

ISWS/CIR-147/81

Circular 147

STATE OF ILLINOIS

DEPARTMENT OF ENERGY AND NATURAL RESOURCES



Water Chemistry of the Illinois Waterway

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ILLINOIS STATE WATER SURVEY
CHAMPAIGN

1981

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ABSTRACT

Physical and chemical water quality characteristics were summarized for 28 locations situated at approximately 10-mile intervals from river mile 3.6 to river mile 270.6 in the Illinois Waterway. Also the waterway was segmented into seven reaches and the water chemistry data for each reach were subjected to statistical evaluation. Long-term average mineral and nutrient transports at three U.S. Geological Survey gaging stations on the Illinois Waterway were evaluated. Nitrate flux at these locations was found to vary from 8.88 to 13.83 lbs/ac/yr. Phosphorus flux varied from 1.20 to 2.96 lbs/ac/yr.

INTRODUCTION

Information concerning the quality of water that will be available in the future is essential in planning for any water-use project. The suitability of a water source for domestic, industrial, or agricultural purposes frequently depends at least partially upon its chemical quality. If a water is not chemically satisfactory for a specific use, an analysis is necessary to determine the type and cost of treatment to make it satisfactory.

Chemical quality data are also useful for such purposes as surveillance of pollution, maintenance of stream quality standards, and observation of the long-term influence of land-use, water-use patterns, etc. Within the past few decades, water quality considerations have become an integral part of multi-purpose water resources planning and management activities.

During 1978 and 1979 the Water Quality Section of the Illinois State Water Survey undertook an extensive program involving the collection and analysis of water samples from the Illinois Waterway. The program was a part of the efforts of the U.S. Army Corps of Engineers to evaluate the feasibility of increasing the average annual diversion of Lake Michigan waters into the Illinois Waterway from the present limit of 3200 cubic feet per second (cfs) to 10,000 cfs. The major purposes of the program were to develop baseline chemistry data throughout the waterway at regular intervals prior to the start of increased diversions and to assess the probable extent and magnitude of the impact of the diverted waters on the water chemistry of the Illinois Waterway. The field work required to obtain the baseline chemical data necessitated the travel of about 4400 river miles by boat. The raw data and the impact assessment of Lake Michigan diversion on the water chemistry of the Illinois Waterway can be found elsewhere (Schnepper et al., 1980).

The purpose of this report is to present in a concise form the observed water chemistry data for the waterway covering a stretch of 270 miles from the confluence of the Illinois River with the Mississippi River to the Dresden Island Lock and Dam.

Also, evaluations are presented of the long-term daily average mineral loads transported by the river at Marseilles, Kingston Mines, and Meredosia. These evaluations are based on the long-term flow data available for the three U.S. Geological Survey (USGS) gaging stations at these locations, in conjunction with the chemical data.

Illinois Waterway

The Illinois River, which is the major part of the Illinois Waterway, is formed by the confluence of the Kankakee and Des Plaines Rivers southwest of Chicago. The river flows nearly westward to Hennepin, where it turns abruptly southwest and finally empties into the Mississippi at Grafton, north of St. Louis (figure 1). The Illinois River proper is 275 miles long, and the entire waterway from Lake Michigan to Grafton is about 326 miles. The waterway consists of a series of eight navigational pools created by locks and dams to maintain water depths needed for commercial barge movements. At normal river stages, the velocity of flow is less than 1 mile per hour. Major tributaries to the waterway, the locations of locks and dams, and river mile designations from the confluence of the Illinois River with the Mississippi River are shown in figure 1.

The waterway receives discharges from industries engaged in such operations as petroleum refining, pulp and paper processing, liquor fermentation and distillation, meat packing, and metal finishing and plating. Twenty-seven municipal sewage treatment plants discharge directly into the Illinois Waterway, of which the major ones are those in the Metropolitan Sanitary District of Greater Chicago and the Greater Peoria Sanitary District.

Acknowledgments

The data collection for this report was sponsored and funded by the Corps of Engineers, Chicago District, U.S. Department of the Army. The report was prepared under the general guidance and supervision of Stanley A. Changnon, Jr., Chief, Illinois State Water Survey, and Ralph L. Evans, Head, Water Quality Section. Debbie Hayn typed the manuscript and Marilyn Innes prepared the final camera ready copy. Illustrations were prepared under the direction of John Brother. Gail Taylor edited the final manuscript. The Champaign District Office of the USGS provided data for the Illinois Waterway in a readily usable form.

DATA COLLECTION

To develop water chemistry data for the Illinois Waterway, 28 river sampling stations were established covering the stretch of about 270 miles from Grafton to the confluence of the Des Plaines and Kankakee Rivers. The sampling locations were approximately 10 miles apart and were chosen to coincide with permanent landmarks such as bridges, range lights, or day markers. River mile designations for these 28 sampling locations will be shown subsequently in table 3.

At each site, two samples were collected at a depth of 3 feet in the channel. One sample, collected with a Juday sampler, was used for the field determination of temperature and dissolved oxygen. Dissolved oxygen was determined by the modified

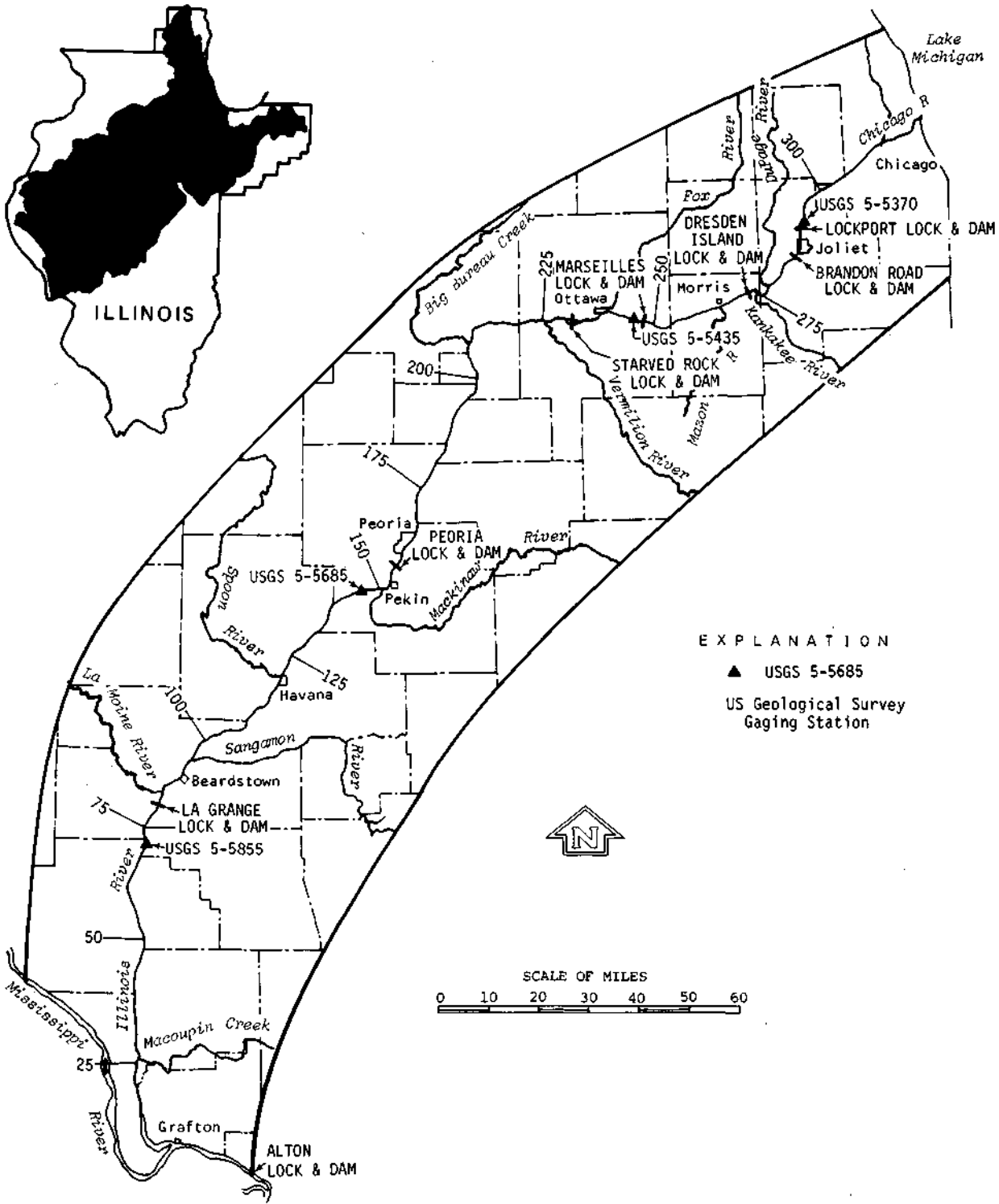


Figure 1. Illinois Waterway and its tributaries

Winkler method. The second sample was collected with a 1000-ml wide-mouthed jar attached to a pole. A portion of this sample was filtered through a 0.45 μ m millipore filter, and the filtrate was collected in small plastic bottles for subsequent laboratory analyses for ammonia, nitrate, and dissolved orthophosphate. (Micropore filtration eliminates any bacterial activity which could alter the species makeup of nitrogen and phosphorus in the samples. This method of sample preservation is considered superior to acidification or the use of other chemical additives.)

The remainder of the second sample was stored in a wide-mouthed tapered glass jar of the type used in home canning. This sample was used in the laboratory for determining pH, turbidity, alkalinity, hardness, total chlorides, total and dissolved solids, and total phosphorus. Standard methods (American Public Health Association et al., 1976) were used in all the analyses except those for ammonium-nitrogen (table 1). Dissolved solids concentrations were determined by computing the difference between total and suspended solids.

Along the approximately 270-mile study stretch, samples were collected at 2-mile intervals for temperature determinations with a thermometer. During the initial stages of this investigation, the boat was stopped every 2 miles, and samples were collected from the surface and from several depths at each station to define the vertical temperature profiles. Because no difference in temperature was detected at different water depths, only surface temperature samples were collected during the rest of the investigation. Also, because the procedure of bringing the boat to a standstill every 2 miles was time consuming, a successful technique was developed and adopted for collecting samples while the boat was in motion.

The depth and location of sampling stations within the waterway were selected on the basis of prior experience. Nevertheless, there were some reservations about using a 3-foot depth and confining the sampling to the navigational channel area. The main concern was the extent of lateral and vertical dispersion as well as probable changes in a "plug" of water during its downstream passage.

To determine whether it would be sufficient to sample at a 3-foot depth, a series of samples were collected throughout the accessible length of the Starved Rock pool on October 11, 1978, at two different depths and at three points on traverses

Table 1. Analytical Procedures

Turbidity	Nephelometric method, using Turner Fluorometer Model 110; Formazin was used as a standard
pH	Glass electrode method using Beckman 4500 meter
Alkalinity	Potentiometric titration to pH 4.5
Hardness	EDTA titrimetric method
Chlorides	Argentometric method
Total solids	Residue on evaporation at 103 to 105°C
Suspended solids	Filtration through Gooch crucible with glass fiber filters and dried at 103 to 105°C
Orthophosphorus	Ascorbic acid method
Total phosphorus	Sample was digested with sulfuric-nitric acid mixtures and determined by ascorbic acid method
Ammonium-N	Phenol-hypochlorite method (Harwood and Kuhn, 1970)
Nitrate-N	Chromotropic method

Table 2. Water Quality of Starved Rock Pool, October 11, 1978*

<i>River mile</i>	<i>pH</i>	<i>Alk</i>	<i>Hard</i>	<i>Turb</i>	<i>TS</i>	<i>SS</i>	<i>Cl⁻</i>
244.0 R-3	7.86	164	317	9.6	516	32	63.0
244.0 R-6	7.87	166	317	8.2	519	31	60.6
244.0 M-3	7.91	164	304	15.1	514	47	63.0
244.0 M-6	7.93	164	284	12.4	506	41	58.2
244.0 L-3	7.93	164	310	6.8	509	41	63.0
244.0 L-6	7.99	164	317	13.7	508	41	58.2
242.0 M-3	7.78	168	317	12.4	495	30	58.2
239.6 R-3	8.56	250	389	6.2	476	29	38.8
239.6 R-6	8.51	248	422	5.5	470	28	33.9
239.6 M-3	7.86	162	350	12.4	462	31	58.2
239.6 M-6	7.92	164	304	11.7	455	33	58.2
239.6 L-3	7.88	164	330	13.1	473	34	58.2
239.6 L-6	7.90	164	340	11.0	482	27	58.2
237.9 M-3	7.97	176	340	13.7	485	34	55.7
236.2 R-3	8.02	185	304	18.6	483	33	53.3
236.2 R-6	8.04	185	323	11.0	517	29	53.3
236.2 M-3	8.09	185	347	11.0	445	36	46.0
236.2 M-6	8.11	187	356	13.1	477	48	48.5
236.2 L-3	8.08	185	297	8.2	448	31	46.0
236.2 L-6	8.09	185	363	10.3	445	34	48.5
234.2 M-3	7.65	172	310	19.3	497	26	48.5
231.7 R-3	8.16	180	337	22.0	543	81	48.5
231.7 R-6	8.07	170	323	25.5	551	104	48.5
231.7 M-3	8.10	178	290	15.1	517	65	48.5
231.7 M-6	8.10	180	323	13.7	507	57	50.9
231.7 L-3	8.12	185	310	17.9	509	61	48.5
231.7 L-6	8.00	176	284	21.3	518	72	48.5

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while moving at approximately stream velocity. The results are shown in table 2. The results for each of the 13 parameters measured indicate that there is no significant change at any of the four traverses. Some differences are found at river mile 239.6 on the right bank, which is where the Fox River enters the waterway, but although there are changes in the vicinity of the confluence, the influence of the Fox River on the waterway is transitory. From these observations it is concluded that sampling at the 3-foot depth within the channel area produced results reflecting the chemical characteristics of the waterway.

Data were collected during eight river trips made between July 18, 1978, and September 26, 1978, and eight trips made between June 5, 1979, and September 19, 1979. This provided a total of 16 sets of observations in all but a very few of the 28 locations on the main stem of the waterway.

The raw data pertaining to all chemical and physical measurements, including computed river flows at the sampling locations, are reported in tabular and graphic form by Schnepfer et al. (1980). Maximum, minimum, and average values are indicated for each of the 13 constituents measured.

Table 2. Concluded

<i>River mile</i>	<i>NH₄-N</i>	<i>NO₃-N</i>	<i>Total PO₄-P</i>	<i>Diss PO₄-P</i>	<i>Temp</i>	<i>DO</i>
244.0 R-3	.87	3.31	.67	.23	14.1	5.60
244.0 R-6	.94	3.37	.69	.28	14.1	5.65
244.0 M-3	.60	3.18	.57	.19	14.0	7.50
244.0 M-6	.63	3.20	.56	.20	14.0	7.60
244.0 L-3	.75	3.31	.58	.25	14.5	7.50
244.0 L-6	.77	3.32	.60	.22	14.6	7.55
242.0 M-3	.78	3.33	.63	.24	14.7	7.00
239.6 R-3	.02	2.86	.22	.08	13.1	9.90
239.6 R-6	.01	2.88	.22	.11	13.1	9.75
239.6 M-3	.76	3.45	.58	.24	15.1	6.50
239.6 M-6	.79	3.43	.58	.28	15.1	6.50
239.6 L-3	.85	3.39	.63	.22	15.0	6.60
239.6 L-6	.76	3.41	.60	.23	15.0	6.55
237.9 M-3	.68	3.27	.56	.23	14.8	7.15
236.2 R-3	.38	3.26	.48	.25	14.9	7.70
236.2 R-6	.41	3.31	.51	.19	14.9	7.70
236.2 M-3	.44	3.29	.50	.18	14.9	7.75
236.2 M-6	.42	3.29	.50	.18	14.9	7.70
236.2 L-3	.46	3.30	.48	.19	14.9	7.90
236.2 L-6	.46	3.34	.48	.29	14.9	7.70
234.2 M-3	.43	3.33	.48	.18	14.3	7.30
231.7 R-3	.34	3.12	.57	.17	13.9	7.70
231.7 R-6	.44	3.08	.59	.20	13.9	7.70
231.7 M-3	.38	3.10	.54	.16	14.0	7.70
231.7 M-6	.38	3.05	.47	.18	13.9	7.60
231.7 L-3	.40	3.08	.51	.22	14.0	7.60
231.7 L-6	.41	3.10	.54	.14	14.0	7.60

* All values in mg/l except turbidity (NTU), temperature (C), and pH

Note: R-3, R-6 = near right bank at 3- and 6-foot depth, respectively

M-3, M-6 = centerline of channel at 3- and 6-foot depth, respectively

L-3, L-6 = near left bank at 3- and 6-foot depth, respectively

RESULTS

Water Quality

The water in the Illinois Waterway is typical of the water in most midwestern streams and rivers: high in alkalinity, total solids, and hardness. Means of observed values for these and seven other parameters are shown in table 3 for all 28 sampling stations established in the waterway. The river mile designations and the total number of observations made at each of these sampling stations are also indicated in this table.

To simplify the data analysis, the waterway was segmented into seven reaches and all the water chemistry data collected within a reach were combined. Figure 2 presents a schematic diagram of the Illinois Waterway and its tributaries, and shows the river reach demarcations. The river reach sites were so chosen that the reaches were neither unduly long nor short and so that the mean and range of observed values of

Table 3. Averages of Chemical Quality Characteristics in the Illinois Waterway at Various Sampling Stations*

<i>River mile</i>	<i>Number of observations</i>	<i>Alk</i>	<i>Hard</i>	<i>Turb</i>	<i>TS</i>	<i>SS</i>	<i>Cl-</i>	<i>NH₄-N</i>	<i>NO₃-N</i>	<i>Total PO₄-P</i>	<i>Ortho PO₄-P</i>
3.6	15	180	291	24.5	488	63	45	0.02	2.8	0.32	0.18
10.3	15	179	300	28.3	484	70	45	0.02	2.8	0.35	0.19
20.7	15	179	294	31.8	508	96	44	0.02	2.7	0.38	0.19
30.6	15	181	293	35.2	528	112	45	0.04	2.8	0.41	0.20
39.3	15	186	285	42.0	561	140	45	0.04	2.8	0.43	0.20
50.0	15	179	293	40.7	565	141	46	0.05	2.8	0.42	0.18
60.8	15	184	301	34.7	518	107	46	0.04	2.7	0.40	0.19
70.0	15	183	291	35.5	530	108	46	0.05	2.7	0.41	0.17
80.2	15	184	300	29.2	509	79	46	0.04	2.8	0.41	0.18
90.2	15	182	298	47.8	597	168	47	0.06	2.9	0.48	0.19
100.9	15	181	302	40.1	571	130	48	0.08	2.9	0.48	0.20
110.2	15	182	299	44.3	598	150	48	0.09	2.9	0.49	0.19
119.9	15	179	294	33.1	544	102	47	0.10	2.9	0.46	0.19
129.9	15	179	292	31.6	545	99	49	0.15	2.9	0.49	0.22
140.1	15	178	295	32.3	542	99	52	0.13	2.9	0.50	0.22
150.2	15	176	289	30.7	535	87	52	0.13	2.8	0.47	0.21
159.9	16	173	282	29.6	514	88	50	0.12	2.7	0.46	0.21
170.9	16	173	282	33.6	509	92	49	0.16	2.9	0.47	0.21
179.9	16	174	285	37.0	503	92	49	0.20	3.0	0.47	0.21
190.0	16	173	286	29.9	506	91	50	0.18	3.1	0.47	0.21
199.8	16	171	281	26.3	489	75	51	0.24	3.2	0.46	0.23
210.2	16	173	280	25.4	474	64	52	0.26	3.2	0.46	0.24
219.8	16	170	284	21.6	471	60	50	0.35	3.1	0.46	0.24
230.1	16	167	272	21.6	461	55	52	0.45	3.0	0.46	0.23
239.6	16	163	273	15.1	471	37	58	0.80	3.0	0.49	0.31
250.0	16	160	272	16.2	455	43	57	1.06	2.8	0.50	0.28
260.4	16	163	264	17.5	472	46	58	1.15	2.7	0.53	0.28
270.6	16	165	264	17.0	459	44	59	1.42	2.5	0.54	0.27

* All values in mg/l except turbidity (NTU)

water quality characteristics at any sampling station were not too different from those for other sampling stations within the same reach.

The results of statistical analyses of the observed water chemistry characteristics for the seven reaches considered in the waterway are given in tables 4 to 10. The mean, range of values, and the standard deviation as a measure of dispersion of the observed values about the mean are all shown in these tables for fourteen parameters. Table 11 shows the mean values of these parameters in all the reaches so the water quality trends in the waterway can be discerned.

The cumulative probability distributions of the observed values of all the parameters except temperature for three reaches within the waterway are shown in figures 3, 4, and 5. These figures represent graphically the water quality conditions in the upper, middle, and lower segments of the "waterway.

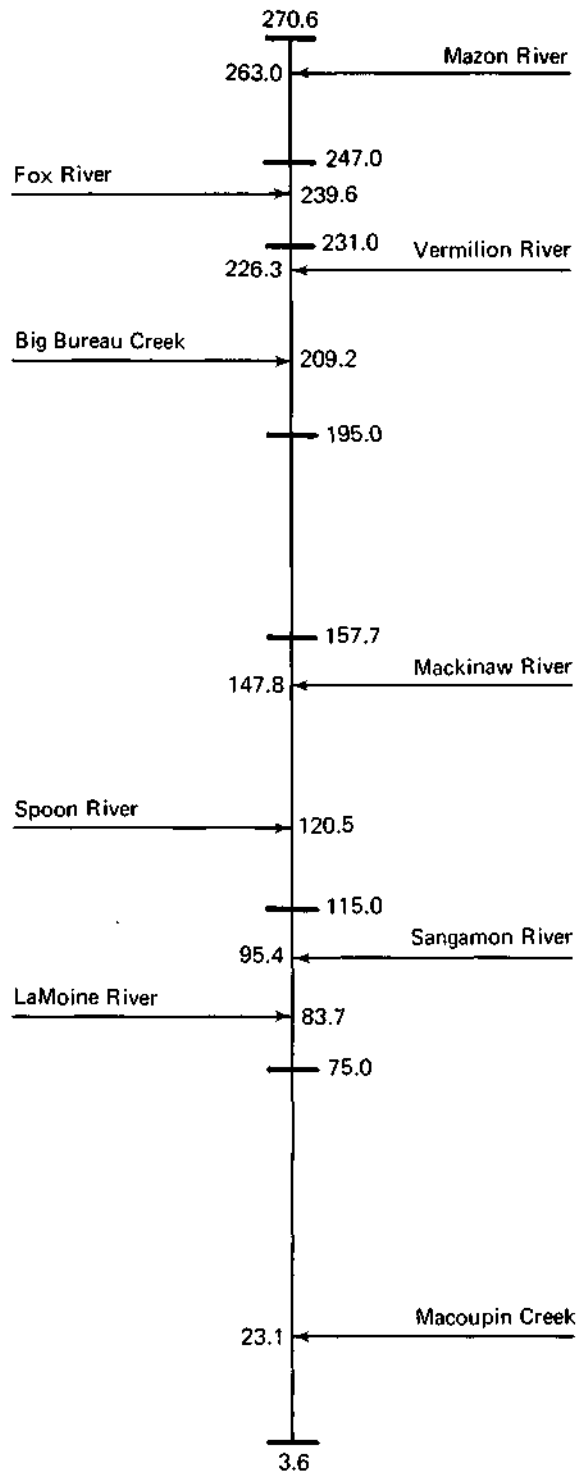


Figure 2. Schematic diagram of the Illinois Waterway and its tributaries, showing the river reach demarcations

Table 4. Water Quality Characteristics of Illinois River
in Reach from River Mile 270.6 to 247.0

(Concentrations in milligrams per liter except as otherwise indicated)

<i>Parameter</i>	<i>Mean</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Standard deviation</i>
pH (dimensionless)		7.6	8.3	
Alkalinity	163	125	199	18
Hardness	267	220	325	23
Turbidity (FTU)	17.2	1.1	42.3	7.8
Total solids	463	214	648	77
Suspended solids	44	18	104	19
Dissolved solids	419	192	590	74
Chloride	57.8	40.7	93.5	9.7
Ammonium-N	1.24	0.49	3.16	0.75
Nitrate-N	2.74	1.75	4.86	0.69
Total phosphate-P	0.52	0.26	0.81	0.11
Dissolved orthophosphate-P	0.27	0.11	0.43	0.08
Temperature (°C)	24.8	20.4	27.5	1.81
Dissolved oxygen	6.3	3.7	8.0	0.96

Note: Results are based on 44 observations

Table 5. Water Quality Characteristics of Illinois River
in Reach from River Mile 247.0 to 231.0

(Concentrations in milligrams per liter except as otherwise indicated)

<i>Parameter</i>	<i>Mean</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Standard deviation</i>
pH (dimensionless)		7.7	8.7	
Alkalinity	166	125	200	18
Hardness	273	215	323	26
Turbidity (FTU)	18.9	3.7	50.8	11.7
Total solids	467	339	628	72
Suspended solids	47	11	96	21
Dissolved solids	420	291	596	75
Chloride	55.0	34.4	77.0	9.6
Ammonium-N	0.64	0.13	2.01	0.50
Nitrate-N	3.06	1.57	5.30	0.88
Total phosphate-P	0.47	0.34	0.62	0.06
Dissolved orthophosphate-P	0.27	0.09	0.41	0.09
Temperature (°C)	24.2	20.20	27.4	1.8
Dissolved oxygen	6.7	4.9	8.7	1.0

Note: Results are based on 30 observations

Table 6. Water Quality Characteristics of Illinois River
in Reach from River Mile 231.0 to 195.0

(Concentrations in milligrams per liter except as otherwise indicated)

<i>Parameter</i>	<i>Mean</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Standard deviation</i>
pH (dimensionless)		7.8	8.8	
Alkalinity	172	127	205	19
Hardness	284	243	327	21
Turbidity (FTU)	25.1	3.4	131.0	20.1
Total solids	480	382	728	71
Suspended solids	67	18	200	40
Dissolved solids	412	225	541	66
Chloride	50.5	71.0	33.9	8.3
Ammonium-N	0.28	0.87	0.00	0.25
Nitrate-N	3.19	4.98	1.54	0.95
Total phosphate-P	0.45	0.83	0.32	0.09
Dissolved orthophosphate-P	0.23	0.39	0.11	0.06
Temperature (°C)	24.2	27.4	19.8	1.8
Dissolved oxygen	6.8	12.4	4.8	1.4

Note: Results are based on 45 observations

Table 7. Water Quality Characteristics of Illinois River
in Reach from River Mile 195.0 to 157.7

(Concentrations in milligrams per liter except as otherwise indicated)

<i>Parameter</i>	<i>Mean</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Standard deviation</i>
pH (dimensionless)		7.6	9.3	
Alkalinity	174	129	208	21
Hardness	285	224	333	25
Turbidity (FTU)	33.6	6.9	131.0	19.1
Total solids	509	392	692	74
Suspended solids	93	34	210	41
Dissolved solids	416	262	524	63
Chloride	49.4	33.9	68.0	77
Ammonium-N	0.17	0.00	0.69	0.16
Nitrate-N	2.97	0.84	4.53	1.11
Total phosphate-P	0.47	0.34	0.70	0.07
Dissolved orthophosphate-P	0.21	0.07	0.47	0.06
Temperature (°C)	24.1	18.7	27.0	2.0
Dissolved oxygen	6.1	3.6	12.8	1.8

Note: Results are based on 60 observations

Table 8. Water Quality Characteristics of Illinois River
in Reach from River Mile 157.7 to 115.0

(Concentrations in milligrams per liter except as otherwise indicated)

<i>Parameter</i>	<i>Mean</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Standard deviation</i>
pH (dimensionless)		8.0	9.2	
Alkalinity	178	148	211	19
Hardness	293	244	350	26
Turbidity (FTU)	32.1	6.7	55.8	13.4
Total solids	542	450	690	67
Suspended solids	97	16.0	212	39
Dissolved solids	445	350	546	54
Chloride	50.0	38.4	69.5	6.9
Ammonium-N	0.13	0.01	0.61	0.13
Nitrate-N	2.86	0.72	5.35	1.21
Total phosphate-P	0.48	0.28	1.04	0.11
Dissolved orthophosphate-P	0.21	0.01	0.39	0.07
Temperature (°C)	24.4	19.5	27.2	2.01
Dissolved oxygen	5.7	3.0	10.9	1.39

Note: Results are based on 60 observations

Table 9. Water Quality Characteristics of Illinois River
in Reach from River Mile 115.0 to 75.0

(Concentrations in milligrams per liter except as otherwise indicated)

<i>Parameter</i>	<i>Mean</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Standard deviation</i>
pH (dimensionless)		7.9	9.1	
Alkalinity	182	148	210	16
Hardness	300	237	363	24
Turbidity (FTU)	40.3	5.6	169.4	29.9
Total solids	569	363	1053	123
Suspended solids	132	15	574	101
Dissolved solids	437	316	525	44
Chloride	47.1	36.3	63.0	6.2
Ammonium-N	0.07	0.00	0.31	0.08
Nitrate-N	2.86	0.82	4.74	1.19
Total phosphate-P	0.46	0.28	1.03	0.12
Dissolved orthophosphate-P	0.19	0.01	0.36	0.07
Temperature (°C)	24.6	18.9	27.5	2.0
Dissolved oxygen	5.1	2.40	9.2	1.4

Note: Results are based on 60 observations

Table 10. Water Quality Characteristics of Illinois River
in Reach from River Mile 75.0 to 3.6

(Concentrations in milligrams per liter except as otherwise indicated)

<i>Parameter</i>	<i>Mean</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Standard deviation</i>
pH (dimensionless)		7.7	8.60	
Alkalinity	182	129	223	18
Hardness	294	221	337	21
Turbidity (FTU)	34.1	3.8	114.2	20.2
Total solids	520	318	887	96
Suspended solids	104	26	404	69
Dissolved solids	416	266	582	54
Chloride	45.3	33.9	58.2	6.3
Ammonium-N	0.03	0.00	0.21	0.04
Nitrate-N	2.77	0.80	4.88	1.13
Total phosphate-P	0.39	0.23	0.61	0.08
Dissolved orthophosphate-P	0.19	0.07	0.42	0.06
Temperature (°C)	25.1	19.20	28.00	1.95
Dissolved oxygen	4.8	2.70	7.30	1.16

Note: Results are based on 120 observations

Table 11. Mean Values of Water Quality Characteristics of Illinois River in River Reaches

(Concentrations in milligrams per liter except as otherwise indicated)

<i>Parameter</i>	<i>River miles</i>	270.8	247.0	231.0	195.0	157.7	115.0	75.0
		<i>to</i> 247.0	<i>to</i> 231.0	<i>to</i> 195.0	<i>to</i> 157.7	<i>to</i> 115.0	<i>to</i> 75.0	<i>to</i> 3.6
pH (dimensionless)		7.6-8.3	7.7-8.7	7.8-8.8	7.6-9.3	8.0-9.2	7.9-9.1	7.7-8.6
Alkalinity		163	166	172	174	178	182	183
Hardness		267	273	284	285	293	300	294
Turbidity (FTU)		17.2	18.9	25.1	33.6	32.1	40.3	34.1
Total solids		463	467	480	509	542	569	520
Suspended solids		44	47	67	93	97	132	104
Dissolved solids		419	420	412	416	445	437	416
Chloride		57.8	55	50.5	49.4	50.0	47.1	45.3
Ammonium-N		1.24	0.64	0.28	0.17	0.13	0.07	0.03
Nitrate-N		2.74	3.06	3.19	2.97	2.86	2.86	2.77
Total phosphate-P		0.52	0.47	0.45	0.47	0.48	0.46	0.39
Dissolved orthophosphate-P		0.27	0.27	0.23	0.21	0.21	0.19	0.19
Temperature (°C)		24.8	24.2	24.2	24.1	24.4	24.6	25.1
Dissolved oxygen		6.3	6.7	6.8	6.1	5.7	5.1	4.8

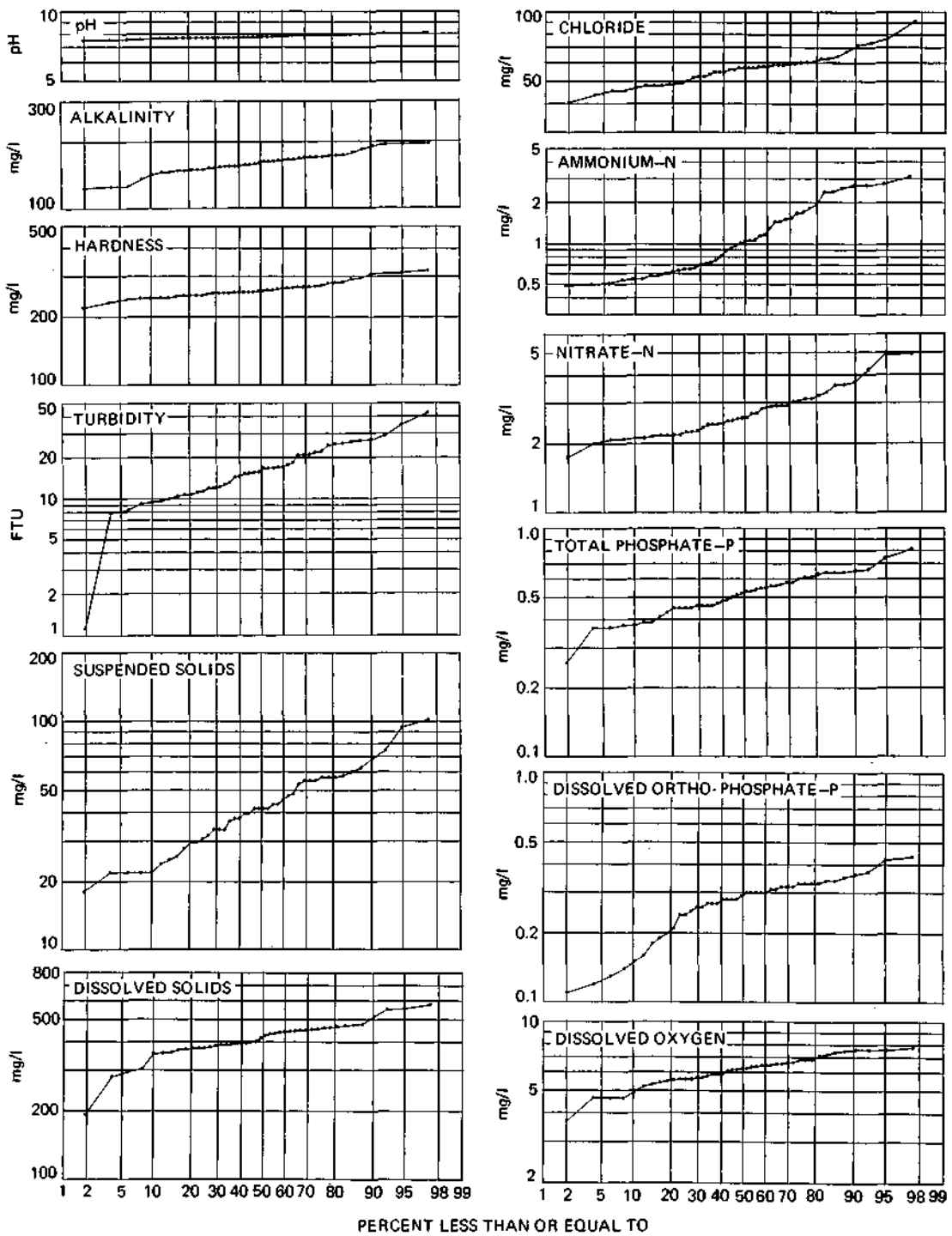


Figure 3. Cumulative probability distribution of water quality characteristics in the Illinois Waterway, river mile 270.6 to river mile 247.0

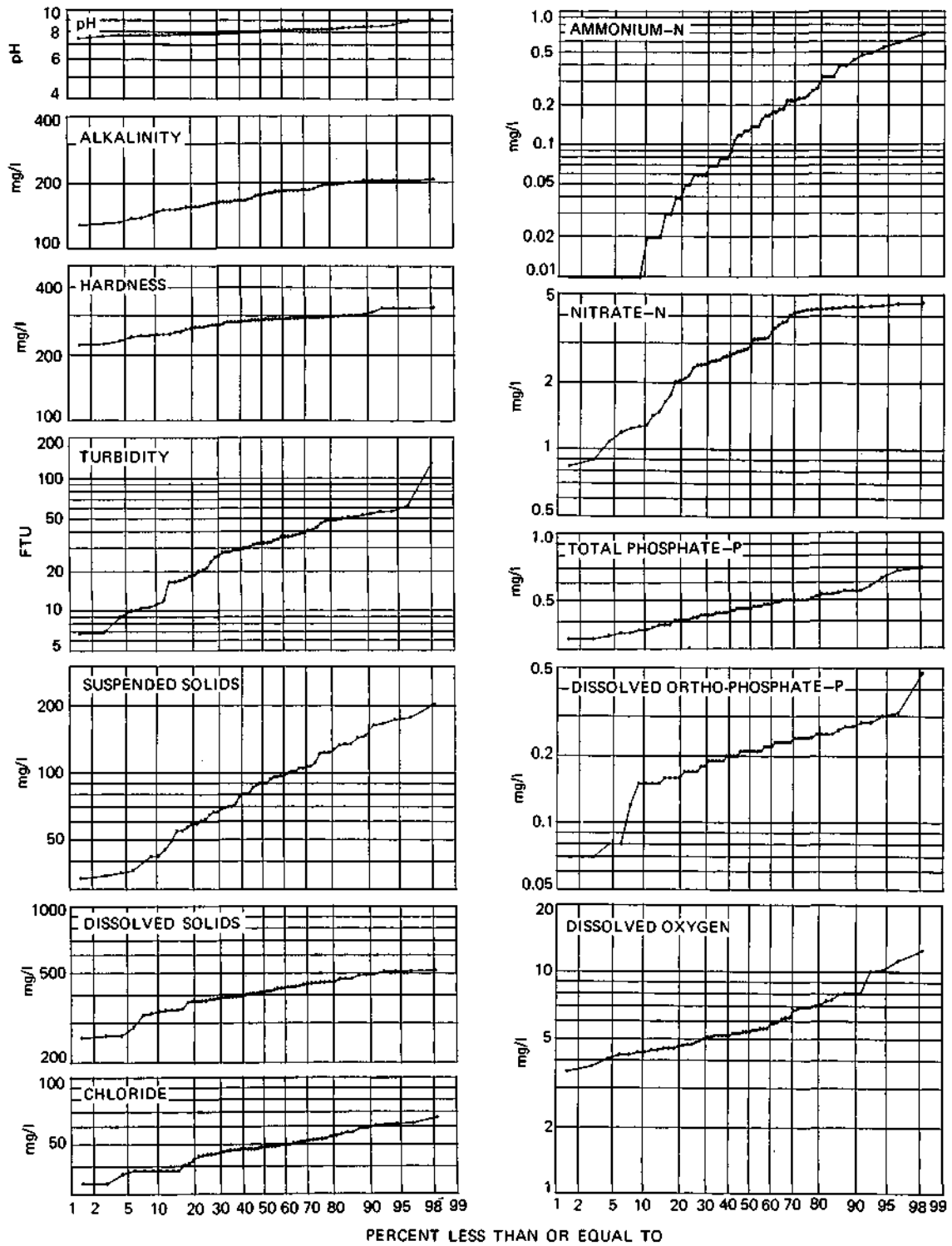


Figure 4. Cumulative probability distribution of water quality characteristics in the Illinois Waterway, river mile 195.0 to river mile 157.7

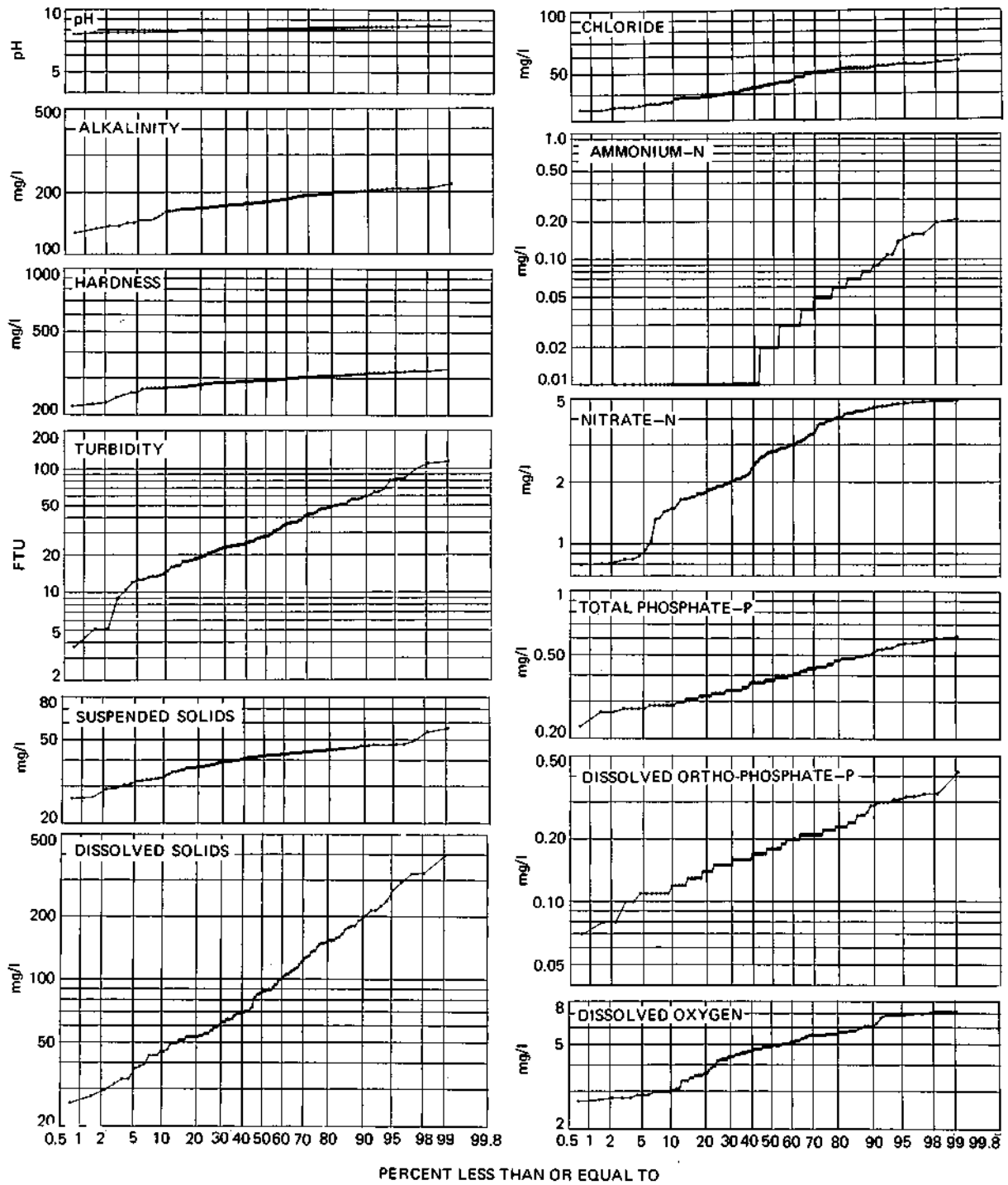


Figure 5. Cumulative probability distribution of water quality characteristics in the Illinois Waterway, river mile 75.0 to river mile 3.6

The pH of the Illinois Waterway samples varied from 7.6 to 9.3 (table 11). Since the pH values are reciprocals of the logarithms of hydrogen ion concentrations in the water samples, arithmetic means of pH values were not computed. Except for an isolated occurrence of pH values greater than 9.0 in the river stretch from river mile 100.9 to 170.9 on September 5, 1978, the range of observed values was within the range of 6.5 to 9.0 stipulated by the Illinois Pollution Control Board (IPCB).

The Illinois Waterway, typical of midwestern streamwaters, is rich in alkalinity and hardness. High alkalinity waters have been reported to have a distinctly unpleasant taste, as they are generally associated with high values of pH, hardness, and dissolved solids. The increasing trend of alkalinity and hardness as the Illinois River flows downstream is discernible (table 11). A similar observation is true for total solids; however, this trend is primarily due to the increased suspended sediment load carried by the waterway in the lower reaches. The dissolved solids concentrations remain practically uniform. Chloride concentrations in the river decrease downstream, which is contrary to the trend observed for alkalinity and hardness.

The concern for nitrogen as a contaminant in water bodies is twofold. First, because of its adverse physiological effects on infants and because the traditional treatment processes do not remove nitrate, concentrations of nitrate plus nitrite as nitrogen are limited to 10 mg/l in public water supplies. Second, a concentration in excess of 0.3 mg/l is sufficient to stimulate nuisance algal blooms (Saywer, 1974). However, no objectionable algal blooms were observed in the waterway during the sampling trips.

The ammonia concentrations are high in the upper reaches of the river, most likely because of the impact of the treated effluent discharges from the Joliet and Chicago metropolitan areas. Ammonia concentrations decrease progressively downstream as ammonia is oxidized to nitrate through biological mediation. Concentrations of nitrate-nitrogen apparently remain uniform (table 11); however, the nitrate load transported through the waterway increases downstream. This aspect will be dealt with in more detail later.

Since phosphorus has been singled out as the most probable limiting nutrient and the one most easily controlled by removal techniques, various facets of phosphorus chemistry and biology have been extensively studied in the natural environment. In any river system, the two aspects of interest for phosphorus dynamics are the phosphorus concentration and the phosphorus flux as a function of time and distance. The concentration itself indicates the possible limitations that this nutrient can place on vegetative growth in the stream, and the phosphorus flux is a measure of phosphorus nutrient input and output rates.

The total average phosphorus concentrations in the first and the last reaches of the waterway were somewhat different, though not radically different, from the values for the other five reaches. The average total phosphorus concentrations in the other five reaches were very nearly the same.

However, a definite decreasing trend in the dissolved orthophosphate-phosphorus is perceptible starting from the upstream reach. This is primarily due to the proximity of the upstream reach to the waste treatment plant discharges from the urban population centers of Joliet and Chicago. The fraction of dissolved phosphate-phosphorus in the total phosphorus content of river samples was found to be higher downstream of waste discharges (Kothandaraman and Evans, 1977). Part of the dissolved phosphate-phosphorus fraction is transformed gradually to the particulate form through biological uptake, adsorption, or other mechanisms.

The mean dissolved oxygen concentrations were generally higher in the upper reaches of the waterway than in the lower reaches. Butts et al. (1970), investigating the dissolved oxygen resources of the LaGrange pool of the Illinois River, found that the critical dissolved oxygen (DO) concentrations (lowest values for DO concentrations) and the subsequent DO recovery occurred in the LaGrange pool. From the mean values reported in table 11, it may be seen that during the present investigation the critical level of DO concentration was not reached even in the river reach from river mile 75.0 to 3.6. This is mainly because of much higher stream flows during the present investigation than the river flows when Butts and his colleagues carried out their study. For example, the measured flows at Kingston Mines (USGS 5-5685) during the present investigation varied from 5670 cfs to 21,000 cfs, whereas during the earlier study the flows at Kingston Mines ranged from 3440 to 6280 cfs. The increased flow and consequently the decreased time-of-travel has shifted the occurrence of critical dissolved oxygen concentrations in the waterway farther downstream.

Long-Term Average Nutrient and Mineral Transports

The computations of long-term average nutrient and mineral transports were made by the flow duration curve method presented by Simmons (1976). This method has been used quite extensively by the U.S. Geological Survey to determine the long-term average suspended solids transport in streams where a very few suspended solids observations were made. In a test case, sediment yields determined by the flow-duration curve method were compared to yields determined by daily sampling techniques; the comparison differed by less than 2 percent. The computation of average sediment yield with daily values is widely accepted as the most accurate method.

The long-term means were computed for the Illinois Waterway at three locations where USGS has maintained flow gaging stations for 40 or more years: Marseilles (USGS 5-5435), Kingston Mines (USGS 5-5685), and Meredosia (USGS 5-5855). The long-term flow records at these gaging stations in conjunction with data on water chemistry characteristics at or very near these three stations were used to compute the long-term mineral and nutrient transports. The methodology of this estimation procedure is discussed briefly here.

The observed nutrient or mineral concentrations of a sample can be converted to an instantaneous transport load by the equation

$$Q_n = 2.697 \times 10^{-3} CQ \quad (1)$$

where Q_n is the instantaneous nutrient discharge in tons per day; C is the concentration in milligrams per liter; and Q is the daily mean discharge in cubic feet per second on the day the sample was collected.

Generally, a relationship exists between chemical concentrations and water discharge in streams (Ledbetter and Gloyna, 1964; Vollenweider, 1968). Consequently, the instantaneous nutrient transport is a factor dependent on stream discharges. This relationship was examined with regard to chloride, ammonium-nitrogen and nitrate-nitrogen, total and dissolved orthophosphate-phosphorus, and suspended and dissolved solids by the least squares curve fit technique, through use of the following three mathematical expressions:

$$y = a + bx \quad (2)$$

$$y = a \exp (bx) \quad (3)$$

$$y = a x^b \quad (4)$$

where y is a dependent variable (instantaneous mineral transport); x is an independent variable (mean daily discharge); and a and b are constants. The expression giving the highest coefficient of correlation was then chosen to define the relationship between nutrient transport and water discharge.

Figure 6 shows the relationship between chloride transports and flow rates (daily mean discharges for the sample collection days) in the Illinois Waterway at the three USGS gaging stations. Table 12 shows the expressions defining the relationship between discharge and load transport at Marseilles, Kingston Mines, and Meredosia. The values for the coefficient of correlation are high and significant in all cases except for ammonium-nitrogen. Equation 2 was found to define the chloride transports and flows best for the Marseilles location with a correlation of 0.90, whereas at the other two locations equation 4 was found to provide the best theoretical fit.

Figure 7 shows the flow-duration curves for the Illinois River at the Marseilles, Kingston Mines, and Meredosia gaging stations. These flow-duration curves were developed by using records covering at least 40 years of daily mean discharge values.

Following the development of the above-mentioned information, computations for the long-term average nutrient and mineral transports were made. As an example, table 13 shows such a computation for chloride transport in the Illinois Waterway at Marseilles. The flow-duration curve (figure 7a) was used to determine water discharges for the corresponding percentages of time shown in column 1 of table 13. Then with the relationship $y = 160.2 + 0.1304 x$ and the flow values in column 2, values shown in column 3 were computed. Average chloride discharges were then computed from the values in column 3 by averaging the numbers at the limits of each time interval. Each average chloride discharge was then multiplied by the corresponding time interval to give the chloride discharge representative of that percentage of total time. The incremental chloride transport values in column 6 were then totaled to give the long-term average chloride transport, in tons per day, for the Illinois Waterway at Marseilles.

In developing the numerical values for column 3 of table 13, extrapolation of the relationship between daily mean flows and instantaneous nutrient transport had to be made beyond the range of observations on which the relationship was derived. This was necessary because the extreme values of stream discharge found in the long-term flow records did not occur during this investigation. Similar computations for other minerals and nutrients were made for the Marseilles location and for the waterway locations at Kingston Mines and Meredosia. The results are tabulated in table 14.

For a comparison of nutrient transports by different streams, unit load factors expressed as pounds per acre of watershed area per year were considered. These values for the Illinois Waterway are shown in table 15. The unit nitrate loads in the Illinois Waterway are shown in table 15. The unit nitrate loads in the Illinois Waterway varied from 8.88 to 13.83 lbs/ac/yr depending on the location considered. These values are in the mid-range of figures reported for other Illinois streams, namely, 3.50 lbs/ac/yr for Fox River at Route 173 (Kothandaraman et al., 1977); 3.51 lbs/ac/yr and 3.47 lbs/ac/yr, respectively, for Big Muddy River and Rayse Creek in Jefferson County (Kothandaraman and Evans, 1979); and 21 lbs/ac/yr for the Kaskaskia River upstream of Shelbyville (Harmeson and Larson, 1970). The unit phosphorus loads in the Illinois Waterway ranged from 1.20 to 2.96 lbs/ac/yr. These values are significantly higher than

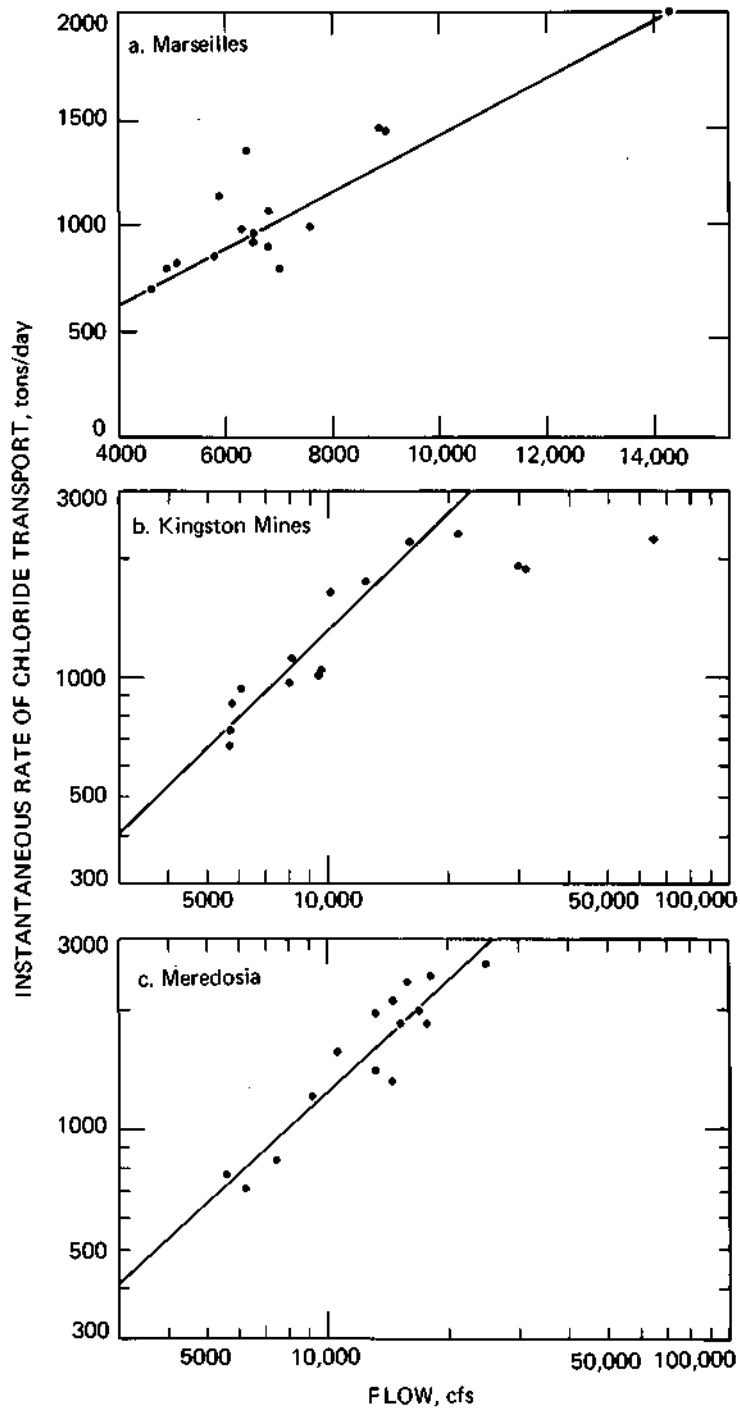


Figure 6. Chloride transport curves for Illinois River at three USGS gaging stations

Table 12. Expressions Defining the Relationship between Discharge and Load Transport, Illinois River
(Concentrations in milligrams per liter)

Parameter	Form of equation	Value of coefficient		Coefficient of correlation
		a	b	
Illinois River at Marseilles				
Chloride	$y = a + bx$	160.2	0.1304	0.90
Ammonium-N	$y = a x^{**}b$	0.0744	0.5961	0.28
Nitrate-N	$y = a x^{**}b$	0.0100	0.9856	0.43
Total phosphate-P	$y = a x^{**}b$	0.00008	1.3263	0.83
Dissolved orthophosphate-P	$y = a + bx$	0.4655	0.00074	0.77
Suspended solids	$y = a + bx$	-528	0.1848	0.85
Dissolved solids	$y = a + bx$	512	1.0742	0.92
Illinois River at Kingston Mines				
Chloride	$y = a x^{**}b$	0.1426	0.9927	0.95
Ammonium-N	$y = a + bx$	-0.7514	0.000427	0.44
Nitrate-N	$y = a + bx$	-11.8583	0.009052	0.81
Total phosphate-P	$y = a + bx$	-0.0487	0.001333	0.95
Dissolved orthophosphate-P	$y = a + bx$	0.7328	0.00051	0.84
Suspended solids	$y = a + bx$	-1336.5	0.3909	0.93
Dissolved solids	$y = a x^{**}b$	1.9519	0.9475	0.97
Illinois River at Meredosia				
Chloride	$y = a x^{**}b$	0.2296	0.9339	0.93
Ammonium-N	$y = a + bx$	-0.7296	0.000161	0.40
Nitrate-N	$y = a x^{**}b$	0.00037	1.3228	0.63
Total phosphate-P	$y = a x^{**}b$	0.000349	1.1204	0.95
Dissolved orthophosphate-P	$y = a x^{**}b$	0.0008998	0.9250	0.77
Suspended solids	$y = a x^{**}b$	0.000256	1.7314	0.88
Dissolved solids	$y = a x^{**}b$	0.8704	1.0256	0.96

Table 13. Computations of Long-Term Average Daily Chloride Transport in Illinois River at Marseilles (River Mile 245.8)

Percentage of time	Flow equaled or exceeded (cfs)	Chloride load (tons per day)	Interval between succeeding percentages of time	Average chloride load for time interval (tons per day)	Average chloride load times interval (tons per day)
0	83,000	10983			
2	31,000	4202	2.0	7593	151.9
4	26,000	3550	2.0	3876	77.5
6	23,000	3159	2.0	3355	67.1
8	21,000	2899	2.0	3029	60.6
10	19,500	2703	2.0	2801	56.0
15	17,000	2377	5.0	2540	127.0
20	15,000	2116	5.0	2247	112.4
25	13,500	1920	5.0	2218	100.9
30	12,500	1790	5.0	1855	92.8
40	10,700	1555	10.0	1673	167.3
50	9,200	1360	10.0	1458	145.6
60	8,000	1203	10.0	1282	128.2
70	6,800	1047	10.0	1125	112.5
80	5,600	890	10.0	969	96.9
90	4,400	734	10.0	812	81.2
95	3,500	617	5.0	676	33.8
100	1,460	351	5.0	484	24.2
				Total	1636.0

Note: Column 1 indicates the percentage of time the flow shown in column 2 is equaled or exceeded

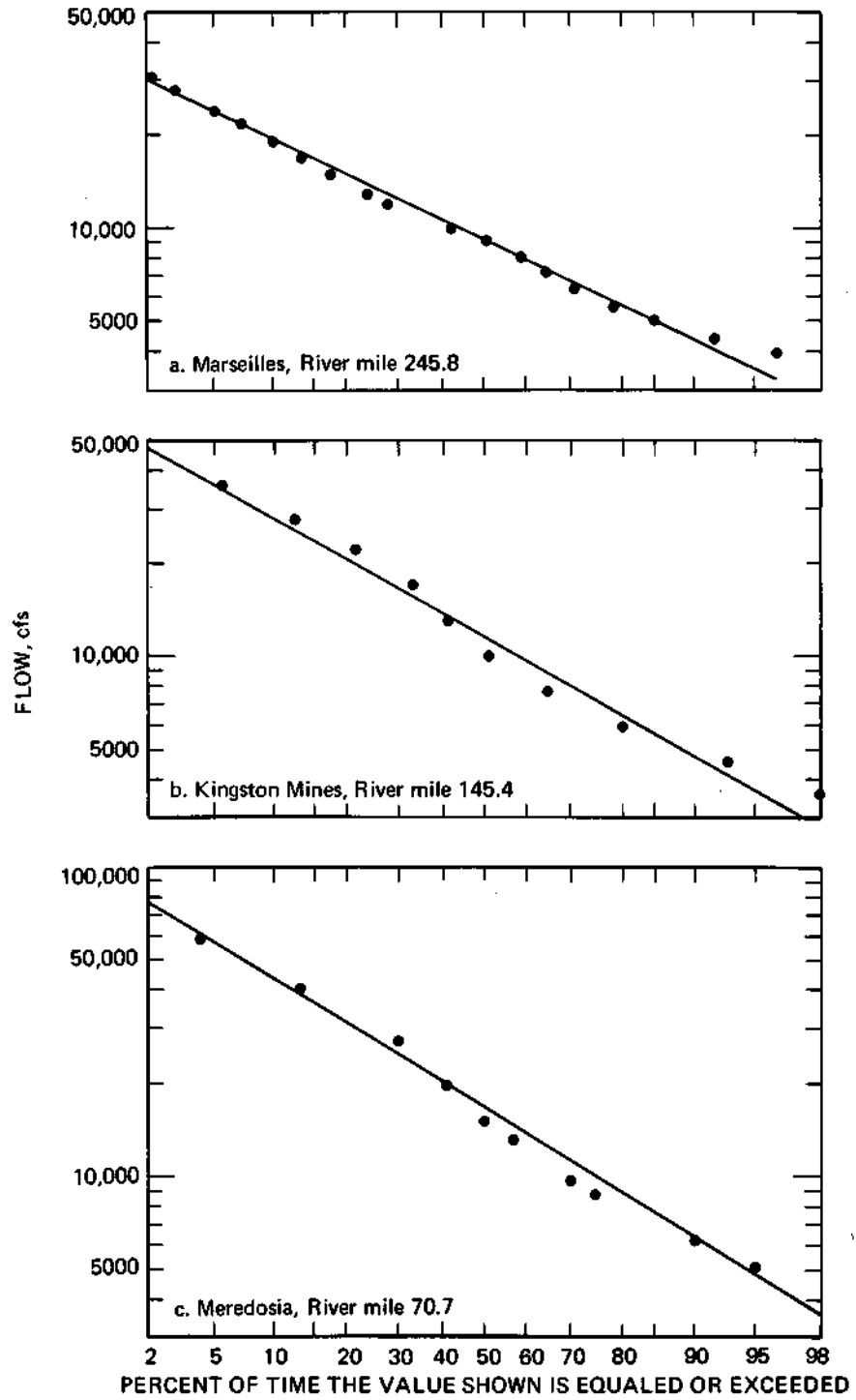


Figure 7. Flow-duration curves for Illinois River at three USGS gaging stations

Table 14. Long-Term Average Mineral Transports in Illinois River

(Tons per day)

<i>Parameter</i>	<i>Marseilles (RM 245.8)</i>	<i>Kingston Mines (RM 145.4)</i>	<i>Meredosia (RM 70.7)</i>
Chloride	1636	1951	2595
Ammonium-N	18.5	5.5	2.9
Nitrate-N	98.6	121.2	234.7
Total phosphate-P	21.1	19.5	26.9
Dissolved orthophosphate-P	8.9	8.2	9.3
Suspended solids	1570	4427	12099
Dissolved solids	12669	17129	25186

Table 15. Unit Load Factors of Minerals Transported by Illinois River

(Pounds per acre per year)

<i>Parameter</i>	<i>Marseilles (RM 245.8)</i>	<i>Kingston Mines (RM 145.4)</i>	<i>Meredosia (RM 70.7)</i>
Chloride	229.5	142.9	115.5
Ammonium-N	2.60	0.40	0.13
Nitrate-N	13.83	8.88	10.45
Total phosphate-P	2.96	1.43	1.20
Dissolved orthophosphate-P	1.25	0.60	0.41
Suspended solids	220.3	324.3	538.6
Dissolved solids	1777.5	1254.7	1121.3

the values reported for other Illinois streams: Kaskaskia River at Shelbyville — 0.17 lbs/ac/yr (Engelbrecht and Morgan, 1959); 0.26 to 0.47 lbs/ac/yr for the Spoon River (Kothandaraman and Evans, 1977); and 0.78 lbs/ac/yr for the Fox River at Route 173 (Kothandaraman et al., 1977).

SUMMARY

A two-year field sampling effort was undertaken by the Water Quality Section of the State Water Survey to collect water chemistry data along the Illinois Waterway. Field sampling and observations were performed from July to September 1978 and June to September 1979. Twenty-eight sampling locations were established at approximately 10-mile intervals covering a stretch of about 270 miles of the waterway. Observations and sample collections were made to determine temperature, dissolved oxygen, turbidity, pH, alkalinity, hardness, chlorides, total solids, suspended solids, orthophosphate-phosphorus, total phosphate-phosphorus, ammonium-nitrogen, and nitrate-nitrogen. In all, 16 physical and chemical data sets were developed.

Water quality characteristics observed in the waterway are summarized and presented for all the sampling locations along the waterway. Also, the waterway was seg-

mented into seven reaches and the water chemistry data for each reach were subjected to statistical evaluation. The results are presented in tabular and graphical form.

Long-term average mineral and nutrient transports by the Illinois River at the three USGS gaging stations at Marseilles, Kingston Mines, and Meredosia were evaluated using the method suggested by Simmons (1976). Nitrate flux at these locations was found to vary from 8.88 to 13.83 lbs/ac/yr. These values are in the mid-range of values reported for other Illinois streams. However, the phosphorus loads, which varied from 1.20 to 2.96 lbs/ac/yr, are several times higher than the values indicated in the literature for other streams in Illinois.

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