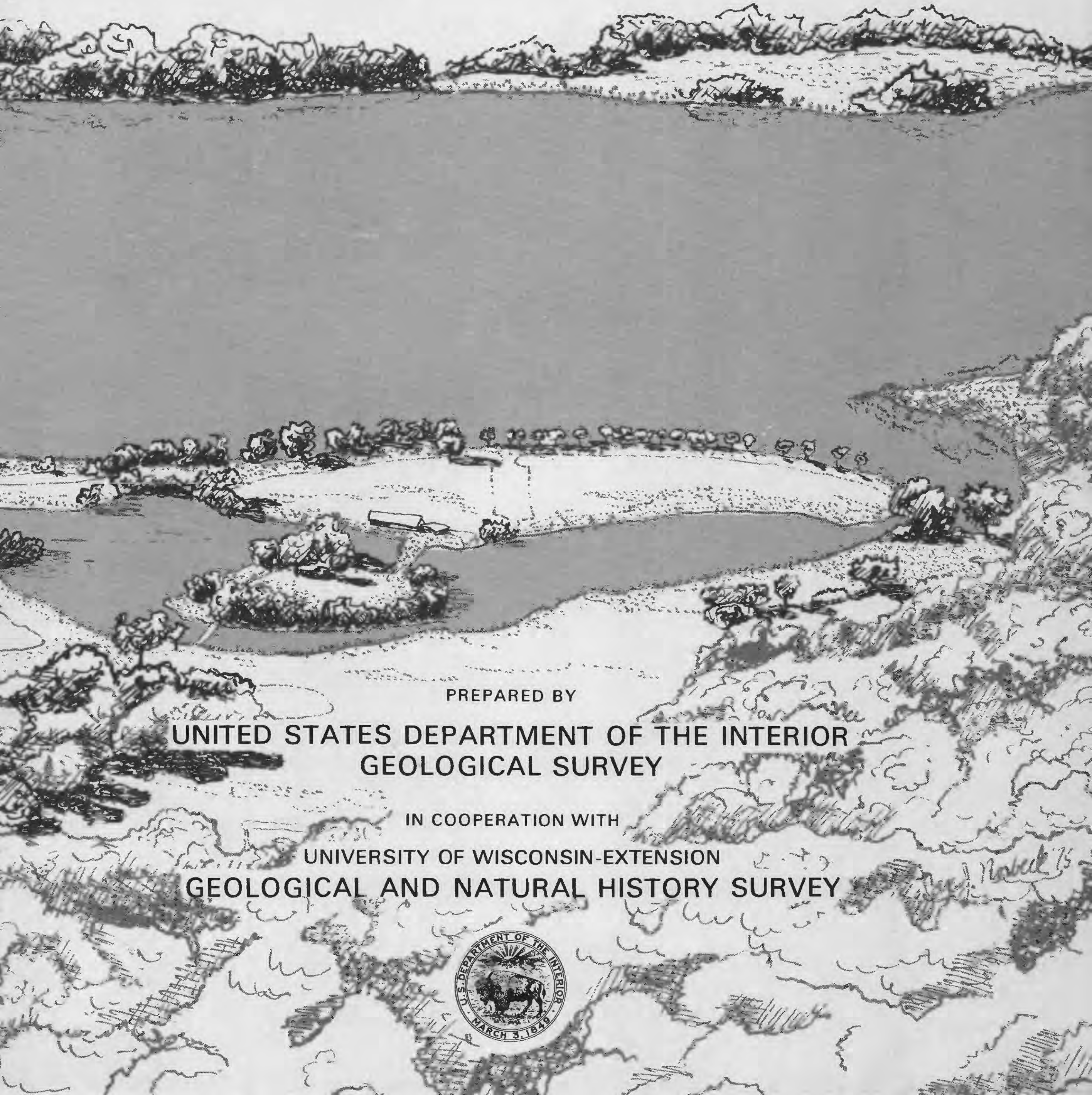
WATER RESOURCES INVESTIGATIONS
17-75

Hydrology of the Lake Wingra Basin, Dane County, Wisconsin



PREPARED BY

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

IN COOPERATION WITH

UNIVERSITY OF WISCONSIN-EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle HYDROLOGY OF THE LAKE WINGRA BASIN, DANE COUNTY, WISCONSIN			5. Report Date July 1975 6.
7. Author(s) E. L. Oakes, G. E. Hendrickson, and E. E. Zuehls			8. Performing Organization Rept No. WRI 17-75
9. Performing Organization Name and Address U.S. Geological Survey 1815 University Avenue Madison, Wisconsin 53706			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey 1815 University Avenue Madison, Wisconsin 53706			13. Type of Report & Period Covered Final 14.

15. Supplementary Notes Prepared in cooperation with the University of Wisconsin-Extension, Geological and Natural History Survey

16. Abstracts A water budget was prepared to identify the components of the hydrologic system in the Lake Wingra basin. The Lake Wingra basin, which includes a small eutrophic lake within the city of Madison, Wisconsin, is partly natural and partly urbanized. Measured and estimated inflow and outflow to and from the lake in one year (June 1972 to May 1973) was about 4.5 metres (15 feet)--approximately twice the volume of the lake. Lake gains are about 25 percent from precipitation on the lake surface, a from nearly equal amounts of surface runoff and ground-water inflow. Lake losses are about 10 percent ground-water outflow, 15 percent evaporation from the lake surface, a 75 percent discharge at the surface outlet. Increased pumpage from municipal and industrial wells in Madison has slowed the flow through the lake. The calculated 1972 water budget for the lake showed gains of about 356 centimetres (140 inches) and losse of about 350 centimetres (138 inches). A discrepancy of about 6 centimetres (2 inches probably was caused by uncertainties in ground-water inflow and outflow and by evapotranspiration and ground-water inflow in the marsh area southwest of the lake.

17. Key Words and Document Analysis. 17a. Descriptors

*Hydrologic budget, *Wisconsin, *Ground water, *Surface water

17b. Identifiers/Open-Ended Terms

*Lake Wingra

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	37
	20. Security Class (This Page) UNCLASSIFIED	22. Price

Hydrology of the Lake Wingra Basin, Dane County, Wisconsin

E.L. Oakes, G.E. Hendrickson, *and* E.E. Zuehls

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations 17-75

Prepared in cooperation with the
University of Wisconsin–Extension,
Geological and Natural History Survey

July 1975

UNITED STATES DEPARTMENT OF THE INTERIOR
Stanley K. Hathaway *Secretary*

GEOLOGICAL SURVEY
V.E. McKelvey *Director*

For additional information write to:

U.S. Geological Survey
1815 University Avenue
Madison, Wisconsin 53706

Contents

Illustrations

Tables

Factors for Converting International System (SI) Units to English Units

Divide SI units	By	To obtain English units
millimetres (mm)	25.4	inches (in)
metres (m)	.0254	inches (in)
metres (m)	.3048	feet (ft)
kilometres (km)	1.609	miles (mi)
square kilometres (km^2)	2.590	square miles (mi^2)
litres (l)	3.785	gallons (gal)
litres per second (l/s)	.06309	gallons per minute (gal/min)
kilograms (kg)	.4536	pounds (lbs)
cubic metres per second (m^3/s)	.02832	cubic feet per second (ft^3/s)
cubic metres per day per square metre [$(m^3/d)/m^2$]	.3048	cubic feet per day per square foot [$(ft^3/d)/ft^2$]

Hydrology of the Lake Wingra Basin, Dane County, Wisconsin

E.L. Oakes, G.E. Hendrickson, *and* E.E. Zuehls

Abstract

A water budget was prepared to identify the components of the hydrologic system in the Lake Wingra basin. The Lake Wingra basin, which includes a small eutrophic lake within the city of Madison, Wis., is partly a protected area and partly an urbanized area. Measured and estimated inflow and outflow to and from the lake in 1 year (June 1972 to May 1973) was about 4.5 metres (15 feet)--approximately twice the volume of the lake. Inflow to the lake is about 25 percent from direct precipitation on the lake surface, and the rest from nearly equal amounts of surface runoff and ground-water inflow. Outflow from the lake is about 10 percent ground-water outflow, 15 percent evaporation from the lake surface, and 75 percent discharge at the surface outlet. Increased withdrawal of water from municipal and industrial wells in Madison has slowed the rate of flow through the lake.

The calculated 1972 water budget for the lake showed gains of about 3,560 millimetres (140 inches) and losses of about 3,500 millimetres (138 inches). A discrepancy of about 60 millimetres (2 inches) probably was caused in part by uncertainties in ground-water inflow and outflow. Effects of evapotranspiration and ground-water inflow in the marsh area southwest of the lake also probably contribute to the discrepancy.

INTRODUCTION

The Lake Wingra basin, within the city of Madison, Dane County, Wis., is a partly protected area and partly urbanized area. The basin (fig. 1) above the lake outlet includes a surface drainage area of 15.74 km^2 (6.07 mi^2). This includes about 75 percent urban area--residential housing, businesses, schools, golf courses, cemeteries, and public parks--and about 25 percent University of Wisconsin Arboretum, an area of forest, prairie, and marsh.

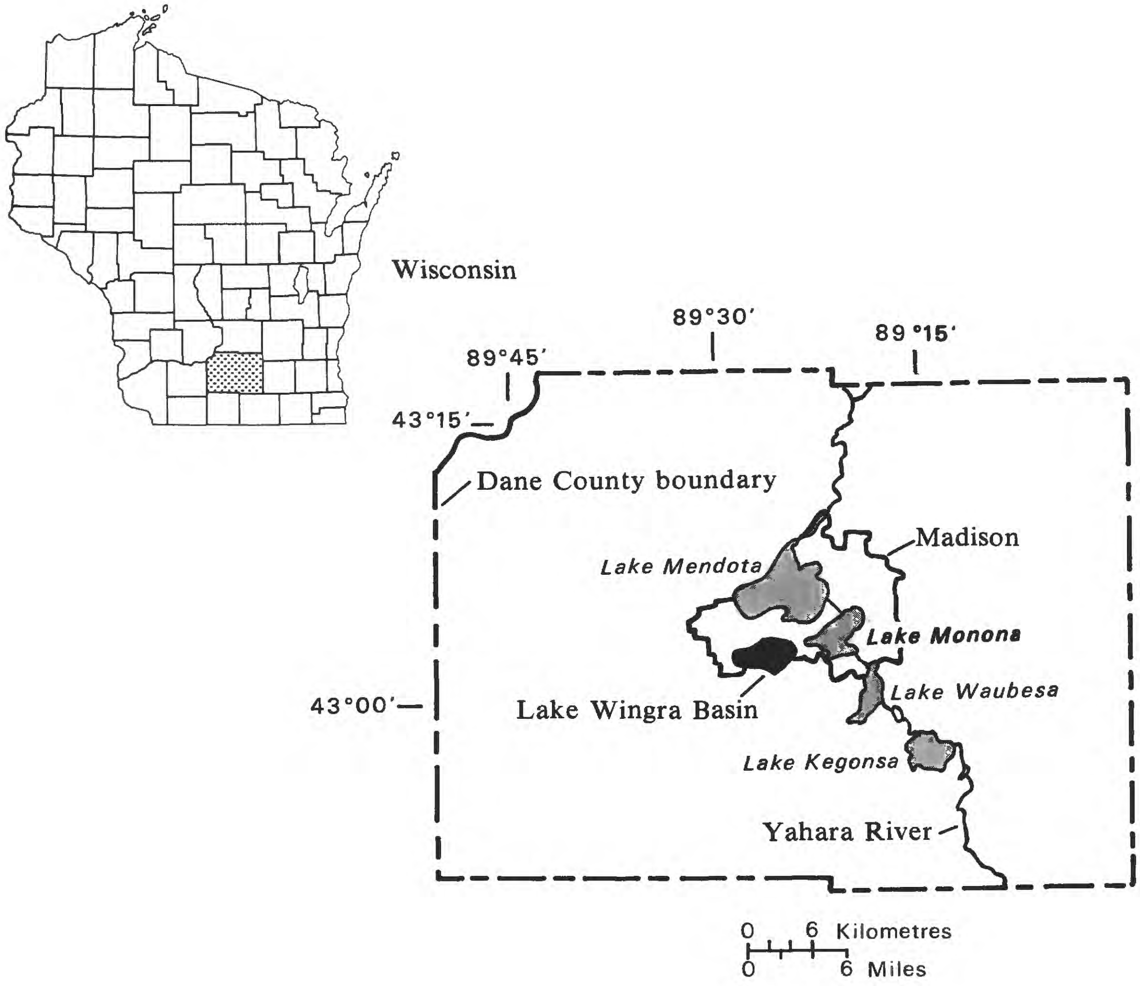


Figure 1. Location of study area in Wisconsin.

Lake Wingra is near the south edge of the city of Madison at about 43°03' N. latitude and 89°24' W. longitude. It is a small 1.37-km^2 (0.53-mi^2) eutrophic lake. It is within the drainage of the Yahara River (fig. 1), which flows into the Rock River, a tributary of the Mississippi River.

The purpose of this report is to describe the hydrologic system in the Lake Wingra basin, with particular emphasis on the hydrologic budget of the lake itself. Support for this overall study was supplied, in part, by the Eastern Deciduous Forest Biome Project, IBP (International Biome Period), funded by the National Science Foundation under Interagency Agreement AG-199, 40-193-69, with the Atomic Energy Commission--Oak Ridge National Laboratory. The IBP funds for the work reported on here were included in the cooperative program with the University of Wisconsin-Extension, Geological and Natural History Survey and matched equally by the U.S. Geological Survey.

Topography and Geology

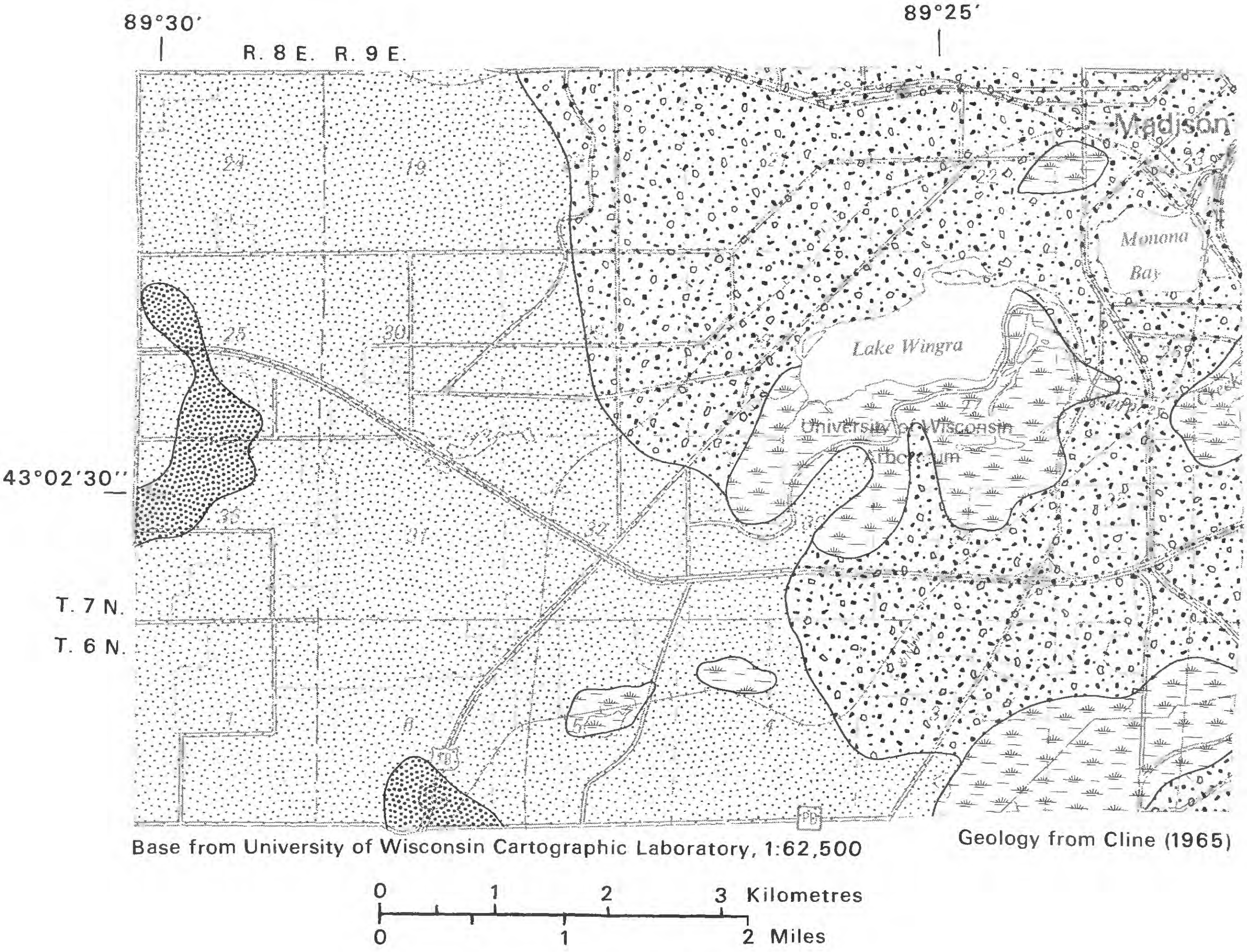
The Lake Wingra basin is in the Yahara River valley (fig. 1). The highest point in the drainage basin is 341 m (1,120 ft) above mean sea level; the lake is 258 m (848 ft) above sea level. The basin is composed chiefly of rolling uplands underlain by glacial moraines and outwash (fig. 2). Areas of low wetlands near the lake are underlain by peat, muck, and marl.

Lake Wingra and related marsh deposits occupy a depression in thick deposits of sand, gravel, and silt. These deposits fill a bedrock valley (figs. 3 and 4), a tributary of the preglacial Yahara River.

Surficial Deposits

Glacial deposits in the Lake Wingra basin consist chiefly of morainal deposits that are largely till (fig. 2). Till is an unsorted, unstratified mixture of silt, clay, sand, gravel, cobbles, and boulders laid down directly by ice. Outwash deposits occur in upland areas of the Lake Wingra basin south and southwest of the lake. Outwash is a sorted water-laid deposit of stratified material, chiefly sand and gravel, deposited by glacial streams. The glacial deposits are thickest, generally around 30-45 m (100-150 ft), in a bedrock valley (fig. 3) trending generally northeast along the orientation of Lake Wingra.

Surficial marsh deposits, outwash and alluvium, cover these morainal deposits over part of the basin. A few small areas of stratified lake deposits of marl, sand, and silt are included in the areas mapped as outwash. Marsh deposits occupy the margins of Lake Wingra on the southwest, south, and southeast. Auger holes through these marsh deposits show only a few feet of organic material overlying 4-24 m (10-60 ft) of lake clay and marl. Beneath the clay, 2-16 m (6-40 ft) of silty sand overlies a few feet of sandy till, which rests on bedrock.



EXPLANATION

Marsh deposits
Muck and peat

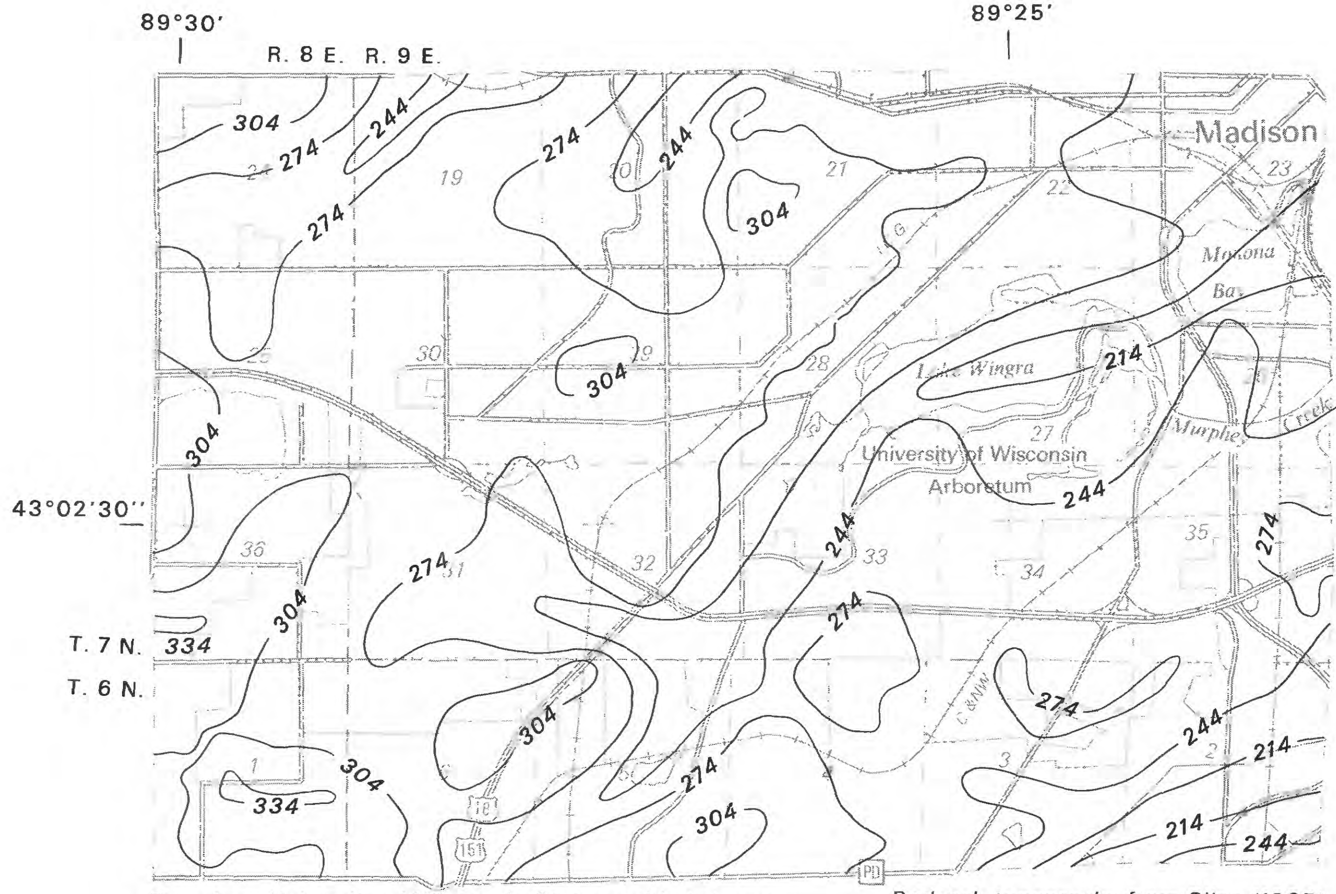
Outwash and alluvium
Mostly sand and gravel, sorted and stratified

Morainal deposits
Clay, silt, sand, gravel, and boulders, mostly unsorted and unstratified

Undifferentiated glacial deposits mainly ground moraine
Clay, silt, sand, gravel, and boulders, unstratified to stratified, unsorted to sorted

—— Contact

Figure 2. Surficial geology.



Base from University of Wisconsin Cartographic Laboratory, 1:62,500

Bedrock topography from Cline (1965)

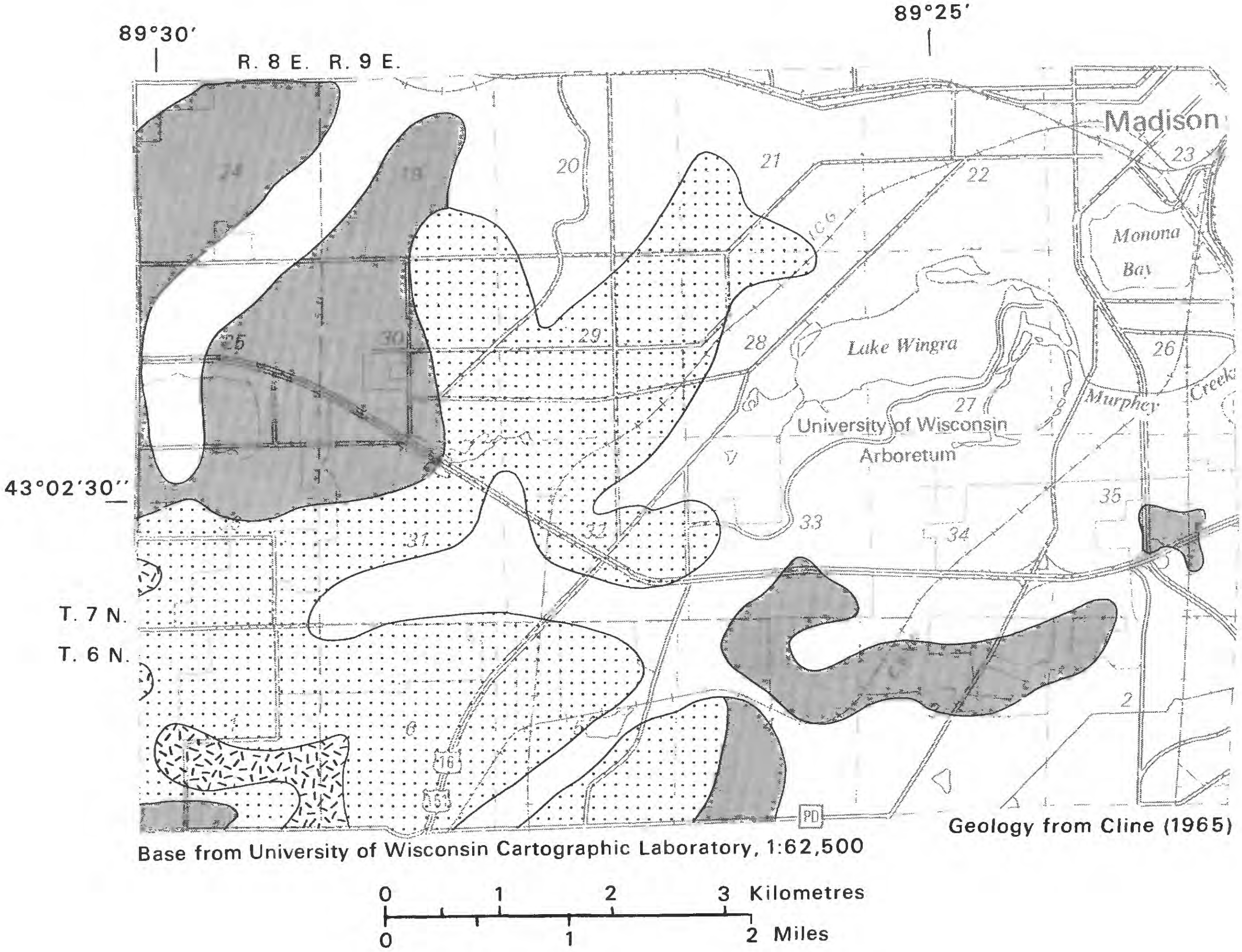
0 1 2 3 Kilometres
0 1 2 Miles

EXPLANATION

Bedrock contour

— 274 — *Shows altitude of bedrock surface. Contour interval 30 metres (100 feet). Datum is mean sea level*

Figure 3. Bedrock topography.



EXPLANATION

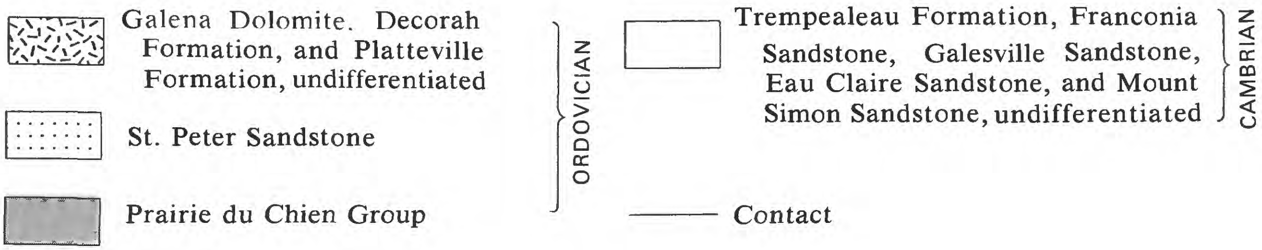


Figure 4. Bedrock geology.

Bedrock

A layered sequence of sedimentary rock underlies the glacial deposits in the basin. These sedimentary rocks are mainly sandstone and dolomite and range in age from Cambrian to Ordovician (table 1). In the basin they dip gently to the south and southeast.

These rocks, particularly the sandstone, are permeable and saturated and are the principal source of water for the Madison area.

The geologic column in the Lake Wingra area is shown on table 1. The Cambrian rocks, which include several sandstones with some dolomite and shale, are as much as 271 m (890 ft) thick in the basin. Overlying the Cambrian rocks, the Prairie du Chien Group may be as thick as 23 m (75 ft). In this basin the St. Peter Sandstone is as much as 38 m (125 ft) thick. Dolomite of the Platteville and Decorah Formations and Galena Dolomite overlie the St. Peter Sandstone to the south but are not present in the Lake Wingra basin. Total thickness of the sedimentary rocks is about 244-274 m (800-900 ft).

Acknowledgments

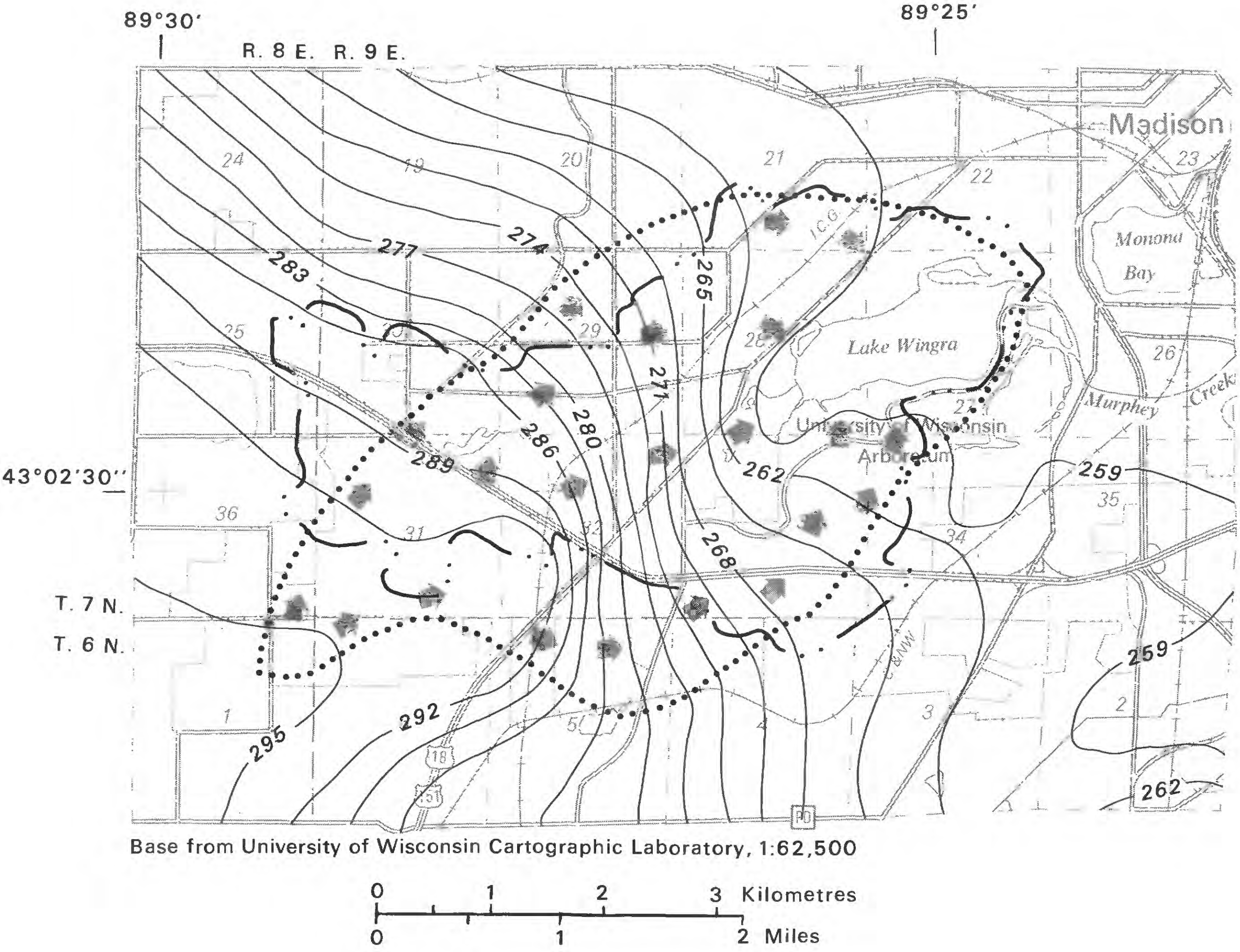
Work on this project was assisted greatly by the contributions of many agencies and individuals. Well logs were supplied by the University of Wisconsin-Extension, Geological and Natural History Survey, and the Wisconsin Department of Natural Resources. Municipal pumpage records were supplied by the city of Madison Water Utility. Evaporation data and other information were furnished by the Lake Wingra Study Office of the University of Wisconsin. Permission for the installation of observation wells was granted by the University of Wisconsin Arboretum Committee and the Nakoma Country Club. Permission for the installation of storm-sewer gages was granted by the city of Madison's Street Department. The authors of this report gratefully acknowledge all of the above assistance. The authors also wish to thank the land and well owners for supplying data on wells and allowing access to sites for the installation of observation wells and rain gages.

HYDROLOGIC SYSTEM OF THE LAKE WINGRA BASIN

The divides that shape the ground-water and the surface-water drainage areas of the Lake Wingra basin differ significantly (fig. 5). The ground-water divide is indistinct and subject to interpretation in the western part of the basin. Near Lake Wingra and Madison, its configuration is altered by the combined effects of recharge and discharge of ground water, including discharge through wells. The surface-water divide differs from the topographic divide because of modification by storm sewers. Both divides are subject to further changes brought about by further urban development. In this report the Lake Wingra basin is considered to be that defined by the surface-water divide, except that ground-water inflow and outflow are computed on the basis of the boundaries of the ground-water basin.

Table 1.--Generalized stratigraphy and aquifer system in the Lake Wingra area.

Era or System	Geologic unit	Dominant lithology	Subsurface hydrologic unit	Saturated thickness (m)
QUATERNARY	Holocene and Pleistocene glacial deposits	Clay, silt, sand	Upper aquifer	15-137
ORDOVICIAN	Galena Dolomite	Dolomite		
	Decorah Formation	Dolomite		
	Platteville Formation	Dolomite		
	St. Peter Sandstone	Sandstone		
	Prairie du Chien Group	Dolomite		
CAMBRIAN	Trempealeau Formation; St. Lawrence Member	Sandstone and dolomite		
	Franconia Sandstone; Ironton Sandstone Member	Sandstone	Sandstone aquifer	137-274
	Galesville Sandstone	Sandstone		
	Eau Claire Sandstone	Sandstone and shale		
	Mount Simon Sandstone	Sandstone		
PRECAMBRIAN	Precambrian rocks undifferentiated	Crystalline rocks	Not an aquifer	



EXPLANATION

—295— Water-table contour
Shows altitude of water table during September 1973. Contour interval 3 metres (10 feet). Datum is mean sea level

— · · — Surface-water divide, as defined by storm sewers

Direction of ground-water flow

•••••••• Ground-water divide

Figure 5. Water table and ground-water movement.

Pumpage by Madison's deep wells from the sandstone aquifer has modified artesian pressures in the Lake Wingra area. This subject has been covered in detail by McLeod (1975).

Data Network

The Lake Wingra basin receives and loses water through natural and man-induced processes. Water income is by direct precipitation and by ground-water underflow. Water loss is by evaporation, transpiration, surface runoff, ground-water underflow, and by withdrawal of water from wells. All of these factors must be accurately accounted for to make practical estimates of the water budget.

To monitor components of the hydrologic system in the Lake Wingra basin, a network of data-collection stations was established (tables 2-5[1/], pl. 1). The discharge of streams, storm sewers, and springs was gaged to define inflow to the lake. Water-level fluctuations in observation wells defined changes in ground-water storage and ground-water movement.

Precipitation was measured at seven locations in or near the Lake Wingra basin (table 2). Two gages were recording gages used during the entire year, and a third recording gage was used from May through October. Four standard rain gages completed the network. An evaporation pan was maintained from April to October each year.

Surface-runoff data were collected at three stream gages and five storm-sewer gages (table 3). Runoff normally occurred only during and immediately after significant rainfall or snowmelt. Therefore, during much of the time there was no discharge. Marshland Creek, a tributary to Lake Wingra, also flowed intermittently. A continuous-recording gage was maintained on this stream. A gage on the Lake Wingra outlet measured discharge from the lake to Murphy Creek. A gage on Murphy Creek, at Beld Street about 1.6 km (1 mi) below the Lake Wingra outlet, measured the lake-outlet flow plus flow from the additional drainage area and seepage or overland flow out of the lake. Five storm-sewer gages collected runoff data from urbanized areas in the Lake Wingra basin. Records from a lake-stage gage on Lake Monona were used in computation of flow records at the Beld Street gage during periods when high stages of Lake Monona caused backwater conditions. The stage of Lake Wingra was continuously monitored at the lake outlet. The stage of Lake Monona also was continuously monitored.

Discharges from three springs were monitored year-round (table 4). Five additional springs were monitored from April to August 1973.

[1/] A two-part system of letters and numbers is used to designate wells and springs in this report. The first part, Dn, is the county abbreviation. The second part is the serial number, assigned in the order that the well or spring was inventoried in the county. Springs are distinguished from wells by the letters "sp" following the serial number.

Table 2.--Meteorological data-collection sites.

	Type of gage	Recorder	Period of record
1809 Golden Oak Lane	Precipitation, weighing	Strip chart	June 24, 1970-June 30, 1974
St. Mary's Hospital	Precipitation, weighing	Strip chart	June 2, 1970-June 30, 1974
Nakoma Country Club	Precipitation, accumulating	Digital	May 27, 1970- 1/
Glenway Golf Course	Precipitation, standard	None	June 25, 1970-June 30, 1974
Town of Madison Town Hall	Precipitation, standard	None	June 8, 1970-June 30, 1974
Arboretum maintenance station	Precipitation, standard	None	June 1, 1970- 1/
4910 Marathon Drive	Precipitation, standard	None	June 1, 1970- 1/
Arboretum maintenance station	Evaporation, pan	None	Apr. 20, 1971-Oct. 31, 1973

1/ To be continued after June 30, 1974.

Table 3.--Surface-water recorder sites.

	Drainage area (km^2)	Control	Period of record
Stream gages			
Marshland Creek	2.51	Weir	Mar. 14, 1971-June 30, 1974
Lake Wingra outlet	15.74	Weir	Dec. 9, 1971- 1/
Murphy Creek at Beld Street	20.86	Flume	Mar. 10, 1971-June 30, 1974
Storm-sewer gages			
Van Buren Street storm sewer	.18	Culvert	Oct. 26, 1971-June 30, 1974
Knickerbocker Street storm sewer	.49	Flume	Dec. 1, 1971-June 30, 1974
Glenway Street storm sewer	1.01	Weir	Oct. 22, 1971-June 30, 1974
Nakoma Road storm sewer	6.06	Weir	Dec. 5, 1971- 1/
Manitou Way storm sewer	.60	Flume	Aug. 19, 1970- 1/
Lake gages			
Lake Monona			Apr. 30, 1970- 1/
Lake Wingra			May 12, 1970- 1/

1/ To be continued after June 30, 1974.

Table 4.--Springflow data-collection sites.

	Frequency of measurement	Control	Gage	Period of record
Dn- 5 sp	Monthly	None	None	June 24, 1970-June 30, 1974
Dn- 6 sp	Weekly	Flume	Staff	July 22, 1970- 1/
Dn- 8 sp	Weekly	Weir	Staff	June 7, 1970- 1/
Dn- 9 sp	Monthly	None	None	Apr. 18, 1973-Aug. 3, 1973
Dn-10 sp	Monthly	None	None	Apr. 18, 1973-Aug. 3, 1973
Dn-11 sp	Monthly	None	None	Apr. 18, 1973-Aug. 3, 1973
Dn-12 sp	Monthly	None	None	Apr. 18, 1973-Aug. 3, 1973
Dn-13 sp	Monthly	None	None	Apr. 18, 1973-Aug. 3, 1973

1/ To be continued after June 30, 1974.

Table 5.--Ground-water data-collection sites.

		Frequency of measurement	Depth (m)	Period of record
Dn- 201,	5900 Hammersley Road	Weekly	90	May 11, 1970-June 30, 1973
Dn- 62,	Arboretum maintenance station	Weekly	61	May 11, 1970-June 30, 1973
Dn-1000	East end of Lake Wingra	Weekly	3	Dec. 16, 1970-June 30, 1973
Dn-1001		Weekly	19	Dec. 16, 1970-June 30, 1973
Dn-1002		Weekly	28	Apr. 5, 1972-June 30, 1973
Dn-1003,	Vilas Park pavilion	Weekly	7	Dec. 17, 1970-June 30, 1973
Dn-1004	NE corner, Nakoma Country Club	Weekly	4	Dec. 17, 1970-June 30, 1973
Dn-1005		Weekly	16	Dec. 17, 1970-June 30, 1973
Dn-1006	Jackson Oak	Weekly	26	June 7, 1971-June 30, 1973
Dn-1007		Weekly	13	June 6, 1972-June 30, 1973
Dn-1008	North end Gardner Marsh	Weekly	25	Apr. 4, 1972-June 30, 1973
Dn-1009		Weekly	9	Apr. 4, 1972-June 30, 1973
Dn-1010	Capitol Drive	Weekly	19	June 6, 1972-June 30, 1973
Dn-1011		Weekly	2	June 6, 1972-June 30, 1973

Water-level fluctuations in bedrock aquifers were monitored at two sites (table 5). Water-level fluctuations in the unconsolidated material above the bedrock were measured at six sites. Grouped wells, one relatively shallow and one or more deep, were measured at five of the six sites to determine potential for vertical movement of water in the glacial drift.

Water Budget for Lake Wingra Basin

A water budget was prepared for the Lake Wingra basin to quantify water movement (table 6). This budget also serves as a framework for the more detailed budget of the lake itself. Measured quantities in the budget are precipitation, surface runoff to and from Lake Wingra, and ground-water discharge to Lake Wingra in visible springs and seeps. All other quantities are estimated.

The following discussion is based chiefly on records for the 1972 calendar year. This was the first full year that hydrologic instrumentation was virtually complete.

Precipitation and Evapotranspiration

In 1972 precipitation on the Lake Wingra basin was about 760 mm (29.9 in), which is about the average annual precipitation for the Madison area. This is equivalent to an average rate of about 0.38 m^3/s (13.4 ft^3/s).

Evaporation from Lake Wingra computed by D. D. Huff (written commun., 1973) was 650 mm (25.6 in), equivalent to a loss of 60 mm (2.4 in) distributed evenly over the entire basin. The evaporation loss was at an average rate of 0.03 m^3/s (1.1 ft^3/s).

Evapotranspiration from the land area of the basin was about 470 mm (18.5 in), equivalent to a loss of 430 mm (16.9 in) distributed evenly over the entire basin. The evapotranspiration loss was at an average rate of 0.21 m^3/s (7.4 ft^3/s). Evapotranspiration was estimated to be the residual water loss from the basin after measurement and computation of all other losses.

The combined evapotranspiration losses from the lake and from the land area equal 490 mm (19.3 in), or a loss rate of 0.24 m^3/s (8.5 ft^3/s).

Ground Water

Recharge to shallow aquifers in the Lake Wingra basin occurs chiefly in the upland areas west and southwest of the lake. Ground water moves generally east and northeast toward the lake. Movement of ground water in the Lake Wingra area is complex because of the response of the sandstone aquifer to large withdrawals of water for municipal and industrial uses. R. S. McLeod (1975) assumed two major aquifers, each having a discrete potentiometric surface in the Madison area. The lower aquifer, termed the "sandstone aquifer", includes the Ironton Sandstone Member of the Franconia Sandstone

Table 6.--Water budget for the Lake Wingra basin, 1972.

	Annual amount for basin area (mm)	Average rate of flow (m^3/s)
Gain:		
Precipitation on land area	690	0.35
Precipitation on lake area	70	.03
Ground-water inflow from outside basin	20	.01
Total gain	780	.39
Loss:		
Evapotranspiration from land area	430	.21
Evaporation from lake area	60	.03
Surface discharge from basin (at lake outlet)	210	.11
Ground-water outflow from basin	80	.04
Total loss	780	.39

and all underlying Cambrian sandstones (table 1). The upper aquifer includes the glacial drift and all bedrock formations overlying the Ironton Sandstone Member. Most high-capacity municipal and industrial wells withdraw water from the sandstone aquifer. Most domestic wells obtain water from the upper aquifer. Water levels used to define the ground-water basin discharging to Lake Wingra (fig. 5) were from wells in the upper aquifer.

Movement of water in the sandstone aquifer is strongly influenced by withdrawal of water from municipal and industrial wells. Movement of water in the upper aquifer also is influenced by this withdrawal, but the influence is less because the low permeability of the stratum at the base of the St. Lawrence Member of the Trempealeau Formation (table 1) inhibits vertical movement of water. Five of the springs discharging into Lake Wingra emerge from the St. Lawrence Member near its base. The low permeability of this member lessens but does not eliminate the influence of withdrawals of water from municipal wells on the springs. Discharge of springs Dn-9 and 10 sp declined from about 12 l/s (190 gal/min) to 9 l/s (143 gal/min) after a nearby city well (Dn-46) (pl. 1) was pumped for 2 days at a rate of about 60 l/s (951 gal/min). Discharge of spring Dn-6 sp, about one-quarter mile farther from the pumping well, was not noticeably affected.

Annual recharge to the upper aquifer in the Lake Wingra basin, including about 20 mm (0.8 in) of ground-water inflow from outside the basin, is estimated to average about 200 mm (8.0 in). This is equivalent to an average rate of about 0.10 m^3/s (3.5 ft^3/s). In 1972 recharge was estimated to be 240 mm (9.4 in), and about 110 mm or 4.3 in (0.05 m^3/s or 1.8 ft^3/s) of this was discharged to Lake Wingra as visible springs and seeps; 30 mm or 1.2 in (0.014 m^3/s or 0.5 ft^3/s) reached the sandstone aquifer. (It is estimated that about half the recharge from the upper aquifer to the sandstone aquifer comes from the thick glacial deposits in the buried bedrock valley beneath Lake Wingra.) About 20 mm or 0.8 in (0.01 m^3/s or 0.4 ft^3/s) is estimated to be lost from the upper aquifer by evapotranspiration (p. 16) from the marshland near the southwest end of the lake.

Surface Water

Surface runoff in the Lake Wingra basin is chiefly in storm sewers and intermittent streams. The only perennial streams in the basin other than the lake outlet are those leading from springs to the lake. In this report, storm sewer names are those used by W. E. Noland (1951).

In 1972 discharge of the storm sewers and intermittent streams to Lake Wingra was about 100 mm or 3.9 in (0.048 m^3/s or 1.7 ft^3/s). Discharge at the lake outlet was about 210 mm or 8.3 in (0.11 m^3/s or 3.9 ft^3/s). The greater discharge at the lake outlet (110 mm or 4.3 in greater) represents the balance between additions to the lake from ground water (including spring discharge) and by precipitation on the lake surface, and losses from the lake by ground-water outflow and by evaporation from the lake surface. Differences in the balance of water entering and leaving the lake are reflected in changes in water stored in the lake. In 1972 the lake level was the same at the end of the year as in the beginning, so there was no net change in storage that year.

Effects of Ground-Water Withdrawal on Surface Water

Before the development of municipal-supply wells in Madison, Lake Wingra undoubtedly received ground-water discharge from both the upper and the sandstone aquifers. Withdrawal of water from municipal and industrial wells eliminated discharge to the lake from the sandstone aquifer and induced recharge from the upper aquifer to the sandstone aquifer, thereby reducing the discharge from the upper aquifer to the lake. Withdrawals of water increased from less than 4,000 m^3/d (140,000 ft^3/d) in 1882 to about 120,000 m^3/d (4,200,000 ft^3/d) in 1970 (R. S. McLeod, 1975). This 30-fold increase in water withdrawals from the lower sandstone aquifer resulted in flow changes between the upper and the sandstone aquifers. R. S. McLeod (1975) computed these flow changes by means of a digital model of the aquifer system in the Madison area. The change in flow rates in the Lake Wingra area by 1970 resulted in increased recharge from the upper aquifer to the sandstone aquifer ranging from about 15 mm (0.6 in) of water in the western part of the basin to about 460 mm (18 in) in the eastern part that year. The average annual increase of recharge from the upper to the sandstone aquifer in the Lake Wingra basin is estimated to be 80 mm (3 in).

The decreased ground-water discharge to the lake caused by pumping from the sandstone aquifer results in a lower rate of flow through the lake (Cline, 1965, p. 61), so the time required to flush the lake is greater. The volume of water moving into and out of Lake Wingra annually is about twice the total volume of the lake. Before the large withdrawals of water from the sandstone aquifer, the volume of water moving through the lake in 1 year must have been even greater.

Water Quality

The quality of water in Lake Wingra depends on the quality of water in the several sources entering the lake and on chemical changes taking place in the lake. Water discharged at the lake outlet is generally representative of the quality of the lake, except during periods of rapid runoff, when mixing may be incomplete.

Surface Runoff

The water entering Lake Wingra through storm drains and Marshland Creek probably is of the calcium magnesium bicarbonate type except during periods of snowmelt, when road salt adds large quantities of sodium and chloride to the runoff (table 7). Specific conductance, an indicator of the concentration of dissolved solids, was measured periodically. It ranged from 180 to 850 micromhos in 10 samples of water from Marshland Creek, and from 80 to 5,000 micromhos in 8 samples from 2 storm sewers (table 8). The variation in quality of the surface runoff is due, in part, to variations in discharge, but the extremely high values occur at times of snowmelt and are attributed to road salt.

Ground Water

The water discharged by springs to Lake Wingra is of the calcium bicarbonate type and is much more uniform in quality than the surface runoff. Chemical analyses of representative samples of water from the springs are listed in table 9. Kluesener (1972, p. 196-202) lists analyses of samples from four of the springs collected about twice monthly from January 1970 through April 1971. Specific conductance and calcium concentration of these samples are summarized below:

Spring number	Specific conductance (micromhos)			Calcium (Ca^{++}) (milligrams per litre)		
	Max	Min	Mean	Max	Min	Mean
Dn- 5 sp	620	540	580	84	61	77
Dn- 6 sp	760	645	690	95	71	88
Dn- 9 sp	920	640	735	103	80	90
Dn-12 sp	640	540	580	87	53	79

Table 7.--Chemical analyses of samples of water from storm sewers and creeks.

[Analyses in milligrams per litre except specific conductance and pH, in standard units.]

	Manitou Way storm sewer	Nakoma Road storm sewer	Glenway Street storm sewer	Knickerbocker Street storm sewer	Van Buren Street storm sewer	Marshland Creek	Lake Wingra outlet
Date collected (1973)	8-23	8-23	8-23	8-23	8-23	4-18	4-18
Calcium (Ca)	11	9.4	8.5	7.4	8.6	65	54
Magnesium (Mg)	3.7	3.4	2.6	2.2	3.1	6.8	25
Sodium (Na)	7.8	7.3	5.4	2.6	6.0	95	38
Potassium (K)	3.1	2.7	2.4	3.5	4.5	3.1	2.8
Bicarbonate (HCO_3)	46	40	35	28	38	136	170
Carbonate (CO_3)	0	0	0	0	0	0	0
Sulfate (SO_4)	11	9.0	10	9.2	11	15	71
Chloride (Cl)	9.2	6.8	3.9	2.0	5.8	190	76
Fluoride (F)	.1	.1	.1	.1	.1	.5	.2
Nitrate (NO_3)	2.7	4.4	3.4	3.4	3.1	.2	2.6
Dissolved solids	77	70	52	46	71	463	327
Hardness $CaCO_3$	42	38	32	28	34	190	239
Hardness Noncarbonate	5	4	4	4	4	78	99
Specific conductance	131	115	96	79	111	820	574
pH	6.7	6.8	6.6	6.5	6.5	7.5	7.5

Table 8.--Discharge and specific conductance of water from Marshland Creek and storm sewers.

Date collected	Discharge (m^3/s)	Specific conductance (micromhos)
	Marshland Creek	
Mar. 14, 1971	0.053	850
Mar. 16, 1971	.018	420
Mar. 29, 1971	.027	620
Mar. 30, 1971	.014	495
Mar. 31, 1971	.016	400
Apr. 12, 1971	.234	450
Apr. 13, 1971	.087	350
June 2, 1971	.004	650
Nov. 2, 1971	.069	180
Apr. 18, 1973	-----	820
	Nakoma Road Storm Sewer	
Mar. 7, 1972	.183	5,000
Mar. 11, 1972	.509	800
Mar. 1, 1973	.430	480
Aug. 23, 1973	-----	115
	Glenway Street Storm Sewer	
Mar. 7, 1972	.067	3,300
Mar. 11, 1972	.150	1,000
Apr. 21, 1972	.342	80
Aug. 23, 1973	-----	96

Springs Dn-9 sp and Dn-6 sp discharge water with a relatively high chloride concentration at times. The chloride probably is derived from infiltration of water containing road salt.

Water discharged to the southwest end of the lake by upward percolation probably is similar to that discharged by the flowing well at the Nakoma Golf Course (Dn-1005). This is a calcium magnesium bicarbonate water similar to that discharged by the springs (table 9).

Table 9.--Chemical analyses of samples of water from springs and a well.

[Analyses in milligrams per litre except specific conductance and pH, in standard units.]

		Dn-5 (spring)	Dn-6 (spring)	Dn-9 (spring)	Dn-12 (spring)	Dn-1005 (well)
Date collected (1973)		4-4	4-4	4-18	4-18	4-4
Calcium (Ca)		77	97	130	90	86
Magnesium (Mg)		35	40	64	41	38
Sodium (Na)		4.7	30	41	5.0	5.0
Potassium (K)		1.1	1.5	3.5	.8	1.7
Bicarbonate (HCO_3)		350	386	442	388	384
Carbonate (CO_3)		0	0	0	0	0
Sulfate (SO_4)		26	38	81	45	35
Chloride (Cl)		9.3	69	140	14	12
Fluoride (F)		.1	.1	.2	.4	.1
Nitrate (NO_3)		13	14	16	3.8	8.3
Dissolved solids		341	506	780	413	376
Hardness	$CaCO_3$	340	408	590	390	370
	Noncarbonate	49	92	220	74	57
Specific conductance		594	853	1,200	665	652
pH		7.8	7.3	7.4	7.6	7.5

Lake Water

Water in Lake Wingra, also of the calcium magnesium bicarbonate type, is lower in dissolved solids (as indicated by specific conductance) than the ground water entering the lake (tables 7 and 9). Kluesener (1972, p. 187-188) lists analyses of 31 samples of water collected from the central part of the lake at a depth of 1 m (3.3 ft). The samples were collected about twice a month from January 1970 through April 1971. Specific conductance of 30 of these samples ranged from 340 to 550 micromhos and averaged 430 micromhos; calcium (Ca^{++}) concentration of 23 of the samples ranged from 21 to 47 mg/l (milligrams per litre) and averaged 34 mg/l. A chemical analysis of a sample of water from the Lake Wingra outlet (Murphy Creek) listed in table 7 has a relatively high sodium chloride concentration, probably attributable to runoff affected by road salt.

WATER BUDGET FOR LAKE WINGRA

A preceding section on the hydrology of the Lake Wingra basin applied to the basin as a whole: the following discussion is concerned with the water budget of one part of the basin--the lake itself. A quantity of water within the basin may be expressed as a water depth on either the entire basin or as a water depth on only the lake. For example, surface-water discharge at the lake outlet in 1972 is equivalent to about 2,380 mm (93.5 in) on the lake surface (table 10) or 210 mm (8.3 in) on the entire basin (table 6).

Water enters Lake Wingra as precipitation on the lake surface, surface runoff, and ground-water inflow; water leaves the lake as water vapor, surface runoff at the lake outlet, and ground-water outflow. The altitude of the lake surface rises and falls with variations in the amount of inflow and outflow. A monthly summary of measured and estimated increments of inflow and outflow from January 1972 through May 1973 is included in table 10. All quantities in the table and in the following discussion are expressed as millimetres on the lake surface.

This study did not include changes in soil moisture and does not include these changes in the water budget.

Precipitation

Precipitation was computed as the average of at least five of the seven rain gages in the Lake Wingra area (numerous difficulties prevented the daily use of all seven). Winter snows on the lake displaces its own weight because of the elasticity of the ice. Consequently, lake levels recorded at the lake gage respond to increments of precipitation in winter as well as in summer. Some discrepancies in the effects of winter precipitation may occur because of snow blowing onto or off the lake. Precipitation in the calendar year 1972 totaled 763 mm (30.1 in) on the lake surface. In the year ending May 31, 1973, precipitation was 1,142 mm (44.96 in). In the 17-month period ending May 31, 1973, precipitation totaled 1,326 mm (52.20 in).

Surface Runoff

About three-fourths of the 14.3-km^2 (5.5-mi^2) land area draining into Lake Wingra is urban (streets and roads, parking lots, houses, lawns, golf courses, cemeteries, and parks); the remaining 3.9 km^2 (1.5 mi^2) is part of the University of Wisconsin Arboretum. Runoff from the urban area is flashy, rising to a peak during or shortly after heavy rains or snowmelt and declining to nothing during rainless periods. Surface runoff from the arboretum area is relatively small. Surface runoff in five storm sewers and in Marshland Creek was measured continuously at six gaging stations (table 3). These gaging stations measure runoff from 10.85 km^2 (4.19 mi^2). On the basis of topography and relative amounts of paved and unpaved areas, surface runoff from the ungaged 3.44 km^2 (1.33 mi^2) was estimated to be about 0.3 of the discharge of the Nakoma Road sewer. Measured and estimated surface runoff in calendar year 1972 was equivalent to 1,112 mm (43.8 in) on the lake surface. In the year ending May 31, 1973, surface runoff was equivalent to 1,663 mm (65.5 in). In the 17-month period ending May 31, 1973, surface runoff was equivalent to 2,262 mm (89.1 in).

Surface runoff is the most variable component of inflow to Lake Wingra. The maximum monthly runoff, 362 mm (14.3 in) for the period January 1, 1972, through May 31, 1973, was more than 100 times the minimum monthly runoff of 3 mm (0.13 in).

Ground-Water Inflow

Ground water enters Lake Wingra by discharge of springs and by seepage through the sediments near the lake margin. Ground-water discharge has been measured at eight springs (table 4 and pl. 1). It has been measured at least monthly at three springs--Dn-5, 8, and 6 sp. Occasional measurements of discharge have been made at four other springs--Dn-12, 13, 10, and 9 sp. A few measurements also have been made of ground-water discharge in lower Marshland Creek and Nakoma Creek, a small stream draining spring Dn-8 sp and Nakoma Golf Course. Another spring near spring Dn-6 sp has not been measured, but discharge is estimated to be one-tenth that of spring Dn-6 sp.

Measured and estimated ground-water discharges to springs and streams are summarized in table 10. In 1972 measured and estimated ground-water discharge to these springs and streams was equivalent to 1,315 mm (51.76 in) on the lake surface. In the year ending May 31, 1973, ground-water discharge was 1,313 mm (51.70 in). In the 17 months ending May 31, 1973, discharge was 1,904 mm (74.98 in).

Ground-water discharge is much less variable than surface runoff. The maximum monthly ground-water discharge for the period January 1, 1972, through May 31, 1973, (140 mm or 5.5 in) was only 1.6 times that of the minimum monthly discharge (860 mm or 2.6 in).

In addition to the visible discharge of springs and seeps, an inflow of ground water occurs by upward percolation to the marsh southwest of the lake and probably through bottom sediments in the southwestern part of the lake itself. Differences in water levels averaging about 2.6 m (8.5 ft) in adjacent wells (both in the upper aquifer) at the Nakoma Golf Course indicate a potential for upward movement of ground water. The deeper well (Dn-1005), screened about 14 m (45.9 ft) below lake level, has water levels averaging about 3.4 m (11 ft) above lake level. The shallower well (Dn-1004), screened about 3 m (9.8 ft) below lake level, has water levels averaging about 0.8 m (2.5 ft) above lake level.

Table 10.--Monthly inflow and outflow and lake-stage changes for January 1972

[All figures in

	Inflow			
	Precipitation	Surface runoff 1/	Springs 2/	Inflow
1972				
January	7	3	116	126
February	7	44	104	155
March	43	362	123	528
April	57	122	131	310
May	70	68	117	255
June	26	5	92	123
July	87	30	86	203
August	194	194	108	496
September	113	141	125	379
October	82	75	107	264
November	26	15	102	143
December	51	53	104	208
1973				
January	39	133	109	280
February	41	156	95	292
March	129	334	116	580
April	194	264	129	588
May	160	263	140	563

1/ About 75 percent of the drainage area was measured; 25 percent was estimated.

2/ Measured and estimated.

3/ Computed from EVAP program of Lake Wingra study office.

Lake Wingra (exclusive of ground-water flow through lake bottom), through May 1973.

millimetres on lake surface]

Outflow			Lake-stage changes		
Evaporation 3/	Discharge at lake outlet	Outflow	Computed change in lake stage	Actual change at gage	Difference, computed minus actual
9	155	164	-38	-21	-17
12	96	108	47	-15	62
36	436	472	56	46	10
54	362	416	-106	-6	-100
108	267	375	-120	-76	-44
129	28	157	-34	-61	27
112	28	140	63	3	60
90	272	362	134	149	-15
52	280	332	47	-18	65
33	205	238	26	-25	51
11	145	156	-13	-37	24
4	104	108	100	61	39
11	316	328	-48	-18	-30
14	304	318	-25	-12	-13
37	644	680	-101	6	-107
53	568	621	-34	61	-95
76	590	666	-102	-12	-90

The quantity of water moving to and from the lake depends on the hydraulic conductivity of the sediments under the lake, the hydraulic gradient between deeper and shallower sediments, and the area over which these differences apply.

The hydraulic conductivity of the sediments underlying the lake is estimated to be 0.02 m/d (0.07 ft/d). This estimate is based on laboratory determinations of five samples of lake-bed materials. Although only about 1 m (3.3 ft) of bottom sediments was sampled at each site, and the samples were considerably compressed in coring, the reported hydraulic conductivities appear reasonable for the materials underlying the lake. The hydraulic gradient between the deeper and shallower sediments at the southwest end of the lake is about 0.24. The estimated upward percolation in this area is 0.02 (hydraulic conductivity) x 0.24 (hydraulic gradient) = 0.0048 $(m^3/d)/m^2$ [0.016 $(ft^3/d)/ft^2$].

Water levels in observation wells suggest that upward percolation to the lake and marsh may occur in an area of 0.26 km^2 (0.10 mi^2). Accordingly, other than springs and seeps listed in table 2, ground-water inflow to the lake is estimated to be 0.0001 m/d (0.0003 ft/d) or 0.36 m/yr (1.2 ft/yr) over the entire lake surface. The rate of ground-water inflow no doubt varies as water levels fluctuate in response to recharge and pumping city wells, but available data are insufficient to determine the magnitude of these variations. Because the data supporting the above estimates are so meager and monthly variations are unknown, this increment of ground-water inflow is not included in the monthly water budget presented in table 10, but it is included in the annual budget presented under "Water Budget--Summary".

Evaporation

Evaporation from the lake and lagoons was estimated by D. D. Huff (written commun., 1973) from a computer program utilizing precipitation, air temperature, dew-point temperature, wind velocity, and solar radiation. Evaporation is greatest in midsummer and least in midwinter. Evaporation is the only item in the water budget that is not directly related to the amount of precipitation. During dry years evaporation from Lake Wingra may be nearly as great as precipitation; in wet years precipitation may be 80 percent greater than evaporation. Evaporation in calendar year 1972 was estimated to total 650 mm (25.6 in). In the year ending May 31, 1973, evaporation was 622 mm (24.5 in). In the 17 months ending May 31, 1973, evaporation was 841 mm (33.1 in).

Not included in these estimates is evaporation and transpiration from the marsh area (0.41 km^2 or 0.16 mi^2) at the southwest end of the lake. On an annual basis evapotranspiration may be offset by precipitation on this area, but evapotranspiration may greatly exceed precipitation during the summer.

A reverse process to evaporation, condensation of water vapor on the lake surface, also may occur when the lake is colder than the air. No estimate has been made of the amount of this condensation, but it would be expected to be relatively large in early spring when the water temperatures generally are lower than air temperatures.

Lake Wingra Outlet

Outflow of Lake Wingra to Murphy Creek, measured continuously at the outlet gaging station, probably is the most accurate of all increments of the water budget. Outflow varies with lake stage and generally is greatest during the spring snowmelt. Discharge at the lake outlet in calendar year 1972 was equivalent to 2,378 mm (93.63 in) on the lake surface. In the year ending May 31, 1973, discharge at the Lake Wingra outlet was 3,484 mm (137.2 in). In the 17-month period ending May 31, 1973, discharge was equivalent to 4,800 mm (189.0 in).

Errors in measurement of discharge could occur if floating debris were to become temporarily lodged in the V-notch control at the gaging station, but no evidence of such debris has been detected. Another possible source of error in lake-outlet discharge is a canal that bypasses the lake-outlet gage. This canal leads from the Vilas Park lagoon and, before September 1972, was occasionally used to flush out the lagoon in summer. No record was kept of the times the canal was opened, and the gate reportedly was opened at times by unauthorized personnel, so the timing and amount of water bypassing the gage are unknown.

Ground-Water Outflow

Water levels in observation wells suggest that downward leakage may occur in an area of about 1 km^2 (0.4 mi^2) at the east end of Lake Wingra. Two adjacent wells near the east edge of the lake (both in the upper aquifer), about 0.5 km (0.3 mi) south of the lake outlet, have a water-level differential of 1.4 m (4.6 ft). The deeper well (Dn-1001), screened 19 m (62 ft) below lake level, has water levels averaging 1.8 m (5.9 ft) below lake level. The shallower well (Dn-1000), screened 2.5 m (8.2 ft) below lake level, has water levels averaging 0.4 m (1.3 ft) below lake level. The estimated downward leakage at the east end of the lake is 0.02 (hydraulic conductivity) x 0.08 (hydraulic gradient) = 0.0016 $(m^3/d)/m^2$ [0.0052 $(ft^3/d)/ft^2$]. Estimated downward leakage from the lake is equivalent to 0.0013 m/d (0.0046 ft/d) or 0.47 m/yr (1.5 ft/yr) over the lake surface.

The rate of ground-water outflow varies as water levels in deep and shallow aquifers vary with fluctuations in recharge and pumpage. Water levels in the two observation wells (Dn-1000 and Dn-1001) apparently are influenced by the rate of pumping of city wells; lower water levels generally correlate with higher pumping rates. Fluctuations in the deeper well are greater than those in the shallower well, and differences in water levels in the two wells suggest a possible correlation with pumpage. Although records of water-level fluctuations in these two wells could be used to indicate changes in the rate of ground-water outflow in the vicinity of the wells, water-level fluctuations in shallow and deep aquifers in other parts of the lake are not recorded. Consequently, ground-water outflow has not been included in the monthly budget in table 10, but it is included in the annual budget presented under "Water Budget--Summary".

Water Budget--Summary

Measurements and estimates of gains and losses to and from Lake Wingra are in approximate balance on an annual basis. For calendar year 1972 the water budget for Lake Wingra is as follows:

GAINS	Millimetres	LOSSES	Millimetres
Precipitation on lake surface[1/]	763	Evaporation from lake surface[4/]	650
Surface runoff[2/]	1,112	Discharge at Lake Wingra outlet[1/]	2,378
Springs[2/]	1,315	Ground-water outflow[3/]	470
Other ground-water inflow[3/]	370		
Totals	3,560		3,498

1/ Measured

2/ Measured and estimated

3/ Estimated

4/ Calculated

The level of Lake Wingra was the same at the end of the year as it was in the beginning, so the measured and estimated additions exceeded the measured and estimated withdrawals by 62 mm (2.5 in). This is less than 2 percent of the total annual budget and is much less than the probable error of any measured or estimated item in the budget.

For the 12-month period ending May 31, 1973, the water budget for Lake Wingra is as follows:

GAINS	Millimetres	LOSSES	Millimetres
Precipitation on lake surface[1/]	1,142	Evaporation from lake surface[4/]	622
Surface runoff[2/]	1,663	Discharge at Lake Wingra outlet[1/]	3,484
Springs[2/]	1,313	Ground-water outflow[3/]	470
Other ground-water inflow[3/]	370		
Totals	4,488		4,576

1/ Measured

2/ Measured and estimated

3/ Estimated

4/ Calculated

The level of Lake Wingra rose 97 mm (3.8 in) during this 12-month period, so the measured and estimated withdrawals exceeded the measured and estimated additions by about 185 mm (7.3 in). This is about 4 percent of the total annual budget.

For the 17-month period ending May 31, 1973, the water budget for Lake Wingra is as follows:

GAINS	Millimetres	LOSSES	Millimetres
Precipitation on lake surface[1/]	1,326	Evaporation from lake surface[4/]	841
Surface runoff[2/]	2,262	Discharge at Lake Wingra outlet[1/]	4,800
Springs[2/]	1,904		
Other ground-water inflow[3/]	530	Ground-water outflow[3/]	670
Totals	6,022		6,311

[1/]Measured

[2/]Measured and estimated

[3/]Estimated

[4/]Calculated

The level of Lake Wingra rose 24 mm (0.96 in) during this 17-month period, so the measured and estimated withdrawals exceeded the measured and estimated additions by 313 mm (12.3 in). This is about 5 percent of the total budget for the 17-month period.

As indicated above, the measured and estimated gains approximately balanced the measured and estimated losses on an annual basis. However, the monthly budget (which does not include ground-water inflow and outflow to and from the lake other than visible springs) shows substantial discrepancy (table 10). During January 1, 1972 through May 31, 1973, these discrepancies ranged from +64 mm (2.5 in) to -107 mm (4.2 in). A negative discrepancy generally occurs when lake stages are high (high discharge), and a positive discrepancy is associated with low lake stages. In other words, when lake stage is high more discharge occurs than is measured at the lake outlet. When lake stage is low, there was more inflow and less outflow than was measured.

These discrepancies are largely the result of ungaged flow bypassing the lake outlet gage, ground-water inflow and outflow components that are not included in the monthly computations, seasonal variation of ice-or soil-moisture storage in the wetland area, and measurement inaccuracies inherent in the several other components of inflow and outflow. When lake stage is high (outlet discharge large) some flow bypasses the outlet gage through the lagoons and a 0.76 m (30-in) storm sewer at the north side of the lake. (Measurements indicate that this flow could exceed 15 mm (0.6 in) per month or 180 mm (7 in) per year.) However, this flow was not gaged continuously but is estimated in the water budget. Data were insufficient to compute monthly variations of ground-water inflow (other than springs) and outflow, or to compute the effect of seasonal changes in ice storage or soil-moisture storage, so these elements probably contribute to the observed discrepancies. However, the budget on an annual basis is probably adequate for predictive purposes and could be much improved on a monthly basis if records of the flow bypassing the lake outlet gage were obtained.

SELECTED REFERENCES

Cline, D. R., 1965, Geology and ground-water resources of Dane County, Wisconsin: U.S. Geol. Survey Water-Supply Paper 1779-U, 64 p.

Cullen, R. S., Jacques, J. E., and Huff, D. D., 1972, Lake Wingra drainage basin, sub-basin configuration: Univ. of Wisconsin, U.S. Internat. Biome Period, Lake Wingra Study map.

Dettman, E. H., and Huff, D. D., 1972, A lake water-balance model: Univ. of Wisconsin, Eastern Deciduous Forest Biome Memo. Rept. 72-126, 22 p.

Huff, D. D., Koonce, J. F., Ivarson, W. R., Weiler, P. R., Dettman, E. H., and Harris, R. F., 1973, Simulation of urban runoff, nutrient loading, and biotic response of a shallow eutrophic lake, in Middlebrooks, E. J., Falkenborg, D. H., and Maloney, T. E., eds., Modeling the eutrophication process: Utah Water Research Laboratory, Utah State University, Logan, p. 33-55.

Juday, Chancey, 1914, Lakes of the Yahara basin, in The inland lakes of Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 27, Sci. Ser. 9, p. 11-29.

Kluesener, J. W., 1972, Nutrient transport and transformation in Lake Wingra, Wisconsin: Univ. of Wisconsin, Eastern Deciduous Forest Biome Memo. Rept. 72-42, 180 p.

McLeod, R. S., 1975, A digital-computer model for estimating drawdowns in the sandstone aquifer in Dane County, Wisconsin: Wisconsin Geol. and Nat. History Survey Inf. Circ. 28, 91 p.

Noland, W. E., 1951, The hydrography, fish and turtle population of Lake Wingra: Trans. Wisconsin Acad. Sci. Arts and Letters, v. 40, pt. 2, p. 5-58.

U. S. GOVERNMENT PRINTING OFFICE: 1975--652-478