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SUSPENDED SEDIMENT AND METALS REMOVAL FROM URBAN RUNOFF BY A SMALL LAKE[1]

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ABSTRACT: A small lake in the Chicago Metropolitan Area was from 91 to 95 percent efficient in removing suspended sediment and from 76 to 94 percent efficient in removing copper, iron, lead, and zinc from urban runoff. Sediments accumulated in the lake in the form of an organic-rich mud at an average rate of 20 millimeters per year; this reduced lake storage and covered potential habitat for aquatic organisms. Copper, lead, and zinc concentrations were closely associated with suspended-sediment concentrations and with silt- and clay-sized fractions of lake sediment. Although concentrations of mercury and cadmium were near detection limits in runoff, measurable concentrations of these metals accumulated in the lake sediments.
(KEY TERMS: detention storage; trap efficiency; urban runoff; suspended sediment; metals; water quality.)

INTRODUCTION

Routing urban runoff through lakes and ponds is a common land-management practice that can reduce flooding in downstream areas. The increased time of travel afforded by such detention storage also allows for settling of suspended sediments and sediment-associated metals from the runoff. This paper discusses sources and quantities of suspended sediment and total recoverable metals in urban runoff, and the deposition of those constituents in a small lake.

Study Area and Methods

Water-quality and streamflow data were collected at the principal inlet (Main Inlet) and the outlets (Submerged Outlet and Surface Outlet) of Lake Ellyn, a 4.1 hm^2 impoundment located in the Village of Glen Ellyn, Du Page County, Illinois (Figure 1). The lake receives drainage from 73 percent of its watershed through Main Inlet, a 1.2- by 1.4-m rectangular culvert that drains the commercial district of the village and residential areas. Residential and parkland areas near the lake are drained by smaller storm drains and by overland flow.

Surficial deposits in the area are of glacial origin, and local topography is characterized by kame deposits. Lake Ellyn was impounded in 1889 by constructing an earthern dam across the narrow valley of a tributary to the East Branch Du Page River. Morphometric and physiographic characteristics of the lake and its watershed are listed in Table 1.

Runoff was sampled 33 times between February 1980 and July 1981. Loads of suspended sediment, copper, iron, lead, and zinc; mean discharge-weighted constituent concentrations; and constituent trap efficiencies were computed for 18 of those runoff periods between April 3, 1980, and June 8, 1981. Computational methods were derived from Heaney and Huber (1979, Chapter 10), Porterfield (1972), and Striegl and Cowan (1987). A variety of events and hydrologic conditions, for all seasons, are represented by the data. Included are snowmelt and low-flow conditions, low-intensity long-duration rainfall, and high-intensity short-duration rainfall.

Stage-discharge relations for the inlet and outlets were determined by methods described in Hulsing (1967), Bodhaine (1968), and Buchanan and Somers (1968). Water discharge at Main Inlet was controlled by channel geometry and by lake elevation. Water discharge was controlled by a concrete weir that maintained the lake elevation at Surface Outlet, and by an adjustable metal-plate weir in combination with a stilling well that was connected to a deep area of the lake by a corrugated metal pipe at Submerged Outlet. Water discharge to the lake averaged 0.003 m^3/s between runoff periods; discharge from the lake was slightly less. Stage was recorded at the inlet and outlets at five-minute intervals for the entire study period. As many as 24 water-quality samples were collected at preprogrammed intervals using stage-activated, automatic pumping samplers throughout the rise, at the peak, and throughout the tail of runoff hydrographs. Samples were either analyzed discretely, or split into discharge-weighted composites. Suspended-sediment concentrations and sediment particle-size distributions were determined according to methods described by Guy (1969). Concentrations of total recoverable metals were determined according to methods described by Skougstad, *et al.* (1979).

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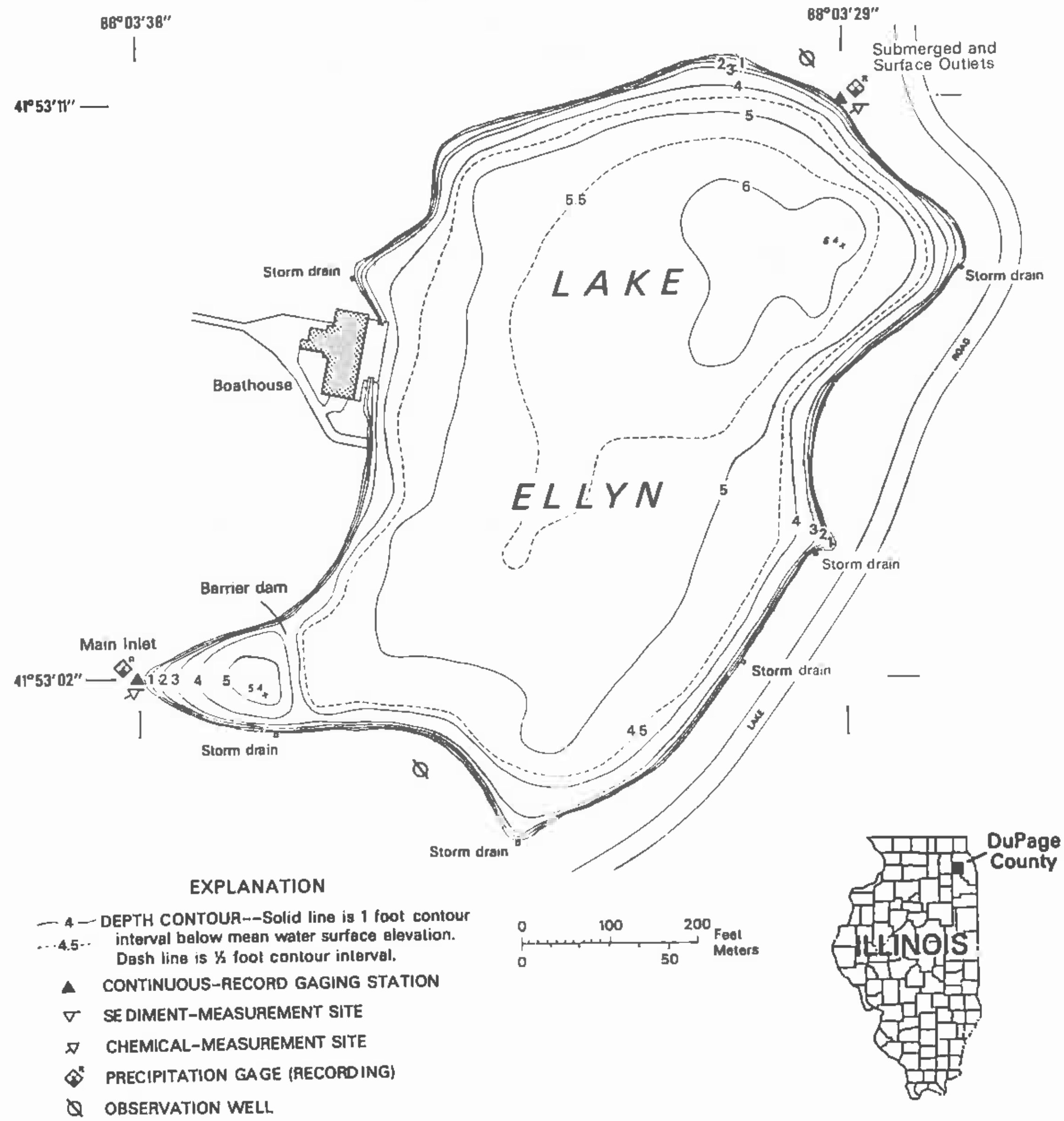

Figure 1. Location and Depth Contours of Lake Ellyn.

Thickness and areal distribution of lake sediments were determined by probing and by coring, and sediment samples were collected using a U.S. Geological Survey BHM-53 core sampler (E. A. Cowan, Northern Illinois University, unpublished Master's thesis, 1982; Guy and Norman, 1970). Particle-size distributions of sediment samples were determined by wet sieving for the fraction greater than 62 μm in diameter and by pipet analysis for smaller size fractions (Guy, 1969). Metals associated with sediment were determined at Northern Illinois University according to methods described by Skougstad, *et al.* (1979).

RUNOFF QUALITY

Suspended Sediment

Naturally occurring suspended sediment results from the weathering of rocks and from erosion, commonly by running water. In developing urban areas, rates of erosion are commonly accelerated because of construction (Walling and Gregory, 1970). After construction, soil erosion may decrease to near or below background levels because vegetation and pavement provide protective cover. However, suspended sediments from those areas may include particles that are not naturally found in streams. Main Inlet samples commonly included pieces of glass, metal, and construction and packaging material. Particles larger than 5-mm diameter

TABLE 1. Morphometric and Physiographic Characteristics of Lake Ellyn and Its Watershed (modified from Hey and Schaefer, 1983).

Total drainage area, km^2	216
Area drained by Main Inlet, km^2	158
Impervious area, in percentage of drainage area	34
Average basin slope, in percent	4.2
Lake volume, m^3	55,280
Maximum depth, m	2.0
Mean depth, m	1.5
Amount of runoff required to replace water in lake, mm	25
Land use as a percentage of drainage area:	
Single-family residential	80
Multiple-family residential	3
Commercial	5
Under construction (bare surface)	0
Parkland and open space	7
Institutional	5

were not collected by the pumping sampler and were usually transported to the lake as bed load.

Concentrations of suspended sediment in runoff ranged from 0 to 1,820 mg/L at Main Inlet, 1 to 35 mg/L at Surface Outlet, and 6 to 75 mg/L at Submerged Outlet. Particle-size distributions of suspended sediment to inflow and outflow samples showed high percentages of silt- and clay-sized materials (Table 2). Suspended sediment originated mostly from soil erosion, decomposition of paved surfaces, and traffic-related sources (Hey and Schaefer, 1983; Sartor, *et al.*, 1974).

Metals Associated With Suspended Sediments

Minimum and maximum concentrations of arsenic, cadmium, chromium, copper, iron, lead, mercury, and zinc for inflow and outflow samples are shown in Table 3. Arsenic was listed with the metals because it behaves like a metal under some chemical conditions. Like suspended sediment, maximum concentrations of chromium, copper, iron, lead, and zinc were lower in outflow than in inflow. Differences between the maximum inflow and outflow concentrations were small for arsenic, cadmium, and mercury, and those constituents were commonly present only in trace amounts.

Iron was the most abundant metal in runoff to Lake Ellyn, having measured concentrations as high as 55,000 μg/L. Background concentrations of iron were generally less than 200 μg/L and were assumed to originate from weathering of iron-bearing minerals. Iron concentrations that exceeded background were attributed to urban sources, which were highly variable in form and concentration. During low-flow periods, iron-oxide floccules of unknown origin were commonly observed in the Main Inlet channel. Runoff samples frequently included rust particles, apparently originating from vehicles and debris on the streets.

Sources of copper, lead, and zinc that were available for washoff by rainfall and runoff in the Lake Ellyn watershed are shown in Figure 2. Sources originated from outside the watershed, such as at industrial areas near Chicago, and from within the watershed. Hey and Schaefer (1983) estimated that atmospheric sources accounted for 10 percent of the copper, 5 percent of the lead, and 23 percent of the zinc. Motor-vehicle traffic and the decomposition of pavement and construction materials were the major sources of available metals within the watershed. Traffic-related sources contributed about 62 percent of the copper, 87 percent of the lead, and 27 percent of the zinc (Hey and Schaefer, 1983); these sources include gasoline, diesel fuel, motor oil, tires, and brake linings (Shaheen, 1975; Pitt and Bozeman, 1980). Other sources of zinc include galvanized metal, nails, and painted surfaces. Vegetation, soils, and residential use of chemicals, such as fertilizers, introduced minor amounts of copper, lead, and zinc to runoff.

Metals adsorb to and are transported with suspended sediment. Adsorption to particle surfaces is greatest in the case of particles that have large surface area-to-mass ratios and negatively-charged surfaces, such as silts and clays. Relations of copper, lead, and zinc concentrations to suspended-sediment concentrations are shown in Figures 3, 4, and 5.

TABLE 2. Particle-Size Distributions of Suspended Sediment in Main Inlet, Submerged Outlet, and Surface Outlet Samples, Lake Ellyn, Illinois, 1980-81 (mg/L, milligrams per liter).

Date	Suspended-Sediment Concentration (mg/L)	Percent Suspended Sediment in Size Class		
		Sand (762 μm)	Silt (4-62 μm)	Clay (<4 μm)
MAIN INLET				
May 16, 1980	60	0	8	92
May 17, 1980	14	0	12	88
May 17, 1980	16	0	5	95
May 17, 1980	477	3	67	30
May 28, 1980	1,080	22	57	21
May 28, 1980	568	15	57	28
May 28, 1980	385	10	61	29
May 28, 1980	342	16	53	31
May 28, 1980	264	3	59	38
July 20-21, 1980	261	31	41	28
August 4, 1980	120	14	41	45
July 12, 1981	249	3	50	47
July 13, 1981	138	3	50	47
August 2, 1981	146	2	50	48
SUBMERGED OUTLET				
May 17, 1980	15	0	12	88
May 28, 1980	25	1	29	70
July 20, 1980	17	3	12	85
August 4, 1980	8	3	18	79
SURFACE OUTLET				
May 16, 1980	16	3	15	82
May 17, 1980	11	0	12	88
May 17, 1980	14	0	14	86
May 28, 1980	24	3	43	54
July 20, 1980	25	3	17	80
August 4, 1980	10	5	19	76

TABLE 3. Minimum and Maximum Concentrations of Metals and Arsenic in Main Inlet, Surface Outlet, and Submerged Outlet Samples, February 21, 1980, to July 13, 1981 (in micrograms per liter).

Constituents	Main Inlet			Surface Outlet			Submerged Outlet		
	Minimum Concentration	Maximum Concentration	Number of Samples	Minimum Concentration	Maximum Concentration	Number of Samples	Minimum Concentration	Maximum Concentration	Number of Samples
Arsenic	1	7	51	1	3	41	0	4	39
Cadmium	0	4	49	0	6	40	0	1	38
Chromium	10	80	50	10	50	41	10	30	40
Copper	2.0	210	103	2	19	64	1	23	62
Iron	310	55,000	104	160	7,500	64	200	2,700	62
Lead	2	1,600	100	0	42	64	0	42	62
Mercury	<0.1	0.4	51	<0.1	0.5	41	<0.1	0.4	39
Zinc	10	950	106	10	80	64	10	320	61

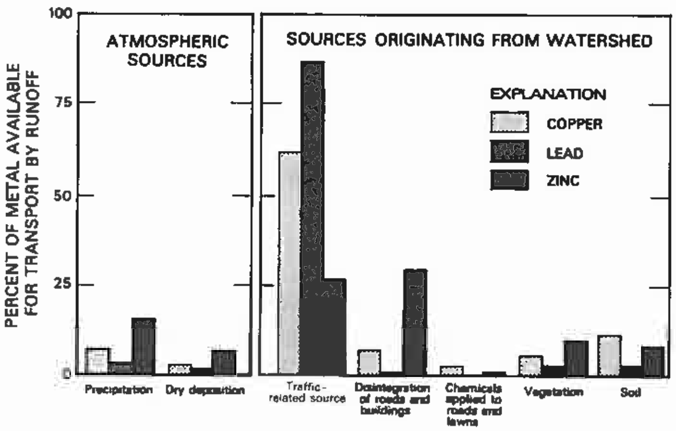

Figure 2. Sources of Copper, Lead, and Zinc Available for Washoff by Rainfall and Runoff in the Lake Ellyn Watershed (data from Hey and Schaefer, 1983).

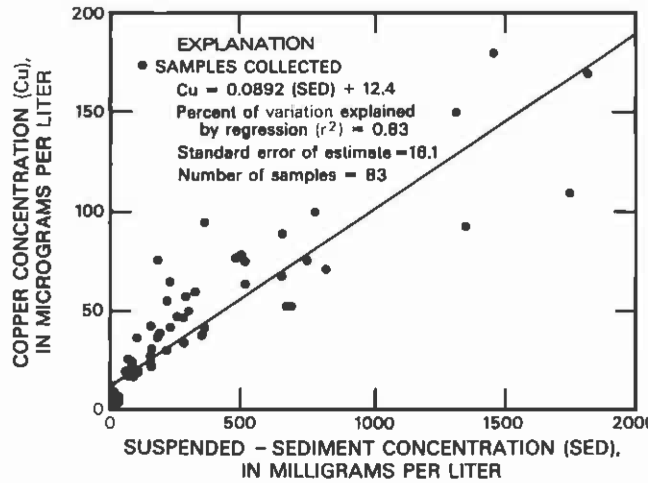

Figure 3. Relation Between Total-Recoverable Copper Concentrations and Suspended-Sediment Concentrations in Samples Collected at Main Inlet.

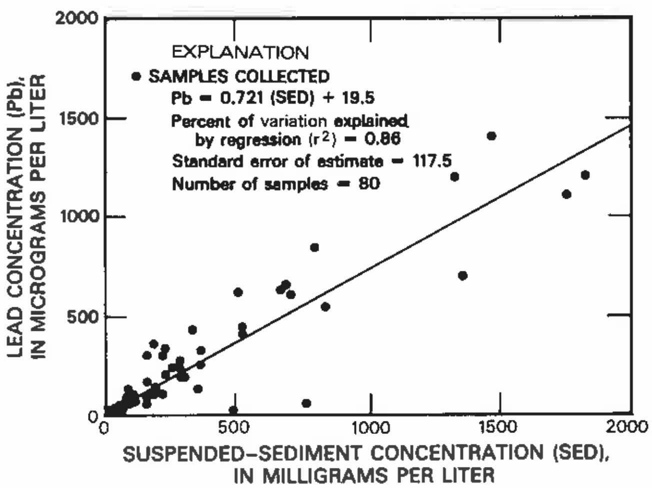

Figure 4. Relation Between Total-Recoverable Lead Concentrations and Suspended-Sediment Concentrations in Samples Collected at Main Inlet.

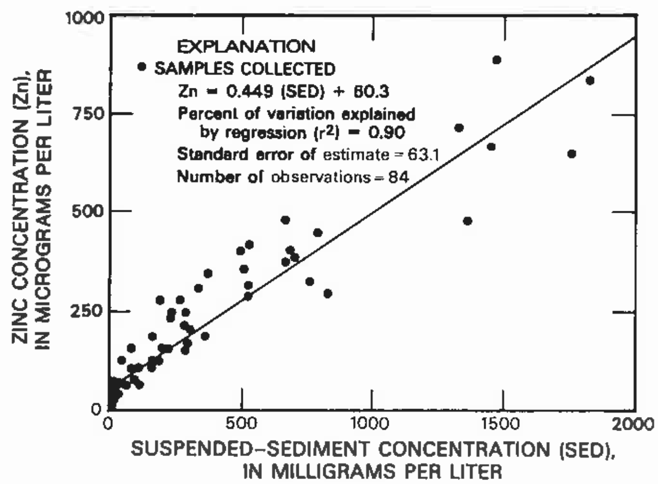

Figure 5. Relation Between Total-Recoverable Zinc Concentrations and Suspended-Sediment Concentrations in Samples Collected at Main Inlet.

TRAP EFFICIENCIES

A general water balance for a lake may be defined by

$$S_{ig} + S_{iu} + G_i + P - S_{og} - S_{ou} - G_o - E = 0 \quad (1)$$

where:

S_{ig} = gaged surface-water inflow volume,

S_{iu} = ungaged surface-water inflow volume,

G_i = ground-water inflow volume,

P = volume of precipitation that falls on the lake surface,

S_{og} = gaged surface-water outflow volume,

S_{ou} = ungaged surface-water outflow volume,

G_o = ground-water outflow volume, and

E = volume of evaporation from the lake surface.

For Lake Ellyn, ground-water interchange was assumed to be negligible because the lake is clay lined, it overlies glacial lake deposits that have low hydraulic conductivities, and the deepest point in the lake is about 3 m above the water table. Precipitation on the lake and evaporation from the lake were considered to be negligible relative to other terms in the water balance. Because all surface-water outflow from Lake Ellyn was gaged, the general water-balance equation reduced to

$$S_{ig} + S_{iu} - S_{og} = 0. \quad (2)$$

The movements of most suspended sediments and metals into and out of Lake Ellyn are surface-water dependent, and errors in calculations of trap efficiencies for those constituents primarily depend on errors in the surface-water balance. Measured inflow volumes for 18 runoff periods between April 3, 1980, and June 8, 1981, represented only 55 percent of total measured outflow volumes. Differences in the measured inflow and outflow volumes were attributed to runoff from ungaged portions of the watershed and to errors in determining discharge at Main Inlet during periods when the measurement section was affected by backwater from the lake. To accommodate for these uncertainties in measured inflow, constituent trap efficiencies were calculated as a range.

Trap efficiency, in percent, may be calculated by

$$T = [1 - \frac{L_o}{L_i}] \times 100 \qquad (3)$$

where:

T = trap efficiency, in percent,

L_o = load of constituent in outflow, and

L_i = load of constituent in inflow.

Because all of the outflow from Lake Ellyn was gaged, L_o was measured. However, loads measured at Main Inlet represented only a fraction of L_i. To account for the uncertainty in L_i from unmeasured inflow, minimum- and maximum-possible inflow loads were determined and used to calculate minimum- and maximum-possible trap efficiencies (T_{min} and T_{max}).

Minimum inflow load (L_{min}) to Lake Ellyn was considered equal to the load measured at Main Inlet. Therefore, T_{min} was calculated by substituting L_{min} for L_i in Equation (3). Calculation of maximum inflow load (L_{max}) was based on the assumption that the total volume of inflow to Lake Ellyn (S_{ig} + S_{iu}) was equal to the measured outflow from the lake (S_{og}), and, because the commercial district of Glen Ellyn drains to Main Inlet, it was assumed that concentrations of constituents in Main Inlet samples were equal to or greater than constituent concentrations in runoff from ungaged areas.

T_{min} and T_{max}, therefore, define a range that brackets the actual trap efficiency of the lake. Ranges in trap efficiencies for suspended sediment, copper, iron, lead, and zinc for 18 runoff periods are listed in Tables 4 to 8. The measured suspended-sediment trap efficiency for Lake Ellyn was slightly greater than the calculated trap efficiency for a normal ponded reservoir with a similar capacity-to-inflow ratio (Figure 6).

TABLE 4. Loads and Trap Efficiencies for Suspended Sediment for 18 Runoff Periods from April 3, 1980, to June 8, 1981, Lake Ellyn at Glen Ellyn, Illinois.

		Main Inlet			Submerged Outlet			Surface Outlet			Trap Efficiency	
Date	Rainfall (mm)	Runoff Volume (m^3)	Mean Concentration (mg/L)	Load (kg)	Runoff Volume (m^3)	Mean Concentration (mg/L)	Load (kg)	Runoff Volume (m^3)	Mean Concentration (mg/L)	Load (kg)	Minimum (percent)	Maximum (percent)
April 3, 1980	9.7	1,990	550	1,200	1,470	5.1	7.51	1,740	3.4	5.90	98.9	99.2
May 17, 1980	11.4	1,920	370	710	3,370	22.0	74.1	3,740	20.0	74.8	79.0	94.3
May 28, 1980	42.9	7,620	1,700	13,000	11,200	20.0	223	8,920	52.0	464	94.7	98.0
July 9, 1980	10.7	1,930	58	112	3,030	14.0	42.4	3,170	21.0	66.6	2.7	69.7
July 20, 1980	40.9	12,100	260	3,160	8,690	26.0	226	7,250	25.0	181	87.1	90.2
August 4, 1980	19.8	4,330	240	1,040	4,980	17.0	84.7	4,590	15.0	68.8	85.2	93.3
August 19, 1980	11.7	5,470	190	1,040	3,940	29.0	114	3,960	22.0	87.2	80.7	86.6
September 22, 1980	13.7	5,180	450	2,330	4,450	14.0	62.2	4,020	22.0	88.5	93.5	96.0
October 24, 1980	18.3	2,820	160	451	2,040	20.0	40.9	2,350	38.0	89.3	71.1	81.1
December 7, 1980	26.9	4,590	380	1,740	4,590	9.5	43.6	5,610	18.0	101	91.7	96.3
February 16, 1981	1.0*	4,360	250	1,090	3,960	6.8	27.0	2,860	3.3	9.44	96.7	97.9
February 22, 1981	16.5	7,360	480	3,530	7,390	9.2	68.0	6,060	8.4	50.9	96.6	98.2
April 3, 1981	10.4	3,770	640	2,410	1,970	35.0	69.1	3,370	24.0	80.9	93.8	95.6
April 22, 1981	18.8	6,000	120	720	4,840	31.0	150	4,500	3.0	13.5	77.3	85.4
April 28, 1981	37.1	9,230	550	5,080	14,200	57.0	807	15,800	21.0	332	77.6	93.1
May 10, 1981	15.7	9,490	83	787	6,090	9.6	58.4	6,540	9.7	63.5	84.5	88.4
May 29, 1981	27.7	10,900	260	2,840	7,160	4.4	31.5	11,600	3.0	34.8	97.7	98.6
June 8, 1981	7.1	3,770	310	1,170	2,740	8.6	23.6	2,680	4.7	12.6	96.9	97.8
Total		103,000	---	42,400	96,100	---	2,150	98,800	---	1,820	---	---
Runoff-Weighted Values		---	410	---	---	22.0	---	---	18.0	---	90.6	95.1

*Runoff measured on this date resulted from snowmelt.

TABLE 5. Loads and Trap Efficiencies for Copper for 18 Runoff Periods from April 3, 1980, to June 8, 1981, Lake Ellyn at Glen Ellyn, Illinois.

		Main Inlet			Submerged Outlet			Surface Outlet			Trap Efficiency	
Date	Rainfall (mm)	Runoff Volume (m^3)	Mean Concentration (μg/L)	Load (kg)	Runoff Volume (m^3)	Mean Concentration (μg/L)	Load (kg)	Runoff Volume (m^3)	Mean Concentration (μg/L)	Load (kg)	Minimum (percent)	Maximum (percent)
April 3, 1980	9.7	1,990	81	0.161	1,470	5.1	0.008	1,740	7.0	0.012	87.6	92.3
May 17, 1980	11.4	1,920	73	0.140	3,370	4.9	0.017	3,740	5.0	0.019	74.3	93.1
May 28, 1980	42.9	7,620	130	0.990	11,200	8.1	0.090	8,920	5.9	0.053	85.6	94.5
July 9, 1980	10.7	1,930	78	0.151	3,030	7.8	0.024	3,170	3.6	0.011	76.8	92.8
July 20, 1980	40.9	12,100	42	0.510	8,690	5.6	0.049	7,250	7.6	0.055	79.6	84.5
August 4, 1980	19.8	4,330	51	0.221	4,980	3.4	0.017	4,590	3.7	0.017	84.6	93.0
August 19, 1980	11.7	5,470	35	0.191	3,940	6.3	0.025	3,960	6.4	0.025	73.8	81.9
September 22, 1980	13.7	5,180	54	0.280	4,450	5.6	0.025	4,020	5.9	0.024	82.5	89.3
October 24, 1980	18.3	2,820	50	0.141	2,040	5.8	0.012	2,350	6.5	0.015	80.9	87.7
December 7, 1980	26.9	4,590	46	0.211	4,590	3.8	0.017	5,610	5.1	0.029	78.2	90.2
February 16, 1981	1.0*	4,360	51	0.222	3,960	7.7	0.031	2,860	6.5	0.019	77.5	85.6
February 22, 1981	16.5	7,360	58	0.427	7,390	6.4	0.047	6,060	5.8	0.035	80.8	89.5
April 3, 1981	10.4	3,770	11	0.041	1,970	6.5	0.013	3,370	6.4	0.022	14.6	40.5
April 22, 1981	18.8	6,000	23	0.138	4,840	5.8	0.028	4,500	4.8	0.022	63.8	76.7
April 28, 1981	37.1	9,230	66	0.609	14,200	6.1	0.086	15,800	7.7	0.122	65.8	89.5
May 10, 1981	15.7	9,490	24	0.228	6,090	5.6	0.034	6,540	5.8	0.038	68.4	76.2
May 29, 1981	27.7	10,900	46	0.503	7,160	6.5	0.047	11,600	8.4	0.097	71.4	83.3
June 8, 1981	7.1	3,770	51	0.192	2,740	5.8	0.016	2,680	8.9	0.024	79.2	85.5
Total		103,000	---	5.36	96,100	---	0.586	98,800	---	0.639	---	---
Runoff-Weighted Values		---	52	---	---	6.1	---	---	6.5	---	77.1	88.1

*Runoff measured on this date resulted from snowmelt.

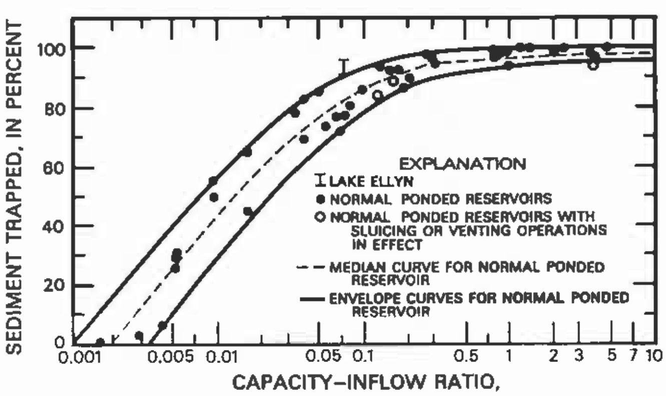

Figure 6. Sediment Trap Efficiency as Related to Capacity-Inflow Ratio for Normal-Ponded Reservoirs and Lake Ellyn (modified from Brune, 1953).

DEPOSITION OF SEDIMENTS

Quantity and Physical Quality of Sediments

The most noticeable effect of routing runoff through Lake Ellyn is the deposition of sediments on the lake bottom. Deposited sediments reduce lake storage, fill shallow areas near inlets, and cover or make unsuitable potential habitat for aquatic organisms. Lake Ellyn was drained and sediments were removed in 1970. Figure 7 shows the thickness and areal distribution of sediments in Lake Ellyn in 1980. About 8,200 m^3 of sediment accumulated in the lake over a 10-year period and resulted in a 13 percent loss in lake storage. A maximum sediment thickness of 1.0 m was measured at the upstream side of a barrier dam near Main Inlet. The area-averaged rate of sediment deposition was calculated to be 20 mm per year. Barrier dams, especially those constructed in series, seem to be useful in reducing sediment transport to downstream areas of detention lakes.

Figure 8 compares settling rates based on particle-size distributions and Stoke's Law to measured settling rates for samples collected at Main Inlet. Settling rates determined by Stoke's Law predicted that about 45 percent of sediments would settle after four hours, whereas measured settling rates showed that 95 percent of sediments settle after four hours. This suggests that particles flocculated, probably as a result of high concentrations of clay-sized sediment and colloidal organic material, and settled more rapidly than they would have as discrete particles. Whipple and Hunter (1981) determined that settling rates of pollutants in urban runoff vary widely, and concluded that particle-size distributions of sediment cannot be translated into settling rates for adsorbed

TABLE 6. Loads and Trap Efficiencies for Iron for 18 Runoff Periods from April 3, 1980, to June 8, 1981, Lake Ellyn at Glen Ellyn, Illinois.

		Main Inlet			Submerged Outlet			Surface Outlet			Trap Efficiency	
Date	Rainfall (mm)	Runoff Volume (m^3)	Mean Concentration (μg/L)	Load (kg)	Runoff Volume (m^3)	Mean Concentration (μg/L)	Load (kg)	Runoff Volume (m^3)	Mean Concentration (μg/L)	Load (kg)	Minimum (percent)	Maximum (percent)
April 3, 1980	9.7	1,990	15,000	29.9	1,470	270	0.398	1,740	240	0.417	97.3	98.3
May 17, 1980	11.4	1,920	7,900	15.2	3,370	270	0.910	3,740	260	0.972	87.6	96.6
May 28, 1980	42.9	7,620	15,000	114	11,200	490	5.47	8,920	580	5.17	90.7	96.5
July 9, 1980	10.7	1,930	36,000	69.5	3,030	500	1.52	3,170	270	0.856	96.6	98.9
July 20, 1980	40.9	12,100	6,400	77.8	8,690	420	3.65	7,250	740	5.36	88.4	91.2
August 4, 1980	19.8	4,330	6,800	29.5	4,980	260	1.30	4,590	400	1.84	89.4	95.2
August 19, 1980	11.7	5,470	4,300	23.5	3,940	410	1.61	3,960	260	1.03	88.8	92.2
September 22, 1980	13.7	5,180	7,600	39.4	4,450	350	1.56	4.020	340	1.37	92.6	95.4
October 24, 1980	18.3	2,820	3,600	10.1	2,040	520	1.06	2,350	520	1.22	77.4	85.6
December 7, 1980	26.9	4,590	9,200	42.2	4,590	610	2.80	5,610	680	3.81	84.3	93.0
February 16, 1981	1.0*	4,360	6,800	29.7	3,960	480	1.90	2,860	240	0.686	91.3	94.4
February 22, 1981	16.5	7,360	4,900	36.1	7,390	500	3.70	6,060	220	1.33	86.1	92.4
April 3, 1981	10.4	3,770	16,000	60.3	1,970	890	1.76	3,370	730	2.46	93.0	95.1
April 22, 1981	18.8	6,000	3,100	18.6	4,840	430	2.08	4,500	360	1.62	80.1	87.2
April 28, 1981	37.1	9,230	9,200	84.9	14,200	780	11.0	15,800	880	13.9	70.7	91.0
May 10, 1981	15.7	9,490	2,800	26.6	6,090	420	2.56	6,540	470	3.08	78.8	84.1
May 29, 1981	27.7	10,900	5,300	57.9	7,160	500	3.58	11,600	330	3.82	87.2	92.6
June 8, 1981	7.1	3,770	4,600	17.3	2,740	420	1.15	2,680	380	1.01	87.5	91.3
Total		103,000	---	782	96,100	---	48.0	98,800	---	50.0	---	---
Runoff-Weighted Values		---	7,600	---	---	510	---	---	510	---	87.5	93.5

*Runoff measured on this date resulted from snowmelt.

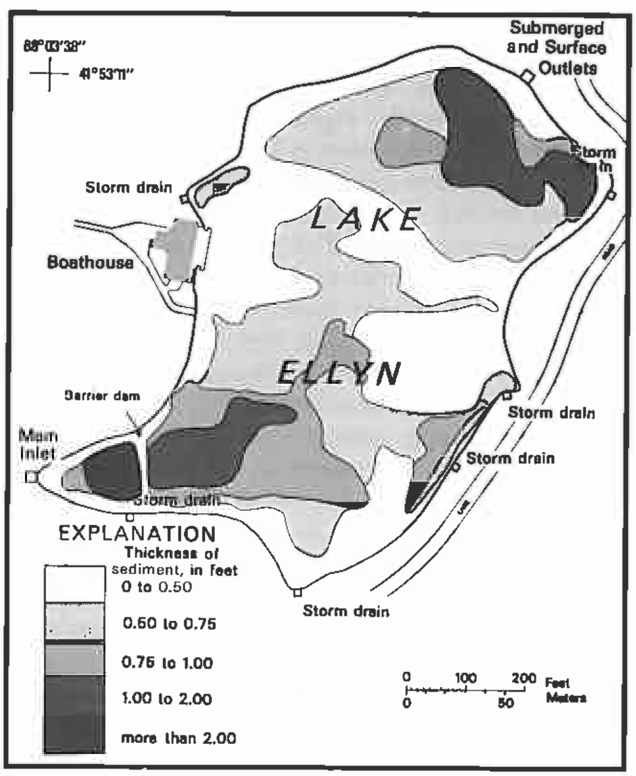

Figure 7. Thickness of Bottom Sediments Accumulated in Lake Ellyn from 1970 to 1980.

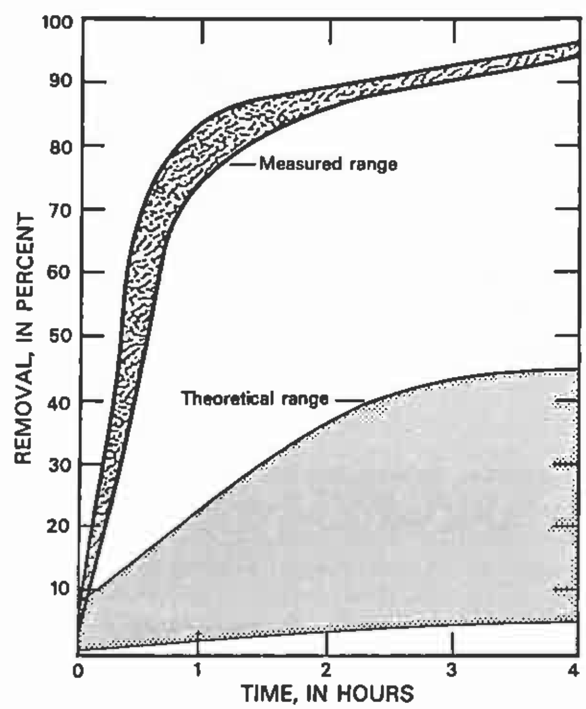

Figure 8. Ranges of Measured and Theoretical Rates of Settling for Suspended Sediment in Samples of Runoff Collected at Main Inlet.

TABLE 7. Loads and Trap Efficiencies for Lead for 17 Runoff Periods from April 3, 1980, to June 8, 1981, Lake Ellyn at Glen Ellyn, Illinois.

		Main Inlet			Submerged Outlet			Surface Outlet			Trap Efficiency	
Date	Rainfall (mm)	Runoff Volume (m^3)	Mean Concentration (μg/L)	Load (kg)	Runoff Volume (m^3)	Mean Concentration (μg/L)	Load (kg)	Runoff Volume (m^3)	Mean Concentration (μg/L)	Load (kg)	Minimum (percent)	Maximum (percent)
April 3, 1980	9.7	1,990	1,200	2.39	1,470	35	0.052	1,740	41	0.071	94.9	96.8
May 17, 1980	11.4	1,920	630	1.21	3,370	33	0.111	3,740	34	0.127	80.3	94.7
May 28, 1980	42.9	7,620	930	7.08	11,200	14	0.156	8,920	11	0.098	96.4	98.6
July 9, 1980	10.7	1,930	460	0.888	3,030	27	0.082	3,170	23	0.073	82.5	94.6
July 20, 1980	40.9	12,100	300	3.64	8,690	17	0.148	7,250	21	0.152	91.8	93.7
August 4, 1980	19.8	4,330	370	1.60	4,980	13	0.065	4,590	16	0.073	91.4	96.1
August 19, 1980	11.7	5,470	190	1.04	3,940	30	0.118	3,960	31	0.123	76.8	83.9
September 22, 1980	13.7	5,180	340	1.76	4,450	23	0.102	4,020	28	0.113	87.8	92.5
October 24, 1980	18.3	2,820	200	0.564	2,040	32	0.065	2,350	37	0.087	73.0	82.7
December 7, 1980	26.9	4,590	120	0.551	4,590	29	0.133	5,610	34	0.191	41.2	73.5
February 16, 1981	1.0*	4,360	420	1.83	3,960	50	0.198	2,860	41	0.117	82.8	89.0
February 22, 1981	16.5	7,360	460	3.39	7,390	52	0.384	6,060	45	0.273	80.6	89.4
April 3, 1981	10.4	3,770	970	3.65	1,970	46	0.091	3,370	46	0.155	93.3	95.3
April 28, 1981	37.1	9,230	380	3.51	14,200	35	0.496	15,800	43	0.680	66.5	89.7
May 10, 1981	15.7	9,490	60	0.569	6,090	40	0.244	6,540	44	0.288	6.5	29.8
May 29, 1981	27.7	10,900	220	2.40	7,160	39	0.279	11,600	40	0.463	69.1	82.0
June 8, 1981	7.1	3,770	300	1.13	2,740	29	0.080	2,680	41	0.110	83.2	88.3
Total		97,000	– – –	37.2	91,300	– – –	2.80	94,300	– – –	3.19	– – –	– – –
Runoff-Weighted Values		– – –	390	– – –	– – –	31	– – –	– – –	34	– – –	83.9	91.7

*Runoff measured on this date resulted from snowmelt.

constituents. This is because of the variety of types of sediment particles present in urban runoff, their different specific gravities, and differences in how they absorb metals and other constituents.

Sediments in Lake Ellyn accumulated in the form of an organic-rich mud (Hill and Hullinger, 1981); sediments collected near inlets had petroleum-oil coating and odor (E. A. Cowan, Northern Illinois University, unpublished Master's thesis, 1982). Particle-size distributions of bottom sediments near Main Inlet, near the center of the lake, and near the outlets are listed in Table 9. Figure 9 is a map of the areal distribution of mean particle sizes found in Lake Ellyn. The mean size of bottom sediments decreases with distance from Main Inlet because of reductions in the carrying capacity of inflowing runoff. Coarsest sediment was deposited near Main Inlet. Sediment in near-shore areas had a wide range of mean particle sizes because of erosion of sand and gravel from the bank. Mean particle sizes were smallest to the deepest areas of the lake.

Metals Associated with Bottom Sediments

Concentrations of metals in bottom sediments are highly correlated to particle size (Rickert, *et al.*, 1977; Kelly and Hite, 1981). Small particles, such as silt, clay, and organic particulates have large surface areas per unit volume, and act as chemical adsorbants (Feltz, 1980). Mean concentrations of copper, iron, lead, and zinc per unit dry weight of Lake Ellyn bottom sediments were inversely proportional to the mean particle size of bottom sediment (Figure 10). This suggests that the greatest concentrations of metals can be found in the deep areas of lakes where the finest sediments are deposited.

Bottom sediments record intermittant discharges and historical inputs of metals and other constituents that may not be detected by periodic water sampling (Rickert, *et al.*, 1977; Feltz, 1980; Wahlen and Thompson, 1980). For example, 23 micrograms of mercury per kilogram of sediment were measured in a Lake Ellyn sediment sample collected near Main Inlet on May 29, 1981, but no mercury was detected in inflow or outflow samples collected on that day.

Concentrations of copper, lead, and zinc associated with Lake Ellyn sediments were similar to those found in road dirt and street sweepings collected from the watershed (Table 10). Mean concentrations of cacmium, copper, and lead reported in a 1979 survey of the chemical characteristics of sediments from 63 Illinois lakes (Kelly and Hite, 1981), are lower than minimum concentrations measured for those metals in Lake Ellyn sediments (Table 11). Mean lead concentrations from Lake Ellyn sediments were 6.4 times greater than the maximum lead concentration reported by Kelly and Hite (1981).

TABLE 8. Loads and Trap Efficiencies for Zinc for 18 Runoff Periods from April 3, 1980, to June 8, 1981, Lake Ellyn at Glen Ellyn, Illinois.

		Main Inlet			Submerged Outlet			Surface Outlet			Trap Efficiency	
Date	Rainfall (mm)	Runoff Volume (m^3)	Mean Concentration (μg/L)	Load (kg)	Runoff Volume (m^3)	Mean Concentration (μg/L)	Load (kg)	Runoff Volume (m^3)	Mean Concentration (μg/L)	Load (kg)	Minimum (percent)	Maximum (percent)
April 3, 1980	9.7	1,990	690	1.38	1,470	21	0.031	1,740	25	0.043	94.6	96.7
May 17, 1980	11.4	1,920	340	0.653	3,370	19	0.064	3,740	21	0.079	78.1	94.1
May 28, 1980	42.9	7,620	550	4.19	11,200	27	0.301	8,920	27	0.241	87.1	95.1
July 9, 1980	10.7	1,930	320	0.618	3,030	32	0.097	3,170	20	0.063	74.1	91.9
July 20, 1980	40.9	12,100	200	2.43	8,690	24	0.209	7,250	36	0.261	80.7	85.3
August 4, 1980	19.8	4,330	200	0.867	4,980	17	0.085	4,590	20	0.092	79.6	90.8
August 19, 1980	11.7	5,470	120	0.656	3,940	19	0.075	3,960	14	0.056	80.0	86.2
September 22, 1980	13.7	5,180	250	1.30	4,450	19	0.084	4,020	24	0.097	86.1	91.4
October 24, 1980	18.3	2,820	64	0.180	2,040	18	0.037	2,350	12	0.028	63.9	76.9
December 7, 1980	26.9	4,590	200	0.918	4,590	30	0.138	5,610	33	0.185	64.8	84.2
February 16, 1981	1.0*	4,360	240	1.05	3,960	26	0.103	2,860	19	0.054	85.0	90.4
February 22, 1981	16.5	7,360	190	1.40	7,390	25	0.185	6,060	31	0.188	73.4	85.4
April 3, 1981	10.4	3,770	600	2.26	1,970	59	0.116	3,370	61	0.206	85.8	90.0
April 22, 1981	18.8	6,000	120	0.720	4,840	38	0.184	4,500	25	0.113	58.8	73.5
April 28, 1981	37.1	9,230	260	2.40	14,200	35	0.496	15,800	42	0.664	51.7	85.1
May 10, 1981	15.7	9,490	80	0.759	6,090	19	0.116	6,540	19	0.124	68.4	76.2
May 29, 1981	27.7	10,900	250	2.73	7,160	57	0.408	11,600	56	0.649	61.3	77.4
June 8, 1981	7.1	3,770	260	0.979	2,740	32	0.088	2,680	19	0.051	85.8	90.1
Total		103,000	– – –	25.5	96,100	– – –	2.82	98,800	– – –	3.19	– – –	– – –
Runoff-Weighted Values		– – –	250	– – –	– – –	510	– – –	– – –	32	– – –	76.4	77.8

*Runoff measured on this date resulted from snowmelt.

TABLE 9. Particle-Size Distribution of Lake Ellyn Bottom-Sediment Samples, in Percent by Weight (modified from Cowan, unpublished Master's thesis, 1981).

Location	Number of Samples	Gravel and Sand (>62 μm)	Silt (4-62 μm)	Clay (<4 μm)
Near Main Inlet	6	22.7	43.5	33.8
Center of Lake	7	10.8	42.6	46.6
Near Outlet	3	6.3	45.3	48.4

SUMMARY

Detention storage in a small lake was from 91 to 95 percent efficient in removing suspended sediment, and from 76 to 94 percent efficient in removing copper, iron, lead, and zinc from urban runoff. Sediments accumulated in the lake at an average rate of 20 mm per year from 1970 to 1980, resulting in a 13-percent loss in lake storage. Concentrations of copper, lead, and zinc were closely associated with suspended-sediment concentrations and with accumulations of fine-grained sediments. Most suspended sediments and lake sediments were silt- and clay-sized. Lake sediments had greater concentrations of metals than other lakes that had been sampled previously in Illinois. Some metals that were present in low concentrations in runoff were concentrated in lake sediments.

ACKNOWLEDGMENTS

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LITERATURE CITED

Bodhaine, G. L., 1968. Measurement of Peak Discharge at Culverts by Indirect Methods. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A3, 60 pp.

Brune, G. M., 1953. Trap Efficiency of Reservoirs. Transactions of the American Geophysical Union 34(3):407-418.

Buchanan, T. J. and W. P. Somers, 1968. Stage Measurement at Gaging Stations. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A7, 28 pp.

Feltz, H. R., 1980. Significance of Bottom Material Data in Evaluating Water Quality. *In:* Contaminants and Sediments, Vol. 1, R. A. Baker (Editor). Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, pp. 271-286.

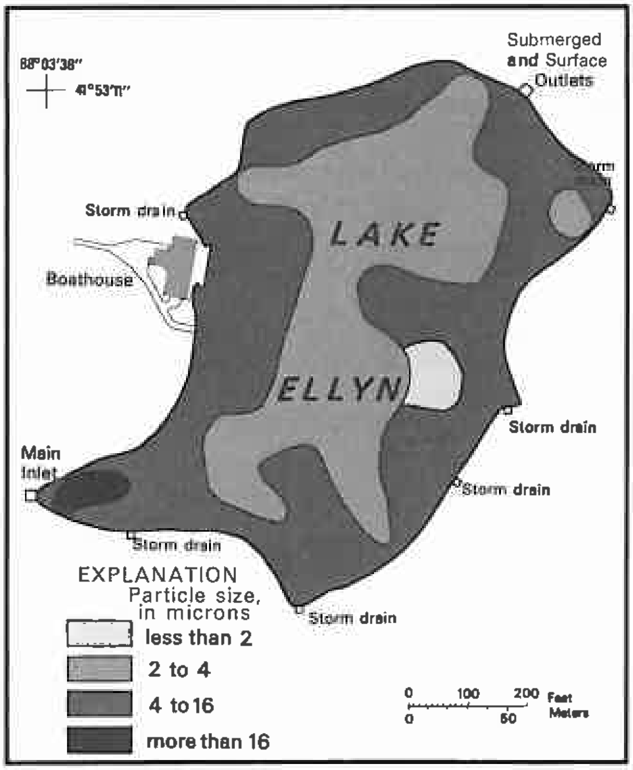

Figure 9. Mean Particle Size of Bottom Sediments in Lake Ellyn in 1980.

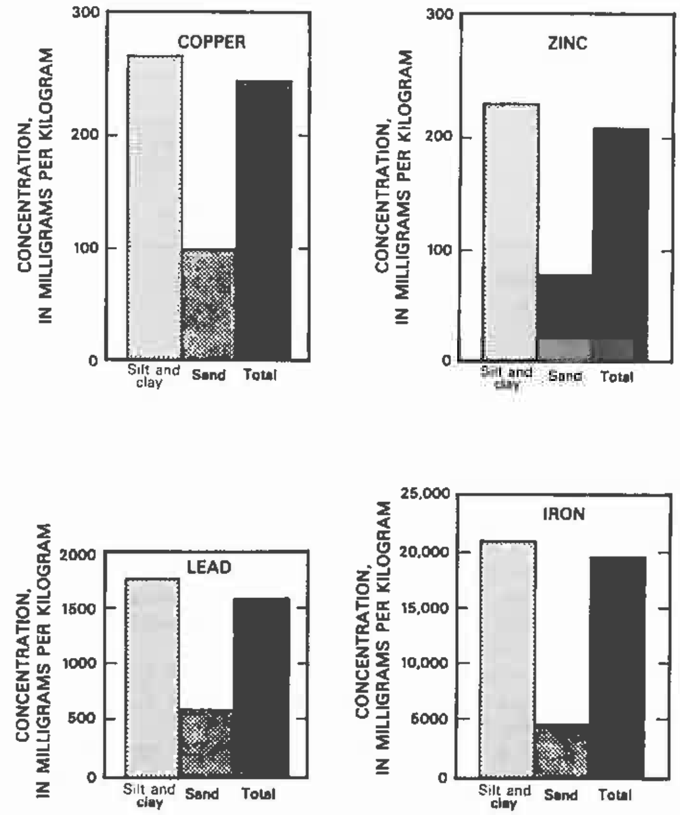

Figure 10. Mean Concentrations of Metals in Lake Ellyn Bottom Sediments, by Particle Size (concentrations in milligrams per kilogram).

TABLE 10. Mean Concentrations of Copper, Lead, and Zinc in Lake Ellyn Bottom-Sediment, Road Dirt, and Street Sweepings Samples, in Milligrams Per Kilogram Dry Weight (modified from Hey and Schaefer, 1983).

	Lake Ellyn Bottom Sediments Size Fraction		Road Dirt: High-Traffic Areas Size Fraction		Road Dirt: Medium-Traffic Areas Size Fraction		Road Dirt: Low-Traffic Areas Size Fraction		Street Sweepings Size Fraction	
Constituent	Silt + Clay (< 63 μm)	Total	Silt + Clay (< 63 μm)	Total	Silt + Clay (< 63 μm)	Total	Silt + Clay (< 63 μm)	Total	Silt + Clay (< 63 μm)	Total
Copper	275	250	131	65	83	42	52	25	77	34
Lead	1,750	1,590	2,130	1,550	1,850	1,310	850	645	1,140	543
Zinc	228	210	605	414	442	217	335	148	472	196

Guy, H. P., 1969. Laboratory Theory and Methods for Sediment Analysis. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter C1, 58 pp.

Guy, H. P. and V. W. Norman, 1970. Field Methods for Measurement of Fluvial Sediment. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C3, 59 pp.

Heaney, J. P. and W. L. Huber, 1979. Urban Rainfall-Runoff Quality Data Base – Update With Statistical Analysis. U.S. Environmental Protection Agency, EPA 600/8-79-004, 241 pp.

Hey, D. L. and G. C. Schaefer, 1983. An Evaluation of the Water Quality Effects of Detention Storage and Source Control. Northeastern Illinois Planning Commission, Chicago, Illinois, 285 pp.

Hill, T. E. and D. L. Hullinger, 1981. Physical, Chemical, and Biological Characteristics of the Sediments from the Lake Ellyn Study Area. Illinois Department of Energy and Natural Resources, Water Survey Contract Report 287, Springfield, Illinois, 28 pp.

Hulsing, Harry, 1967. Measurement of Peak Discharge at Dams by Indirect Methods. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A5, 29 pp.

Kelly, M. H. and R. L. Hite, 1981. Chemical Analysis of Surfacial Sediments from 63 Illinois Lakes, Summer 1979. Illinois Environmental Protection Agency, Division of Water Pollution Control, Springfield, Illinois, 92 pp.

TABLE 11. Concentrations of Cadmium, Copper, Iron, Lead, and Zinc in Bottom Sediments from 63 Illinois Lakes and Lake Ellyn (modified from Kelly and Hite, 1981; Cowan, unpublished Master's thesis, 1982).

	Concentrations, in Milligrams Per Kilogram Dry Weight							
	63 Illinois Lakes				Lake Ellyn			
	N	Mean ± 1 Standard Deviation	Minimum	Maximum	N	Mean	Minimum	Maximum
Cadmium	272	⩽1	<0.5	8	7	4	3	6
Copper	273	42 ±56	3.0	560	15	250	73	790
Iron	273	27,080 ±8,890	4,300.0	55,000	15	19,420	3,630	28,000
Lead	273	57 ±43	3.0	250	15	1,590	410	5,100
Zinc	273	113 ±66	11.0	750	15	210	3	500

Pitt, R. and M. Bozeman, 1980. Water Quality and Biological Effects of Urban Runoff on Coyote Creek, Phase 1 – Preliminary Survey. U.S. Environmental Protection Agency, EPA 600/2-80-104, 73 pp.

Porterfield, George, 1972. Computation of Fluvial-Sediment Discharge. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C3, 66 pp.

Rickert, D. A., *et al.*, 1977. A Synoptic Survey of Trace Metals in Bottom Sediments and Willamette River, Oregon. U.S. Geological Survey Circular 715-F, 27 pp.

Sartor, J. D., G. B. Boyd, and F. J. Agardy, 1974. Water Pollution Aspects of Street Surface Contaminants. Journal of the Water Pollution Control Federation 46(3):458-467.

Shaheen, D. G., 1975. Contributions of Urban Roadway Usage to Water Pollution. U.S. Environmental Protection Agency, EPA-600/2-75-004.

Skougstad, M. W., M. J. Fishman, L. C. Friedman, D. E. Erdman, and S. S. Duncan, 1979. Methods for Determination of Inorganic Substances in Water and Fluvial Sediments. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, 626 pp.

Striegl, R. G. and E. A. Cowan, 1987. Relations Between Quality of Urban Runoff and Quality of Lake Ellyn at Glen Ellyn, Illinois. U.S. Geological Survey Water-Supply Paper 2301, 59 pp.

Wahlen, M. and R. C. Thompson, 1980. Pollution Records from Sediments of Three Lakes in New York State. Geochimica et Cosmochimica Acta 44(2):333-339.

Walling, D. E. and K. J. Gregory, 1970. The Measurement of the Effects of Building Construction on Drainage Basin Dynamics. Journal of Hydrology 2:129-144.

Whipple, W., Jr. and J. V. Hunter, 1981. Settleability of Urban Runoff Pollution. Journal Water Pollution Control Federation 53(12): 1726-1731.