EFFECTS OF URBAN RUNOFF ON LAKE ELLYN

AT GLEN ELLYN, ILLINOIS

By Robert G. Striegl

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CONVERSION FACTORS

Multiply inch-pound unit	By	To obtain SI unit
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
acre	0.4047	hectare
square foot (ft^2)	0.09294	square meter (m^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
gallon (gal)	3.785	liter (L)
ounce, avoirdupois (oz)	28.35	gram (g)

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ABSTRACT

Detention of urban runoff was observed to have physical, chemical, and biological effects on a small lake located near Chicago, Illinois. Accumulated bottom sediments reduce lake storage and have comparatively high concentrations of metals and organic compounds. Concentrations of many constituents dissolved in the lake water are seasonally cyclic, with annual concentration peaks during the winter. Maintenance of desirable benthic invertebrate and fish communities, and development of undesirable phytoplankton blooms appear to be inhibited by sediments deposited on the lake bottom or suspended in the lake water.

INTRODUCTION

Lakes provide multiple benefits to urban areas. Besides recreational and aesthetic benefits, urban lakes have increasingly been used as environmental controls, including flood and sediment control. The control of runoff quality by detention storage in Lake Ellyn, a 10.2-acre, 45 acre-foot impoundment located in the western Chicago suburb of Glen Ellyn, Illinois, is discussed by Hey and Schaefer (1983) and Striegl (1984). The object of this paper is to discuss some of the physical, chemical, and biological effects of urban runoff on Lake Ellyn.

Study Area

Lake Ellyn (fig. 1) receives drainage from a 534-acre urban watershed. Physiographic and land-use characteristics of the watershed are listed in table 1. Surface-water inflows to the lake are confined to storm drains, with the exception of overland flow from a small area of parkland that immediately surrounds the lake. The main storm drain (Main Inlet) carries runoff from approximately 70 percent of the watershed. Lake outflows are controlled by two weirs (Submerged Outlet and Surface Outlet) located on the opposite side of the lake from Main Inlet.

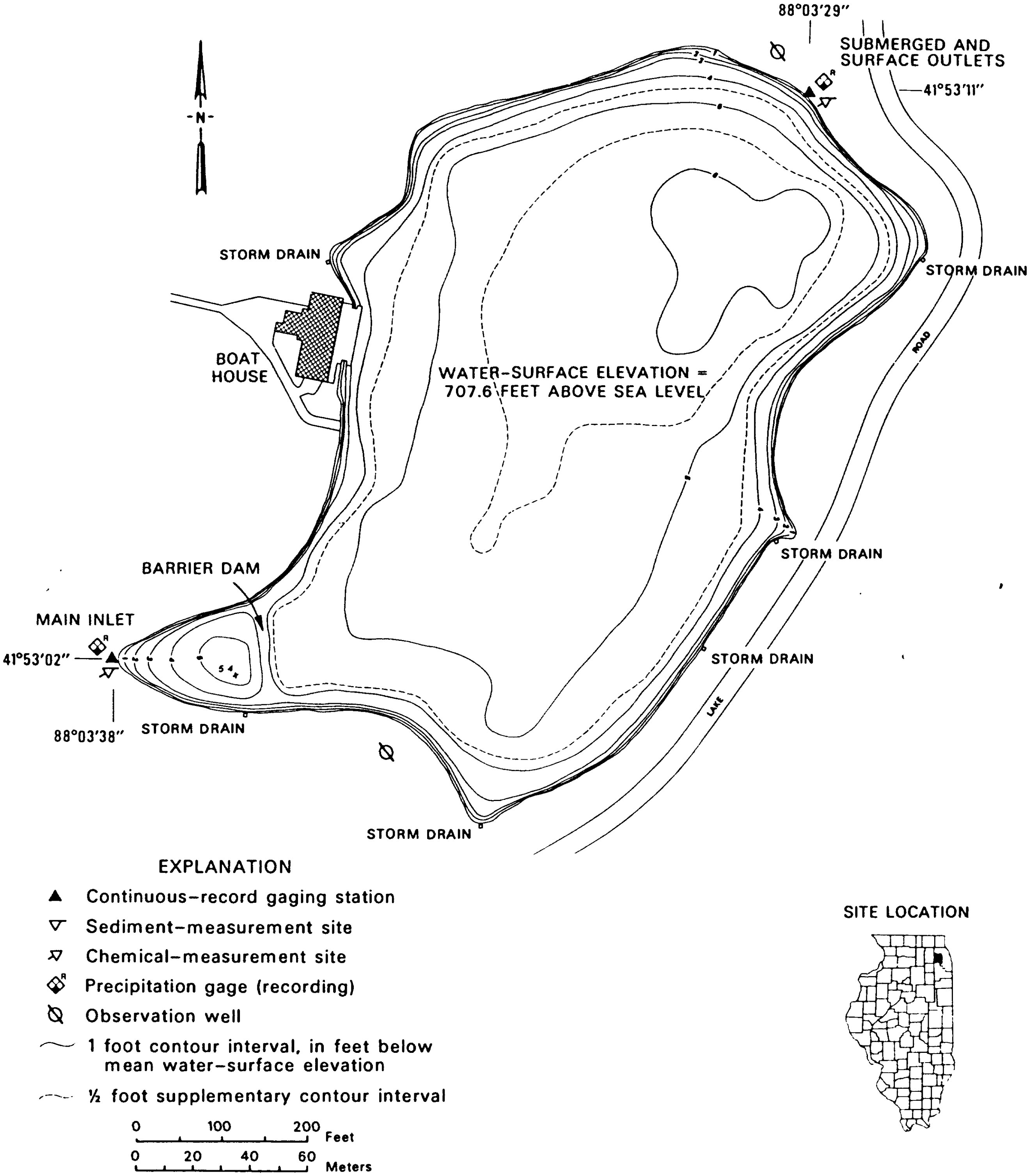

Figure 1.--Location and depth contours at Lake Ellyn at Glen Ellyn, Illinois.

Table 1.--Physiographic and land-use characteristics of the Lake Ellyn watershed

[Modified from Hey and Schaefer, 1983]

Total drainage area, in acres	534
Impervious area, in percentage of drainage area	34
Average basin slope, in percent	4.2
Lake volume, in acre feet	44.8
Inches of runoff required to fill lake	1.0
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

Methods of Study

Information presented in this paper is based on data collected by several investigators (table 2). Physical characteristics of Lake Ellyn, including size, shape, bathymetry, and depth of accumulated sediments were determined from aerial photographs and by direct measurement (Cowan, 1982). Lake, Main Inlet, Submerged Outlet, and Surface Outlet stages were recorded according to methods described by Buchanan and Somers (1968); and stage-discharge relations were determined using methods from Hulsing (1967), Bodhaine (1968), and Buchanan and Somers (1969).

Discrete samples of inflow and outflow were collected by stage-activated automatic pumping samplers. All samples collected for organic analyses, and many samples collected for inorganic analyses during the second study year, were composited prior to analysis. Samples were analyzed for chemical and sediment concentrations and particle-size distribution by methods described by Guy (1969), Goerlitz and Brown (1972), and Skougstad and others (1979). Methods used for priority-pollutant analyses were provided to contract laboratories by the U.S. Environmental Protection Agency (USEPA) (Hey and Schaefer, 1983). Chemical and sediment loads were computed for each sampled runoff period with equations derived from Heaney and Huber (1979).

Table 2.--Agencies involved in data collection for the Lake Ellyn study

Agency	Data collected
Du Page County Regional Planning Commission	Land-use surveys
Illinois Department of Conservation	Fish census
Illinois State Water Survey	Atmospheric deposition Benthic invertebrates Lake-water quality Lake-sediment quality
Northeastern Illinois Planning Commission	Land-use surveys Road-dirt accumulations Snow survey Soil survey
Northern Illinois University	Lake morphology Lake-sediment quality and quantity
U.S. Environmental Protection Agency	Organic compound analysis of water and sediments
U.S. Geological Survey	Lake-outflow quality and quantity Lake-sediment quality Phytoplankton enumeration Precipitation Runoff quality and quantity

Samples of lake-bottom sediment were collected by coring (Cowan, 1982) and by Ekman dredge (Hill and Hullinger, 1981). Dredged samples for biological analysis were washed through a 30-mesh sieve, and benthic invertebrates were picked from the residue. Methods for the chemical and biological analysis of lake sediments are described in Hill and Hullinger (1981), Cowan (1982), and Hey and Schaefer (1983).

Fish-species diversity and relative abundances were assessed by single-census sampling with a boat-mounted electroshocker.

Acknowledgments

Funds for the Lake Ellyn study were provided by the USEPA as part of the Nationwide Urban Runoff Program, and by the Illinois Department of Energy and Natural Resources through the Northeastern Illinois Planning Commission. The Village of Glen Ellyn, the Glen Ellyn Park District, and Glenbard West High School provided the study area and logistical assistance.

EFFECTS OF URBAN RUNOFF ON LAKE ELLYN

Physical

Physical effects of runoff on Lake Ellyn are primarily associated with the volume of runoff flowing into and out of the lake, and with the amount of sediments transported by the runoff. Surface runoff from 95 percent of the predominantly urban watershed enters storm drains that empty into the lake. The Main Inlet storm drain conveys runoff to the lake quickly, and has discharge hydrographs that peak sharply and are of short duration (fig. 2). Outlet hydrographs have lower peaks and are of longer duration. Inflowing water following heavy rains appears to have sufficient energy to mix the lake, preventing prolonged chemical and temperature stratification in summer. The difference between inflow and outflow volumes for a runoff period will temporarily increase lake storage and cause lake levels to rise. Lake-level fluctuations contribute to bank erosion and may disturb littoral communities (Moss, 1980).

Figure 3 shows water-discharge hydrographs and dissolved-solids and suspended-solids concentration graphs for Main Inlet, and for combined flow at Submerged Outlet and Surface Outlet during the July 20-21, 1980, rainfall-runoff period. Suspended-solids concentrations vary in direct proportion to water discharge at Main Inlet and are consistently low in the outflow. Calculations of suspended-solids loads for 17 runoff periods sampled between April 1980 and June 1981 indicate that 88 to 94 percent of the suspended solids that enter the lake remain there (Striegl, 1984).

Lake Ellyn was drained, and bottom sediments were removed in 1970. Figure 4 shows the thickness of sediments accumulated in the lake from 1970 to 1980 as measured by coring and by using a sediment probe (Cowan, 1982). Calculation of sediment volumes from planimetry of the sediment thickness map indicates that 1.38×10^5 cubic feet of sediments were deposited over the 10-year period, giving an average accumulation rate of 0.8 inch per year (Cowan, 1982). Thickest accumulations were found on the upstream side of a barrier dam located near Main Inlet (fig. 4). Sampled sediments were an organic-rich mud and had an average of 14 percent volatile solids (Hill and Hullinger, 1981). The percentages of silt- and clay-sized fractions in sediments increase with distance from Main Inlet (table 3).

Settling-column measurements (Hey and Schaefer, 1983) of the rates of settling of solids from samples collected at Main Inlet following rainfall indicate that measured rates of settling are faster than theoretical rates calculated by Stoke's Law (fig. 5). The measured rate suggests that small particles transported to the lake in runoff flocculate and settle rather than remain in suspension. High organic solids concentrations in the runoff may enhance particle flocculation (Stumm and Morgan, 1981).

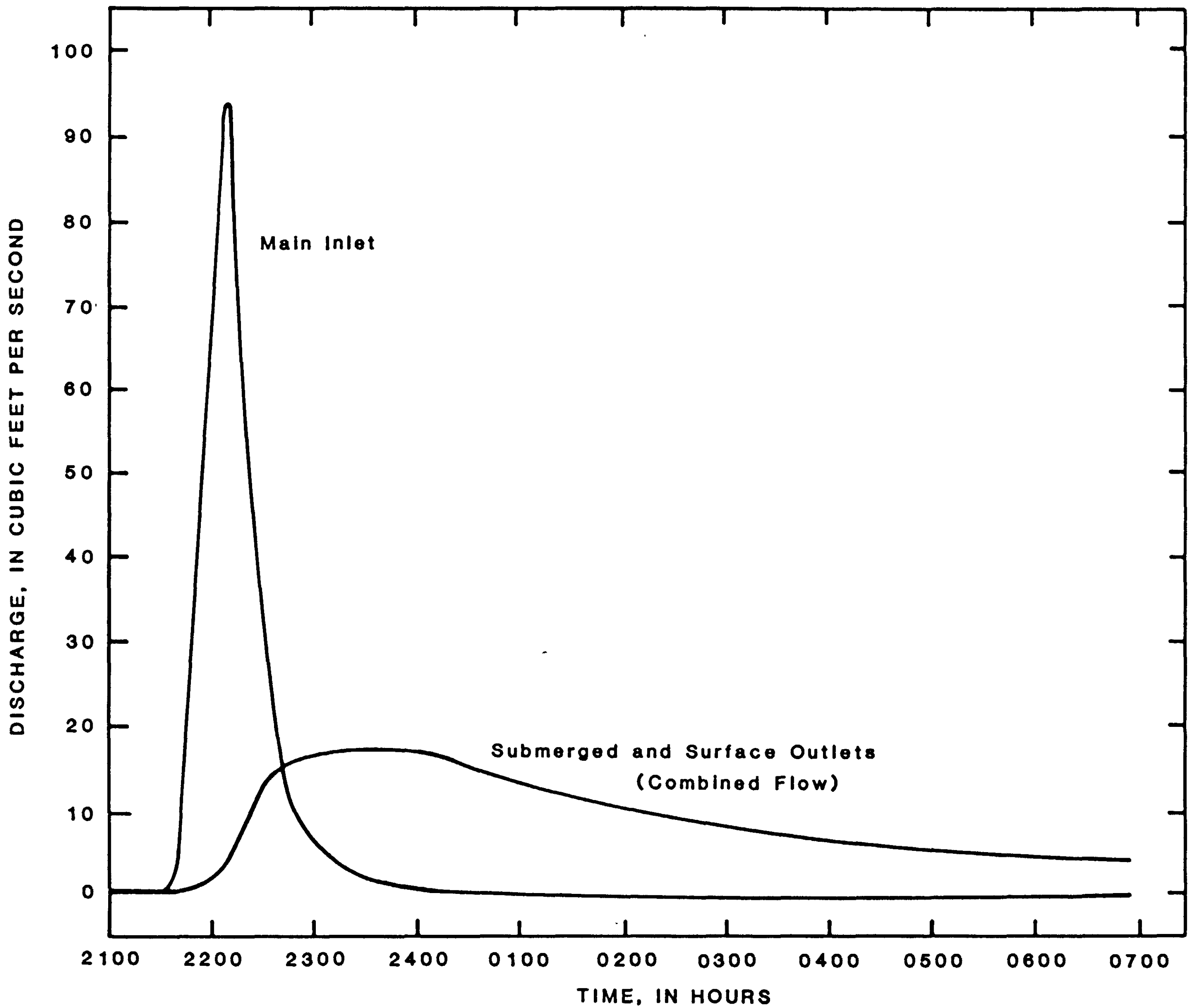

Figure 2.--Water discharges following rainfall at Main Inlet and Submerged and Surface Outlets, July 25-26, 1981.

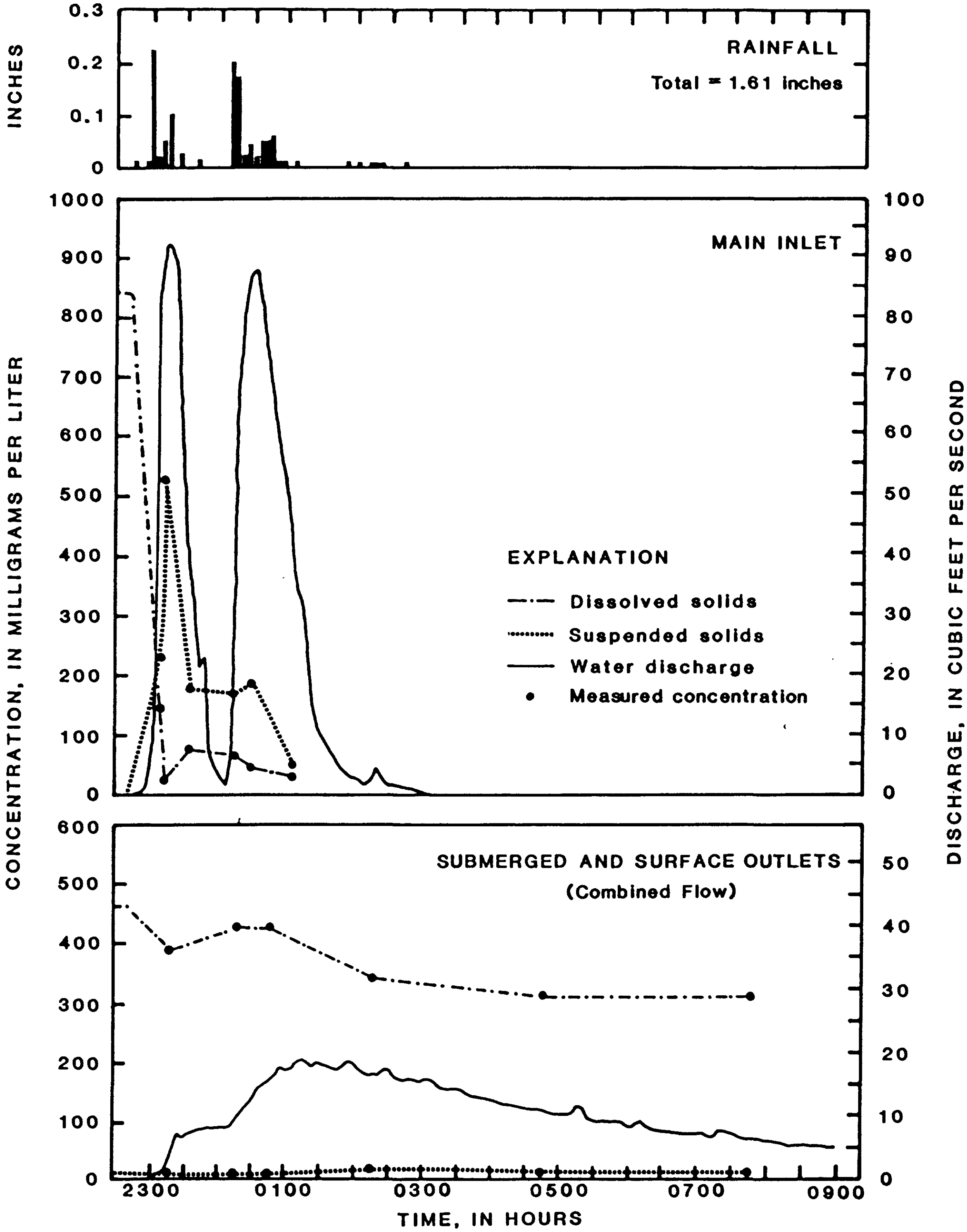

Figure 3.--Rainfall, water discharge, and suspended-sediment and dissolved-solids concentrations versus time, July 20-21, 1980, at Lake Ellyn.

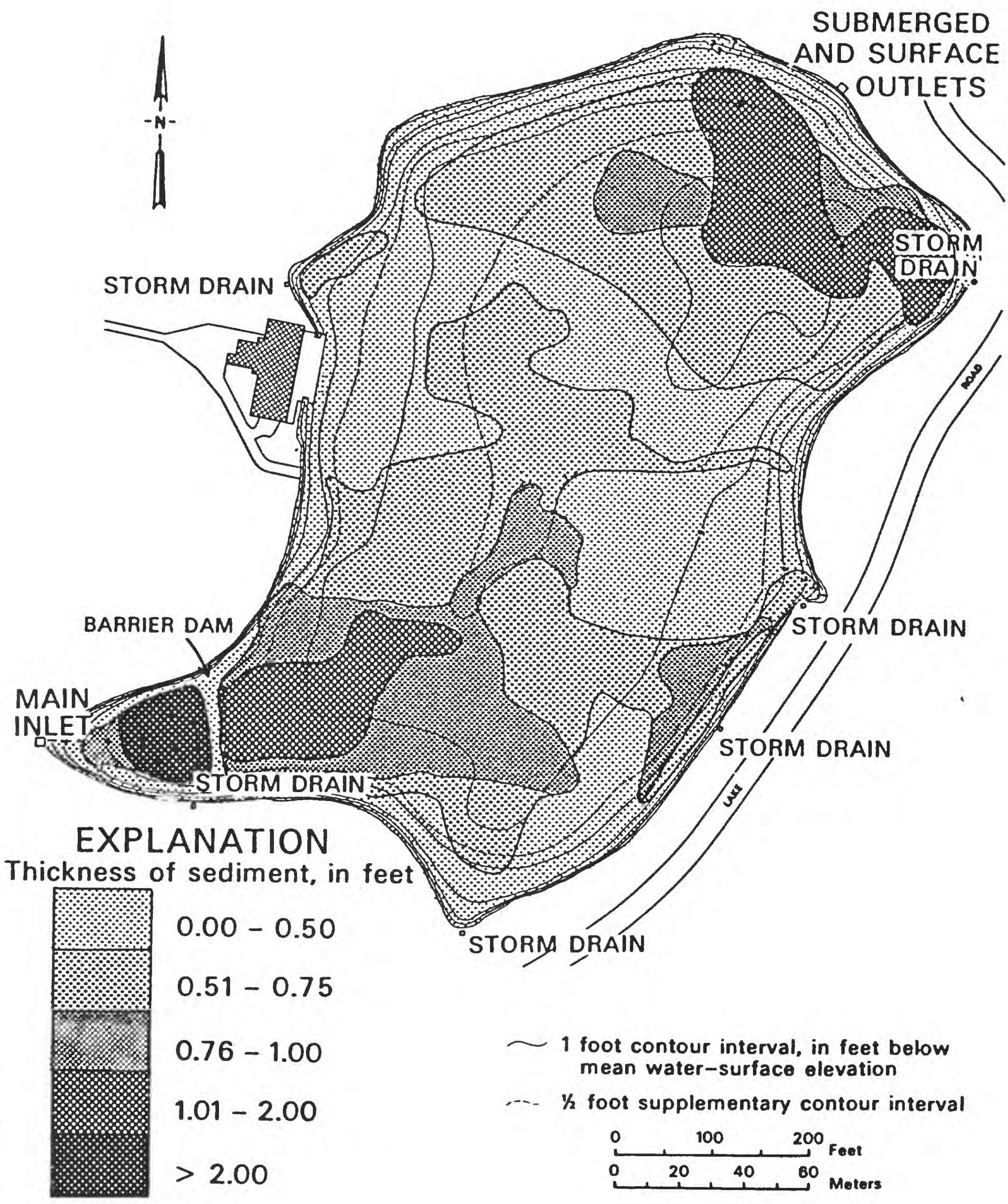

Figure 4.--Thickness of bottom sediments accumulated in Lake Ellyn from 1970 to 1980.

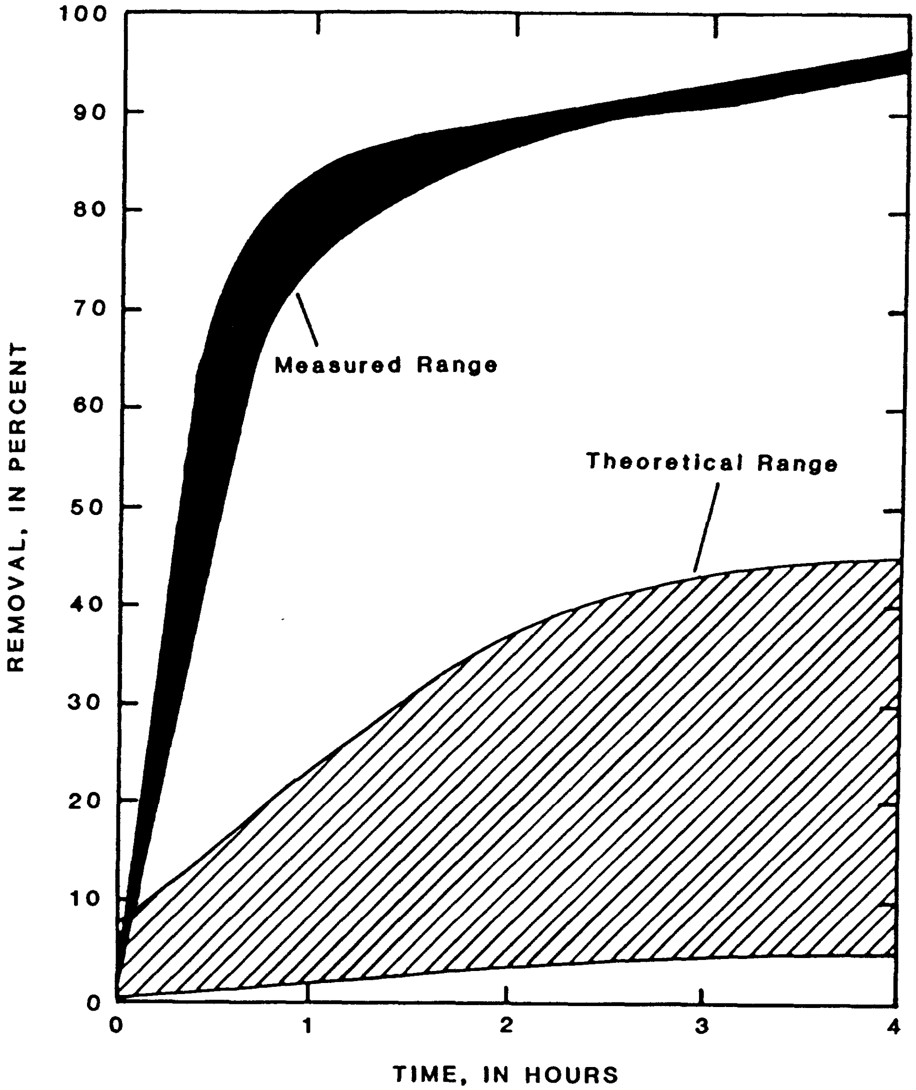

Figure 5.--Ranges of measured and theoretical rates of settling for suspended solids in samples of runoff collected at Main Inlet.

Table 3.--Particle-size distribution of Lake Ellyn bottom-sediment samples, in percent by weight

[Modified from Cowan, 1982]

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

Chemical

Ranges in concentrations for 18 dissolved and suspended constituents measured in discrete and composite samples collected at Main Inlet and at the lake outlets from February 1980 to August 1981 are listed in table 4. Inlet concentrations show high variability when compared to outlet concentrations. Factors which contributed to concentration variability included discharge, season, chemical use in the watershed, antecedent rainfall conditions, and rainfall intensity (Hey and Schaefer, 1983).

Mean concentrations of copper, lead, and zinc associated with lake sediments and with road dirt and street sweepings collected from within the watershed are listed in table 5. Lead concentrations in lake sediments were similar to those found with particles accumulated on road surfaces in high and medium traffic areas. Copper concentrations were greater and zinc concentrations were less by similar comparison. Mean concentrations of copper, lead, and zinc reported in a 1979 survey of the chemical characteristics of sediments from 63 Illinois lakes (Kelly and Hite, 1981) are lower than concentrations in Lake Ellyn sediments for all three metals (table 6). Maximum concentrations of copper and lead in Lake Ellyn sediments were greater than maximum concentrations reported from the survey, with maximum lead concentrations from Lake Ellyn sediments being 20 times greater than the maximum survey concentration and mean lead concentrations from Lake Ellyn being 4.5 times greater than the maximum survey concentration.

Bottom-sediment samples and composite storm-runoff samples collected at Main Inlet and at the lake outlets on May 29, 1981, were analyzed by a USEPA contract laboratory for the 129 USEPA priority pollutants. Organic compounds identified by this analysis are listed in table 7. Of the 17 organic compounds identified, 9 were found in the Main Inlet sample and 13 were found in the bottom-sediment sample, but only 2 were detected in the outlet sample. Most

Table 4.--Ranges of constituent concentrations measured in discrete and composite samples collected at Main Inlet and at the lake outlets, February 1980 to August 1981

[Concentration in milligrams per liter]

Constituent	Main Inlet	Lake outlets
Dissolved solids	17 -1,290	261 -1,480
Suspended solids	0 -3,070	0 - 276
Calcium	4.5 - 130	23 - 90
Chloride	4.3 - 700	55 - 650
Magnesium	1.3 - 59	13 - 39
Sodium	2.5 - 460	23 - 380
Copper, dissolved	0 - .120	0 - .008
Copper, total	.002- .210	.001- .023
Iron, dissolved	0 - 15	0 - .190
Iron, total	.310- 55	.16 - 7.5
Lead, dissolved	0 - .037	0 - .008
Lead, total	.002- 1.60	0 - .042
Zinc, dissolved	.004- .260	0 - .070
Zinc, total	.010- .950	.010- .320
Nitrogen, dissolved	.27 - 5.7	.22 - 3.3
Nitrogen, total	.27 - 26	.38 - 5.3
Phosphorus, dissolved	.01 - .32	ND - .30
Phosphorus, total	.03 - 2	.02 - .95

ND = None detected.

Table 5.--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]

Constituent	Lake Ellyn bottom sediments Size fraction Silt + clay (<63 µm)	Lake Ellyn bottom sediments Size fraction Total	Road dirt High-traffic areas Size fraction Silt + clay (<63 µm)	Road dirt High-traffic areas Size fraction Total	Road dirt Medium-traffic areas Size fraction Silt + clay (<63 µm)	Road dirt Medium-traffic areas Size fraction Total	Road dirt Low-traffic areas Size fraction Silt + clay (<63 µm)	Road dirt Low-traffic areas Size fraction Total	Street sweepings Size fraction Silt + clay (<63 µm)	Street sweepings Size fraction 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

Table 6.--Concentrations of copper, lead, and zinc in bottom sediments from 63 Illinois lakes and Lake Ellyn

[Modified from Kelly and Hite, 1981; Hey and Schaefer, 1983]

	Concentrations, in milligrams per kilogram dry weight					
	63 Illinois lakes			Lake Ellyn		
	Mean ± 1 standard deviation	Minimum	Maximum	Mean	Minimum	Maximum
Copper	42 ± 56	3	560	250	73	790
Lead	57 ± 43	3	250	1,590	410	5,100
Zinc	113 ± 66	11	750	210	3	500

Table 7.--Concentration of organic compounds in Lake Ellyn inflow, outflow, and bottom sediments, May 29, 1981

[Modified from Hey and Schaefer, 1983]

Chemical characteristic	Concentration[1] Inflow (Micrograms per liter)	Concentration[1] Outflow (Micrograms per liter)	Concentration[1] Bottom sediment (Micrograms per kilogram dry weight)
Acenapthene	ND	ND	540
Anthracene	5	2	1,300
Benzo (a) anthracene	ND	ND	3,800
Dibenzo (a, h) anthracene	ND	ND	4,200
Benzene	D	ND	ND
Chrysene	4.5	ND	3,400
Fluoranthene	11.5	ND	3,700
Benzo (k) fluoranthene	ND	ND	14,000
Fluorene	ND	ND	580
Bis (2-ethylhexyl phthalate)	ND	ND	690
Phenathrene	5	2	2,800
Pyrene	9.5	ND	3,000
Benzo (a) pyrene	ND	ND	12,000
Ideno (1, 2, 3-cd) pyrene	ND	ND	15,000
Dichloromethane	D	ND	ND
Tetrachloroethene	D	ND	ND
Toluene	D	ND	ND

[1]D = Detected, but not quantified.
ND = Not detected.

organic compounds are probably associated with fine solids in runoff that are deposited in the lake. Soluble organic compounds that are present in the inflow but not in the outflow may be diluted to below analytically detectable concentrations, may volatilize, or may enter into chemical reactions while in the lake. Organic analysis of composite storm-runoff samples collected on May 17, 1980, detected DDD, DDE, DDT, dieldrin, phenols, 2,4,5-TP, and 2-4D in the outflow. These compounds were not detected in 1981.

Chloride, sodium, calcium, and magnesium concentration graphs (fig. 6) for outflow from Lake Ellyn show a seasonal cycle with a peak in late winter and a trough in September or October. Peaks in chloride and sodium in figure 6 can be attributed to application of deicing salt in the watershed. The calcium and magnesium peaks may also be attributed to deicing salts. Calcium chloride is commonly added to deicing salt to promote melting at low temperatures, and calcium and magnesium carbonates are added as anti-caking agents. In addition, longer lake-water residence times during winter and potentially higher carbon dioxide partial pressures under ice cover may both contribute to dissolution of calcium and magnesium from lake sediments (Stumm and Morgan, 1981). Seasonal low in-lake concentrations of chloride, sodium, calcium, and magnesium are less than concentrations found in inlet low-flow samples, indicating dilution of lake water by storm runoff. This suggests that winter inputs of these constituents are flushed during spring and summer, and are not causing chemical-concentration buildup in lake water. Concentration buildup of deicing salt chemicals has been observed to cause chemical stratification in other lakes in urban areas (Judd, 1970; Free and Mulamouttil, 1983). Dissolved copper, lead, and zinc do not exhibit seasonal concentration cycles at Lake Ellyn.

Biological

The deposition of solids in Lake Ellyn results in an organic-rich mud bottom that provides unsuitable substrate for many rooted plants and benthic invertebrates (Fassett, 1940; Pennak, 1953). No rooted submergent plants are present in Lake Ellyn. Three taxa of benthic macroinvertebrates (*Chaoborus*, Chironomidae, and Tubificidae) have been identified in Ekman dredge samples collected from three locations in Lake Ellyn (fig. 7). Numbers of organisms per square meter of substrate are listed in table 8. All have special adaptations for surviving in soft sediments and are tolerant of anoxic conditions (Hill and Hullinger, 1981).

Single-census electroshocking by the Illinois Department of Conservation indicated that six species of fish are present in Lake Ellyn (table 9). Of these, only green sunfish and goldfish were observed to have reproductively-active populations. Attempts to stock bluegill and largemouth bass have been unsuccessful. Although the stocked fish survive, they do not reproduce (Hey and Schaefer, 1983). Green sunfish and goldfish spawn in shallows where there has been bank reinforcement and where emergent rooted plants are present. Largemouth bass and bluegills require coarse sediments in deeper waters for nest building and spawning (Pflieger, 1975). No such substrate is present in the limnetic zone of Lake Ellyn (Cowan, 1982).

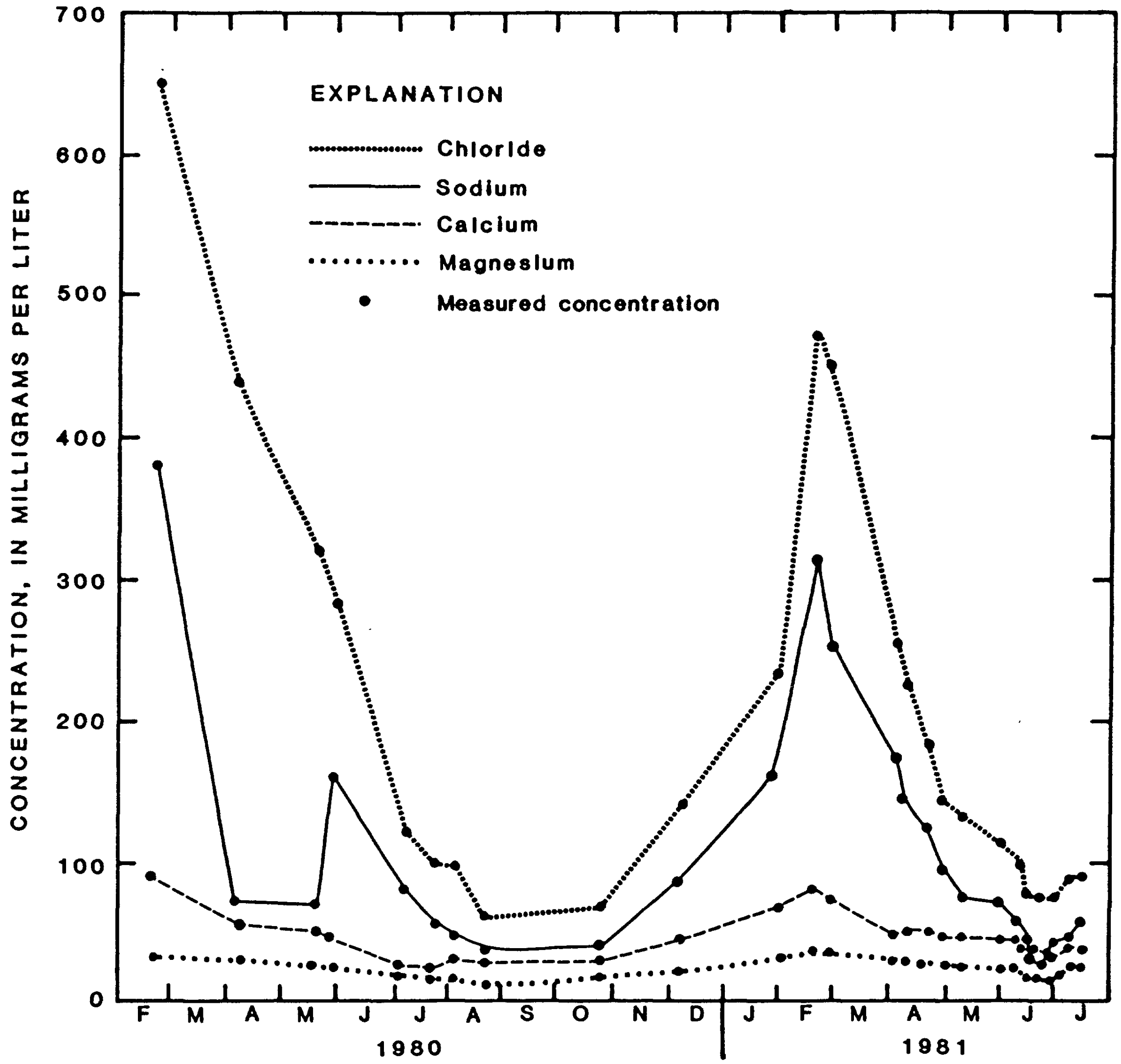

Figure 6.--Concentrations of chloride, sodium, calcium, and magnesium in outflow from Lake Ellyn, 1980-81.

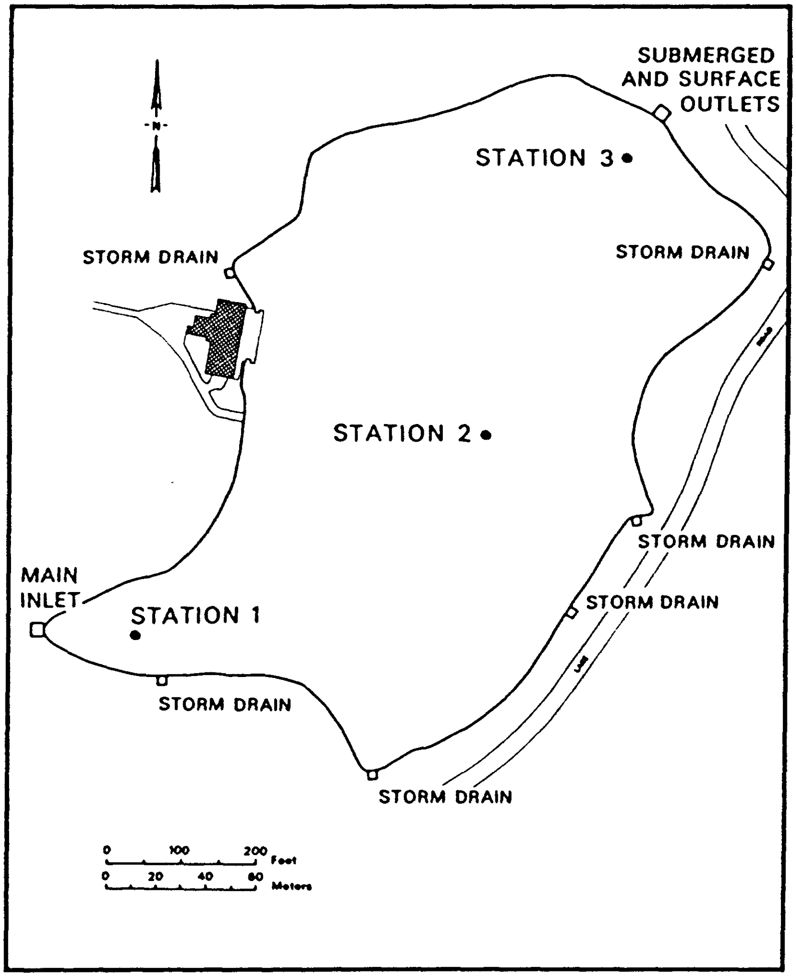

Figure 7.--Macroinvertebrate sampling locations
at Lake Ellyn.

Table 8.--Benthic macroinvertebrates in Lake Ellyn (individuals per square meter of substrate)

[Modified from Hill and Hullinger, 1981]

Date of sample	Chaoborus			Chironomidae			Tubificidae		
	Station			Station			Station		
	1	2	3	1	2	3	1	2	3
Oct. 18, 1979	220	2,670	1,938	431	144	0	72	14	0
Dec. 17, 1979	1,033	1,808	603	1,435	1,119	2,196	144	172	14
Mar. 25, 1980	172	1,593	1,507	287	2,024	3,933	115	603	14
May 28, 1980	86	660	703	57	14	43	345	230	43
July 29, 1980	517	3,818	1,751	14	0	0	86	129	14

Table 9.--Results of 30-minute electrofishing survey of Lake Ellyn, June 10, 1980

[Illinois Department of Conservation, written commun., 1980]

Fish species	Number of fish	Length, in millimeters	Comments
Sunfish family (Centrarchidae)			
Largemouth bass (*Micropterus salmoides*)	4	330-368	From previous stocking
Bluegill (*Lepomis macrochirus*)	17	114-165	From previous stocking
Green sunfish (*Lepomis cyanellus*)	32	51-127	Successfully reproducing
Minnow family (Cyprinidae)			
Goldfish (*Carassius auratus*)	32	140-241	Successfully reproducing, many lesions on fins and body
Carp (*Cyprinus carpio*)	1	584	
Catfish family (Ictaluridae)			
Black bullhead (*Ictalurus melas*)	1	241	

Occasional algal blooms occur in Lake Ellyn. Phytoplankton counts from a lake water sample collected in July 1980, showed Anabaena flos-aquae densities in excess of 600,000 cells per milliliter. However, relatively few blooms occur, even with high nutrient concentrations. This may possibly be attributed to short lake-water residence times during the summer that prohibit extensive algal production, and to suspended particles in the water that inhibit light penetration and photosynthesis below the first few inches of the water surface.

SUMMARY

Detention of urban runoff in Lake Ellyn has resulted in the accumulation of fine-grained organic rich sediments on the lake bottom. These sediments have high concentrations of metals when compared to other Illinois lakes and accumulate some organic compounds.

Chloride and sodium concentrations in lake water exhibit seasonal cycles that have concentration peaks that correspond to periods of deicing salt application in the watershed. Calcium and magnesium concentrations have similar, less exaggerated cycles. Concentrations of dissolved metals do not cycle seasonally.

Benthic macroinvertebrate populations are limited to three taxa that tolerate soft sediments and anoxic conditions. Sport fishes that have been stocked in the lake have not reproduced. Algal blooms occur infrequently even though nutrient concentrations are high. Algal production is possibly limited by short lake water residence times and low light penetration.

REFERENCES

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 p.

Buchanan, T. J., and Somers, W. P., 1968, Stage measurement at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A7, 28 p.

----- 1969, Discharge measurements at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A8, 65 p.

Cowan, E. A., 1982, Deposition of bottom sediment in Lake Ellyn, Glen Ellyn, Illinois: De Kalb, Ill., Department of Geology, Northern Illinois University, unpublished Masters thesis, 109 p.

Fassett, N. C., 1940, A manual of aquatic plants: Madison, Wisconsin, University of Wisconsin Press, 405 p.

Free, B. F., and Mulamouttil, G. G., 1983, The limnology of Lake Wabukayne, a stormwater impoundment: Water Resources Bulletin, v. 19, no. 5, p. 821-827.

Goerlitz, D. F., and Brown, Eugene, 1972, Methods of analysis of organic substances in water: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A3, 40 p.

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 p.

Heaney, J. P., and Huber, W. L., 1979, Urban rainfall-runoff quality data base--Update with statistical analysis: U.S. Environmental Protection Agency, EPA 600/8-79-004, 241 p.

Hey, D. L., and Schaefer, G. C., 1983, An evaluation of the water quality effects of detention storage and source control: Chicago, Northeastern Illinois Planning Commission, 285 p.

Hill, T. E., and Hullinger, D. L., 1981, Physical, chemical, and biological characteristics of the sediments from the Lake Ellyn study area: Illinois Department of Energy and Natural Resources, State Water Survey, Contract Report 287, 28 p.

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 p.

Judd, J. H., 1970, Lake Stratification caused by runoff from street deicing: Water Research, v. 4, p. 521-532.

Kelly, M. H., and Hite, R. L., 1981, Chemical analysis of surficial sediments from 63 Illinois lakes, summer, 1979: Illinois Environmental Protection Agency, Division of Water Pollution Control, 92 p.

Moss, Brian, 1980, Ecology of freshwaters: London, Blackwell Scientific Publications, 332 p.

Pennak, R. W., 1953, Freshwater invertebrates of the United States: New York, The Ronald Press Company, 769 p.

Pflieger, W. L., 1975, The fishes of Missouri: Missouri Department of Conservation, 343 p.

Skougstad, M. W., Fishman, M. J., Friedman, L. C., Erdman, D. E., and Duncan, S. S., 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 p.

Striegl, R. G., 1984, Effects of an urban lake on stormwater runoff and quality, in Blake-Coleman, W., ed., Proceedings of a conference on urban effects on water quality, Urbana, Illinois, October 20-21, 1983: Illinois Department of Energy and Natural Resources, Document No. 84/06, p. 74-83.

Stumm, Werner, and Morgan, J. J., 1981, Aquatic chemistry: New York, John Wiley and Sons, 780 p.