State Water Survey Division
SURFACE WATER SECTION
AT THE
UNIVERSITY OF ILLINOIS

Illinois Department of
Energy and Natural Resources

SWS Contract Report 309

SEDIMENT AND HYDROLOGIC BUDGETS FOR THE LAKE OF THE WOODS WATERSHED, CHAMPAIGN COUNTY, ILLINOIS

by

Paul Makowski, P.E., Assistant Hydrologist
and
Ming T. Lee, Ph.D., P.E., Engineer

Prepared for the
Illinois Environmental Protection Agency

Champaign, Illinois
February 1983

CONTENTS

SEDIMENT AND HYDROLOGIC BUDGETS FOR
THE LAKE OF THE WOODS WATERSHED,
CHAMPAIGN COUNTY, ILLINOIS

by

Paul Makowski
and
Ming T. Lee

INTRODUCTION

The Illinois State Water Survey has determined hydrologic and sediment budgets for Lake of the Woods, a recreational facility owned by the Champaign County Forest Preserve District.

Field data were collected from May through September 1981 by Water Survey personnel with the assistance of employees from the Forest Preserve District.

This report summarizes the results of the study.

Acknowledgments

The work described was performed by the authors as part of their regular duties at the Illinois State Water Survey. The project was conducted under the administrative guidance of Michael L. Terstriep, Head of the Surface Water Section, and Stanley A. Changnon, Jr., Chief of the State Water Survey.

„ The field data collection was conducted by the personnel of the Champaign County Forest Preserve District, under the direction of Ronald Pennock, Executive Director. Ron Lowery, a Champaign County Soil Conservationist, Soil Conservation Service, provided technical information for the soil loss assessment. Professor Kent Mitchell of the Department of Agricultural Engineering, University of Illinois, provided the rainfall-runoff data for Allerton farm watersheds. Many Water Survey employees helped in the preparation of this report. Douglas Jones and William Fitzpatrick helped to install rain gages and staff gages. William Bogner conducted the lake sedimentation survey. John Brother, Linda Riggin, and William Motherway prepared the illustrations. Lynn Weiss, Kathleen Brown and Pam Lovett typed the manuscript. Krishan P. Singh reviewed the manuscript and made numerous suggestions.

The work presented herein was supported by the Illinois Environmental Protection Agency under the Clean Lake Program, Section 304 of PL 92-500. The authors express their thanks to the sponsors.

DESCRIPTION OF THE STUDY AREA

Lake of the Woods is a small impoundment on an intermittent stream about 1300 feet upstream from the Sangamon River. The dam is situated in Champaign County, about 1 mile east of the village of Mahomet, Illinois, in Sections 11 and 14, Township 20N., Range 7E. The dam lies at 40°-12' north latitude and 88°-23' west longitude.

The construction of Lake of the Woods in 1947 was a joint enterprise between the two adjacent landowners, Olen Parkhill and Don Keene. The landowners planned either to sell lakeshore lots or create a private resort along the banks of the 14.6 acre lake.

In 1948 the Champaign County Forest Preserve District purchased the property along with 300 acres of adjoining land. The District began a development program for the area and by 1950 had constructed Lake of the Woods Park, the first county park in Champaign County.

In 1949, the Champaign County Sportsman Club purchased 20 acres of land across the road from the head of the lake. In 1952 the District raised the water level of the lake by 5 feet by building up the dam and spillway, which increased the area of the lake to 25 acres. An additional increase in the spillway level was made in 1954 when a 1.5-foot flashboard was installed. This placed the spillway crest at its present elevation of 710.0 feet msl (above mean sea level).

In 1954, vandals used dynamite to destroy two 2-foot-square sluice gates in the spillway wall. Repairs were made in 1954-1955 by removing the gates and filling the sluice gates with concrete. Currently there are no operating devices associated with the project (US Army Corps of Engineers, 1980).

The structural integrity of the dam was endangered twice, once by wind wave action and once by burrowing animals. Prompt action by the District prevented any extensive damage.

The Lake of the Woods basin has been heavily developed since construction of the lake. Residential contruction has been the main type of development although much of the basin remains agricultural. A map of the watershed is shown in figure 1.

GEOLOGICAL AND SOIL DESCRIPTION OF THE DRAINAGE BASIN

Geological Description

The Lake of the Woods basin lies over the buried Mahomet Valley in its Bloomington Ridged Plain of the Till Plains Section of the Central Lowland Physiographic Province (Leighton et al., 1948). This valley system extends from the Indiana state line 120 miles westward to the Illinois River Valley. Most of the bedrock surface of the Mahomet Valley is made up of rocks of the Pennsylvanian age. Due to the proximity of the basin to the LaSalle anticlinal belt, rocks of Mississippian, Devonian, and Silurian age also form the bedrock surface. Glacial drift completely covers the

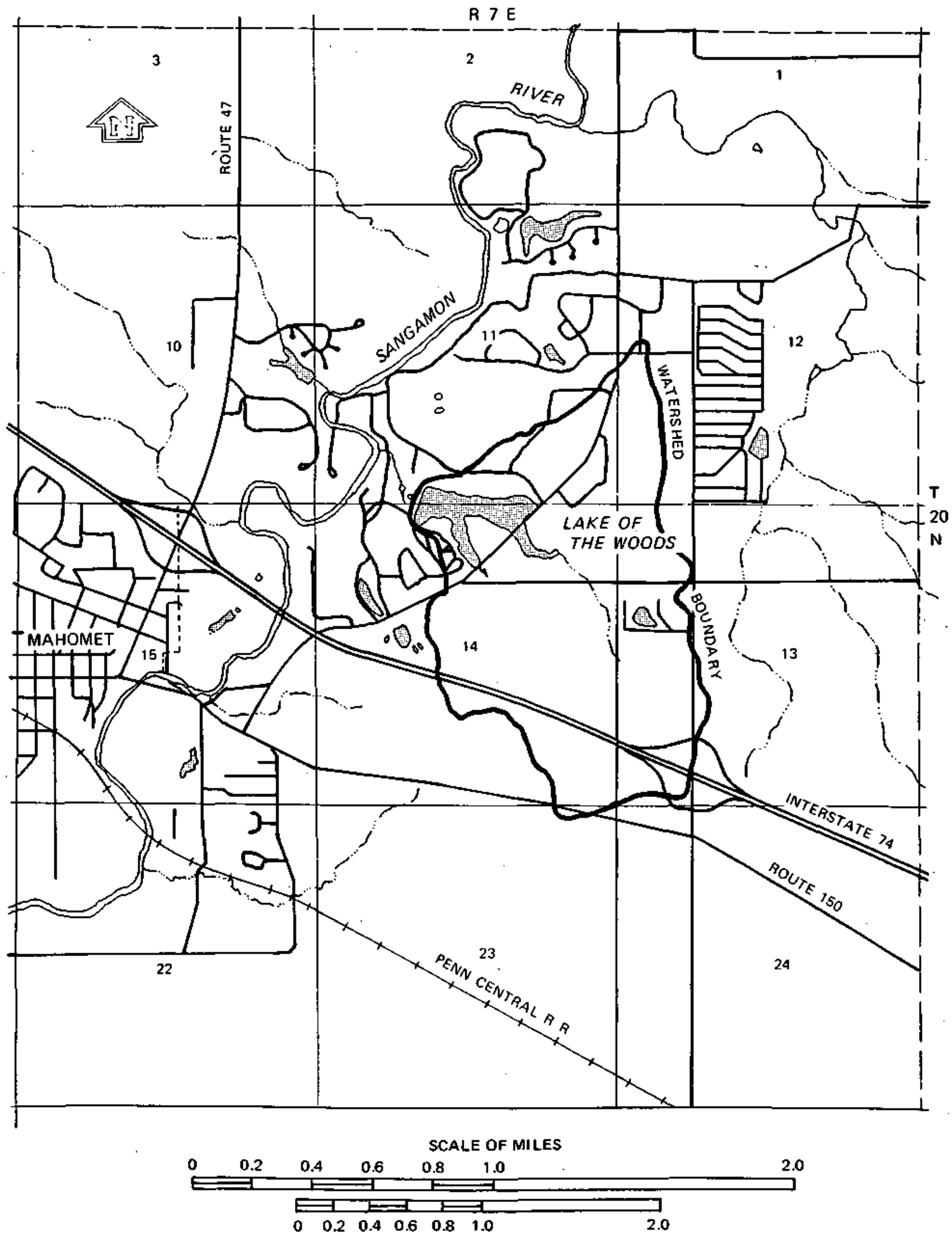

Figure 1. Location of Lake of the Woods watershed, Champaign County, Illinois

bedrock. The depth of the drift is approximately 350 feet in the Lake of the Woods basin.

The basin area underwent three major periods of glaciation. The first period of glaciation was the Kansan, the deposits of which occupy the deepest portion of the Mahomet Valley. The deposits of this period subdued the topography of the valley. The Kansan deposits consist of silty till underlain by thick beds of sand and gravel. The next period of glaciation was the Illinoian. The deposits from this period completely obliterated the Mahomet Valley. These deposits contain widespread lenses of sand and gravel intercalated in the glacial drift. The most recent period of glaciation was the Wisconsinan. These deposits are composed chiefly of till or fine sands except for local occurrences of sand and gravel. The Illinoian deposits, with a cover of Wisconsinan loess, form the bulk of the glacial materials of the basin.

Groundwater Hydrology

The land surface of the basin slopes towards the Sangamon River and the groundwater table roughly parallels the land surface (Visocky and Schicht, 1969). The water from the lake recharges the groundwater below the lake's surface. The significance of this groundwater recharge will be detailed in the section dealing with the hydrologic budget of the lake.

Topography

Large sections of the land surface have level or gently rolling topography interrupted by low broad morainic ridges (Visocky and Schicht, 1969). The majority of the ridges have gentle slopes so local relief is normally low. Within the drainage area of the basin, elevations range from a maximum of 790 feet msl to a lake elevation of 710 feet msl. The Sangamon River, which is located approximately 1300 feet downstream of the lake, has an average water surface elevation of 675 feet.

The average slope of the Lake of the Woods basin is appproximately 4 percent, which places the basin in the gently to moderately sloping category. Slope information was obtained from the soils map of the area as well as from a USGS contour map. The area within each slope range is presented in table 1.

Table 1. Ranges of Slopes in the Lake of the Woods Basin

Slope range (%)	Area (acres)	Percentage of basin area
0-2	158.0	26
2-4	216.4	36
4-7	184.4	30
7-12	14.8	2
Water	35.6	6
TOTALS	609.2	100

Soils

The principal soil type within the drainage area of the lake is silt loam. A detailed soils map is shown in figure 2 and may be used to ascertain the soil type and average slope of the area, and to estimate erosion conditions within the basin (Mount, 1982). The hydrologic group for each soil type is also shown in figure 2.

The soils map symbols consist of a number or combination of numbers and a letter. The initial number indicates the type of soil. A capital letter following the number indicates the class of slope. Symbols without

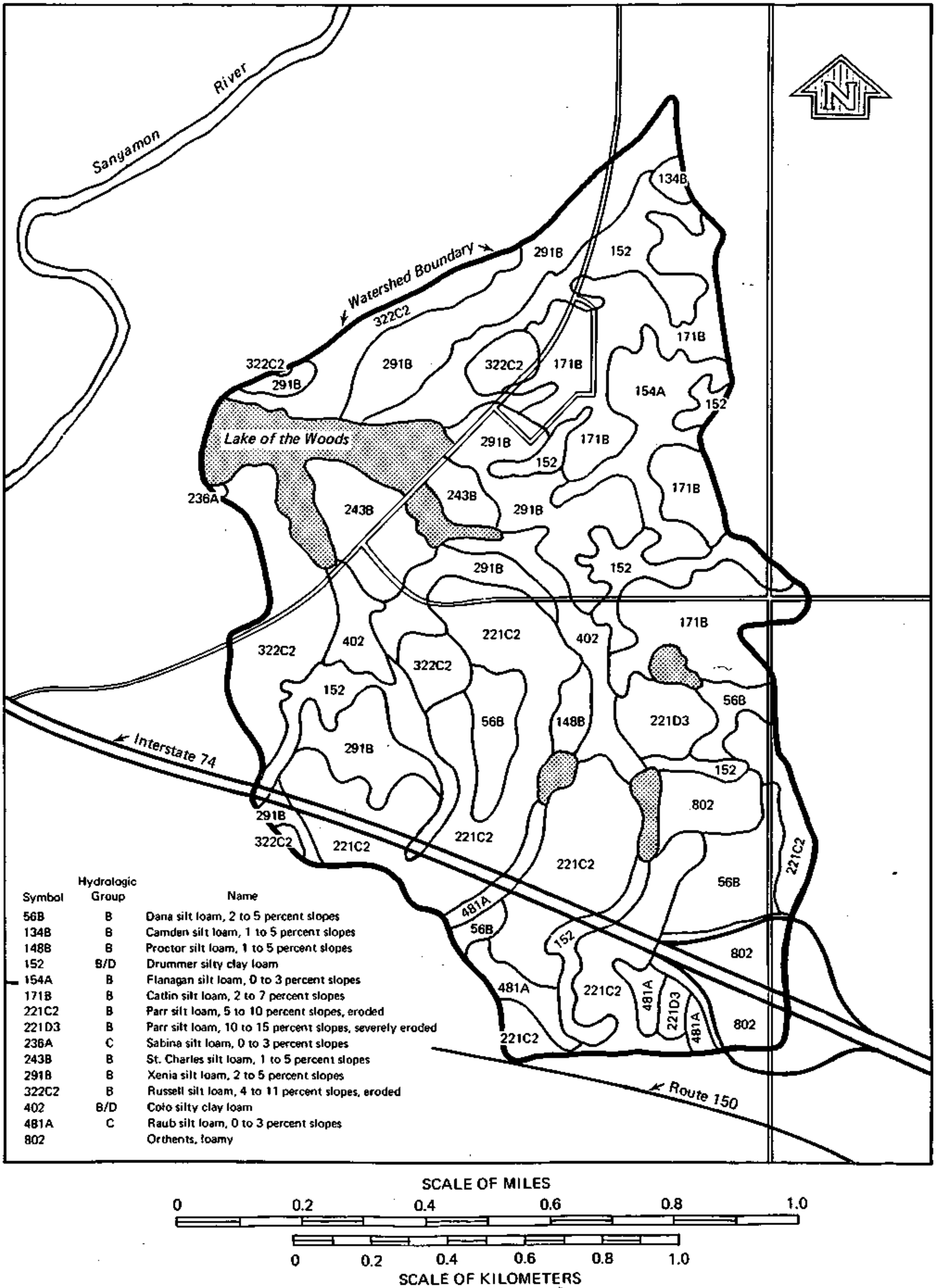

Figure 2. Soils map of Lake of the Woods watershed

a slope letter are for nearly level soils. The final number denotes the degree of erosion.

The slope symbols (capital letters) have the following definitions:

Slope symbol	Slope description	Slope range (%)
A	Nearly level	0-2
B	Gently sloping	2-4
C	Moderately sloping	4-7
D	Strongly sloping	7-12
E	Very strongly sloping	12-18
F	Steep	18-30

The erosion symbols (numbers) have the following definitions:

Erosion symbol	Erosion description	Inches of original soil surface remaining
None	None to slight	More than 7
2	Moderate	3 to 7
3	Severe	Less than 3, or plow layer is largely sub-surface material

The hydrologic soil group is a classification which indicates the runoff potential of a soil. The following descriptions apply to the hydrologic groups:

Hydrologic group symbol	Hydrologic group description
A	High infiltration rates
B	Moderate infiltration rates
C	Slow infiltration rates
D	Very slow infiltration rates

High infiltration rates signify a low runoff potential, and low infiltration rates signify a high runoff potential. The infiltration rate is the minimum rate of infiltration obtained for a bare soil after prolonged wetting. The influences of both the surface and the horizons of a soil are thereby considered (Mockus, 1972). The omission of a hydrologic group symbol indicates that the hydrologic group has not been determined. A dual hydrologic group symbol such as "B/C" indicates the drained/undrained situation.

SEDIMENT BUDGET

Introduction

As described in the previous section, the soils of the Lake of the Woods watershed are predominantly silt loam. The soils in the watershed recently were mapped by the USDA (Mount, 1982). The soils map of the watershed is shown in figure 2. The major soil types and their acreages are tabulated in table 2. The soil type with the largest acreage in the watershed is Parr silt loam (4-7 percent slope) which covers about 126 acres or 20.7 percent of the watershed. The second major soil is Xenia silt loam (2-4 percent slope) covering about 13.8 percent of the watershed area. The flat slope soils are mostly Drummer and Flanagan.

Table 2. Lake of the Woods Watershed Soil Types

Soil type		Acreage	Percent of total acreage
56B	Dana silt loam	34.4	5.65
134B	Camden silt loam	2.0	0.33
148B	Proctor silt loam	3.2	0.52
152	Drummer silt clay loam	68.8	11.29
154A	Flannagan silt loam	21.2	3.48
171B	Catlin silt loam	70.0	11.49
221C2	Parr silt loam	126.0	20.68
221D3	Parr silt loam	14.8	2.43
236A	Sabina silt loam	0.4	0.07
243B	St. Charles silt loam	22.4	3.68
291B	Xenia silt loam	84.4	13.85
322C2	Russell silt loam	58.4	9.59
402	Colo silty clay loam	21.6	3.54
481A	Raub silt loam	15.2	2.50
802	Orthents loamy	30.8	5.06
	Water	35.6	5.84
	Totals	609.2	100.00

Soil Loss Assessment

A field reconnaissance in the watershed indicated that the major land disturbance activities seem to occur in the cropland (cultivated agricultural land). Therefore, a decision was made to perform a detailed soil loss computation on the cropland. For the other land use categories, only an estimated soil loss rate was assigned to each land use category.

For the estimation of the cropland soil loss rate, the boundaries of the soil types in the cropland were delineated and measured from a land use map as shown in figure 3. Table 3 shows the soil types and acreages of the cropland. The Universal Soil Loss Equation, USLE (Wischmeier and Smith, 1978) was used as a tool to compute the soil loss rates. A brief description of the USLE is as follows:

$$A = RKSLCP$$

where A is the average annual soil loss rate in tons per acre per year, R is the rainfall factor, K is the soil erodibility factor, S is the steepness factor, L is the slope-length factor, C is the cropping factor, and P is the conservation practice factor. A more detailed description of the USLE can be found elsewhere (Wischmeier and Smith, 1978; Walker and Pope, 1979; Peterson and Swan, 1979).

The rainfall factor in Champaign County is assigned as 180. The soil erodibility factor of each soil type was obtained from soil description files which are available from the Soil Conservation Service, State Office at Champaign. The slope and slope-length factors were determined through a consultation with the Champaign County District conservationist. The cropping factor was assigned as 0.4 on all the cropland since the croplands are mostly in conventional tillage and corn-soybean rotation. The conser-

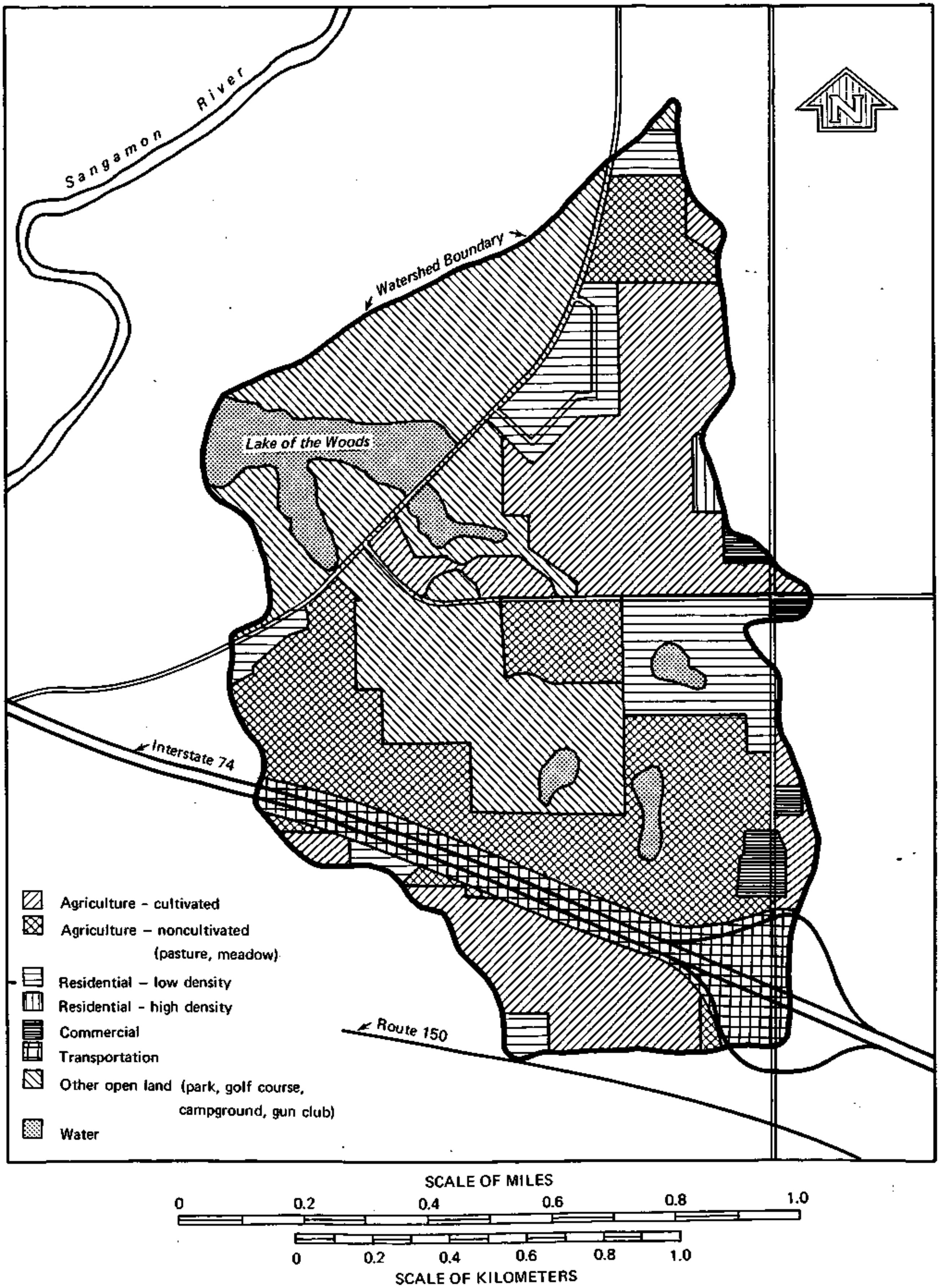

Figure 3. Land use map of Lake of the Woods watershed

Table 3. Soil Loss Assessment of Cropland in the Lake of the Woods Watershed Champaign County, Illinois

Sample no.	Soil type	Acreage	Soil erodibility K	Slope (%)	Slope length (ft)	Cropping factor C	Conser-vation practice P	Soil loss rate, A (tons/ac/yr)	Total amount of gross erosion (tons)
A	Drummer (152)	2.4	0.28	1.0	100	0.4	1.0	2.6	6.1
B	Catlin (172B)	9.6	0.32	2.5	200	0.4	1.0	6.7	64.5
C	Drummer (152)	2.0	0.28	0.5	50	0.4	1.0	1.0	2.0
D	Flanagan (154A)	20.0	0.28	1.0	200	0.4	1.0	3.1	62.7
E	Catlin (171B)	5.6	0.32	3.0	150	0.4	1.0	7.2	40.1
F	Drummer (152)	7.6	0.28	1.0	150	0.4	1.0	2.9	22.3
G	Catlin (171B)	4.8	0.32	2.0	100	0.4	1.0	5.6	26.9
H	Catlin (171B)	3.6	0.32	4.0	150	0.4	1.0	10.5	37.9
I	Drummer (152)	1.2	0.28	0.5	75	0.4	1.0	1.0	1.2
J	Xenia (291B)	15.2	0.37	3.0	175	0.4	1.0	8.8	133.9
K	Parr (221B)	0.8	0.32	2.0	50	0.4	1.0	3.6	2.7
L	Colo (402)	1.2	0.28	0.2	50	0.4	1.0	0.2	0.2
M	St. Charles (243B)	2.8	0.37	3.0	150	0.4	1.0	8.3	23.2
N	Xenia (291B)	5.2	0.37	3.0	100	0.4	1.0	7.3	37.7
O	Parr (221C2)	0.8	0.32	5.0	50	0.4	1.0	8.5	6.8
P	Parr (221C2)	0.8	0.32	1.0	50	0.4	1.0	2.2	1.8
Q	Parr (221C2)	2.8	0.32	2.0	75	0.4	1.0	4.0	11.3
R	Russell (322C2)	0.8	0.37	4.0	25	0.4	1.0	6.0	4.8
S	Xenia (291B)	1.2	0.37	2.0	50	0.4	1.0	4.1	5.0
T	Parr (221C2)	0.8	0.32	5.0	100	0.4	1.0	12.1	9.7
U	Raub (481A)	1.2	0.28	1.0	150	0.4	1.0	2.9	3.5
V	Dana ((56B)	2.8	0.32	3.0	125	0.4	1.0	7.2	20.1
W	Raub (481A)	6.4	0.28	1.0	100	0.4	1.0	2.5	16.3
X	Parr (221C2)	6.4	0.32	5.0	125	0.4	1.0	14.6	93.2
Y	Drummer (152)	4.8	0.28	0.5	150	0.4	1.0	2.0	9.4
Z	Parr (221C2)	14.4	0.32	4.0	100	0.4	1.0	9.0	129.0
AA	Parr (221C2)	4.8	0.32	5.0	100	0.4	1.0	11.9	57.0
AB	Raub (481A)	2.4	0.28	1.0	50	0.4	1.0	2.0	4.7
AC	Parr (221D3)	1.6	0.32	10.0	75	0.4	1.0	26.9	43.0
AD	Raub (481A)	7.6	0.28	2.0	50	0.4	1.0	3.1	23.8
	Totals	141.0							900.8

Avg. 6.39 tons/ac/yr

vation practice factor was assigned as 1.0 since there are no significant contouring and terracing practices in the watershed.

On the basis of the soil information compiled in the watershed, the soil loss rates of all the cropland were computed. The total amount of the soil loss for each soil type was obtained through the multiplication of soil loss rate and soil acreage. The results indicated that the total amount of soil loss from the cropland amounts to 900.8 tons per year. The average soil loss rate for the cropland would be 6.39 tons per acre per year. The detailed breakdowns for each soil type in the cropland are shown in table 3.

Table 4 shows the soil loss rate for the other land use categories. The non-cultivated agricultural lands are mostly pasture and meadow. Even though these lands have slopes of 4 to 7 percent, the lands are well covered. The soil loss rate for these lands was assigned as 1.0 tons per acre per year. In the residential area, a low density of 1.0 tons per acre per year and a high density of 1.5 tons per acre per year were assigned. It is worthwhile to note here that these soil loss rates may be too high for the present condition of surface covering. However, the soil loss assessment is addressed to the long-term average. The period of construction of residential developments may have exceeded this value in the past. For similar reasons, the soil loss rate for commercial areas was assigned as 1.0 tons per acre per year; for transportation- land it was 2.00 tons per acre per year; and for other open space land it was 1.50 tons per acre per year.

Table 4. Soil Loss in the Lake of the Woods Watershed
Champaign County, Illinois

Land use	Acreage	Average soil loss rate (tons/ac/yr)	Total gross erosion (tons/yr)
Agriculture - cultivated	141	6.39	900.8
Agriculture - non-cultivated	131	1.00	131.0
Residential - low density	63	1.00	63.0
Residential - high density	2	1.50	3.0
Commercial	13	1.00	13.0
Transportation	46	2.00	92.0
Other open space	173	1.50	259.5
Total	569*		1462.3

*This total acreage is different from the total acreage shown previously for soil types (table 2), due to map measurement differences.

On the basis of the results in table 4, the total amount of soil loss would amount to 1462.3 tons per year. The major sources of soil loss are cultivated agricultural land, pasture, and open space.

Sediment Deposition and Delivery Ratio

According to the sedimentation survey by the Illinois State Water Survey (Bogner, 1981), the annual sedimentation rate from the watershed was 1.45 tons per acre per year during the period 1948 to 1980. The trap efficiency of Lake of the Woods was estimated on the basis of Brune's curve (1953). Using the average annual runoff of 8.87 inches, the average inflow would amount to 457 ac-ft. Thus, the average capacity-inflow ratio is computed as 0.528. On the basis of Brune's curve, the trap efficiency of Lake of the Woods would amount to 97 percent.

The sediment delivery ratio is computed as the amounts of deposited sediments divided by the amount of soil loss from the watershed and the trap efficiency. Based on the information presented, the sediment delivery ratio of Lake of the Woods amounts to 63 percent.

HYDROLOGIC BUDGET

Introduction

A hydrologic budget is a bookkeeping procedure that consists of various components of inflow, outflow, and change of storage within the lake. These components are investigated to determine their relative importance in the hydrologic budget as well as their effect on the water surface elevation of the lake under different precipitation scenarios. These scenarios include: 1) a long-term average, 2) a drought, and 3) a period of field data collection. The methodology, the sources of data used in this study, and the results are presented.

Methodology

The hydrologic budget is based on a solution of the continuity equation: the inflow minus the outflow equals the change in storage. Whether the inflow or the outflow is greater will determine if the change in storage is a positive or negative quantity. As shown in figure 4, there are a number of components of inflow and outflow that are taken into account in the hydrologic budget.

Precipitation contributes the major part of the inflow, directly or indirectly. A portion of the precipitation that falls on the ground may be lost to interception, evapotranspiration, depression storage, and infiltration, which may be collectively referred to as "losses" for convenience. The portion of the precipitation which is not part of these losses enters the lake as runoff. Precipitation which falls on the lake will experience no such losses and, therefore, is a direct contribution to the inflow. Inflow may come from other sources such as direct pumpage into the lake and groundwater.

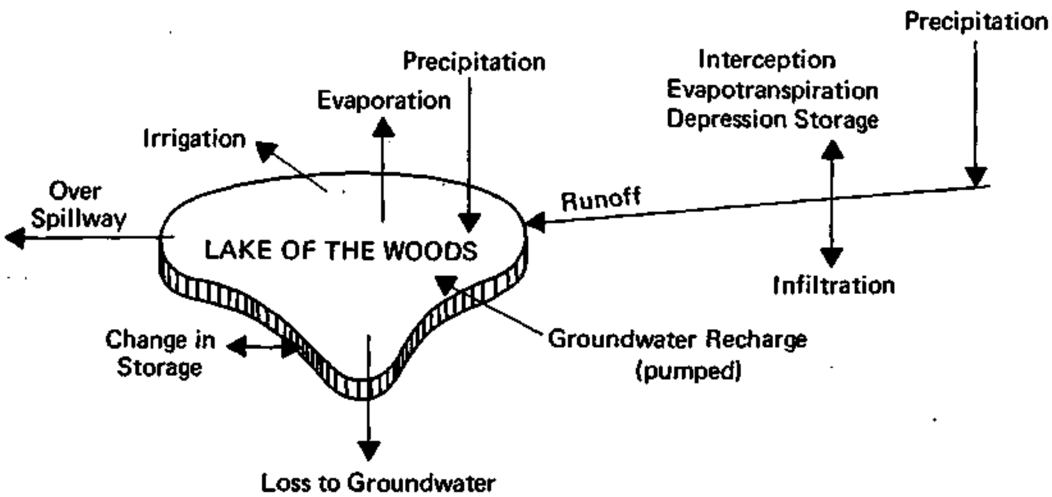

Figure 4. Schematic diagram of the lake water budget

Outflow in the hydrologic budget includes evaporation, irrigation, flow over the spillway, and losses mentioned previously. Groundwater may contribute to the inflow or the outflow.

The hydrologic budget for Lake of the Woods may be expressed in equation form as:

$$AS = G - P + D + R - L - E - I - Q$$

where

G = pumped groundwater into the lake

P = pumpage for irrigation

D = direct precipitation on the lake

R = precipitation on the watershed subject to losses

L = losses due to interception, depression storage, evapotranspiration, and infiltration

E = evaporation from the lake's surface

I = flow from the lake to groundwater

Q = flow over the spillway

AS = increase (+) or decrease (-) in the lake storage

A brief explanation of the components of the hydrologic budget follows.

During the summer months, groundwater is pumped into the beach area of* the lake to supplement the inflow. The pumped groundwater not only supplements the inflow but also exchanges the ambient lake water with cooler and less turbid groundwater. To provide this exchange the well is pumped even when the lake level is above the spillway. During certain periods when the irrigation system pumpage rates are noticeably drawing the lake down, this well is in operation 24 hours per day. In addition to supplying water for the lake, the well also supplies the bathhouse. The amount of water consumed at the bathhouse is deducted from the amount of flow pumped from the well and the result is the quantity that is pumped into the lake.

The golf course next to the lake is irrigated with the water from the lake. Irrigation of the golf course greens and tees began in 1950 and was extended to the fairways in 1969. The irrigation pumpage is not metered, so the quantity of this flow is not known. From estimates of the approximate length of time of pumpage and the pump capacities, the amount of flow drawn from the lake for irrigation may be estimated.

The automated irrigation system for the 18-hole and the par 3 golf courses consists of three turbine pumps located in two pump houses on the . north side of the lake. An 8-inch-diameter suction pipe draws water from a cistern-type reservoir built into the bank. A 6-inch-diameter pipe distributes the water to a maze of pipes which then convey the flow to sprinklers on the greens, tees, and fairways.

Precipitation on the lake differs from the precipitation on land in that precipitation which falls on the lake is not subject to any losses. Precipitation which falls on land is initially lost to interception and depression storage. Once these deficits are overcome water is then lost to infiltration and evapotranspiration. The evaporation component occurs only from the surface of the lake.

If the groundwater table is higher than the lake's surface, water would flow to the lake, and if the lake's surface is higher than the groundwater table, then the water would flow out of the' lake.

Flow over the spillway and storage are interdependent. The water level of the lake may be below the primary spillway elevation when the inflows exceed the outflows. A positive change in the storage indicates that the lake is filling and will continue until the spillway elevation is reached, when the excess inflow will leave the lake by discharging over the spillway.

Data Sources and Computations

The long-term average and drought conditions as well as a period of field collection are 'investigated. Each situation may have its own sources of data as well as a particular method of analysis. Each source of data is discussed with respect to its component of the hydrologic budget.

1. Long-Term Average (1949-1979)

a. Pumped groundwater into the lake. Information on the capacity of the pump as well as the number and type of fixtures in the bathhouse was furnished by Bob Carlier of the Champaign County Forest Preserve District. The calculated flow rate required for the bathhouse is 20 gpm (gallons per minute). The pump's capacity is 150 gpm and it runs for 8 hours 15 minutes per day. The actual flow rate of water into the lake is 130 gpm. The pump operates only during the recreational season. It was assumed to pump 10 days in May and September, and every day in June, July, and August. The flow rate obtained is an average for the entire month.

b. Pumpage for irrigation. Information was provided by Dick Noughton, the golf pro. There are three pumps: 20 HP (150 gpm), 40 HP (300 gpm), and 75 HP (550 gpm). The irrigation system is run by pressure loss, i.e., demand. The greater the demand, the greater the pressure loss, and the more pumps that will run. Since there are no meters or time schedule, the actual usage is unknown. The period of irrigation is assumed to be the second half of April (15 days) through the first half of October . (15 days) and daily for the months May, June, July, August, and September. The drier months require more irrigation. It was assumed that 300 gpm was used for the irrigation of the greens and tees and 550 gpm was used for the irrigation of the greens, tees, and fairways, which was to occur 25 percent of the time during the months of June, July, and August. The times of irrigation varied: 3 hours per day in April and October, 4 hours per day in May, 6 hours per day in June and September, and 8 hours per day in July and August.

c. Direct precipitation on the lake. The precipitation data were provided by the Department of Agricultural Engineering, University of Illinois (Kent Mitchell) and came from their Allerton farm watershed which is located in Monticello, Illinois. The data from two rain gages in this watershed were used. The data were averaged to provide an estimate of precipitation over the watershed. The precipitation was adjusted to better reflect the long-term average. From areal long-term average precipitation and the precipitation data provided by the Department of Agricultural Engineering, a multiplier was obtained for the yearly rainfall and was used to modify the monthly values.

d. Precipitation on the watershed subject to losses. The data were obtained from the same source as described in section 1c.

e. Losses due to interception, depression storage, evapotranspiration, and infiltration. There were no data for this component. Quantities were determined from the difference between precipitation over the watershed and runoff. Losses represent the percentage of precipitation not comprising runoff. This section will deal with runoff. Runoff is difficult to obtain through measurements in the Lake of the Woods watershed. The hydrologic budget was constructed on a monthly basis so that detailed measurement was not required. No long-term runoff data are available for Lake of the Woods, but long-term average flow rate data were available for other drainage areas in the vicinity of the lake. These data were obtained from the USGS and the University of Illinois, Department of Agricultural Engineering. Three drainage areas, both larger and smaller than the Lake of the Woods watershed, were used to develop a regression equation having discharge as the ordinate and drainage area as the abscissa. Through use of the drainage area for Lake of the Woods, an average monthly discharge could be found from the regression equation. A regression equation was developed for each of the twelve months of the year.

f. Evaporation from the lake's surface. An eleven-year average of monthly pan evaporation data for Urbana, Illinois, was obtained from the Climatology Section of the Illinois State Water Survey. Monthly pan to lake coefficients were used (Roberts and Stall, 1967) to estimate the evaporation from the lake. The volumes of precipitation and evaporation were calculated by using the average lake surface area, which was assumed to be constant even though there are minor fluctuations in the lake surface elevation. On the average, the effect of the change in the lake area on the precipitation and evaporation volumes will be rather small.

g. Flow to/from the lake from/to the groundwater. Available well records of the area were analyzed and it was determined that the groundwater follows the ground surface, which slopes to the Sangamon River. In the vicinity of the lake, the elevation of the groundwater table appears to be 706 feet (Sanderson and Zewde, 1976). The elevation of the surface of the lake is 710 feet. Therefore, there is a loss of water from the lake to the groundwater. Glacial drift underlies the lake and a coefficient of permeability was estimated to be 0.01 gallons per foot per day (provided by A. P. Visocky, State Water Survey, personal communication, 1982). Assuming the head to be the difference between the surface of the lake and the groundwater table, the loss rate to groundwater is in the order of 0.0032 cubic feet per second. This flow rate is assumed to be constant throughout the year.

h. Flow over the spillway. There were no data sources for this component, and computations are discussed in section 1i.

i. Increase or decrease in lake storage. There were no data sources for this component. As previously mentioned, this component is related to flow over the spillway and both components are the solution to the hydrologic budget equation. Any storage in the lake above the spillway occurs only during a runoff event. After precipitation ceases, the stage of the lake falls until inflow equals outflow. On a monthly basis the storage component above the spillway does not vary. During this time there is outflow over the spillway and there is no storage. If the water level drops below the spillway there is a decrease in storage while outflow equals zero. When the water level starts to increase so does the storage. This continues until the water level reaches the spillway elevation, when there is no more storage available and outflow over the spillway occurs.

2. Drought Conditions (October 1952-September 1955)

a. Pumped groundwater into the lake. The time of pumpage was assumed to be twice that used in the long-term average so that the amount of water entering the lake doubles. This additional pumpage is required to compensate for the lack of runoff.

b. Pumpage for irrigation. The pumpage was assumed to remain the same as in the long-term average, discussed in section 1b.

c. Direct precipitation on the lake. The data were obtained from the same source as mentioned in section 1c. The data were obtained from the average of two rain gages on the Allerton farm watershed for the 36 months of the drought.

d. Precipitation on the watershed subject to losses. The data source and computations are identical to those mentioned in section 1c.

e. Losses due to interception, depression storage, evapotranspiration, and filtration. There were no data for this component. Quantities were determined from the difference between precipitation over the watershed and runoff. This section will deal with runoff. The runoff data for the drought conditions could not be analyzed with the same method as the long-term data because of the variability of the base flows. Therefore, data were obtained from the Department of Agricultural Engineering, University of Illinois (Prof. Kent Mitchell, personal communication, 1981). The Allerton farm watershed, with a drainage area of 390 acres, was selected. The runoff data were expressed in inches so that they could be applied to the Lake of the Woods watershed.

f. Evaporation from the lake's surface. Lake evaporation was obtained for Urbana, Illinois, for October 1952 through September 1955 (Roberts and Stall, 1967).

g. Flow to/from the lake from/to groundwater. The data sources and calculations remained as in section 1g.

h. Flow over the spillway. There were no data sources for this component, and computations are discussed in section 2i.

i. Increase or decrease in lake storage. There were no data sources for this component. This component of the hydrologic budget as well as flow over the spillway were obtained as a solution to the hydrologic budget equation.

3. Period of Actual Data Collection (May 1981 through September 1981)

a. Pumped groundwater into the lake. Information was furnished by Bob Carlier of the Champaign County Forest Preserve District. The actual number of days of pumpage were obtained as were the number of days when precipitation occurred. When it is raining, it is assumed that the bathhouse is not in use so 150 gallons per minute enters the lake. Days of pumpage were 9 in May, 30 in June, 31 in July, 26 in August, and 3 in September.

b. Pumpage for irrigation. Data were obtained from Dick Noughton. The fairways were irrigated 3 times, twice in June and once in July. No irrigation occurred during rain days. Days of irrigation were 25 in May, 19 in June, 22 in July, 24 in August, and 28 in September. The duration of irrigation per day was 4 hours in May; 6 hours in June, August, and September; and 8 hours in July.

c. Direct precipitation on the lake. The data came as a result of the placement by the Illinois State Water Survey of a rain gage in the lake's watershed.

d. Precipitation on the watershed subject to losses. These data were obtained from the same source as noted in section 3c.

e. Losses due to interception, depression storage, evapotranspiration, and infiltration. There were no data for this component. Quantities were determined from the difference between precipitation over the watershed and runoff. Solving the hydrologic budget yields the unknown runoff. With knowledge of the precipitation over the watershed and the runoff, losses could be estimated.

f. Evaporation from the lake's surface. Pan data corresponding to the months of data collection were obtained from the Climatology Section of the Illinois State Water Survey. Pan to lake coefficients were used to calculate lake evaporation (Roberts and Stall, 1967).

g. Flow to/from the lake from/to groundwater. The sources of data and calculations are identical to those in section 1g.

h. Flow over the spillway. Data were collected daily by the park personnel, who read a staff gage located near the spillway. These stage data were then converted to a flow rate by using a spillway rating curve. The observed values of stage are assumed to reflect a daily average. If precipitation occurred, the instantaneous reading may not represent the average daily flow rate. As a solution, each precipitation event was analyzed separately to determine an average stage for the day. This analysis was done by using a runoff ratio with the amount of precipitation that fell to determine runoff. This runoff was then used to calculate the average daily stage. This rating curve was based on data obtained through a site survey conducted by the Illinois State Water Survey.

i. Increase or decrease in lake storage. The data were obtained through the same source as discussed in section 3h. In addition, lake stage and volume curves (Bogner, 1981) were used to convert stage in the lake to a surface area and lake volume.

Results and Discussion

The components of the" hydrologic budgets are tabulated in tables 5, 6, and 7 in the units of cubic feet per second. If the customary units of the' component are inches, both cfs and inches are presented in the totals. Components headed with a (+) are an input to the budget while a (-) indicates an output. When the values in columns 3 through 10 are summed the result should be zero. The values in columns 1 and 2 (precipitation and losses) are included in the hydrologic budget for computing runoff.

The discussion of the results will be detailed in three sections: 1) long-term average, 2) drought, and 3) period of field data collection.

1. Long-Term Average

The hydrologic budget for the long-term average is shown in table 5. The loss to groundwater is comparatively small. Thus, exfiltration from the lake may be assumed to be a negligible part of the hydrologic budget and therefore is not included in the computations. The exfiltration rate was assumed to remain constant throughout the year since neither the groundwater table nor the water surface of the lake fluctuates to any great extent.

Both the irrigation and the groundwater pumpage to the lake (columns 7 and 8) are seasonal. The quantity of flow used for irrigation is greater than that pumped into the lake, primarily because there were more months of irrigation. If the inflow was deficient, the groundwater could be pumped more hours per day.

The very small change in storage corresponds to a lake level near the spillway. There are two months with no outflow over the spillway. These two months have little runoff, which normally contributes a major part of the inflow. This low runoff is due to low precipitation and to high losses that probably result from harvesting followed by plowing, which allows more water to seep into the ground. The runoff is high in the winter because the ground is frozen.

June receives the most rain while January receives the least. Runoff is greatest in April when the ground is still partially frozen and least in October. As is to be expected, the maximum evaporation occurs in June and July when there are few cloudy days and the sun's intensity is greatest.

The runoff ratio indicates how much precipitation resulted in runoff. The runoff ratio for the year is 23 percent. The maximum runoff ratio is 47 percent and occurs in April, while October has a runoff ratio of 1 percent.

Table 5. Hydrologic Budget for Lake of the Woods - Long-Term Average (1949-1979)
(Values in cubic feet per second)

Month	1 Precipitation over watershed (+)	2 Losses (-)	3 Runoff (+)	4 Precipitation over lake (+)	5 Evaporation (-)	6 Loss to GW* (-)	7 Irrigation (-)	8 Groundwater recharge (Pumped) (+)	9 Change in storage	10 Outflow over spillway (-)
January	1.40	1.12	0.28	0.07	0.03	0.0032	0	0	0	0.32
February	1.44	1.14	0.30	0.07	0.03	0.0032	0	0	0	0.34
March	2.32	1.33	0.99	0.12	0.06	0.0032	0	0	0	1.05
April	3.32	1.76	1.56	0.17	0.12	0.0032	0.04	0	0	1.57
May	3.12	1.80	1.32	0.16	0.17	0.0032	0.11	0.03	0	1.23
June	3.47	2.22	1.25	0.17	0.20	0.0032	0.20	0.10	0	1.12
July	3.35	2.61	0.74	0.17	0.20	0.0032	0.27	0.10	0	0.54
August	2.81	2.41	0.40	0.14	0.18	0.0032	0.27	0.10	0	0.19
September	2.88	2.79	0.09	0.14	0.14	0.0032	0.17	0.03	-.05	0
October	2.25	2.22	0.03	0.11	0.09	0.0032	0.04	0	+.01	0
November	2.04	1.99	0.05	0.10	0.03	0.0032	0	0	+.04	0.08
December	1.90	1.80	0.10	0.10	0.02	0.0032	0	0	0	0.18
TOTAL										
cfs	30.30	23.19	7.11	1.52	1.27	0.0384	1.10	0.36	-	6.62
Inches	37.90	28.95	8.87	37.90	31.49	-				

*This column is not considered in the hydrologic budget since the values are an order of magnitude less than the other components

The hydraulic retention time is the time for the water in the lake to be replaced by new flow. On the basis of the average outflow over the spillway, the hydraulic retention time is 195 days. This value is calculated by taking the volume of the lake below the spillway and dividing it by the average flow rate.

2. Drought

The hydrologic budget for the drought condition is shown in table 6. The effect of a drought in lowering the lake level was considered by taking the data from three consecutive dry years, October 1952 to September 1955. It was assumed that irrigation and pumped groundwater inflow were calculated for the long-term average. The minimum lake elevation was determined to be 1.6 feet below the spillway, and it occurred in the thirteenth month after the drought started. Corresponding to this water surface elevation, the surface area would have decreased by approximately 2 acres or 7 percent of the original surface area.

As is to be expected during a drought, the evaporation rate was higher because there were fewer cloudy days. The increase over the long-term average was 13 percent. Losses were 10 percent less than long-term losses because there was 24 percent less precipitation. Actually, a larger percentage of precipitation that fell on the watershed resulted in losses. The three-year average runoff ratio was 9 percent. Runoff was 70 percent less than the long-term average. There were thirteen months without runoff. Both March 1953 and March 1955 have high runoff ratios: 61 percent and 72 percent, respectively. This probably was due to the ground being frozen and the snow cover melting. Flow over the spillway was 76 percent less than the long-term average.

Table 6. Hydrologic Budget for Lake of the Woods - Drought
(Values in cubic feet per second)

Month	1 Precipitation over watershed (+)	2 Losses (-)	3 Runoff (+)	4 Precipitation over lake (+)	5 Evaporation (-)	6 Loss to GW* (-)	7 Irrigation (-)	8 Groundwater recharge (Pumped)(+)	9 Water surface elev.	9 Change in storage	10 Outflow over spillway (-)
October 1952	0.94	0.94	0	0.05	0.10	0.0032	0.04	0	709.6	-0.09	0
November	2.16	2.16	0	0.11	0.05	0.0032	0	0	709.8	+0.06	0
December	0.91	0.91	0	0.04	0.01	0.0032	0	0	710.0	+0.03	0
January 1953	1.16	1.16	0	0.06	0.01	0.0032	0	0	710.0	0	0.05
February	1.66	1.66	0	0.08	0.05	0.0032	0	0	710.0	0	0.03
March	4.87	3.66	1.21	0.24	0.06	0.0032	0	0	710.0	0	1.39
April	1.15	0.45	0.70	0.06	0.11	0.0032	0.04	0	710.0	0	0.61
May	1.32	1.17	0.15	0.07	0.15	0.0032	0.11	0.07	710.0	0	0.03
June	4.14	3.91	0.23	0.21	0.25	0.0032	0.20	0.21	710.0	0	0.20
July	2.74	2.66	0.08	0.14	0.23	0.0032	0.27	0.21	709.7	-0.07	0
August	0.97	0.96	0.'01	0.05	0.22	0.0032	0.27	0.21	709.3	-0.22	0
September	0.55	0.55	0.00	0.03	0.19	0.0032	0.17	0.07	708.7	-0.26	0
October	1.55	1.54	0.01	0.08	0.11	0.0032	0.04	0	708.5	-0.06	0
November	0.45	0.45	0.00	0.02	0.05	0.0032	0	0	"708.4	-0.03	0
December	0.96	0.78	0.18	0.05	0.03	0.0032	0	0	708.9	+0.20	0
January 1954	1.01	0.98	0.03	0.05	0.02	0.0032	0	0	709.1	+0.06	0
February	0.83	0.77	0.06	0.04	0.05	0.0032	0	0	709.2	+0.05	0
March	1.34	1.26	0.08	0.07	0.07	0.0032	0	0	709.5	+0.08	0
April	3.30	3.05	0.25	0.17	0.14	0.0032	0.04	0	709.9	'+0.24	0
May	2.60	2.54	0.06	0.13	0.19	0.0032	0.11	0.07	709.7	-0.04	0

Table 6. Concluded

	1	2	3	4	5	6	7	8	9		10
June	1.13	1.05	0.08	0.06	0.24	0.0032	0.20	0.21	709.6	-0.09	0
July	2.17	2.14	0.03	0.11	0.26	0.0032	0.27	0.21	709.2	-0.18	0
August	4.70	4.42	0.28	0.24	0.17	0.0032	0.27	0.21	709.8	+0.29	0
September	0.39	0.39	0	0.02	0.18	0.0032	0.17	0.07	709.3	-0.26	0
October	3.18	3.18	0	0.16	0.07	0.0032	0.04	0	709.5	+0.05	0
November	0.32	0.32	0	0.02	0.05	0.0032	0	0	709.4	-0.03	0
December	1.10	1.10	0	0.06	0.03	0.0032	0	0	709.5	+0.03	0
January 1955	2.14	2.14	0	0.11	0.01	0.0032	0	0	709.6	+0.10	0
February	2.20	2.03	0.17	0.11	0.04	0.0032	0	0	710.0	+0.15	0.09
March	1.02	0.29	0.73	0.05	0.07	0.0032	0	0	710.0	0	0.71
April	2.45	1.90	0.55	0.12	0.17	0.0032	0.04	0	710.0	0	0.46
May	3.58	3.17	0.41	0.18	0.18	0.0032	0.11	0.07	710.0	0	0.37
June	3.18	2.38	0.80	0.16	0.18	0.0032	0.20	0.21	710.0	0	0.79
July	3.50	3.32	0.18	0.18	0.23	0.0032	0.27	0.21	710.0	0	0.07
August	0.83	0.64	0.19	0.04	0.23	0.0032	0.27	0.21	709.7	-0.06	0
September	2.66	2.66	0	0.13	0.16	0.0032	0.17	0.07	709.5	-0.13	0
TOTALS											
3 yr annual average (cfs)	23.05	20.90	2.16	1.17	1.46	0.0384	1.10	0.78	-		1.60
3 yr annual average (in.)	28.86	26.09	2.70	28.86	36.26	-	-	-	-		-
Difference from average	-24%	-10%	-70%	-24%	+13%	0%	0%	+117%	-		-76%

*This column is not considered in the hydrologic budget since the values are an order of magnitude less than the other components

An additional column (water surface elevation) was added in column 9. This water surface elevation corresponds to the change in storage. Late summer/early fall appear to be the most critical periods with respect to the elevation of the lake. The combination of the minimum elevation of the lake and the low spring precipitation leaves the lake level below the spillway for 20 consecutive months.

3. Period of Field Data Collection

The hydrologic data for 1981 are shown in table 7. This field data collection lasted for five months, May through September 1981. This period corresponds to the recreational season of the lake. Precipitation was 74 percent above the long-term average. The evaporation was down 18 percent from the same time period of the long-term average. Increased precipitation led to increased losses (48 percent), increased runoff (155 percent), and increased outflow over the spillway (226 percent). Precipitation also affected irrigation, which was down 36 percent, and the amount of ground-water pumped into the lake (down 3 percent). The lake level remained above the spillway crest during the entire period of data collection.

It must be remembered that the monthly budget is an average. Although it is stated that the lake level does not fall below the spillway on a monthly average, it should not be assumed that during the entire month there is flow over the spillway every day. In fact, during the data collection period there was no flow over the spillway on 34 occasions (17 percent of the time). These no-flow times are negated by times of high flow. The average of all flows is 2 cfs. If the highest flow was dropped, the average flow rate would be 1.4 cfs. A flow rate of 0.8 cfs occurred most often (20 percent of the time). In fact, 50 percent of all the flows were at or below 0.5 cfs.

Table 7. Hydrologic Budget for Lake of the Woods - May through September 1981
(All elements have units of cfs)

Month	1 Precipitation over watershed (+)	2 Losses (-)	3 Runoff (+)	4. Precipitation over lake (+)	5 Evaporation (-)	6 Loss to GW* (-)	7 Irrigation (-)	8 Groundwater recharge (Pumped) (+)	9 Change in storage	10 Outflow over spillway (-)
May	4.75	2.60	2.15	0.24	0.12	0.0032	0.09	0.03	0	2.21
June	5.19	2.89	2.30	0.26	0.18	0.0032	0.11	0.11	0	2.38
July	6.06	4.31	1.75	0.30	0.15	0.0032	0.16	0.11	0	1.85
August	8.40	5.61	2.79	0.42	0.14	0.0032	0.13	0.09	0	3.03
September	2.79	2.08	0.71	0.14	0.14	0.0032	0.16	0.01	0	0.56
TOTALS										
cfs	27.19	17.49	9.70	1.36	0.73	0.0160	0.65	0.35	-	10.03
Inches	34.26	21.96	12.18	34.26	18.21	-		-		
Difference from average**	+74%	+48%	+155%	+74%	-18%	0%	-36%	-3%	-	+226%

**Five month totals

*This column is not considered in the hydrologic budget since the values are an order of magnitude less than the other components

SUMMARY AND CONCLUSIONS

1) A sediment budget was determined for the Lake of the Woods watershed. The soil loss assessment was conducted by utilizing the Universal Soil Loss Equation (USLE). The reservoir sediment survey was performed in 1981. The results indicated that the total amount of soil loss was 1462 tons per year. The cropland, consisting of 141 acres or about 25 percent of the watershed, contributed about 900 tons of soil loss per year. The other land use categories, including open space in the park, residential and commercial areas, and pastures (about 75 percent of the watershed), contributed less than 562 tons per year of soil loss. The sedimentation survey results indicated that the lake capacities have been reduced about 13.5 percent since 1948. The annual sedimentation rate of the lake was 1.45 tons per year. The trap efficiency of Lake of the Woods was estimated to be 97 percent. The sediment delivery ratio of the Lake of the Woods watershed amounts to about 63 percent.

2) A hydrologic budget was constructed for the lake. The results indicated that under various precipitation conditions the lake level will not drop significantly. The drought produced a 1.7-foot drop in the lake level with a corresponding surface area decrease of 9 percent from normal pool. An analysis of the long-term average revealed a negligible decrease in the water level. The analysis of the 1981 data showed that the lowest daily lake elevation reached was 0.07 feet below the spillway. This is a daily reading and not a monthly average. At no time did the monthly hydrologic budget show a drop of the lake level below the spillway in the five months of data collection. The time of the year that the lake level reached its lowest elevation was late summer and early autumn.

REFERENCES

Bogner, W. C. 1981. Sedimentation Survey of the Lake of the Woods, Mahomet, Illinois. Illinois State Water Survey Contract Report 281.

Brune, G. M. 1953. Trap Efficiency of Reservoirs. Trans., Am. Geophys. Union, Vol. 34, pp. 407-418, June.

Leighton, M. M., G. E. Ekblaw, and Leland Horberg. 1948. Physiographic Divisions of Illinois. Illinois State Geological Survey Report of Investigation 129.

Mockus, V. 1972. Hydrologic Soil Groups. In National Engineering Handbook, Section 4, Hydrology. United States Department of Agriculture, Soil Conservation Service.

Mount, H. R. 1982. Soil Survey of Champaign County, Illinois. United States Department of Agriculture, Soil Conservation Service, in cooperation with Illinois Agricultural Experiment Station.

Peterson, A. E., and J. B. Swan. 1979. Universal Soil Loss Equation: Past, Present, and Future. Soil Science Society of America, Special Publication Number 8.

Roberts, W. J., and J. B. Stall. 1967. Lake Evaporation in Illinois. Illinois State Water Survey Report of Investigation 57.

Sanderson, E. W., and E. Zewde. 1976. Groundwater Availability in Champaign County. Illinois State Water Survey Circular 124.

United States Army Corps of Engineers. 1980. Inspection Report, National Dam Safety Program, Lake of the Woods Dam, Champaign County, Illinois, Inventory Number 00511, United States Army Engineer District, Chicago.

Visocky, A. P., and R. J. Schicht. 1969. Groundwater Resources of the Buried Mahomet Bedrock Valley. Illinois State Water Survey Report of Investigation 62.

Walker, R. D., and R. A. Pope. 1979. Estimating Your Soil Erosion Losses with the Universal Soil Loss Equation (USLE). Cooperative Extension Service University of Illinois at Urbana-Champaign.

Wischmeier, W. H., and D. D. Smith. 1978. Predicting Rainfall Erosion Losses -- A Guide to Conservation. Planning. U. S. Department of Agriculture, Agriculture Handbook No. 537.