and Tapolca STP did not meet these requirements. These three plants discharge relatively large quantity of treated water into the western part of Lake Balaton (the Keszthely and the Szigliget basins) even if it is indirectly led to the lake; about 15,800 m^3/day (Zalaegerszeg STP), 12,000 m^3/day (Keszthely STP), and 4,200 m^3/day (Tapolca STP). Furthermore capacities of Zalaegerszeg STP and Keszthely STP will be expanded to 22,700 m^3/day and 31,000 m^3/day respectively by 2010 according to the existing program. Therefore, upgrading/improvement of these three major plants should be emphasized. It would be technically possible if an advanced wastewater treatment is properly applied.

(3) Evaluation of External Loads Reduction Measures

1) Phosphorous reduction efficiency

River water purification

The lower reservoir of Kis-Balaton is expected to reduce T-P load of Zala River by 30～40% as a long-term effect. As already mentioned in the chapter of pollution load analysis, Zala River discharges approximately 45 tons/year of T-P load into Lake Balaton. Thus the lower Kis-Balaton would reduce T-P load to the lake by 14～18 tons/year.

As a whole, river water purification systems are expected to reduce T-P load discharged into Lake Balaton by 30 %. The total T-P load of rivers except Zala River is estimated to be 53 tons/year (including T-P load of four stormwater pumping stations). Thus the river water purification systems except Kis-Balaton would reduce T-P load to the lake by 16 tons/year.

Soil erosion control of rural areas in upper catchment areas

Reduction of TP by soil erosion control in upper rural areas is estimated based on the equation below:

$$\frac{\sum E_{pi} \times A_{ci}}{\sum E_{pi} \times A_i} \times L_{rural} \times E_{TP} = L_{reduction}$$

where i : erosion potential category,
E_{pi} : erosion potential (ton/ha/year),
A_{ci} : area covered by the facilities with erosion potential of E_{pi}(ha),
A_i : area with erosion potential of E_{pi}(ha),
L_{rural} : total TP load from rural areas (tonTP/year),
E_{TP} : reduction efficiency for TP,
$L_{reduction}$: reduction of TP (tonTP/year)

Assuming E_{TP} is about a half of reduction efficiency of SS, which is 0.55 based on the soil particle distribution of the Study Area, E_{TP} of 0.3 is employed. The total erosion potential in the area covered by the erosion control facilities is estimated by MTA-TAKI Data to be $\Sigma(E_{pi} \times A_{ci}) = 25,411$ tons/year, and the total erosion potential in rural areas in the whole catchment area to be $\Sigma(E_{pi} \times A_i) = 61,452$ tons/year. Thus values of $L_{reduction}$ are estimated as follows:

Catchment Area	L_{rural} (tonsP/year)	$L_{reduction}$ (tonsP/year)
Northern	24.9	3.1
Southern	30.5	3.8
Zala (Western)	30.1	3.7
total	85.5	10.6

Total TP load reduction in whole catchment area by soil erosion control in upper rural areas is estimated 10.6 tons/year, consisting of 3.1 tons/year in the northern area, 3.8 ton/year in the southern area, and 3.7 ton/year in the western area.

Urban run-off control in direct catchment areas

As a whole, urban run-off control systems are expected to reduce T-P load discharged into Lake Balaton by 30 %. As already mentioned in the chapter of pollution load analysis, the total T-P load of whole systems is estimated to be 32 tons/year. Thus the urban run-off control systems would reduce T-P load to the lake by 10 tons/year.

Further development of sewerage systems

T-P load reduction by further development of sewerage systems is estimated as follows:

Catchment Area	Northern	Western	Southern	total
Population newly covered by sewerage (person)	21,355	28,869	30,250	80,474
T-P load reduction (gray water: t/year) unit load = 0.5g/d/c	3.9	5.3	5.5	14.7

The figures mean loads of gray water discharged from houses except excreta, because the load of excreta is treated by cesspool even at present though its contribution to external load is uncertain. About 15 tons/year of T-P load would be reduced before being collected by sewer network. These loads are collected by sewer network, treated by sewage treatment plants and finally discharged to the lake or diverted to other catchment areas.

Upgrading/improvement of sewage treatment level

When three major sewage treatment plants are upgraded or improved to meet the target (T-P 0.7 mg/l) of the sewerage development program, T-P load will be reduced as follows:

Sewage Treatment Plant	Zalaegerszeg	Keszthely	Tapolca	total
Present T-P concentration of effluent (mg/l)	1.0	2.8	1.1	-
Future treatment capacity (m^3/day)	22,700	31,000	4,800	58,500
Net reduction of T-P load by upgrading or improvement (ton/year)	2.5	23.8	0.7	27.0

About 27 tons/year of T-P load would be reduced after being treated by these major three plants. These loads are finally discharged to Lake Balaton through rivers or channel. Thus the total T-P load discharged to the lake would be reduced by 22 tons/year when runoff rate is assumed 0.8.

2) Cost efficiency

River water purification

Kis Balaton Project would cost 8,278,690 thousand HUF (construction) and 845,500 thousand HUF/year (O/M). This means that the total project cost for 20 years is 25,189,000 thousand HUF to reduce T-P load by 14~18 tons/year. This means that an investment of one (1) HUF can reduce T-P load by 11~14 mgP/year.

As for purification facilities of other rivers than Zala River, the total project cost for 20 years is 9,054,200 thousand HUF to reduce T-P load by 16 tons/year. This means that an investment of one (1) HUF can reduce T-P load by 35 mgP/year.

Soil erosion control of rural areas in upper catchment areas

The most likely facility is a type of settling reservoir or sedimentation pond. A typical facility is shown in *Figure 4.8*, which is designed for a capacity of 0.28 m^3/sec to cover a catchment area of 1 km^2. Assuming 0.116 m^3/sec (=10,000 m^3/day) is a typical design capacity, the construction cost of settling reservoir is 326,190 thousand HUF and the O/M cost is 370 thousand HUF/year (see Appendix-D of Supporting Report). The total area covered by soil erosion facilities is estimated 6,362 ha, thus the total project cost for 20 years is 51,228,000 thousand HUF. This means that an investment of one (1) HUF can reduce T-P load by 4 mgP/year.

Urban run-off control in direct catchment areas

Cost efficiency of urban run-off control must be lower than that of river water purification. Because, this method needs more costs for collection of run-off water from many small creeks and drains and for land acquisition than the river water purification method does.

Further development of sewerage systems

According to the report on sewerage development by KHVM (1996), the total project cost is about 53,000,000 thousand HUF excluding O/M cost. T-P load would be reduced by 15 tons/year at most. Thus an investment of one (1) HUF can reduce T-P load by 6 mgP/year.

Upgrading/improvement of sewage treatment level

According to the latest report of KHVM (1998), cost efficiency for upgrading of the existing sewage treatment plant (STP) is several hundred HUF/year to reduce one (1) gram of T-P load. For example, improvement of sewage treatment level of Tapolca STP (from T-P 1.8 mg/l to 0.7 mg/l) means that an investment of one (1) HUF can reduce T-P load by 4 mgP/year.

3) Results of evaluation

Above discussions are summarized in the following table.

From the view point of cost efficiency, river purification systems including Kis-Balaton are the most effective measures for external phosphorous reduction.

Upgrading/improvement of sewage treatment level is not cost-effective, but it would be the most effective measures from the technical point of view in order to reduce phosphorous load intensively.

Type of Measures	T-P load Reduction Efficiency (tons/year)	Cost Efficiency to reduce T-P load (mgP/year/HUF)
River water purification (Kis-Balaton)	14~18	11~14
River water purification (29 rivers (except Zala River) and 4 pumping stations)	16	35
Soil erosion control of rural areas	11	4
Further development of sewerage systems	15	6
Upgrading/improvement of sewage treatment level	22	4