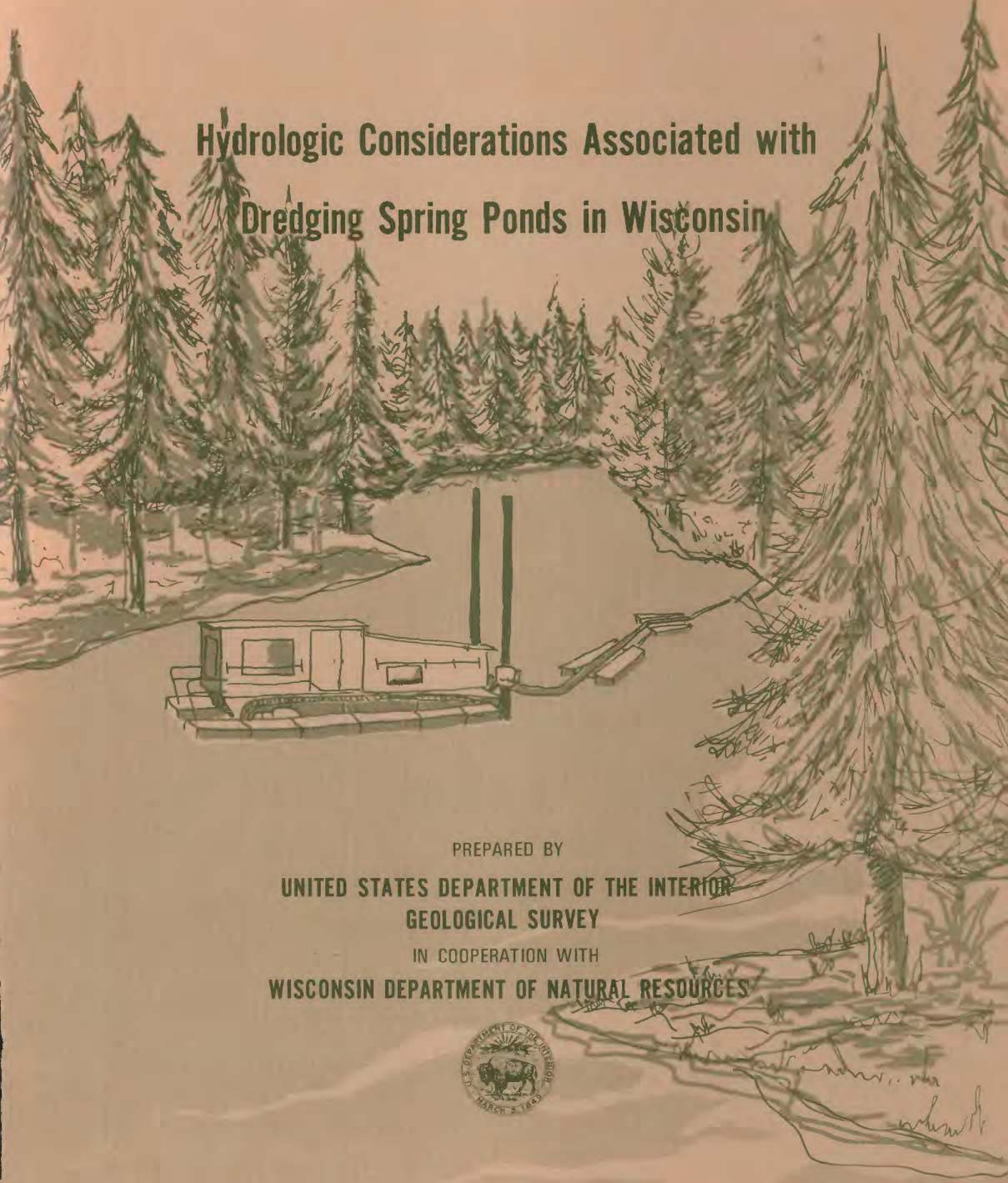
WATER RESOURCES INVESTIGATIONS 77-18

Hydrologic Considerations Associated with Dredging Spring Ponds in Wisconsin



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16. Abstracts

Spring ponds (small spring-fed bodies of water) are natural features of some glaciated areas. The purpose of this study was to determine the hydrology of three spring ponds in northeastern Wisconsin and the effect that dredging has had on the ponds. Sediments were dredged from Sunshine and Krause Ponds. Maxwell Pond, which was not dredged, was used as a hydrologic control.

Sediment accumulation since glaciation caused a 2-fold reduction in the surface area of Sunshine Pond and a 4-fold reduction in the area of Krause Pond. Volume reduction caused by sediment accumulation was 9-fold in Sunshine Pond and 28-fold in Krause Pond.

Dredging 4.2 acre-feet of sediment from Sunshine Pond caused a 41-percent increase in ground-water inflow. Dredging 4.0 acre-feet of sediments from Krause Pond caused only a 2-percent increase in ground-water inflow.

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FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

Factors for converting English units to SI units are shown to four significant figures.

English	Multiply by	SI
acres	4.047×10^{-1}	ha (hectares)
acre-ft (acre-feet)	1.233×10^{3}	m^3 (cubic meters)
ft^3/s (cubic feet per second)	2.832×10^{-2}	m^3/s (cubic meters per second)
ft (feet)	3.048×10^{-1}	m (meters)
in (inches)	2.54×10^{1}	mm (millimeters)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)

Hydrologic Considerations Associated with Dredging Spring Ponds in Wisconsin

W.J. Rose

ABSTRACT

Spring ponds (small spring-fed bodies of water) are natural features of some glaciated areas and have a continuous flow of ground water entering through their bottoms and exiting through surface outlets.

Dredging has been used to restore ponds that have been filled in part or totally by sediment. The purpose of the study was to determine the hydrology of selected spring ponds and the effect that dredging has had on the ponds. Three ponds, Maxwell, Sunshine, and Krause Ponds, in northeastern Wisconsin were studied. Sediments were dredged from Sunshine and Krause Ponds. Maxwell Pond, which was not dredged, was a hydrologic control to aid in distinguishing changes produced by dredging from those that were natural.

Ground water from glacial deposits is the source of most of the water flowing in spring ponds and streams in the study area. Average annual ground-water recharge in the study area is about 13 inches. Ground-water discharge contributed 97 percent of the total flow in the Red River, a typical stream in the study area, during the 1973 water year.

Ground water and surface water in the study area are of a calcium magnesium bicarbonate type. Dissolved-solids concentration ranges from 170 to 250 milligrams per liter. Temperature of ground water discharging into the spring ponds in the study ranged from 6° to 7° Celsius.

Accumulation of silt, clay, marl, and organic material since glaciation caused a reduction in both surface area and volume of spring ponds. Reduction in surface area was two-fold in Sunshine Pond and four-fold in Krause Pond. Reduction in volume was 9-fold in Sunshine Pond and 28-fold in Krause Pond.

Ground-water discharge supplied 99.0, 99.5, and 96.0 percent of the total flow into Maxwell, Sunshine, and Krause Ponds, respectively. Average flow in Maxwell Pond outlet from October 1968 to December 1973 was 1.86 cubic feet per second with a maximum daily mean flow two times greater than the average flow. Average flow in Sunshine Pond outlet during October 1968 to June 1970 (before dredging) was 0.48 cubic feet per second; the maximum daily mean flow was 1.6 times greater than the average flow. In Krause Pond outlet during October 1968 to April 1971 (before dredging) the average flow was 0.48 cubic foot per second; the maximum daily mean flow was 3.2 times greater than the average flow.

In 1970, 4.2 acre-feet of sediment was dredged from Sunshine Pond. Dredging improved the hydraulic connection between the pond and the aquifer, resulting in a 41 percent increase in ground-water inflow.

During 1971, 4.0 acre-feet of sediment was dredged from Krause Pond. Only a 2 percent increase in ground-water inflow was achieved because clay and silt layers underlying most of the pond were not affected by dredging.

INTRODUCTION

Bodies of water in kettle depressions in some glaciated areas of Wisconsin, locally called "spring ponds", are fed by ground water entering through the bottom and shore, and are drained through a surface outlet. They range in size from less than an acre to many acres. Because of popular local usage, the term "spring pond" is used in this report.

Some spring ponds provide a suitable habitat for game fish. A steady flow of high-quality water enables some spring ponds and the streams into which they flow to support trout.

Sedimentation since the time of glaciation has greatly reduced the surface area and volume of water in spring ponds. In some ponds less than a foot of water overlies several feet of sediment. In extreme cases ponds become entirely filled with sediment. In addition to reducing pond volume, sediment probably degrades fish habitat by reducing the rate of ground-water inflow.

In recent years, attempts have been made to restore spring ponds in advanced stages of sedimentation. The most common restoration technique has been to remove a large volume of sediment by dredging. Basic knowledge of spring-pond hydrology will help in planning and appraising the effectiveness of restoration projects.

PURPOSE AND SCOPE

This report describes the hydrology of selected spring ponds and the effect that dredging has had on the ponds and their surrounding areas. The report emphasizes the water budgets for the ponds, discusses the hydrologic system which contains the ponds, and briefly describes water quality in the study area.

This study was conducted in cooperation with the Wisconsin Department of Natural Resources (DNR). The study supplemented and coincided with a DNR study of spring-pond ecology.

Three spring ponds, all within 10 mi of each other, were selected for study. The study ponds are representative of many spring ponds in northeastern Wisconsin that have large accumulations of sediment. The limits of the study area were set so as to include the ground-water system supplying the spring flow, and the streams into which the three ponds flow. The geology and hydrology of the study area are typical of many glaciated areas in which spring ponds occur. Information gained in this study for evaluating spring-pond hydrology and the effects of dredging should be useful for evaluating spring ponds in similar areas.

METHOD OF STUDY

Hydrologic monitoring began in October 1968 and continued through November 1973. Two of the three study ponds were dredged by the DNR using a hydraulic dredge--Sunshine Pond in the summer of 1970 and Krause Pond in the summer of 1971. Maxwell Pond, undredged, served as a hydrologic control to help distinguish changes resulting from dredging from natural changes.

Data collection consisted of single, periodic, or continuous hydrologic or geologic measurements. Continuous-recording stream gages monitored flow in the pond outlet channels. Water levels in observation wells were measured at 4- to 6-week intervals to define local ground-water fluctuation and hydraulic gradients. Table 1 is a summary of principal wells used in the study. Recorders monitored water temperature in the ponds and in their outlets. Borings in and near the ponds were used to determine the extent and character of sediments. Hydrographic mapping by the DNR of the ponds before and after dredging were used to determine dredged volumes and changes in bottom configurations. Chemical analyses of water from the ponds and selected observation wells before and after dredging indicated the effect of dredging on water quality.

In addition to the monitoring networks at each pond, data were obtained to define the general hydrology of the study area. Water-level altitude in wells, streams, and lakes were measured to construct a water-table map from which the direction of ground-water movement was determined. Data from a gaging station, which was operated on the Red River during the 1973 water year, defined some of the flow characteristics of a typical stream in the study area. The water-table map and Red River flow data provided a basis for estimating average annual recharge.

Table 1.--Summary of principal wells used in study

Well number[1/]	General location	Depth (ft)	Water quality analyses in table 2	Flowing
La-338	0.2 mi north of Krause Pond	68	Yes	No
La-429	6 mi southeast of Antigo	100	No	No
La-430	10 ft south of Krause Pond	30	Yes	Yes
La-464	3 mi northwest of Polar	89	Yes	No
La-492	70 ft south of Krause Pond	30	No	No
La-493	10 ft south of Krause Pond	10	No	Yes
La-494	10 ft south of Krause Pond	20	No	Yes
La-495	20 ft north of Krause Pond	15	No	Yes
La-496	20 ft north of Krause Pond	30	No	Yes
La-507	Northeast shore of Sunshine Pond	13	No	Yes
La-508	10 ft west of Sunshine Pond	30	Yes	Yes
La-509	70 ft southwest of Sunshine Pond	27	No	No
La-510	Northwest shore of Sunshine Pond	10	No	Yes
La-511	10 ft southwest of Maxwell Pond	10	Yes	Yes
La-512	40 ft west of Maxwell Pond	5	No	Yes

[1/] A two-part system of letters and numbers is used to designate wells in this report. The first part, La, is the county abbreviation. The second part is the serial number assigned in the order that the well was recorded in the county.

THE STUDY AREA

LOCATION

The study area is in Langlade County in northeastern Wisconsin near the city of Antigo (fig. 1). The eastern part of the area is in the Wolf River basin and the western part is in the Wisconsin River basin (pl. 1). Locations of the three study ponds are shown on figure 1 and plate 1.

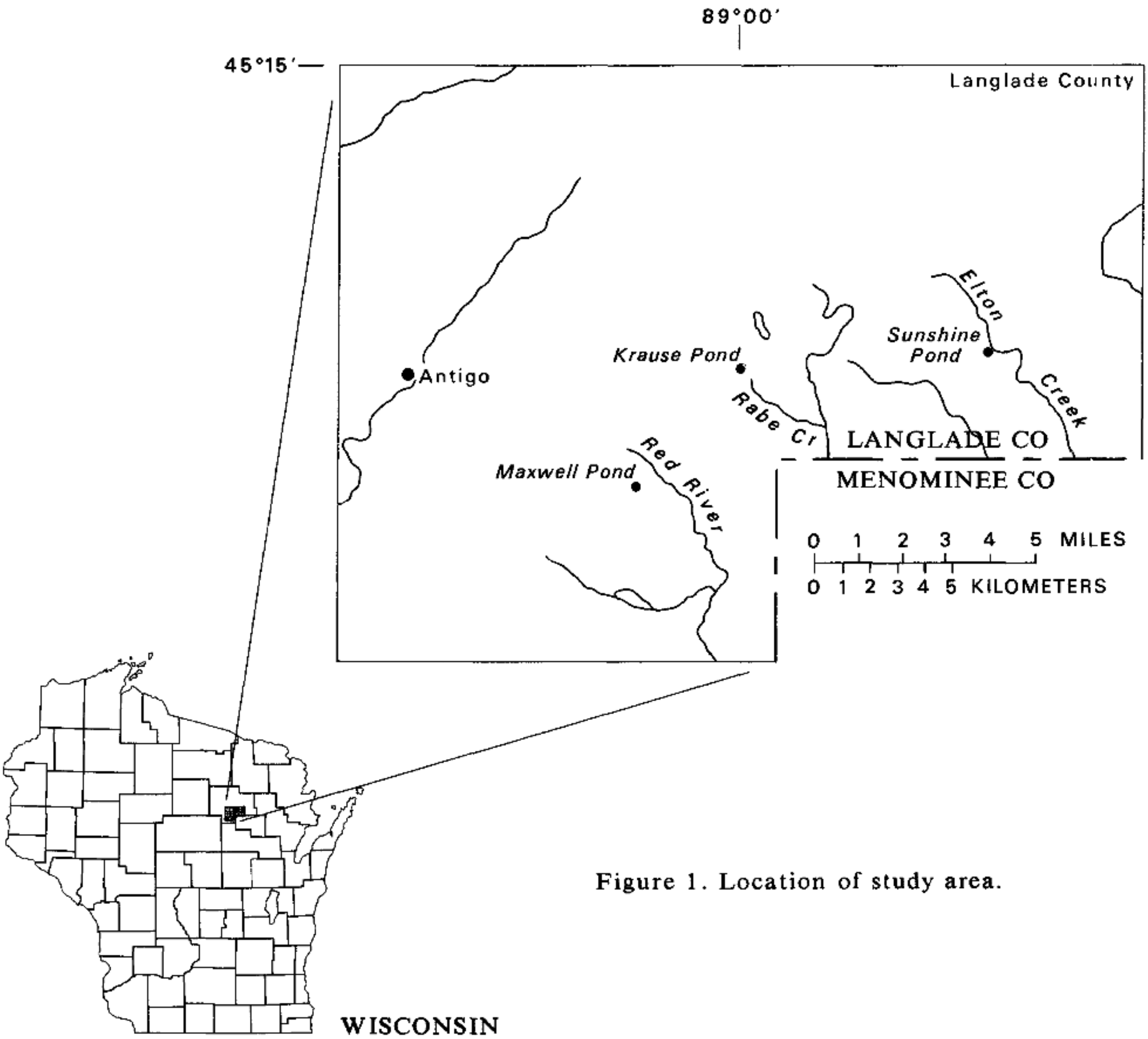


Figure 1. Location of study area.

GEOLOGY AND HYDROLOGY

The topographic and geologic characteristics of the study area form a fixed "framework" upon which variable climatic factors act to cause ground-water movement and flow in springs and streams. Figure 2 illustrates the relationship between climatic factors, ground-water levels, spring-pond outflow, and streamflow. The rising water level in well La-429 after February 1973 reflects the ground-water recharge from snowmelt and rainfall. Base flow in the Red River and in Maxwell Pond outlet reflect the rising ground-water levels after February 1973. Snowmelt and rainfall in March 1973 caused greater than normal flow in the Red River.

Glacial deposits are the main aquifer. The western part of the study area is a relatively flat glacial outwash plain with surface drainage toward Spring Brook. The eastern part, an area of end moraines and pitted outwash, is characterized by sharp local relief, many kettle depressions and, in general, poorly developed surface drainage. Impermeable crystalline bedrock of Precambrian age underlies the glacial deposits.

Approximately 13 in of the average annual precipitation in the study area becomes ground-water recharge. Average annual precipitation at Antigo, based on National Weather Service records during 1931-60, is 30.82 in. Average annual recharge was calculated on the basis of 12 base-flow discharge measurements on the Red River during 1962-72. It was assumed that average annual recharge is approximately equal to average annual ground-water discharge above the gaging site. Recharge characteristics of the Red River basin are probably typical of most of the study area.

The 13 in of annual recharge compares favorably with recharge in other parts of Wisconsin having similar sand and gravel glacial deposits. Weeks and Stangland (1971, p. 53) determined that average recharge for seven stream basins in the central sand plain of Wisconsin ranged from 9.5 to 14.3 in during a 3-year period.

The ground-water basins of spring ponds and streams in the eastern part of the study area are larger than their topographic basins. Large sections of the ground-water basins are within the Spring Brook topographic basin (pl. 1).

Because of the high annual recharge and the large size of ground-water basins, ground-water discharge constitutes most of the streamflow in the southeastern part of the study area. As a result, streamflow is stable. During the 1973 water year, 97 percent of the total flow in the Red River was ground-water discharge. The minimum daily flow was only about 25 percent less than the mean flow.

Surface water and ground water in the study area are of a calcium magnesium bicarbonate type. The hardness of water, based on about 40 analyses, ranged from 103 to 220 mg/L (milligrams per liter). Dissolved-solids concentration ranged from 170 to 250 mg/L. The chemical composition of water from selected wells and spring ponds are given in table 2.

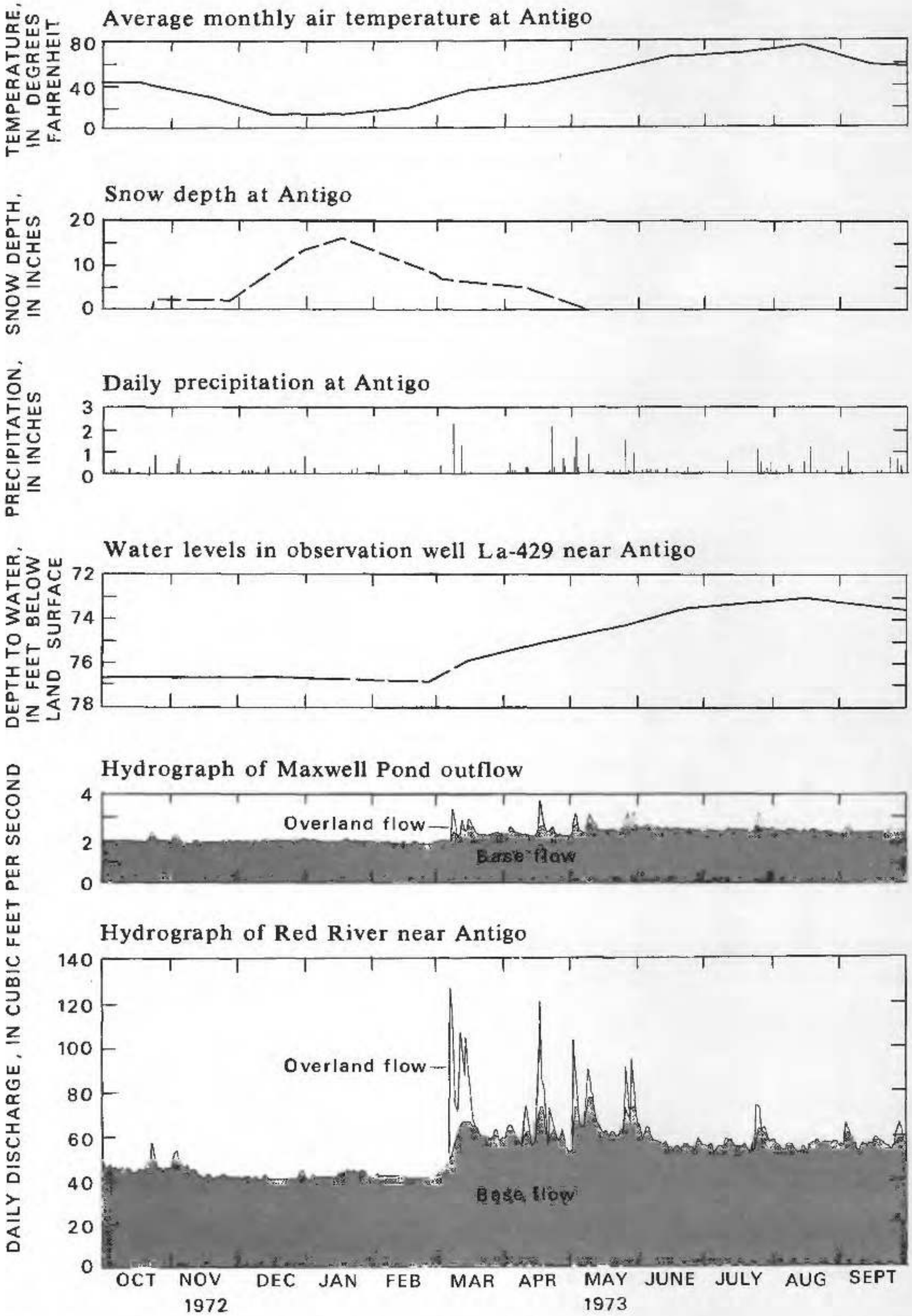


Figure 2. Comparison of temperature, snow depth, precipitation, ground-water levels, spring-pond outflow, and stream discharge.

Table 2.--Selected chemical analyses

(Chemical constituents given in milligrams per

Source of water	Date of collection	Discharge from spring pond (ft^3/s)	Depth of well (ft)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)
Well La-430	5-25-73		30	12	0.71	0.06	40	18
Well La-511	10-29-70		10	17	.01	.02	48	19
Well La-508	10-29-70		30	15	.29	.07	41	18
Well La-338	10-30-70		68	16	.02	0	47	22
Well La-464	9-22-71		89	14	.02	0	53	21
Maxwell Pond outlet	11-10-69	1.7		26			39	16
Maxwell Pond outlet	5- 8-72	1.9		13	.02	0	33	18
Sunshine Pond outlet (before dredging)	11-10-69	.48		16			40	19
Sunshine Pond outlet (after dredging)	5-12-71	.71		12	0	0	41	20
Krause Pond outlet (before dredging)	10-20-69	.54		23			43	18
Krause Pond outlet (after dredging)	5- 9-72	.58		15	.03	.01	34	20
Krause Pond outlet (after dredging)	8-24-72	.73		12	.20	.03	29	15

1/ Residue on evaporation at 180°C

of water from spring ponds and wells

liter. Analyses by U.S. Geological Survey.)

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids[1/]	Hardness as $CaCO_3$	Specific conductance in micromhos per centimeter at 25°C	pH (standard units)
1.7	0.9	198	0	6.2	4.8	0.2	4.7	198	180	318	7.8
2.2	.9	220	0	12	2.0	.4	14	203	200	371	8.0
2.1	1.6	206	0	13	2.0	.5	3.1	180	180	335	7.7
2.2	1.1	234	0	18	3.0	.5	9.0	221	210	394	7.8
.5	.8	202	0	22	11	.1	28	249	220	411	7.5
3.7	.8	180	8	4.3	1.1	.3	4.6	194	164	314	8.5
1.7	.6	174	5	5.8	1.0	.3	3.7	162	160	287	8.4
2.1	1.6	204	4	7.1	1.4	.5	1.7	184	178	341	8.3
2.1	1.6	216	0	8.0	1.5	.3	.8	193	180	344	7.8
3.0	1.0	206	0	7.5	1.5	.3	3.7	200	181	341	7.9
1.7	.8	190	0	9.0	2.0	.3	3.2	178	170	308	7.5
1.6	.7	142	0	7.8	3.0	.4	1.8	170	140	236	7.2

MAXWELL POND

LOCATION AND PHYSICAL DESCRIPTION

Maxwell Pond is about 6 mi southeast of Antigo, in the NW¼ sec. 3, T. 30 N., R. 12 E. The pond discharge flows into the Red River. The area near the pond is wooded and characterized by hilly end-moraine topography and by boulder till.

The surface area of Maxwell Pond (fig. 3) is 2.4 acres; mean depth is 2.8 ft. The water depth in 53 percent of the pond is less than 2 ft. However, one area at the west end of the pond is more than 16 ft deep.

WATER BUDGET FOR MAXWELL POND

Inflow

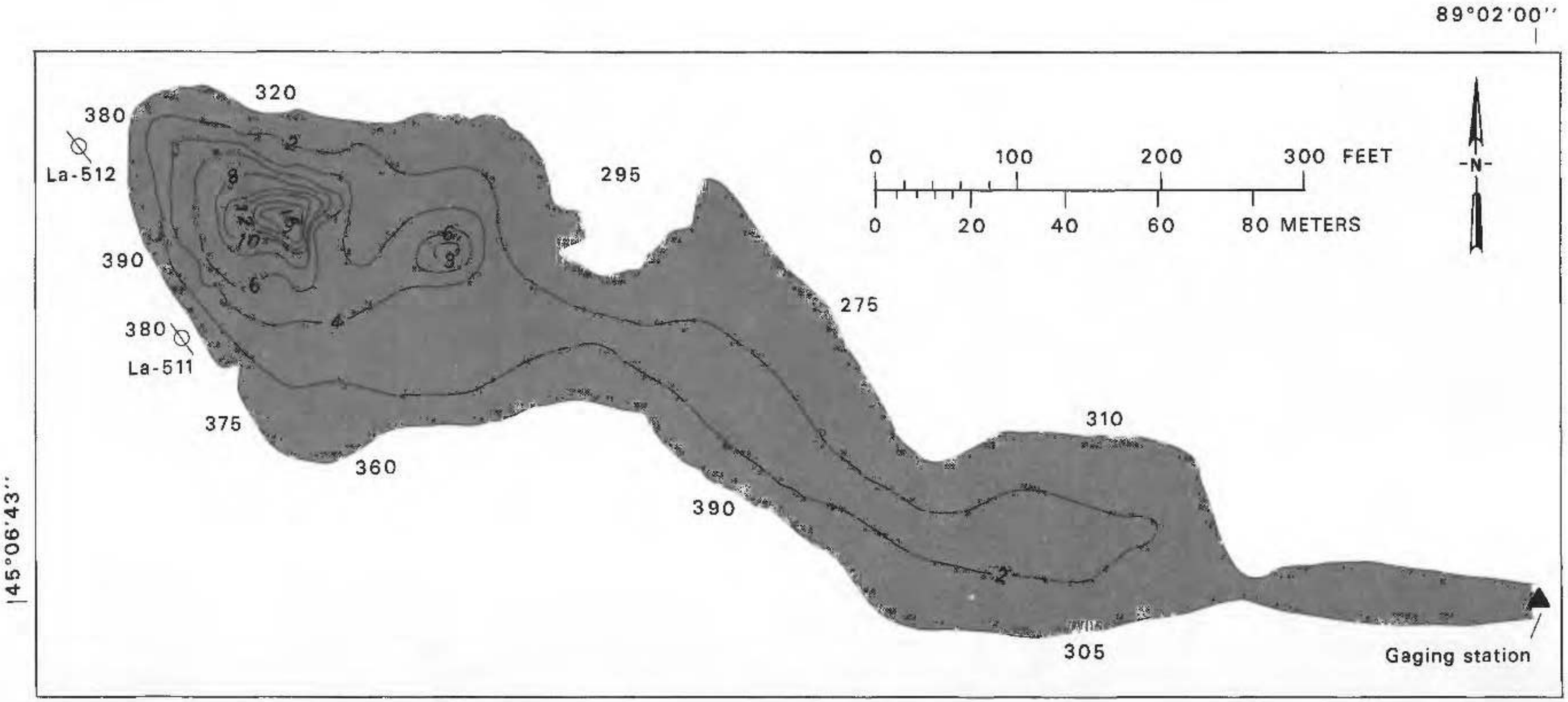
Water enters the pond as ground-water discharge, overland flow, and precipitation on the pond surface. Ground water enters the pond directly as discharge through the pond bottom and indirectly as spring discharge that emerges near the shore and flows overland into the pond. Based on an analysis of the pond-outflow hydrograph, ground-water discharge supplied 99 percent of the water entering the pond from October 1968 through December 1973. The remaining 1 percent was supplied by overland flow and precipitation on the pond surface.

"Boiling" action in the sediments, an indication of ground-water discharge, occurs randomly in the pond. This indicates a hydraulic potential for upward ground-water movement through the entire pond bottom. The occurrence and rate of discharge is locally controlled by the permeability of the underlying sediments. Virtually no ground water enters the pond in areas underlain by highly impermeable clay or silt.

About half of the total ground-water discharge is estimated to be from shore springs. Measurement of flow from the springs was not practical because most of the discharge emerges within about 60 ft of the shore and moves overland to the pond without collecting in channels in measurable quantities. The largest of the shoreline springs, which has a discharge of about 0.3 ft^3/s, emerges several hundred feet north of the pond and flows overland in a single channel to the pond.

Outflow

Water leaves the pond through the outlet channel at the east end and by evaporation from the water surface. The average flow in the outlet from October 1968 to December 1973 was 1.86 ft^3/s. Evaporation from the water surface was estimated on the basis of records of evaporation from a standard evaporation pan at Rainbow Reservoir, which is about 50 mi northwest of Antigo. Greatest pan evaporation at Rainbow Reservoir during the October 1968



EXPLANATION

La-512	Observation well and number
390	Specific conductance of ground-water seepage, in micromhos per centimeter at 25 degrees Celsius
—10—	Line of equal pond depth *Interval 2 feet*

Figure 3. Hydrographic map of Maxwell Pond.

to December 1973 period was 5.81 in in July 1970 (U.S. Dept. of Commerce, 1971, p. 212). Evaporation from the pond surface in July 1970 was estimated to be less than 1 percent of the water leaving the pond.

The fluctuation in discharge in the pond outlet channel is relatively small. From October 1968 to December 1973 the maximum daily discharge was only about twice the average discharge. Flow-duration curves for the Maxwell Pond outlet channel are shown in figure 4. Due to higher-than-average precipitation from August 1972 through May 1973, the average flow during the 1973 water year was 20 percent greater than the average flow during 1969-72. The steepness at the high ends of the flow-duration curves was caused by precipitation on the pond surface and by overland flow.

Flow in the outlet channel fluctuates seasonally. It is greatest during the spring because snowmelt and rainfall increase ground-water discharge. Flow in the outlet is usually lowest in late winter. The relationship between precipitation, ground-water levels, and pond discharge is illustrated in figure 5.

WATER QUALITY

The ground water near Maxwell Pond is a calcium magnesium bicarbonate type, which is characteristic of ground water in the study area. An analysis of water from observation well La-511 is given in table 2; this well is a flowing well 10 ft deep about 10 ft from the pond.

The specific conductance, which is related to total dissolved solids in ground water discharging into the pond, ranged from 275 to 390 micromhos per centimeter at 25°C. The values of specific conductance, which are shown in figure 3 at the approximate locations where ground water was discharging, were determined in November 1972.

The chemical quality of water in the outlet channel probably reflects the average quality of pond inflow. Specific conductance, measured at 6-week intervals from 1969-73, averaged 300 micromhos and ranged from 255 to 340 micromhos. Chemical analyses of water taken from the outlet channel are given in table 2.

The temperature of the ground-water discharge to the pond is nearly constant throughout the year. The temperature of water from observation well La-511, monitored at 6-week intervals from May 1970 to October 1973, ranged from 6° to 6.5°C. Because well La-511 discharges water that was moving under ground toward the pond, it is reasonable to assume that the temperature of water from the well represents the temperature of the ground-water discharge to the pond.

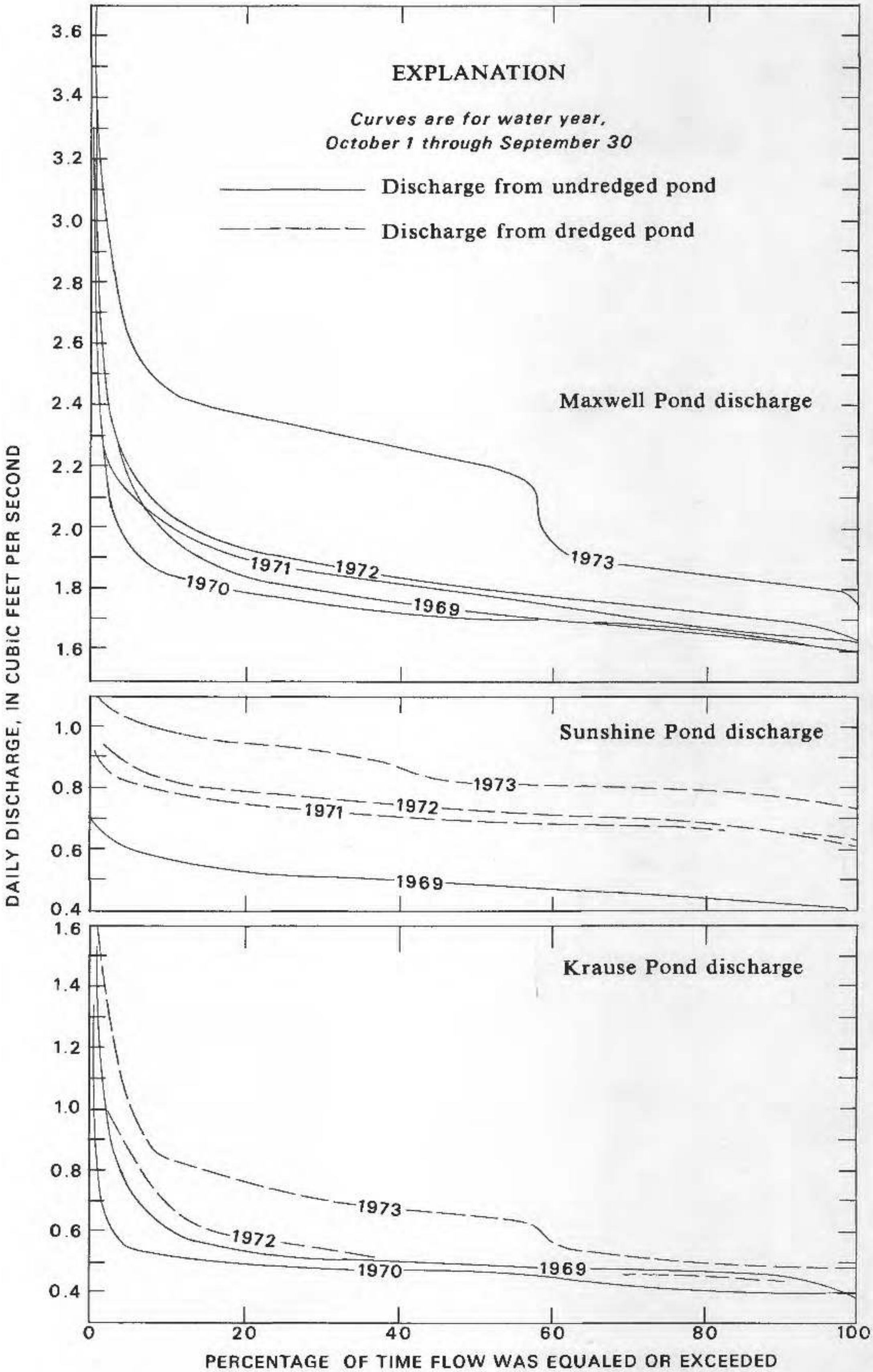


Figure 4. Flow-duration curves for Maxwell, Sunshine, and Krause Pond outlets.

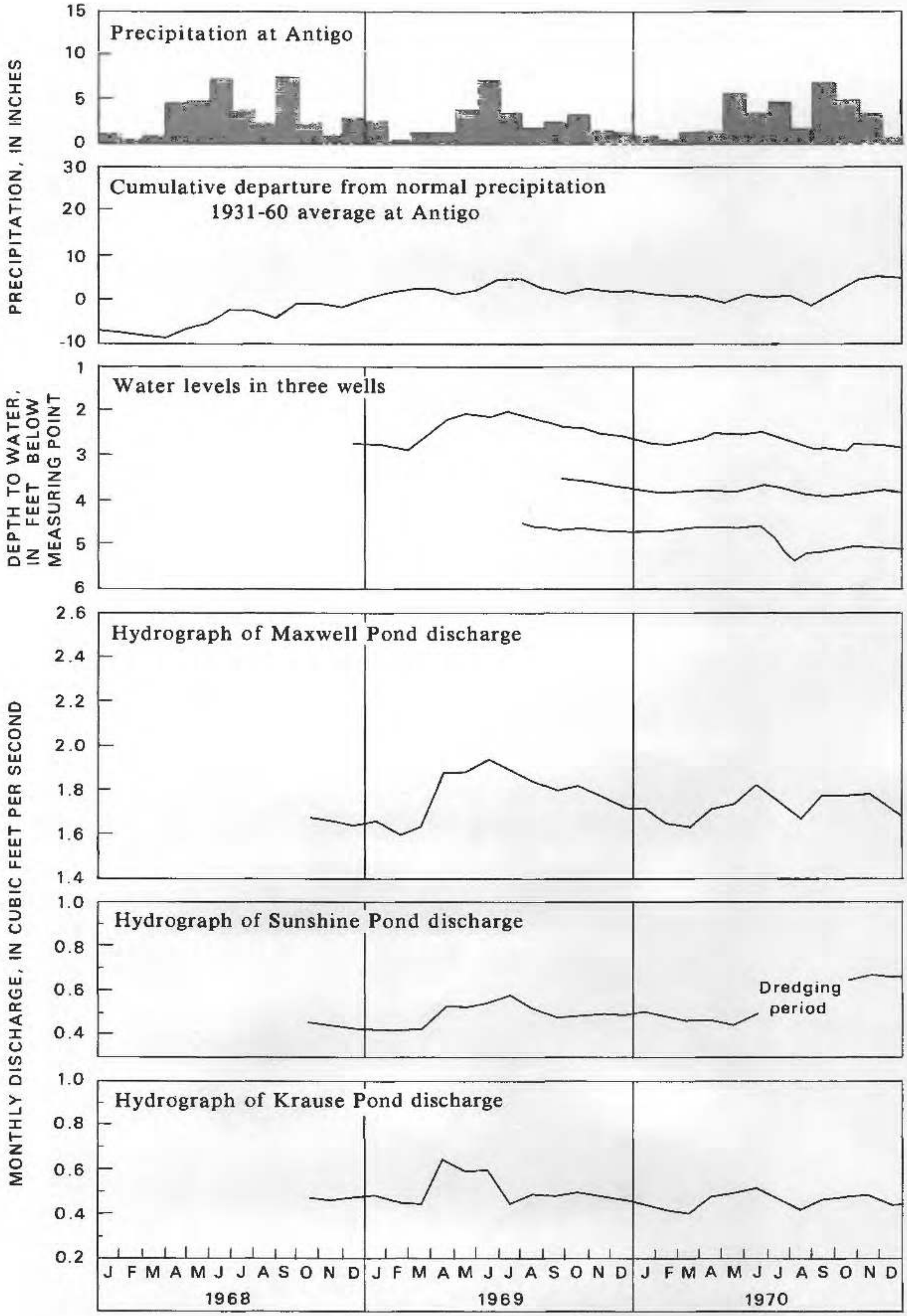
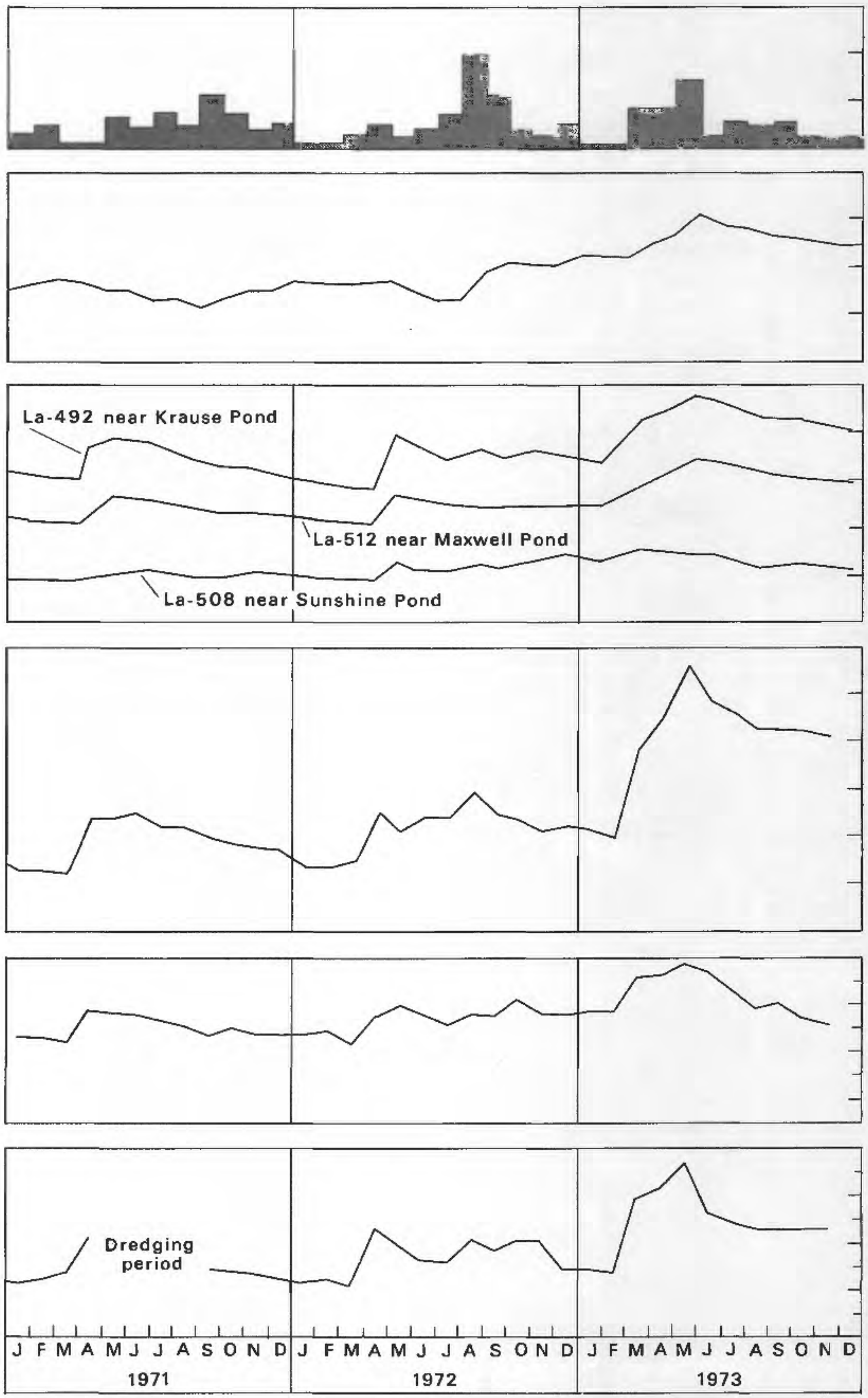


Figure 5. Comparison of precipitation,



ground-water levels, and spring-pond discharge

Water temperature in Maxwell Pond changed with depth. Temperature was measured at depths of 0.5 and 8.0 ft by temperature recorders at the west end of the pond. From January 1, 1970, to December 31, 1972, the temperature at 0.5 ft ranged from 4.5° to 23.0°C. During the same period, the temperature at 8.0 ft fluctuated less, from 1.5° to 9.5°C.

The temperature in the pond outlet (east end) was similar to the temperature near the surface of the pond. Temperatures measured in the outlet at 6-week intervals ranged from 6.5° to 21.5°C during the period October 1968 to December 1973.

SUNSHINE POND

LOCATION AND PHYSICAL DESCRIPTION

Sunshine Pond is about 1 mi south of the village of Elton and 14 mi east of Antigo in the SE¼ sec. 21, T. 31 N., R. 13 E. Sunshine Pond flows into Elton Creek. The area near the pond is characterized by hilly end-moraine topography and deposits of boulder till, and is similar to the area surrounding Maxwell Pond.

The predredging bottom configuration of Sunshine Pond is shown in figure 6. The predredging surface area of Sunshine Pond (fig. 6) was 0.88 acre; the volume was 1.4 acre-ft. The mean depth was 1.6 ft, and the maximum depth was about 4 ft.

SEDIMENTS

Accumulation of sediments in Sunshine Pond and in other spring ponds began when the ponds were formed and continues to the present. As the depth of sediments increased, changes in the hydrology and biology of the ponds occurred. A brief general discussion of the types and sources of sediments will be helpful before discussing sediments in Sunshine Pond itself.

In this report sediments are grouped into three main types--clastic, marl, and organic.

Clastic sediments are derived from the glacial deposits surrounding the ponds. They are composed of clay, silt, and sand-size particles. Most clastic sediments were transported by water to the ponds, but some may have been transported by wind.

Marl, also known as boglime, is composed primarily of calcium carbonate precipitated from ground water discharging into the ponds. The pH of water in the ponds, which is influenced by aquatic plants, influences the rate at which calcium precipitates as calcium carbonate or marl (Hem, 1970, p. 132). Marl usually occurs in clay or silt-size particles.

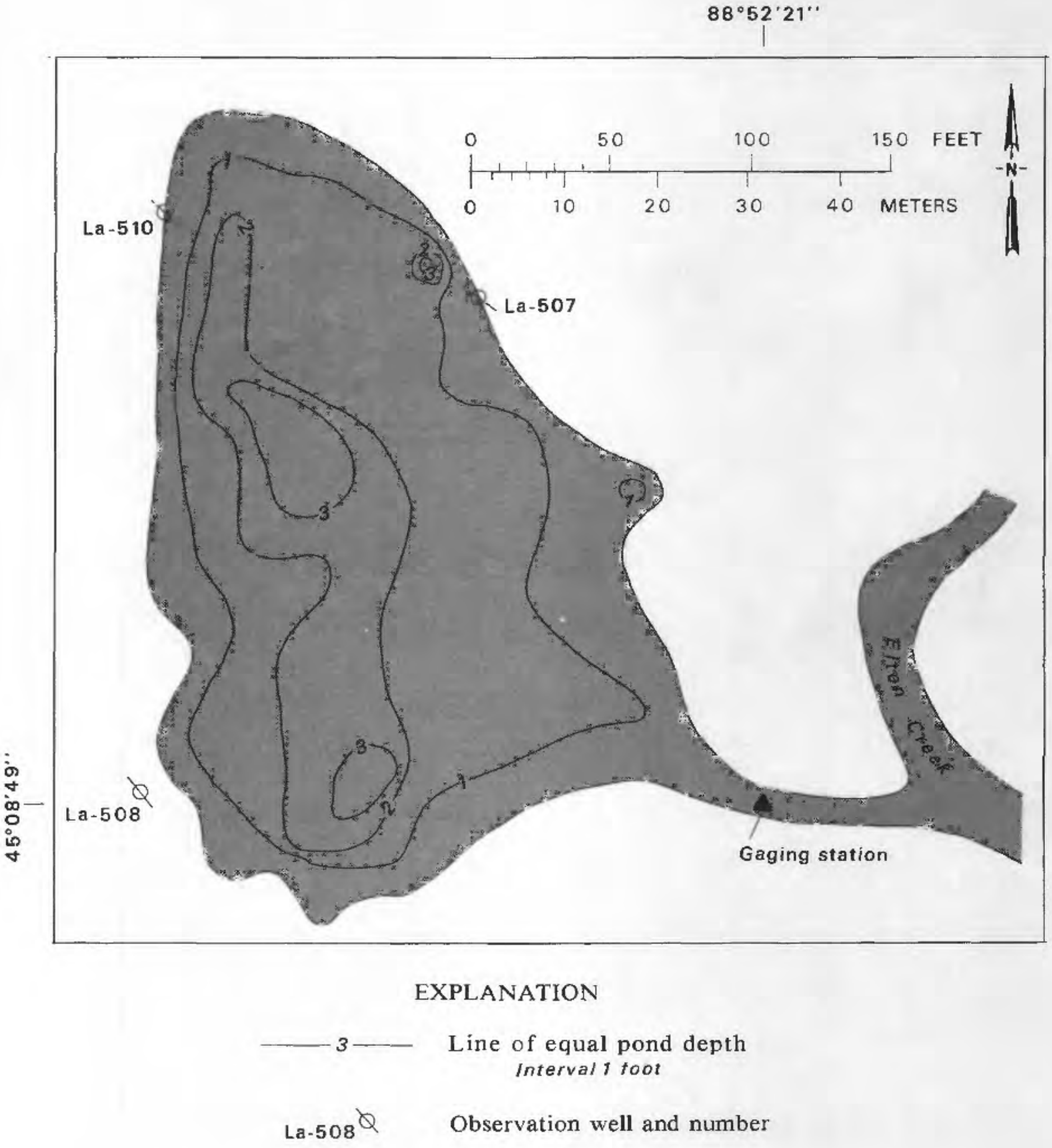


Figure 6. Hydrographic map of Sunshine Pond in 1967 before dredging.

Organic sediments consist of aquatic and terrestrial vegetation in various stages of decomposition. Terrestrial plant debris is transported into the ponds by wind, water, and gravity. Peat-like organic sediments, derived from accumulated plant debris, collect along the shores of many ponds. These deposits then are carried into the ponds by water from spring discharge and overland flow. In some places the buildup along the shores becomes thick enough to slump into the ponds.

All three types of sediments occurred in Sunshine Pond. Clastic sediments were present primarily as a layer of clay and silt separating marl and organic sediments from the underlying glacial deposits. Marl and organic sediments were generally intermixed, indicating simultaneous deposition. However, isolated pockets of almost pure marl occurred in some deep areas. Composition of the sediments above these pockets showed increased organic content and decreased marl content as water depth decreased. Pieces of wood ranging from small fragments to large tree limbs were scattered throughout the sediments.

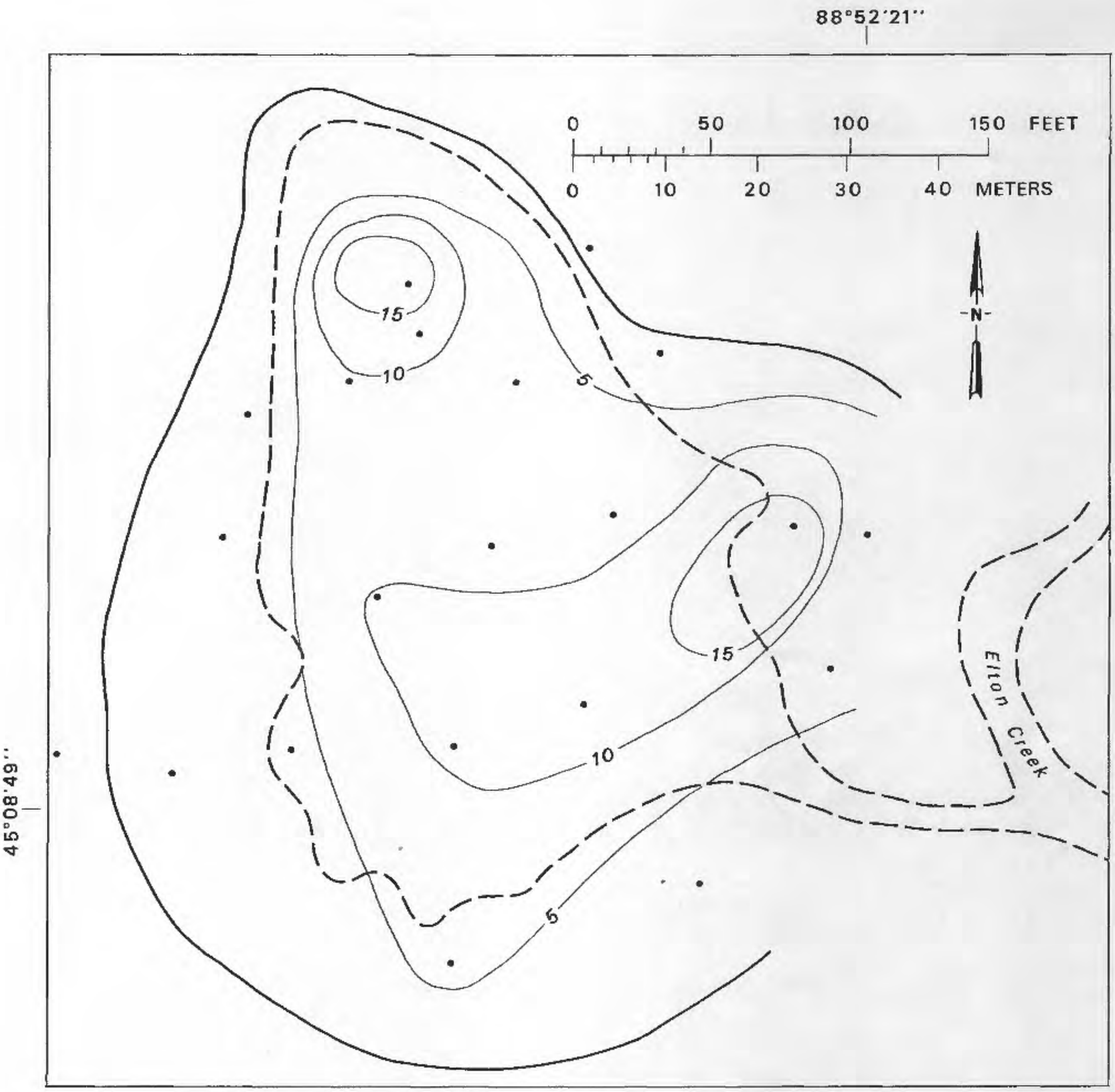
Accumulation of sediments greatly reduced the area and volume of the pond. The initial (or presedimentation) area of the pond (fig. 7) was about 1.9 acres or about twice as large as in 1967. Presedimentation volume was about 12 acre-ft or about nine times greater than in 1967.

Analyses of data from 21 test borings indicate that initially Sunshine Pond was not a pond, but, rather, an appendage or enlargement of Elton Creek. Near the east end of the pond the borings penetrated lenses of sand and gravel imbedded within organic sediments. The lenses appear to be streambed alluvium deposited by Elton Creek sometime in the past when it flowed into and out of the south end of the pond. As time passed, sediments, many of which were probably deposited by Elton Creek, accumulated along the east end of the pond and eventually separated the pond from the creek.

WATER BUDGET FOR SUNSHINE POND

Inflow

Water enters Sunshine Pond as ground-water discharge, overland flow, and precipitation on the pond surface. Essentially all ground-water enters directly through the bottom of the pond. In contrast to Maxwell Pond, where shore springs supply about half of the total inflow, shore spring discharge at Sunshine Pond is negligible and only occurs locally along the west shore. Based on an analysis of the pond outlet discharge hydrograph, ground-water discharge accounted for 99.5 percent of the water entering the pond during the predredging monitoring period, October 1968 through June 1970. The remaining 0.5 percent was from precipitation on the pond surface and overland flow.



EXPLANATION

Approximate boundary of pond before deposition of sediments

10 — Generalized line of equal pond depth before deposition of sediments *Interval 5 feet*

Pond boundary before dredging (1967)

• Test boring site

Figure 7. Hydrographic map of Sunshine Pond before deposition of sediments.

Outflow

Almost all water leaving the pond discharges through the outlet. A minor amount evaporates from the pond surface. The average flow in the outlet channel during the predredging monitoring period (October 1968 - June 1970) was 0.48 ft^3/s. As in the case of Maxwell Pond, evaporation was equivalent to less than 1 percent of the water leaving the pond through the outlet.

Flow fluctuated less in the Sunshine Pond outlet than in the Maxwell Pond. During the predredging monitoring period, the maximum daily mean flow was only 1.6 times greater than the average flow. The flow response to a single rainfall, such as the 1.7 in rainfall of May 21-22, 1970, is much less pronounced in the Sunshine Pond outlet than in the Maxwell Pond outlet (fig. 8).

Records of flow in Sunshine Pond outlet showed seasonal trends similar to flow trends in Maxwell Pond outlet. The greatest flow occurred during the spring, when ground-water discharge increased in response to snowmelt and rainfall. The lowest flow occurred during late winter when precipitation was small or in the form of snow. The relationship between precipitation and pond discharge is shown in figure 5.

WATER QUALITY

Ground-water discharge at Sunshine Pond is of a calcium magnesium bicarbonate type, which is characteristic of ground water in the study area. An analysis of water from flowing observation well La-508 (fig. 6) is given in table 2. Values of specific conductance measured April 18, 1973, from three flowing wells, La-507, -508, and -510 (fig. 6) were 370, 340, and 345 micromhos, respectively.

The chemical quality of the pond discharge was similar to the chemical quality of the inflow. Analyses of water from the outlet channel are given in table 2. Changes in the chemical quality of water passing through the pond probably were slight because of the relatively short time in storage. Before the pond was dredged, it took about 35 hours for average inflow to equal the volume of water in the pond.

The temperature of the ground-water discharge and of the water in the outlet at Sunshine Pond during the predredging period was similar to that at Maxwell Pond. The temperature of the ground-water discharge was estimated from measurements of the temperature of water from three flowing wells in and near the pond. It ranged from 6.5° to 7.0°C. During 1969 the temperature in the pond outlet ranged from 2.0° to 22°C.

DREDGING

Sunshine Pond was dredged during June-September 1970 with a hydraulic dredge. The dredge (fig. 9) was equipped with a revolving cutter head on

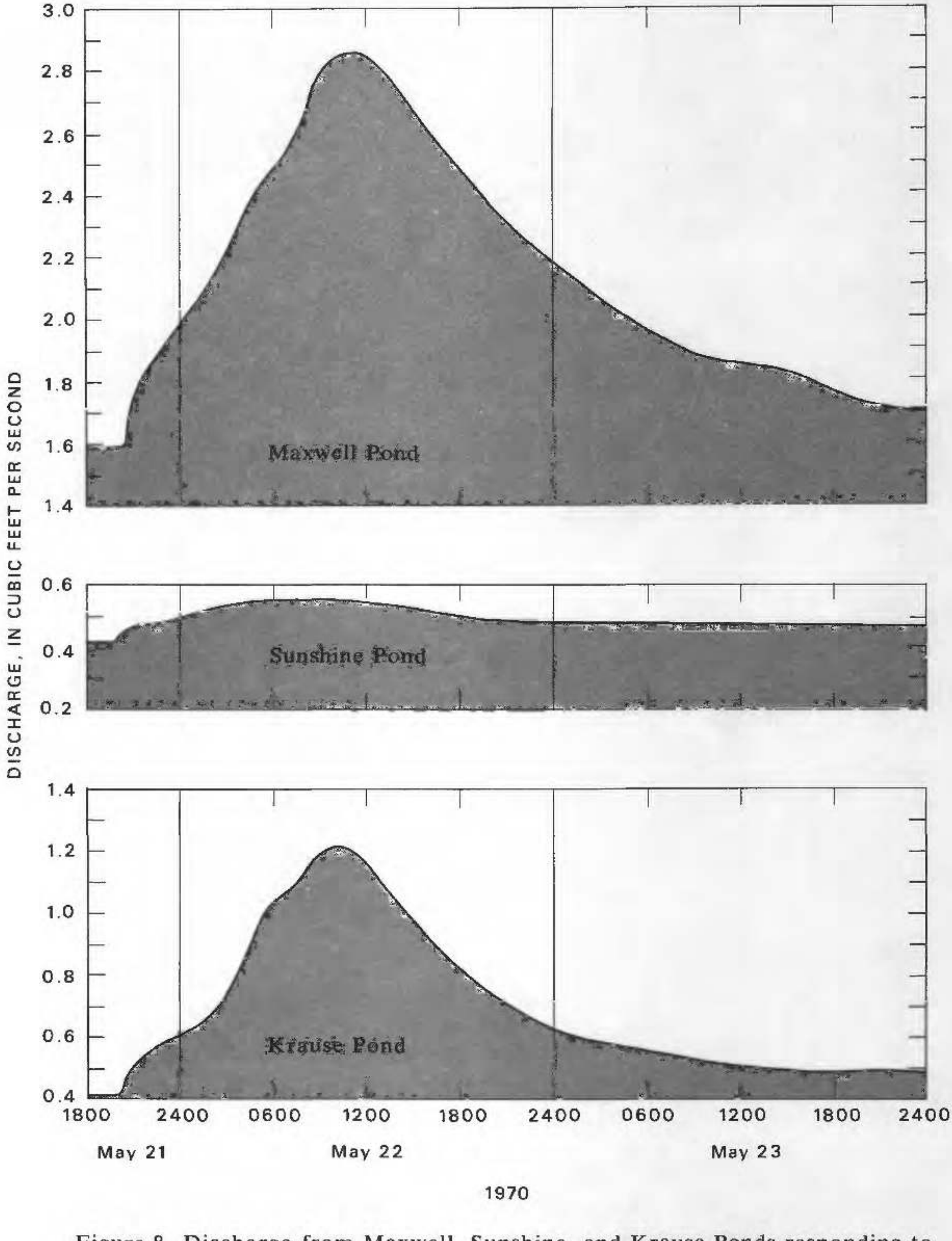


Figure 8. Discharge from Maxwell, Sunshine, and Krause Ponds responding to 1.7 inches of rainfall.

Figure 9. Hydraulic dredge in operation at Sunshine Pond.

the end of a 12-ft boom that loosened and broke up the sediments. The dredged sediments were pumped in a slurry through an above-ground pipeline to the spoil-disposal area--a kettle depression about 500 ft north of the pond. About 4.2 acre-ft of sediment was removed in layers by making repeated passes with the dredge over the pond.

Tree limbs buried in the sediments caused frequent delays in the dredging. Because the dredge could not break up and remove tree limbs, a light-weight crawler tractor was used to pull the limbs from the pond.

During the early stages, dredging was delayed because of insufficient water. The pumping rate of the dredge was about 2 ft^3/s, whereas ground-water inflow to the pond was only about 0.5 ft^3/s. As dredging progressed and the volume of the pond increased, more water was stored during periods of nonoperation. Consequently, delays caused by insufficient water occurred less frequently.

CHANGES CAUSED BY DREDGING

Physical

Dredging increased the volume of the pond about four times, but increased the surface area by only about 7 percent. After dredging, the volume was 5.6 acre-ft, and the surface area was 0.94 acre. The post-dredging shoreline coincided with the predredging shoreline except near the northwest and southwest corners of the pond. Trees at the water's edge prevented the dredge from enlarging the surface area of the pond in most places.

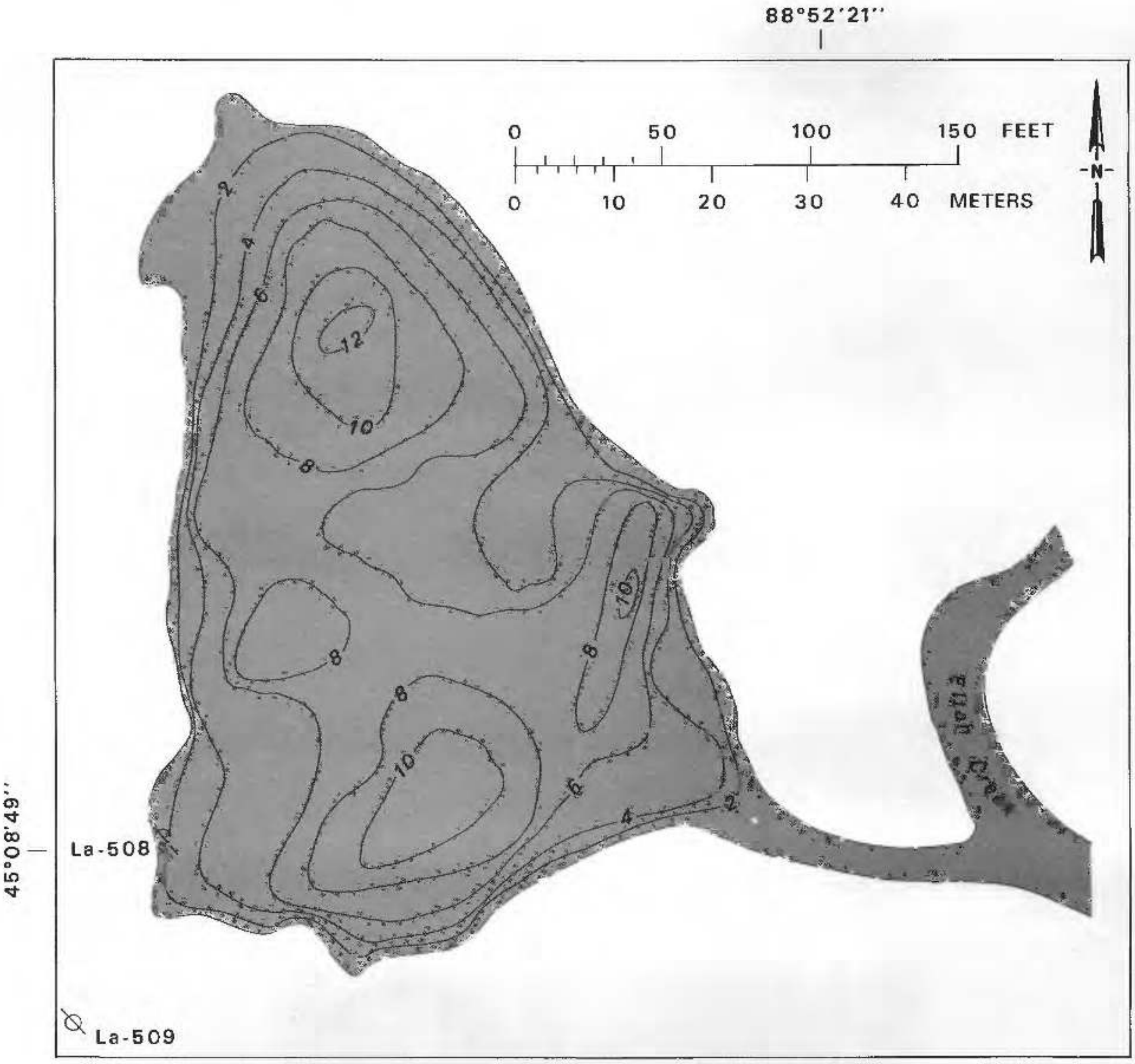
The pond-bottom configuration after dredging bore little resemblance to the predredging configuration. Contours on the pond bottom in figure 10 indicate three areas where the postdredging depth was greater than 10 ft. The mean depth of the pond after dredging was 6.0 ft or about 3.8 times greater than before dredging.

Pond Inflow-Outflow

The most significant hydrologic change caused by dredging Sunshine Pond was increased flow into and out of the pond. Flow in the outlet was 55 percent greater after dredging than before. However, part of the increased flow resulted from greater-than-normal precipitation during the postdredging monitoring period. Analysis of flow records from Sunshine and Maxwell Ponds and precipitation records indicates that dredging produced a 41 percent increase in flow into and out of Sunshine Pond. The remaining 14 percent was caused by greater-than-normal precipitation.

Increased ground-water discharge after dredging was probably caused by interception of underflow (ground water moving beneath the pond toward other discharge points downgradient). Water supplied by interception of underflow is at the expense of ground-water discharge elsewhere. Interception of underflow could not be verified by a discernible reduction in ground-water discharge elsewhere because the reduced discharge was shared by many discharge points downgradient.

Evidence indicates that the increased flow into the pond was not supplied by the release of ground water from storage. The release of water from storage would have caused a steady decline in the nearby water table, a reduction in flow from nearby springs, and a reduction of water in nearby wet areas. No such decline or reduction occurred.



EXPLANATION

La-508 — Observation well and number

—6— Line of equal pond depth
Interval 2 feet

Figure 10. Hydrographic map of Sunshine Pond in 1970 after dredging.

Ground-Water Levels

Dredging caused the water level in observation well La-508 to drop about 0.5 ft, while the water level in well La-509 was not noticeably affected. Well La-508 is in the southwest corner of the pond, and well La-509 is about 70 ft southwest of the pond (fig. 10). The drop in water level in well La-508 indicates a reduction in the hydrostatic head in the aquifer below the pond, but does not indicate a lowering of the water table. This head reduction meant that the pond sediments were partly retarding ground-water inflow. Dredging reduced the retarding effect of the sediments.

Water Quality

The chemical quality of water flowing into and out of Sunshine Pond was affected little by dredging. The concentrations of calcium, magnesium, bicarbonate, sulfate, and chloride in water in the outlet channel were slightly higher after the pond was dredged than before (table 2). Measurements of the specific conductance of water in the outlet before and after dredging indicate a slight increase in the concentration of dissolved solids. The average of 13 specific conductance measurements before dredging was 330 micromhos; the average of 27 measurements after dredging was 355 micromhos.

KRAUSE POND

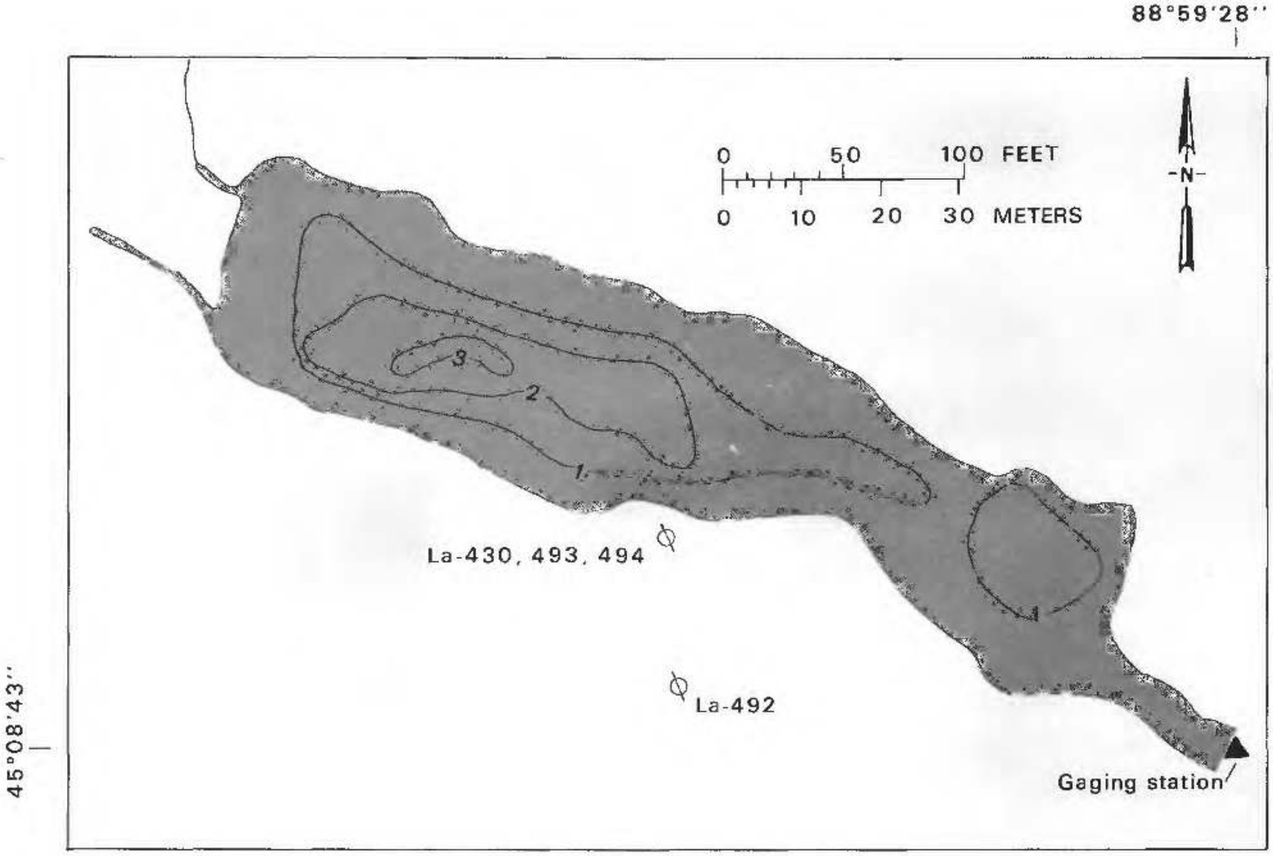
LOCATION AND PHYSICAL DESCRIPTION

Krause Pond is about 7 mi east of Antigo and 1.5 mi south of the village of Polar, in the NE¼ sec. 28, T. 31 N., R. 12 E. Krause Pond flows into Rabe Lake, which is near the headwaters of Rabe Creek. The topography near Krause Pond is much less hilly than at either Maxwell or Sunshine Ponds. The glacial deposits consist of outwash to the north of the pond and till to the south.

The lines of equal depth on the pond bottom (fig. 11) show the predredging configuration of the pond. The surface area was 0.8 acre, and the volume was 0.8 acre-ft. The mean depth was 1.0 ft, and the maximum depth was about 3.5 ft.

SEDIMENTS

The accumulation of sediments radically changed the shape, area, and volume of Krause Pond. In contrast to the long, narrow, shallow pond that existed in 1967, the presedimentation pond was oval-shaped and more than 20 ft deep (fig. 12). The surface area of the initial pond was about 3.0 acres or roughly four times larger than in 1967. The volume was 22 acre-ft or about 28 times greater than in 1967.



EXPLANATION

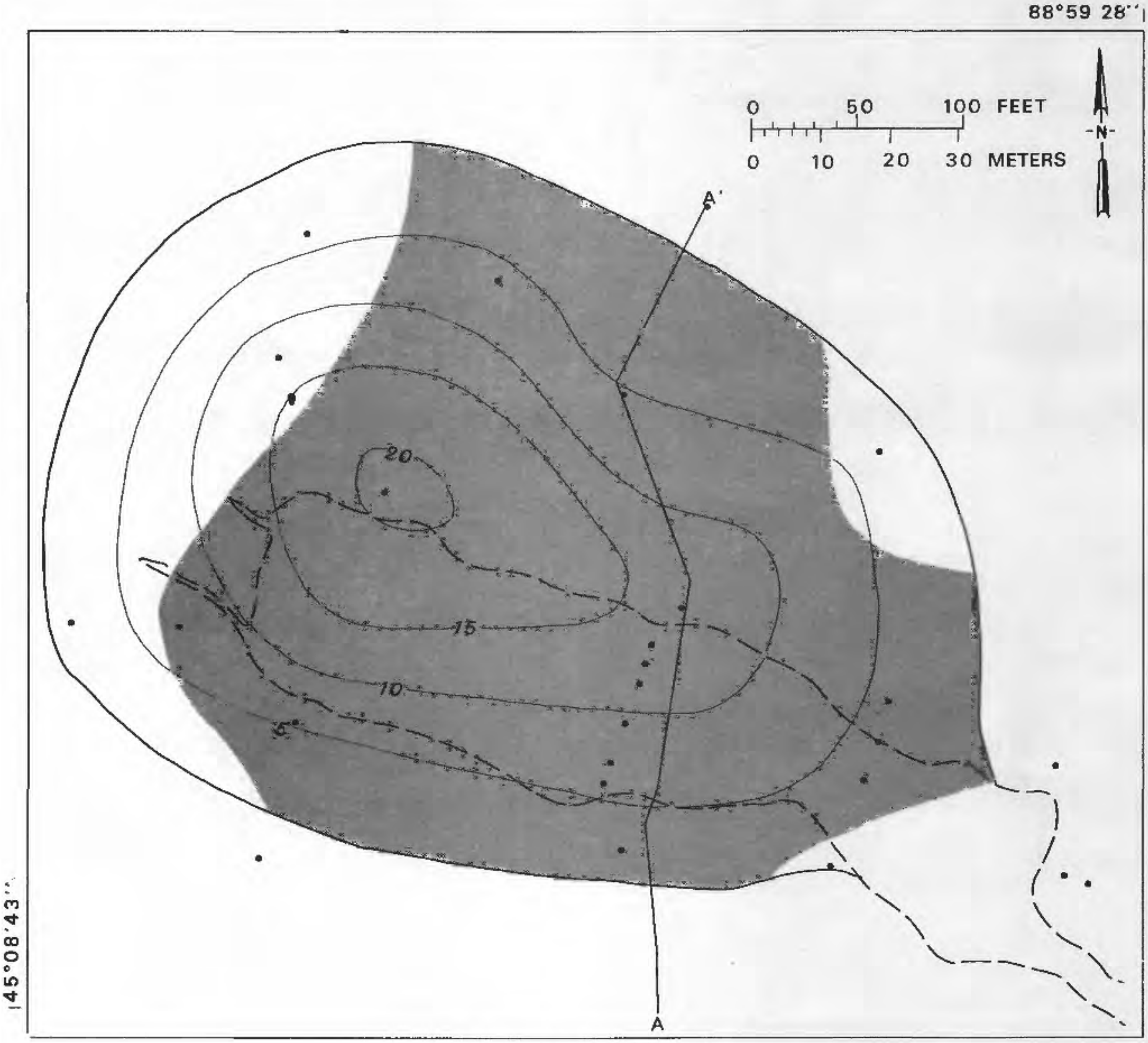
La-492 Observation well and number

2 Line of equal pond depth
Interval 1 foot

Figure 11. Hydrographic map of Krause Pond in 1967 before dredging.

The types of sediments found in Krause Pond were the same as those in Sunshine Pond.

The clastic sediments occurred primarily as a layer of clay and silt separating the marl and organic sediments from the underlying glacial deposits. The clay and silt layer was not present at the east and west ends of the pond (fig. 12), but was more than 3 ft thick in spots along the south shore of the pond. Minor amounts of clay, silt, and fine sand were mixed with the marl and organic sediments. These interspersed clastic sediments usually occurred near shore areas and probably were eroded from the adjacent slopes.



EXPLANATION

A——A' Location of section shown in figure 13

——— Approximate boundary of pond before deposition of sediments

—5— Generalized line of equal pond depth before deposition of sediments
Interval 5 feet

— — — Pond boundary before dredging (1967)

[shaded box] Approximate area where marl and organic sediments are underlain by clay and silt

• Test boring site

Figure 12. Hydrographic map of Krause Pond before deposition of sediments.

In general, marl and organic sediments were mixed. However, pockets of almost pure marl occurred in some deep areas of the pond. Pieces of wood, including some tree limbs, were scattered through the sediments. Organic and marl sediments in Krause Pond were subjectively classified on the basis of color, texture, and physical properties (F. P. Baxter, written commun., 1970). Samples of materials in each classification were analyzed to determine the percentages of carbonates and organic solids they contained. The composition of a generalized vertical column for a deep area of Krause Pond is given in table 3 (based on Baxter's findings and six borings).

Data in table 3 suggest certain trends. The percentage of carbonates increased with depth, though the high concentration (51 percent) of carbonates in "black humified semisolid" was an unexplainable exception to this trend. The percentage of dry solids increased with depth, ranging from 5.5 percent for "black humified liquid" to 40.7 percent for "white marl".

WATER BUDGET FOR KRAUSE POND

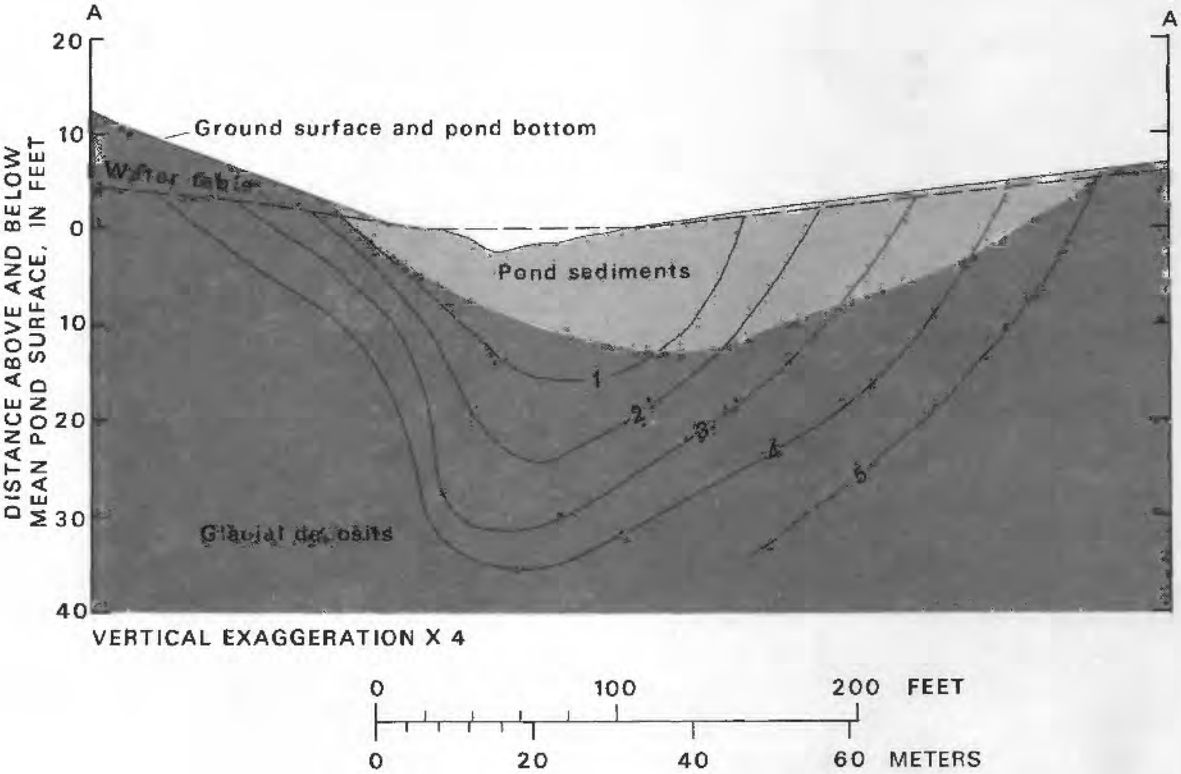
Inflow

Ground-water discharge, overland flow, and precipitation on the pond surface supply the water entering the pond. Ground water enters the pond directly as discharge through the pond bottom and indirectly as spring discharge that emerges at the land surface near the shore. Based on an analysis of the pond-outflow hydrograph, ground-water discharge was estimated to have supplied 96 percent of the total inflow during the predredging period (October 1968 through April 1971). The remaining 4 percent of inflow was supplied by overland flow and precipitation on the pond surface.

Ground-water gradients below and near the pond indicate a hydraulic potential for ground-water inflow through the entire pond bottom. Generalized lines of equal static head are given in figure 13. The lines of equal static head are based on water-level measurements made at 12 observation wells before the pond was dredged. Despite the hydraulic potential for ground-water discharge to the pond, such inflow is probably slight where the pond is underlain by silt and clay.

The area west of the predredged pond boundary probably supplies most ground-water discharge to the pond because this area is not underlain by the flow-retarding layer of clay and silt. Water percolates upward through the marl and organic sediments there, emerges at land surface as spring discharge and flows to the pond. Some water from this area may be percolating laterally through the sediments and discharging directly into the pond.

Small channels in which flow occurred in measurable quantities carry about 40 percent of the total pond inflow. Unchanneled spring discharge and water percolating laterally to the pond could not be measured. The bulk of the remaining ground-water discharge occurs at the east end of the pond, where the clay and silt layer also is absent.



EXPLANATION

—— 2 —— Generalized line of equal static head above mean pond surface (July 1970)
Interval 1 foot

Figure 13. General distribution of hydrostatic head in north-south section across Krause Pond.

The percentage of inflow supplied by overland flow to Krause Pond was greater than for either Maxwell or Sunshine Pond. This probably is caused by the effects of greater wet areas near Krause Pond. Because wet areas have near-saturated soils, most precipitation runs off as overland flow.

Outflow

Almost all outflow from Krause Pond occurs as discharge through the pond outlet. The average flow in the outlet during the predredging period was 0.48 ft^3/s. As was the case at Maxwell and Sunshine Ponds, evaporation from the pond surface was equivalent to less than 1 percent of the flow in the outlet channel.

Table 3.--Qualitative description and composition of materials in a typical column in a deep area of Krause Pond (Adapted from Baxter, written commun., 1970)

Qualitative description of materials between pond-water surface and glacial deposits	Approximate thickness (ft)	Water and solids		Composition of solids		
		Water (percent)	Solids (percent)	Carbonate solids (percent)	Organic solids (percent)	Inorganic plant remains and clastic sediments (percent)
(Water)						
Black humified liquid	2-5	94.5	5.5	24	27	49
Black humified semisolid	1-3	80.2	19.8	51	18	31
Black marl	1	78.1	21.9	22	50	28
Brown marl	1	81.5	18.5	49	40	11
Brown marl ("rubbery" consistency)	1	74.6	25.4	85	5	10
White marl	1	59.3	40.7	94	2	4
Mixed marl and clay	<1	----	----	--	--	--
Silt and clay	0-4	----	----	--	--	--
(Glacial deposits)						

Flow fluctuated more in Krause Pond's outlet channel than in the outlet channels of either Maxwell or Sunshine Ponds, although seasonal fluctuations were similar (fig. 5). During the predredging period, the maximum daily mean flow was 3.2 times as great as the average flow. Flow-duration curves (fig. 4) for Krause and Sunshine Ponds are similar in shape in the duration range from 10 to 100 percent. The curves in the 0 to 10 percent duration range, the range most affected by overland flow, are steeper for Krause Pond than for Sunshine Pond. This reflects the greater contribution overland flow makes to pond inflow at Krause Pond. The flow response in the outlet channel to a rainfall of 1.7 in is shown in figure 8.

WATER QUALITY

The ground-water inflow at Krause Pond is similar in chemical quality to ground water elsewhere in the study area. An analysis of water from flowing observation well La-430 near the south shore of the pond is given in table 2. The specific conductance of water from flowing observation wells and spring discharge in and near the pond ranged from 280 to 360 micromhos. Flow in Krause Pond outlet was similar in chemical quality to ground-water discharge except when affected by runoff from precipitation.

The greatest changes in the chemical quality of outflow occurred when overland flow contributed to the inflow. Because overland flow was less mineralized than ground water, ground-water inflow was diluted. After a heavy rainfall on August 24, 1972, the concentration of most chemical constituents in water of Krause Pond outlet was less; a seven-fold increase in the concentration of iron occurred, however (table 2).

The occurrence of marl as a major constituent of the pond sediments indicates that some calcium precipitates from the water passing through the pond. However, differences between the concentrations of calcium in the ground-water inflow and the pond outflow were too small to be detected.

The temperature of ground-water inflow, water in the pond, and water in the outlet channel was similar to that at Maxwell and Sunshine Ponds. During the study period the temperature of ground-water discharge, determined by measurements of several flowing wells and of springs in and near the pond ranged from 6.5° to 7.0°C. Pond water, at a point 0.5 ft below the surface, fluctuated in response to air temperature changes; it ranged from 6.5° to 17.0°C during 1969. Near the pond bottom about 3.5 ft below the pond surface temperature ranged from 4.0° to 8.5°C during 1969. The temperature of water in the pond outlet from April 1, 1970, through March 31, 1971, ranged from 0.5° to 22°C.

DREDGING

Dredging of Krause Pond began in June 1971 and was completed in August 1971, using the same equipment used for dredging Sunshine Pond. Most dredging was done by hydraulic dredge. A small area near the southeast shore, which was intended to serve as a trout spawning area, was excavated with a backhoe. About 4.0 acre-ft of sediment was dredged from the pond and pumped to a depression about 2,000 ft southwest of the pond.

Tree-trunk removal and insufficient water caused intermittent delays. The dredge pumping rate was about 2 ft^3/s; whereas, the rate of the ground water discharging to the pond was about 0.5 ft^3/s. Delays caused by insufficient water became less frequent as dredging increased the storage of the pond during periods of nonoperation.

CHANGES CAUSED BY DREDGING

Physical

Dredging increased the volume of Krause Pond about 600 percent and enlarged the surface area about 14 percent. After dredging, the volume was 4.8 acre-ft and the surface area was 0.89 acre. The greatest area enlargement was made at the east and west ends of the pond. Trees along the pond shore prevented area enlargement in most other places.

Most sediment was removed from the west end of the pond, resulting in water depths of more than 12 ft (fig. 14). The mean depth of the pond after dredging was about 5.5 ft or roughly 5.5 times greater than before dredging. Firm silty-clay, sand, and gravel containing scattered cobbles and boulders occurred near the surface at the east end of the pond and was not conducive to removal by dredging. Consequently, in this part of the pond only a 1- to 2-ft thickness of sediment was removed.

Pond Inflow-Outflow

Pond inflow increased only slightly as a result of dredging. Flow in the outlet channel during the postdredging water years of 1972 and 1973 was 23.5 percent greater than during the predredging water years of 1969 and 1970. However, most of this increase resulted from greater-than-normal precipitation. Analysis of flow records from Krause and Maxwell Ponds and precipitation records indicates that dredging increased the flow by only about 2 percent.

Although approximately the same volume of sediment was dredged from Sunshine and Krause Ponds, the percentage flow increase at Sunshine Pond was 20 times greater than at Krause Pond. The removal of sediment from Sunshine Pond improved the hydraulic connection between the pond and the aquifer, thus enabling the pond to intercept additional underflow. Most of Krause Pond, however, was underlain by highly impermeable silt and clay sediments (fig. 12). Removal of marl and organic sediments without removal of the underlying silt and clay did not significantly improve the hydraulic connection between the pond and the aquifer.

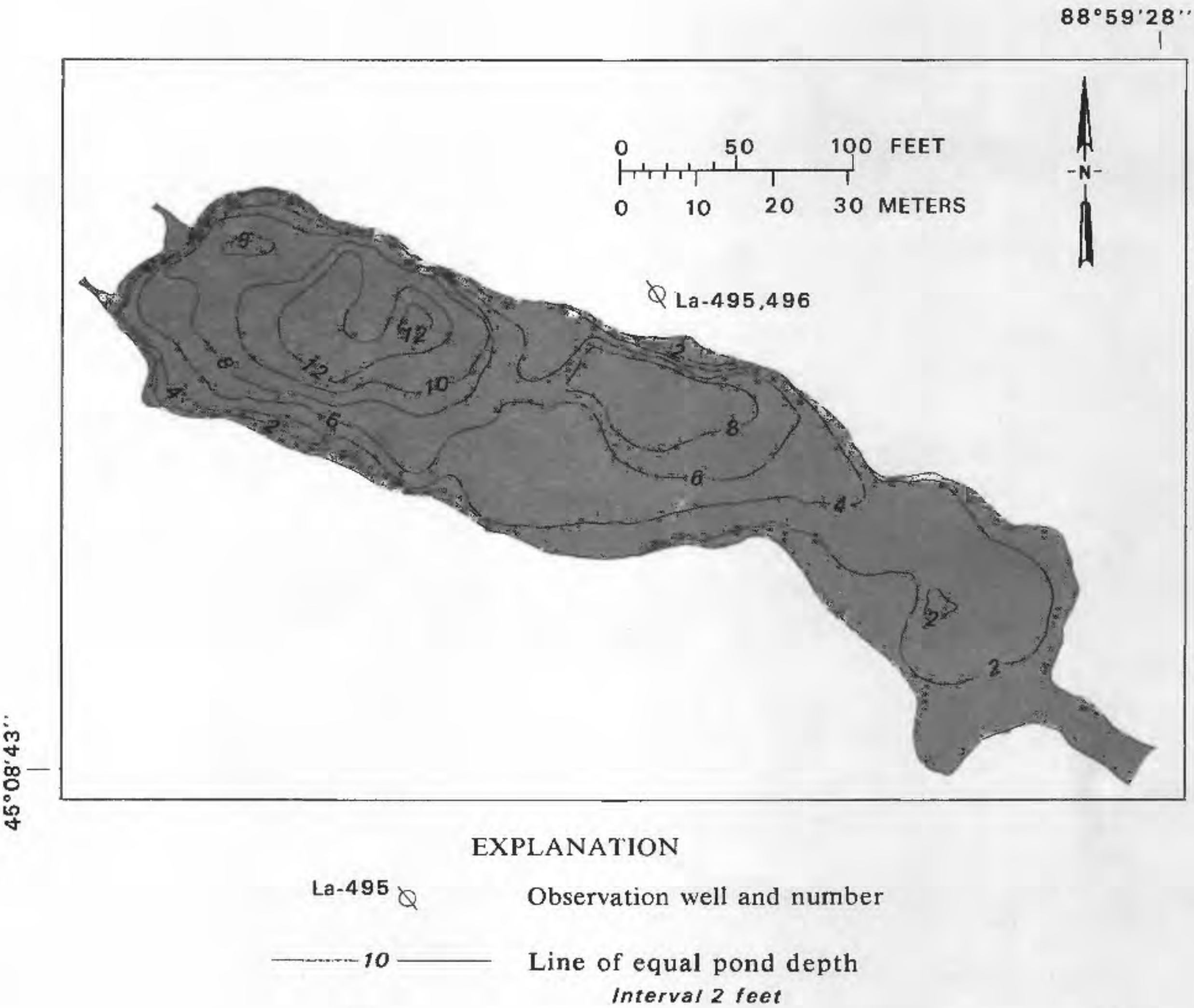


Figure 14. Hydrographic map of Krause Pond in 1971 after dredging.

Ground-Water Levels

With one exception, water levels in wells in and around the pond were not affected by dredging. This indicates that the gradients in the aquifer below and near the pond were not significantly changed by the dredging.

Removal of organic sediments to a depth of 9 ft in part of the pond adjacent to well La-495 (fig. 14), which is 15 ft deep, reduced the hydrostatic head in nearby sediments. The water level in well La-495 defines the hydrostatic head near the bottom of the organic sediments, which were about

14 ft thick at the well. After dredging the water level in well La-495 dropped about 0.4 ft. However, the water level in well La-496, which was 30 ft deep and located only about 2 ft west of well La-495, was not affected by dredging. The unchanged water levels in the deeper well indicate a poor hydraulic connection between the organic sediments and the aquifer.

Water Quality

The chemical quality of water flowing from Krause Pond was not changed noticeably by dredging. Chemical analyses of two water samples collected from the outlet after dredging show a slight decrease in the concentrations of most constituents (table 2). However, these samples were collected when overland flow from snowmelt and rainfall was entering the pond and diluting the ground-water discharge. The specific conductance of water flowing from the pond before dredging was almost identical to that after dredging was completed. Before dredging, in 1970 and 1971, the average of 13 specific conductance measurements was 345 micromhos. After dredging, in 1971-73, the average of 19 specific conductance measurements was 347 micromhos.

SUMMARY

Glacial deposits are the main aquifer in the study area and supply most of the flow in spring ponds and streams. Average annual recharge to the aquifer is 13 in. Ground-water basins in the eastern part of the study area, which includes the three spring ponds, are larger than their corresponding topographic basins. The combined effect of high annual recharge and large ground-water basins causes stable flow in streams and from the spring ponds. During the 1973 water year, 97 percent of the flow in the Red River was ground-water discharge.

Surface water and ground water in the study area are a calcium magnesium bicarbonate type having a dissolved-solids concentration ranging from 170 to 250 mg/L.

Accumulation of silt, clay, marl, and organic sediments since glaciation has greatly reduced the volume of the study ponds. Sediment accumulation caused a 9-fold reduction in the volume of Sunshine Pond and a 28-fold reduction in the volume of Krause Pond.

Flow from the study ponds was fairly constant, showing little seasonal or diurnal fluctuation. During October 1968 to December 1973, the maximum daily flow from Maxwell Pond was only twice the average flow. During the predredging monitoring periods, the maximum daily flow from Sunshine Pond was 1.6 times greater than the average flow and the maximum daily flow from Krause Pond was 3.2 times the average flow. The lowest flows occurred during late winter and the highest during early spring, when ground-water discharge increased in response to recharge from snowmelt and rainfall.

Most of the water entering the study ponds was supplied by ground water discharging into or near the ponds. Ground-water discharge supplied 99.0, 99.5, and 96.0 percent of the total flow into Maxwell, Sunshine, and Krause Ponds, respectively. The remaining inflow was supplied by overland flow and precipitation on the pond surfaces.

Sunshine and Krause Ponds were dredged during the study. Dredging increased the volume of Sunshine Pond about four times and the volume of Krause Pond about six times. Dredging caused a 41 percent increase in flow into Sunshine Pond and only a 2 percent increase in flow into Krause Pond. At Sunshine Pond dredging improved the hydraulic connection between the pond and the underlying aquifer, which resulted in increased interception of underflow. At Krause Pond, however, a highly impermeable layer of silt and clay underlay the sediments preventing significant improvement of the hydraulic connection between the pond and the aquifer. Consequently, dredging did not produce a significant increase in the interception of underflow at Krause Pond.

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