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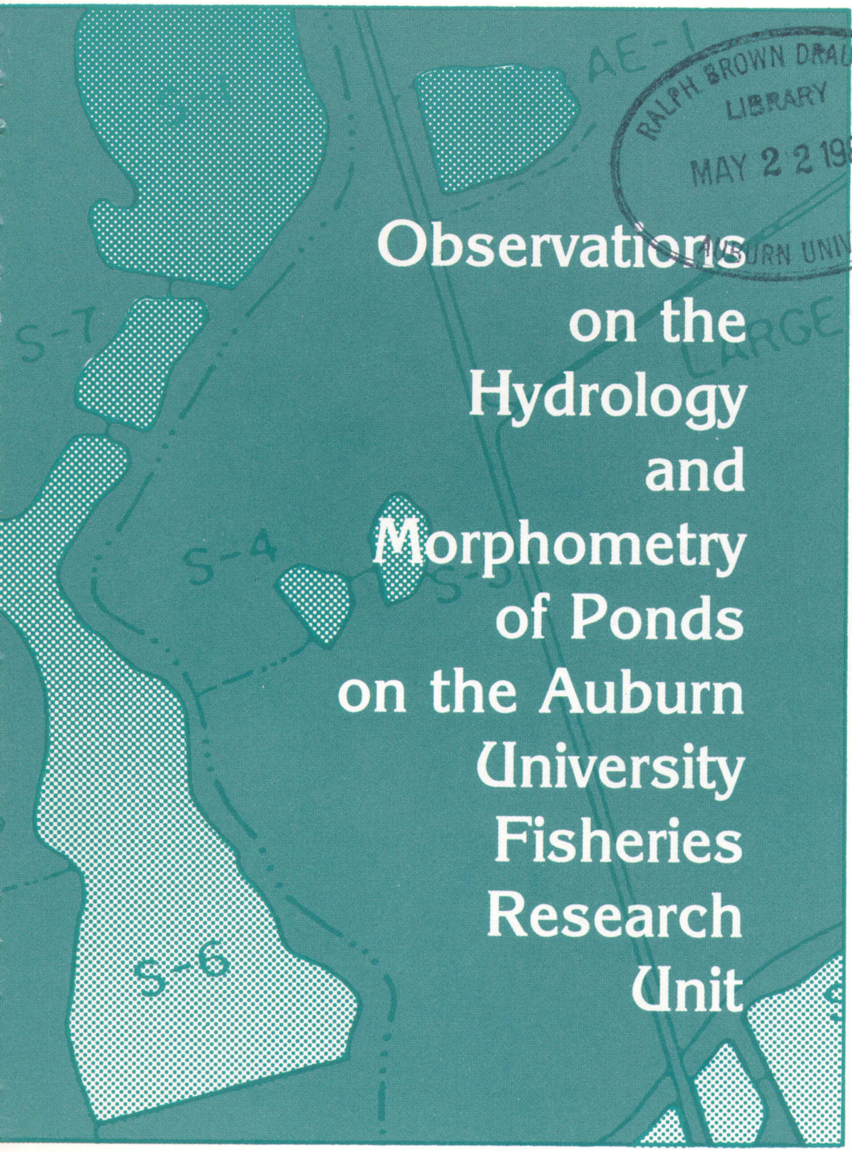

Observations on the Hydrology and Morphometry of Ponds on the Auburn University Fisheries Research Unit

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OBSERVATIONS ON THE HYDROLOGY AND MORPHOMETRY OF PONDS ON THE AUBURN UNIVERSITY FISHERIES RESEARCH UNIT

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INTRODUCTION

THE AUBURN UNIVERSITY Fisheries Research Unit is located 4 miles north of Auburn, Alabama, on Lee County Highway 147. It is comprised of an area of small experimental ponds filled from a large water supply pond and an area of larger experimental and water supply ponds filled primarily by storm runoff. Some of the larger ponds also receive inflow from small streams and springs.

Although ponds on the Fisheries Research Unit have been employed for fish culture research since the 1940's, little is known about the hydrology of the ponds and watersheds or about the morphometry of the ponds. Objectives of this report are: (1) to give information on rainfall, storm runoff, seepage, evaporation, and water storage in ponds, (2) to present water budgets for ponds, and (3) to provide information on morphometrical features of the ponds. Because the ponds are similar in many respects to farm ponds across the Southeastern United States and there are few data on pond hydrology and morphometry, these findings will be of interest to those responsible for construction and management of ponds.

Study Areas

Aerial photographs provided by the USDA Soil Conservation Service were used to prepare a map of the Fisheries Research Unit, figure 1. The hydrologic unit containing the large pond research area was delineated by stereoscopic examination of aerial photographs and field observations, and its acreage was determined by

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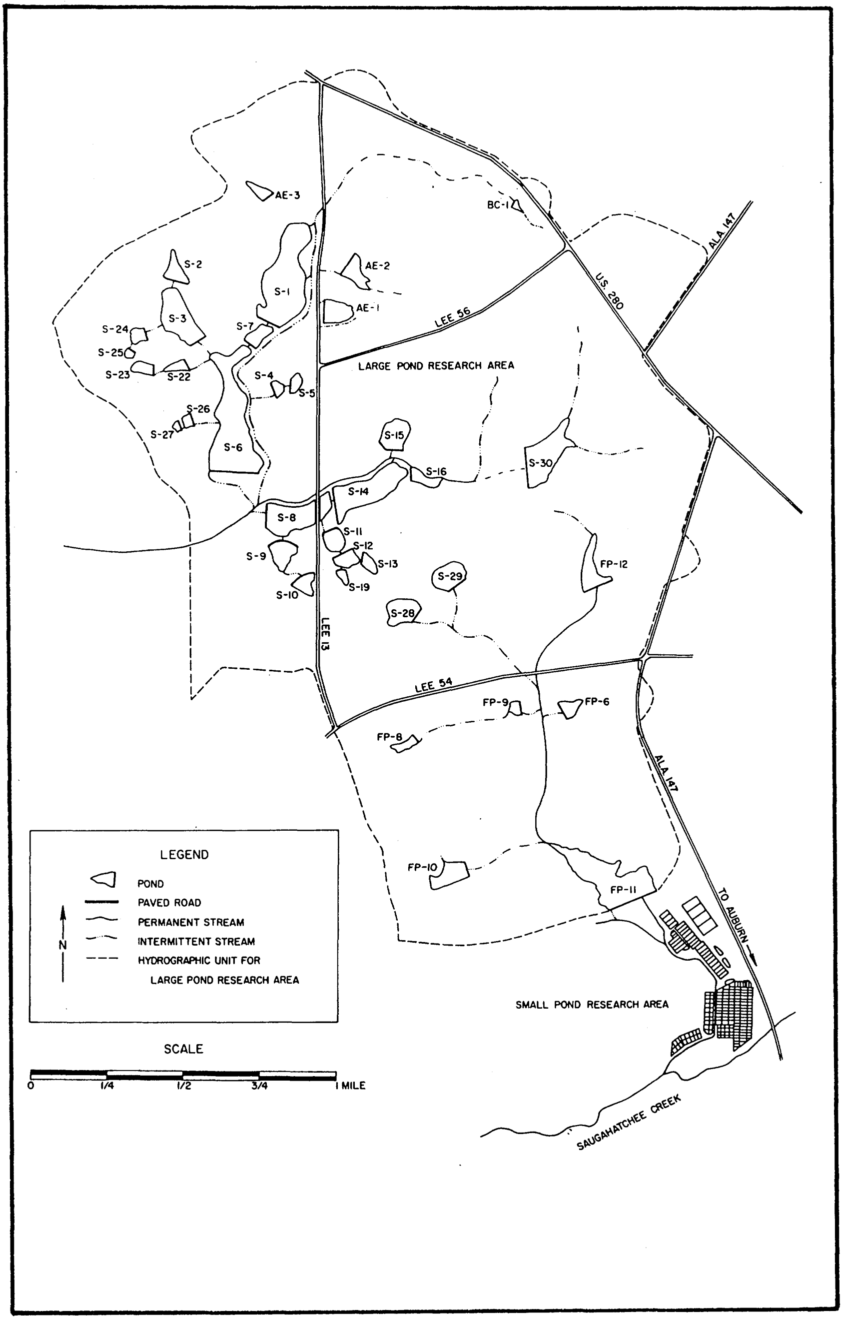

FIG. 1. The Auburn University Fisheries Research Unit.

planimetry. Two drainage basins occur within the 2,310-acre hydrologic unit, but for purposes of this study, they were combined.

Soils are of the following groups: Pacolet, Toccoa, Gwinnett, and Hiwassee *(11)*. According to the Soil Conservation Service *(18)*, these soils have moderate infiltration rates, are well-drained, and have moderately fine to moderately coarse textures. By use of the United States Geological Survey, 75-minute topographic maps and the method of Viessman et al. *(21)*, the average slope of the hydrologic unit was determined as 4.0 percent. The average annual temperature is 63.5°F. January is the coldest month (average = 46.0°F) and July is the hottest month (average = 79.6°F). Annual rainfall averages 56.0 inches at Auburn *(12)*.

The hydrologic unit was divided into subunits as follows:

Subunit	*Area (acres)*
Woods	1,334
Pasture	523
Ponds	199
Meadows	93
Paved roads and right-of-way	57
Row crops	45
Dirt roads and right-of-way	30
Areas around buildings and storage areas	26
Permanent streams	3
TOTAL	2,310

Forested areas have been cut for timber during the past 10 years and mostly replanted in pine trees. The forest floor is generally covered with about 0.5 inch of litter. The humus layer is loose and averages about 1 inch deep. Pastures are completely covered with grass and lightly grazed. Ponds are surrounded by a band of centipede grass that is 25 to 100 feet wide and mowed regularly. Meadows are well drained and mowed for hay. Corn is cultivated on contoured fields and the fields are left fallow after harvest.

Ponds were constructed by building earthen dams across watersheds to impound storm runoff. Dams have a clay core extending below ground level to reduce seepage *(9)*. Most ponds have a concrete spillway shaped like a rectangular weir, but some have only a grass-lined spillway. In several cases, more than one pond was constructed on a watershed, so that one pond is just behind and above the first, figure 1. Although ponds are filled and their water levels maintained primarily by storm runoff, overflow and seepage from one pond may enter another, figure 1, and some ponds receive inflow from streams. An intermittent stream begins near pond BC-1 and passes beside S-1, S-7, and S-6, figure 1. This stream flows through a marsh at the northeast end of S-1, and water from the marsh enters S-1 through two pipes. Overflow from S-1 passes into S-7 and finally into S-6. The stream carries little water except after heavy rains. A small, permanent stream originates east of pond S-16 and flows through S-16. This stream is connected by a pipe to S-14, and overflow from S-14 feeds S-8, figure 1. Another small, permanent stream starts below FP-12 and flows south to empty into the water supply pond (FP-11) for the small pond research area, figure 1. Several other ponds (S-28, S-30, FP-9, FP-10, FP-12, AE-2, and BC-1) receive the discharge of small, intermittent streams. A spring discharges into S-28, and there is apparently a spring in the bottom of pond S-15.

The small pond research area is on a 175-acre hydrologic unit that drains into Saugahatchee Creek, figure 1, but the natural drainage of this unit has little influence on the ponds. Part of the drainage from the large pond research area enters a water supply pond (FP-11, figure 1) and water from this pond is conveyed by pipeline to the small ponds. There are 194 small ponds ranging from 0.044 to 1.0 acre for a total of 26.8 acres. Average depths range from 2.5 to 3.5 feet; 3 feet will be taken as average depth. Ponds were formed by embankments built around storage areas. Runoff from embankments enters ponds, but watersheds only average 50 percent of pond areas. Hence, most storm runoff from surrounding land bypasses ponds and enters Saugahatchee Creek. Pond bottoms are above the original land surface, so groundwater does not seep into the small ponds. Climate of the small pond research area is essentially identical to that of the large pond research area.

MATERIALS AND METHODS

Shorelines of ponds were mapped by traditional surveying techniques. Outline maps were drawn to scale and the positions of survey stakes were identified. The stakes permitted establishment of a grid over the pond surface, figure 2. Range poles were placed at opposite ends of the pond and a boat with electric trolling motor was used to traverse the length of the transect between two range poles. Workers on each side of the pond aligned themselves so the transects across the pond could be established. These workers ascertained when the boat reached an intersection of two transects and a sounding was made with a 25-foot rod calibrated to 0.1 foot. Traverse lines were established on the scale drawing of the pond and the depth at each intersection was plotted. The number of transects varied from 6 to 22, depending on pond area. Soundings per pond

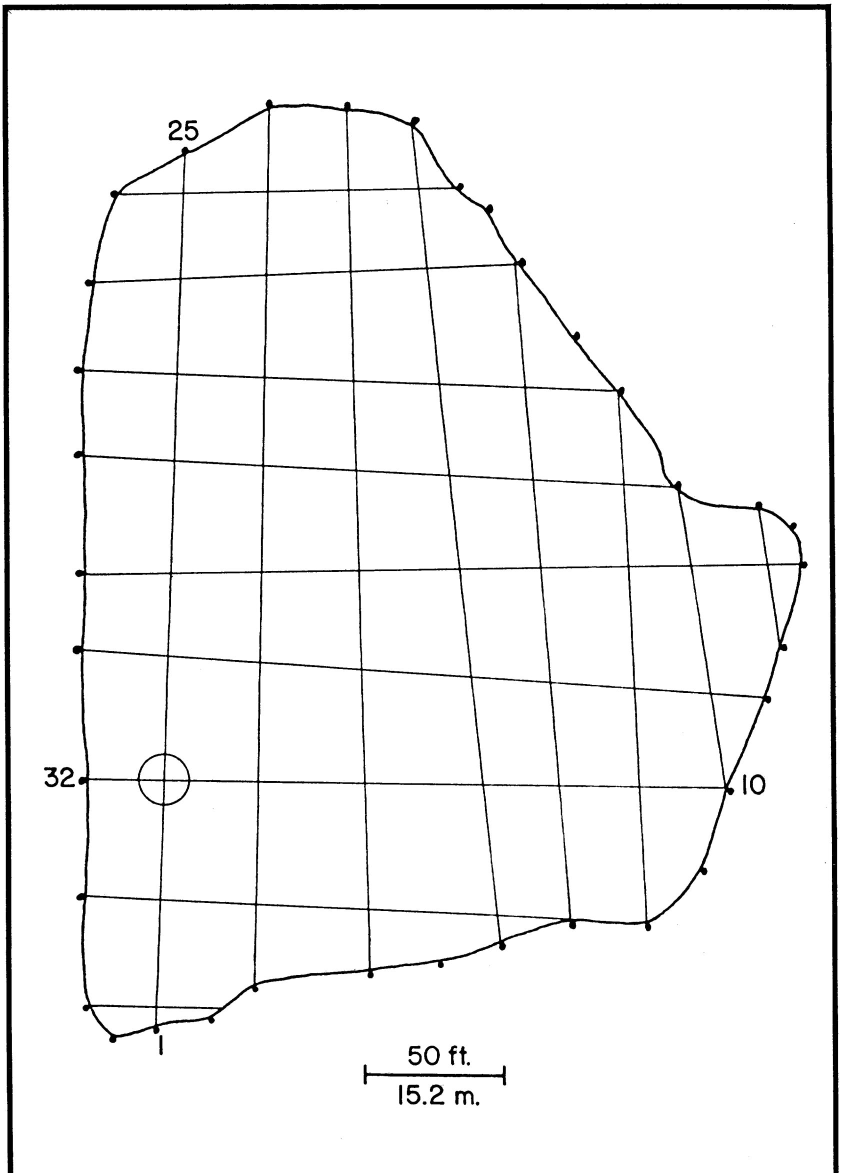

FIG. 2. Illustration of sounding for mapping ponds. Positions of stakes (dots) were established by transit readings and the outline drawn. Range poles were placed at stakes 1 and 25 and boat moved across pond while aligned between poles. Workers on shore aligned boat between stakes 10 and 32. Sounding was made at intersection in circle. Procedure was repeated until soundings were made at all intersections in grid.

ranged from 36 to 171. Contours were drawn at 1-foot intervals. Volumes of succeeding strata (volumes bounded by succeeding contour lines) were computed with the following equation *(23)*:

$$\text{Volume} = \frac{h}{3}(a_1 + a_2 + \sqrt{a_1 + a_2});$$

where;

Volume = volume in acre-feet between contour line 1 and contour line 2;
a_1 = area in acres within contour line 1;
a_2 = area in acres within contour line 2;
h = vertical distance in feet between contour lines 1 and 2.

The sum of volumes of the several succeeding strata was the pond volume.

Staff gauges which could be read to the nearest 0.01 foot were placed in 25 ponds of the large pond research area. Beginning in late March 1982 and continuing until early February 1983, stage changes were recorded weekly. During weeks when water was not flowing out the spillway of a pond and rainfall was less than 0.2 inch, seepage was computed as:

Seepage = [(stage at time 1 + rainfall)-stage at time 2] - evaporation.

Seepage estimates for all ponds were averaged by month.

Rain gauges were placed beside a pond in the small pond research area and near three ponds (AE-1, S-23, and S-28) on the large pond research area. The gauge at the small pond research area was read daily; others were read two or three times each week.

A class A evaporation pan was positioned near the rain gauge at the small pond research area. A hook gauge facilitated accurate estimates of water level changes in the pan. Catch of the rain gauge allowed corrections of water-level changes in the evaporation pan so evaporation could be estimated on rainy days. Evaporation from ponds was estimated as 0.7 times pan evaporation *(7)*.

Storm runoff estimates for the large pond research area were made for each rain during the period July 1, 1982, through June 30, 1983, by a technique developed by the Soil Conservation Service *(18)*. Soils were assigned to a particular hydrological group based on texture; the hydrologic soil group, 5-day antecedent moisture condition, and site cover were then used to obtain a runoff-curve number.

There were nine different site-cover complexes. The appropriate runoff curve provided the depth of storm runoff expected from a particular rain. The amounts of runoff from each site-cover complex were summed to give total storm runoff. Two ponds (E-67 and E-72) in the small pond research area were fitted with staff gauges, and water meters (Neptune, Trident 8) were placed on inlet pipes. Beginning July 1, 1982, and continuing until June 30, 1983, stage changes were read daily and each periodic addition of water from the pipeline was metered. Runoff from the embankments was estimated by the runoff-curve number technique *(18)*. Modifications of the hydrologic equation,

$$\text{Gains} = \text{losses} \pm \text{change in storage},$$

and data on stage changes in ponds, rainfall, runoff, pond evaporation, and water additions were used to estimate gains and losses; to partition gains into rainfall, runoff into ponds, and regulated water additions; to divide losses into net seepage out of ponds, pond evaporation, and overflow through drain pipes. All terms were expressed in inches of water depth. The appropriate modifications of the hydrologic equation were taken from Boyd *(3)*.

Several hypothetical water budgets were also computed. Each budget consisted of some or all of the following terms:

Gains	*Losses*
Rainfall	Evaporation
Runoff	Seepage out
Seepage in	Spillway overflow
Regulated inflow	Regulated discharge

Individual gains and losses were estimated by techniques described above, and procedures given by Boyd *(4)* were followed in making hypothetical budgets.

Volume development of ponds was calculated by the equation *(23)*:

$$\text{Volume development} = 3\left[\frac{\text{mean depth}}{\text{maximum depth}}\right].$$

The following equation *(23)* was employed for computing shore development:

$$\text{Shore development} = \frac{s}{2\sqrt{a\P}};$$

where; s = length of shore line in feet;
a = area of pond in square feet;
$\P$ = 3.1416

RESULTS AND DISCUSSION

Hydrology of Large Ponds

Areas and Volumes

The 36 ponds ranged from 0.72 to 26.0 acres in area, with maximum volumes of 2.3 to 193.2 acre-feet. The total area and volume were 199.2 acres and 1,156.3 acre-feet, respectively. Hence, the average depth of ponds was 5.8 feet. Area and volume data for ponds are presented in Appendix table 1. Maps of ponds showing submerged contours at 1-foot intervals are also provided in Appendix figures 1-36.

Ponds are located on 2,310 acres (199 acres of ponds and 3 acres of streams), so 2,108 acres of watershed yield storm runoff. It was not possible to determine exactly what percentage of the watershed areas drained into ponds, but at least 90 percent appeared to drain directly or indirectly into the 36 ponds. For purposes of computations, it was assumed all storm runoff from the watersheds entered ponds. Thus, the average watershed size was 10.6 acres per acre of pond surface. Of course, there was considerable variation in watershed size among ponds, but labor was not available to map watersheds of each pond.

Rainfall

Monthly rainfall data for the rain gauge at the small pond research area are reported in table 1. The three gauges on the large pond research area were not read daily, so occasionally the catch was for days in 2 months. Hence, monthly records based on catches of these gauges would be questionable. However, annual totals of 62.81, 62.56, and 62.03 inches were reliable, and they agree well with the annual catch of the rain gauge at the small pond research area. Hence, it was justifiable to use only data from the gauge on the small pond research area for computations.

Although monthly rainfall totals for July 1982 through June 1983 did not differ greatly from normal monthly rainfall, table 1, annual rainfall was 5.33 inches above normal. Over the past 20 years, annual rainfall at Auburn has varied from 43.45 to 82.95 inches, but only twice has it exceeded 60 inches *(12)*. The span July 1982 through June 1983 must be considered somewhat wetter than normal.

Total volumes of rain falling per month on the 2,310-acre hydrologic unit are given in table 2. Of the annual total of 11,807 acre-feet, 1,017 acre-feet (8.6 percent) fell directly onto pond surfaces, and a negligible quantity (15.3 acre-feet, 0.13 percent) was intercepted by streams.

Storm Runoff

Estimates of storm runoff for the 12-month period July 1982 through June 1983 are reported in table 1. Greatest computed storm runoff occurred between November 1 and March 31, when 21.6 percent of rainfall became runoff. For the remainder of the year, storm runoff was only 1.8 percent of rainfall, and there was no runoff during May, June, September, and October. Annual storm runoff was 12.9 percent of annual rainfall. The seasonal storm runoff pattern described here is that which typically occurs in the Southeastern United States *(6, 13, 16)*. The percentage of annual rainfall computed to become storm runoff is within the range of values reported for other areas of the Southeastern United States *(6)*.

TABLE 1. MEASURED (1982-83) RAINFALL AND EVAPORATION AT THE AUBURN UNIVERSITY FISHERIES RESEARCH UNIT COMPARED WITH NORMAL RAINFALL AND EVAPORATION AT AUBURN, ALABAMA, AND STORM RUNOFF ESTIMATES FOR WATERSHEDS OF THE LARGE POND RESEARCH AREA

Month	1982-83 rainfall	Normal[1] rainfall	1982-83[2] evaporation	Normal[1,2] evaporation	Storm[3] runoff
	In.	*In.*	*In.*	*In.*	*In.*
July	6.73	5.38	5.17	5.01	0.01
August	4.41	4.07	4.25	4.68	.40
September	1.84	4.20	3.39	3.81	.0
October	1.72	2.51	2.62	3.17	.0
November	6.37	3.89	1.87	2.02	1.35
December	8.59	5.51	1.41	1.05	1.77
January	5.13	4.83	1.14	.78	1.22
February	4.19	5.32	1.74	1.32	.20
March	9.97	6.93	2.60	2.87	2.87
April	6.35	5.21	3.84	3.90	.08
May	2.19	3.90	4.35	4.44	.0
June	3.84	4.25	4.06	5.45	.0
Total	61.33	56.00	36.44	38.50	7.90

[1] National Weather Service *(12)*.
[2] Class A pan evaporation X 0.7.
[3] Computed by SCS technique *(18)*.

The total volume of storm runoff from 2,108 acres of watersheds was 1,389 acre-feet, 1,303 acre-feet of which was generated between November 1 and March 31, table 2. The volume of rain falling directly onto pond surfaces was almost as great as the volume of storm runoff available to flow into ponds. There are two permanent

TABLE 2. VOLUMES OF RAINFALL, RAINFALL INTERCEPTED BY PONDS AND STREAMS, AND STORM RUNOFF FOR THE LARGE POND RESEARCH AREA, 1982-83

Month	Rainfall	Storm runoff	Pond interception	Stream interception
	Acre-ft.	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*
July	1,296	2	112	1.7
August	849	70	73	1.1
September	354	0	31	.5
October	331	0	29	.4
November	1,226	238	106	1.6
December	1,654	311	142	2.1
January	988	214	85	1.3
February	807	36	69	1.0
March	1,919	504	165	2.5
April	1,222	14	105	1.6
May	422	0	36	.5
June	739	0	64	1.0
Total	11,807	1,389	1,017	15.3

streams originating on the hydrologic unit. These streams convey considerable water following heavy rains—peak flows were roughly estimated at 2,000 to 5,000 gallons per minute (0.37 to 0.93 acre-foot per hour) immediately after heavy winter rains. However, base flow (ground water seeping into streams) is quite low, and stream discharges were roughly estimated to be 200 to 500 gallons per minute during dry weather.

Evaporation

Evaporation rates (pan evaporation x 0.7), table 1, were lowest in winter and reached a maximum in July. Monthly evaporation rates for July 1982 through June 1983 were similar to normal evaporation rates for Auburn, table 1; total annual evaporation for the period of measurement was 2.06 inches lower than normal. There is some evidence that turbidity from phytoplankton or suspended clay particles raises surface water temperatures and increases evaporation from ponds *(8)*. Ponds differed considerably in turbidity, but for lack of data to relate turbidity, surface water temperature, and evaporation, all ponds were assumed to have identical rates of evaporation.

Seepage

Average net seepage rates, table 3, were based on measurements made in 8 or more of a series of 20 ponds. However, the value for March was a guess because all ponds were overflowing. Net seepage was out of ponds during all months except March and April when

TABLE 3. SEEPAGE ESTIMATES FOR PONDS ON THE LARGE POND RESEARCH AREA, 1982-83

Month	No. of ponds	Average seepage/day	Standard error
		In.	
July	12	−0.16	0.05
August	16	− .18	.04
September	15	− .21	.05
October	20	− .16	.04
November	15	− .08	.02
December	11	− .03	.01
January	12	− .04	.01
February	9	− .02	.01
March[1]	Extrapolated	+ .03	--
April	8	+ .08	.06
May	11	− .06	.02
June	11	− .06	.02

[1] Water was flowing out spillways of all ponds used in measurements.

water seeped into most ponds. Seepage out was greatest from July to October. Water seeps out of ponds through dams, and it may seep into or out of ponds through bottoms. When the water table is high, small springs are known to issue into several of the ponds, and two ponds have permanent springs in their bottoms.

Many of the ponds are constructed so that one pond backs water up to the base of the dam of another pond, figure 1. Seepage through the dam of the upper pond enters the lower pond. Because of this arrangement, the lower ponds have more stable water levels than the upper ponds. This principle is illustrated by stage changes in ponds S-11, S-12, S-13, and S-19, figure 3. Seepage through the dams of S-13 and S-19 enters S-12, and seepage through the dam of S-12 enters S-11. Between April 5 and November 9, the water level decreased in S-13 by 2.49 feet and in S-19 by 2.80 feet. Water levels in S-11 and S-12 remained virtually constant. Over the same period, the average stage change was 1.93 feet (standard error = 0.13 foot) for 14 "upper" ponds and 0.26 foot (standard error = 0.18 foot) for 8 "lower" ponds. A few ponds on the Fisheries Research Unit have stable water levels because they receive year round inflow from springs or streams.

Seepage from ponds will vary greatly depending on soils and construction techniques. Seepage losses from 50 small bodies of water in Minnesota averaged 0.04 inch per day; the maximum was 0.06 inch per day *(1, 10)*. Annual seepage—primarily through the dam—from a pond near Auburn averaged 0.26 inch per day; a few measurements during the summer in 12 other ponds gave seepage values of 0.13 to 1.32 inches per day with an average of 0.45 inch per day, according to Parsons *(13)*. Ponds with seepage rates above 0.20 inch per day were located well up slope on watersheds. Parsons'

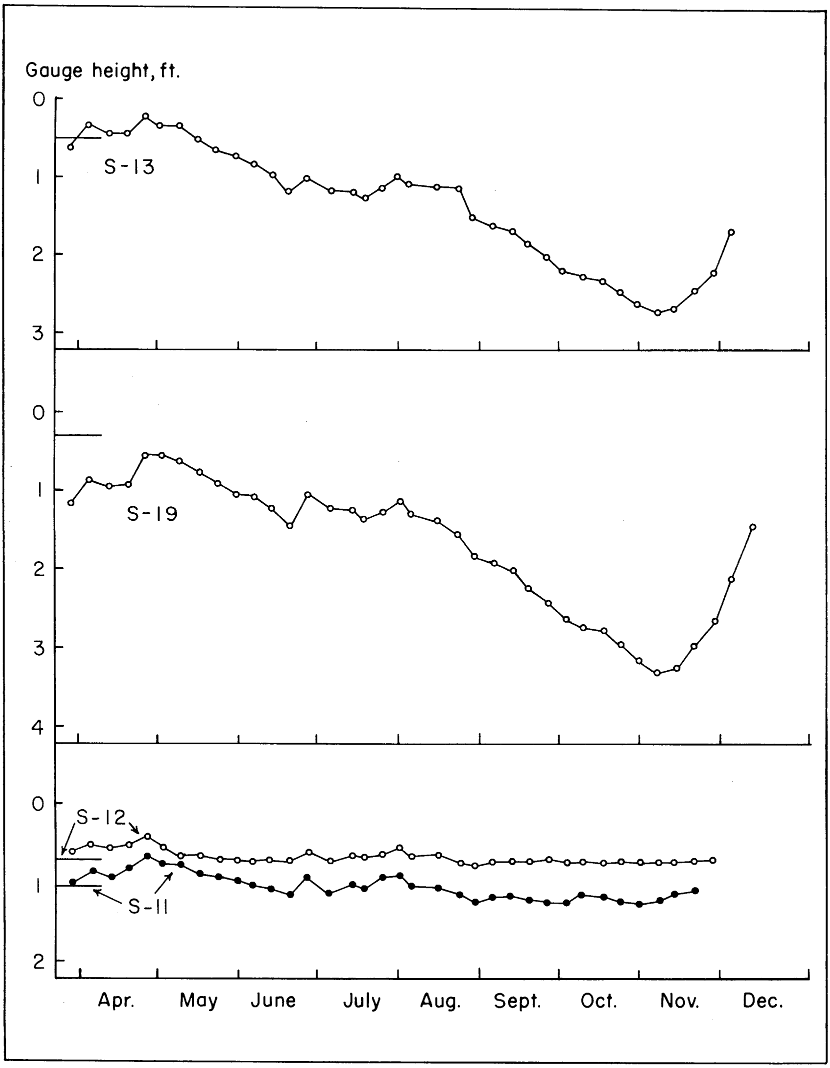

FIG. 3. Water-level changes during 1982 in four ponds on the Auburn University Fisheries Research Unit. The horizontal lines between 0 and 1-foot marks on Y-axis represent gauge heights when water just begins to flow out spillways. Ponds were drained in late November and early December.

seepage values for ponds near Auburn are somewhat greater than those reported in table 3. Parsons also noted that ponds on less porous soils of the Alabama Black Belt Prairie had seepage rates of 0.02 to 0.18 inch per day—average of 0.06 inch per day.

Water Budgets

Data on rainfall, runoff, seepage, and evaporation were used to prepare a water budget for a hypothetical pond, table 4. The hypothetical pond is 1 acre in area; it has a 10.6-acre watershed (average watershed size per acre for ponds on large pond research area); it does not receive inflow from streams or ponds; the depth is 6 feet over the entire area (ponds averaged 5.8 feet deep). With the exception of constant depth, the hypothetical pond does not differ greatly from "upper" ponds on the large pond research area.

It was assumed for computations that the hypothetical pond was full on April 1. Because rainfall, runoff, and evaporation data were collected for July 1982 through June 1983, reordering of data was necessary. Nevertheless, this procedure should be satisfactory for illustrative purposes.

There was a small amount of overflow during April and the pond was full on May 1, table 4. The water level steadily declined between May 1 and October 31 since rainfall and runoff were not sufficient to offset seepage out and evaporation. Computed change in water level for the hypothetical pond was 24.22 inches between May and October, table 4. The observed changes in water levels of "upper" ponds over this period averaged 23.16 inches. Of course, observed water-level changes in "lower" ponds were less than

Table 4. Water Budget for a 1-Acre Pond with a 10.6-Acre Watershed; All Values Are in Inches of Water Depth (Water Flows from Spillway When Water Level Is 72.00 Inches)[1]

Month	Rainfall	Runoff	Evaporation	Seepage	Overflow	Water depth
	In.	*In.*	*In.*	*In.*	*In.*	*In.*
April	6.35	0.85	3.84	+2.40	5.76	72.00
May	2.19	.0	4.35	−1.86	.0	67.98
June	3.84	.0	4.06	−1.80	.0	65.96
July	6.73	.11	5.17	−4.96	.0	62.67
August	4.41	4.24	4.25	−5.58	.0	61.49
September	1.84	.0	3.39	−6.30	.0	53.64
October	1.72	.0	2.62	−4.96	.0	47.78
November	6.37	14.31	1.87	−2.40	.0	61.49
December	8.59	18.76	1.41	− .93	14.50	72.00
January	5.13	12.93	1.14	−1.24	15.68	72.00
February	4.19	2.12	1.74	− .56	4.01	72.00
March	9.97	30.42	2.60	+0.93	38.72	72.00

[1] See text for description of pond and watershed.

computed changes. The hypothetical pond refilled during November and early December and overflow occurred during the rest of December, January, February, and March. All but one of the 36 ponds on the large pond research area were overflowing in March 1983, and most were overflowing by December 1982.

Some ponds on the large pond research area are drained in the fall for fish harvest; most farm ponds are not drained. Assuming ponds on the large pond research area are similar to the hypothetical pond and not drained in the fall, only 2 acre-feet of water must be replaced per acre of pond for refilling. Thus, much of the rain and storm runoff entering ponds during winter and early spring cannot be stored. In the example, table 4, storm runoff equal to 22.92 inches of depth was stored by the 1-acre pond before overflow occurred in December. For all 199 acres of ponds, this equals 380 acre-feet—total storm runoff during the year was computed as 1,380 acre-feet, table 2. Spillway discharge between December and April was 78.67 inches for a 1-acre pond, or 1,305 acre-feet for all ponds. The discrepancy of 296 acre-feet represents rain that fell directly into ponds and then flowed through spillways. If ponds were not present and the 199 acres were proportioned to other land uses in the same manner as the rest of the hydrologic unit, total storm runoff would be 1,520 acre-feet—only 215 acre-feet more than the computed spillway discharge.

These computations suggest that even a great number of ponds on a hydrologic unit do not drastically reduce storm runoff. The watersheds of the hydrologic unit studied here are almost completely controlled by ponds. In fact, there are likely few areas in the United States with 1 acre of pond per 10.6 acres of watershed. According to the Soil Conservation Service *(19)*, there are 62,587 acres of ponds in Alabama—1 acre of pond per 527 acres. However, as shown above, an abundance of farm ponds on a watershed is known to cause some reduction in storm runoff, especially during years of low rainfall *(5, 14)*.

If the hypothetical pond were drained in October and refilling started on November 1, water depths at the end of each month and overflow during the month would be as follows:

Month	*Depth of water (in.)*	*Spillway discharge (in.)*
November	16.56	0.0
December	41.52	.0
January	57.24	.0
February	61.20	.0
March	72.00	27.96
April	72.00	5.76
May	67.98	.0

Spillway discharge for all ponds would amount to 559 acre-feet. Of course, most of the stored water would be discharged when ponds were drained in the fall.

Computations of water-level increases in a pond initially empty show the necessity of having adequate watershed to generate sufficient runoff to fill a pond and to maintain it during dry years. The Soil Conservation Service *(20)* recommended 2 acres of watershed for each acre-foot of storage in ponds in the vicinity of Auburn. For a pond with an average depth of 6 feet, the recommended watershed is 12 acres per surface acre of pond, about the same ratio observed on the Fisheries Research Unit.

Hydrology of Small Ponds

Measured Water Budgets of Two Ponds

Water budgets for ponds E-67 and E-72 are presented in table 5. The water budgets are considered highly reliable because ponds were full at the beginning and at the end of the 12-month period and the gains and losses (in inches) balanced closely:

Pond	*Gains*	*Losses*	*Difference*
67	91.38	92.62	1.24
72	189.03	195.88	6.85

The major differences in budgets for the ponds were the amounts of seepage out of ponds and the amounts of water added to replace seepage. Pond E-67 did not seep badly; the annual loss to seepage was 27.95 inches (average = 0.077 inch per day). Seepage was much greater in E-72; the annual loss was 159.22 inches (average = 0.436 inch per day).

TABLE 5. MEASURED WATER BUDGETS FOR TWO, 0.1-ACRE PONDS IN 1982-83

Month	Rain	Runoff	Water added E-67	Water added E-72	Evaporation	Seepage E-67	Seepage E-72	Overflow E-67	Overflow E-72
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
July	6.73	0.13	0.0	13.42	5.17	4.19	16.09	0.0	0.0
August	4.41	1.35	1.78	17.07	4.25	3.04	17.63	2.40	.0
September	1.84	.0	5.08	21.00	3.39	2.44	15.20	.0	.0
October	1.72	.0	1.21	14.70	2.62	3.65	15.28	.0	.0
November	6.37	.73	5.62	7.62	1.87	2.80	12.98	.96	.0
December	8.57	1.36	.0	.0	1.41	2.57	10.56	7.00	.0
January	5.13	.52	.0	.0	1.14	1.93	9.07	2.83	.0
February	4.19	.13	.0	.0	1.74	2.19	9.80	1.08	.0
March	9.97	.83	.0	.0	2.60	2.00	10.10	6.47	.0
April	6.35	.82	.0	5.37	3.84	2.74	11.65	.48	.0
May	2.19	.66	5.14	20.42	4.35	3.77	15.29	.0	.0
June	3.84	.0	4.71	21.59	4.06	3.64	15.79	.0	.0
Total	61.31	6.53	23.54	121.19	36.44	34.96	159.44	21.22	.0

Boyd *(3)* measured water budgets for E-67, E-72, and two other small ponds from April through October 1981, so the objective of the 1982-83 study was to determine if seepage during November through March was similar to that of other months. Seepage followed no obvious seasonal patterns in E-67, table 5. In E-72, seepage was somewhat less during winter months. However, water could not be added during winter because the pipeline was drained to prevent freezing, and water levels could not be controlled. The water level in E-72 declined steadily, and the decline reduced the head for seepage. Nevertheless, even if seepage was greater during winter in E-72, the observed differences between winter and summer seepage was much less than that found for large ponds, table 3. It seems reasonable to assume that seepage rates do not vary greatly with season in the small ponds, and that an average seepage rate based on measurements over several months is adequate for computation of water budgets. Seepage rates for only two ponds are not representative of the entire 194-pond complex. Boyd *(3)* measured seepage during summer and fall in 55 of the ponds. The average, 0.20 inch per day, will be used in computations below.

Water Budget of Complex

In calculating this budget, it was assumed all ponds were full April 1 and losses were replaced by water additions at the end of each month. Results are given in inches and in acre-feet of water for the 26.8-acre complex, table 6. During most months, rainfall and runoff were less than seepage and evaporation, so water must be applied from the pipeline to keep ponds full. In the budget, overflow only occurred when monthly rainfall and runoff were greater than monthly evaporation and seepage—water levels were far enough below drains to permit storage of all rainfall and runoff. In reality, some ponds may be too full to store all water entering from a given storm, table 5. The total amount of water required from storage to keep ponds full is 95.6 acre-feet, table 6. Ponds are normally drained and refilled once each year, requiring an additional 80.4 acre-feet. Thus, the total water requirement from storage for the complex is 176 acre-feet—provided no water is wasted by permitting ponds to overflow and no ponds are drained and refilled more than one time each year.

The primary water supply pond (FP-11) contains 140.6 acre-feet when full. In practice, small ponds are normally drained between October and December and refilled in late fall or early winter.

TABLE 6. CALCULATED WATER BUDGET FOR THE 26.8-ACRE COMPLEX OF SMALL PONDS ON THE FISHERIES RESEARCH UNIT; WATER ADDED REPRESENTS WATER REMOVED FROM STORAGE TO MAINTAIN PONDS; PONDS WERE FULL ON APRIL 1

Month	Rainfall		Runoff		Watter added		Evaporation		Seepage		Overflow	
	In.	*A.-ft.*	*In.*	*A.-ft.*	*In.*	*A.-ft.*	*In.*	*A.-ft.*	*In.*	*A.-ft.*	*In.*	*A.-ft.*
April	6.35	14.2	0.82	1.8	2.67	6.0	3.84	8.6	6.00	13.4	0.0	0.0
May.	2.19	4.9	.66	1.5	7.70	17.2	4.35	9.7	6.20	13.8	.0	.0
June.	3.84	8.6	.0	.0	6.22	13.9	4.06	9.1	6.00	13.4	.0	.0
July	6.73	15.0	.13	.3	4.51	10.1	5.17	11.5	6.20	13.8	.0	.0
August.	4.41	9.8	1.35	3.0	4.69	10.5	4.25	9.5	6.20	13.8	.0	.0
September	1.84	4.1	.0	.0	4.45	9.9	3.39	7.6	6.00	13.4	.0	.0
October.	1.72	3.8	.0	.0	7.10	15.8	2.62	5.8	6.20	13.8	.0	.0
November	6.37	14.2	.73	1.6	.77	1.7	1.87	4.2	6.00	13.4	.0	.0
December	8.59	19.2	1.36	3.0	.0	.0	1.41	3.1	6.20	13.8	2.34	5.2
January	5.13	11.4	.52	1.2	1.69	3.8	1.14	2.5	6.20	13.8	.0	.0
February.	4.19	9.3	.13	.3	3.02	6.7	1.74	3.9	5.60	12.5	.0	.0
March	9.97	22.2	.83	1.9	.0	.0	2.60	5.8	6.20	13.8	2.00	4.5
Total	61.33	136.7	6.53	14.6	42.82	95.6	36.44	81.3	73.00	162.7	4.34	9.7

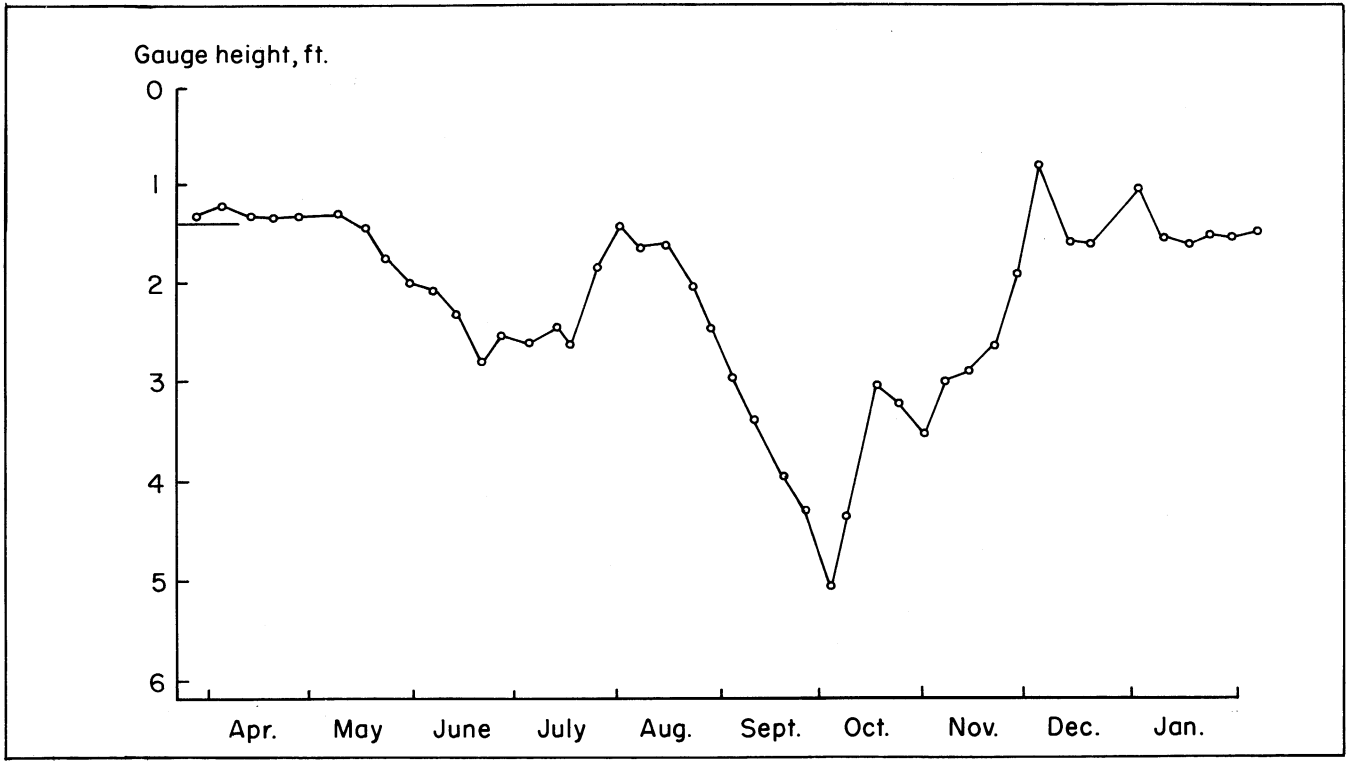

FIG. 4. Water-level changes during the period April 1982 to January 1983 in the water-supply pond (FP-11) for the small pond research area.

During winter, FP-11 is usually overflowing, and it is normal for all small ponds and FP-11 to be full May 1. Between May 1 and October 31, 77.4 acre-feet of water must be removed from FP-11 to keep small ponds full. The area of FP-11 is 20.1 acres, and natural water losses would reduce its volume by about 40.6 acre-feet between May and October if storm runoff and rainfall were the only sources of water (estimated from data in table 4). Natural losses plus consumptive use in small ponds would require about 118 acre-feet—83.9 percent of total volume. Fortunately, a small stream feeds FP-11, and additional water can be released into the stream from ponds S-29, S-30, and FP-12. A pipeline not shown in figure 1 connects S-30 to the intermittent stream which flows into FP-12. Another pond is presently being constructed below FP-12 to provide additional water reserves for the small pond research area.

Water-level changes in FP-11 between April and December 1982 are provided in figure 4. Water level declined moderately during May and June, and then the level rose following release of water from storage in some ponds on the large ponds research area. The water level decreased sharply during August and September, but it increased in mid-October when some ponds on the large pond research area were drained. Following this, the water level dropped until early November, and then the pond refilled as conditions favored greater storm runoff.

Morphometry of Ponds

Average depths of individual ponds (volumes in acre-feet divided by areas in acres) ranged from 2.50 feet to 8.63 feet; the average depth of all ponds was 5.03 feet with a standard error of 0.23 foot. Note that the average depth obtained in this manner is less than that computed earlier by dividing the total volume of all ponds by the total area of all ponds. The large variation in depth observed in ponds in the same vicinity illustrates that one should not assume, as is often done for chemical treatments of ponds, that all ponds are about 5 feet average depth. Such an assumption would greatly underestimate chemical concentrations in some ponds and overestimate them in others.

Bottoms of ponds were remarkably regular in slope towards the deepest points where drain pipes were located (see contour maps, Appendix figures 1-36). In 13 of the 36 ponds, one or more depressions or ridges interrupted the regular decline in contours towards the drains. For example, in FP-12, 9-, 10-, and 11-foot contour lines occur outside the major 9-foot contour line and within the 8-foot contour line at the north end of the pond, Appendix figure 36. If the pond was drained through the pipe within the 20-foot contour, water would remain within the 9- to 11-foot contours of the small depression. Although several ponds have such irregularities in their bottom contours, none of the anomalies seriously impedes pond draining.

It is recommended that edges of ponds be deepened so that no areas are less than 1.5 to 2 feet deep *(4, 9, 15, 20)*. In combination with pond fertilizaton to promote phytoplankton turbidity, deep edges limit areas over which the bottom receives adequate light for initiation of aquatic weed growth. Unfortunately, many of the ponds on the Fisheries Research Unit have large expanses of water above the 2-foot contour (examine maps of S-7, S-13, S-16, S-19, FP-6, and FP-9 in Appendix figures 7, 13, 16, 17, 31, and 33). Percentage of pond area less than 2 feet deep varied from 7.0 percent in S-14 to 36.0 percent in S-16; the average for all ponds was 17.0 percent (standard error = 1.20). Edges were deepened when ponds were initially constructed (mostly in the 1940's), but since then erosion and siltation have formed extensive areas of shallow water. Experience with ponds in the Southeastern United States suggests that most ponds have water less than 1.5 to 2 feet deep.

Bottoms of sportfish ponds are quite important for production of fish food organisms. Pond fertilization increases phytoplankton growth, which in turn favors high abundances of zooplankton and bottom organisms *(4, 15)*. Increased phytoplankton abundance also favors shallow thermal and chemical stratification. Waters more than 4 to 6 feet deep are often devoid of oxygen and bottom muds are also anaerobic *(2, 4)*. Percentages of pond bottoms above 5-foot contours ranged from 27.5 percent in AE-1 to 100 percent in S-27. The average for all ponds was 55.2 percent (standard error = 3.14). Hence, 50 percent or more of the bottoms of most of the ponds would remain aerobic during stratification.

Sudden overturns (destratification) of thermally stratified ponds resulting from strong winds, heavy rains, or unseasonably cool weather can result in oxygen depletion and fish kills *(4, 17)*. Therefore, large volumes of deep, anaerobic water are undesirable in fish ponds. Volumes of water below 5-foot contours varied from 0 in S-27 to 46.5 perecent in AE-1; the average was 24.6 percent (standard error = 2.97 percent). Most ponds did not have a particularly large volume below the 5-foot contour. Depth-volume graphs

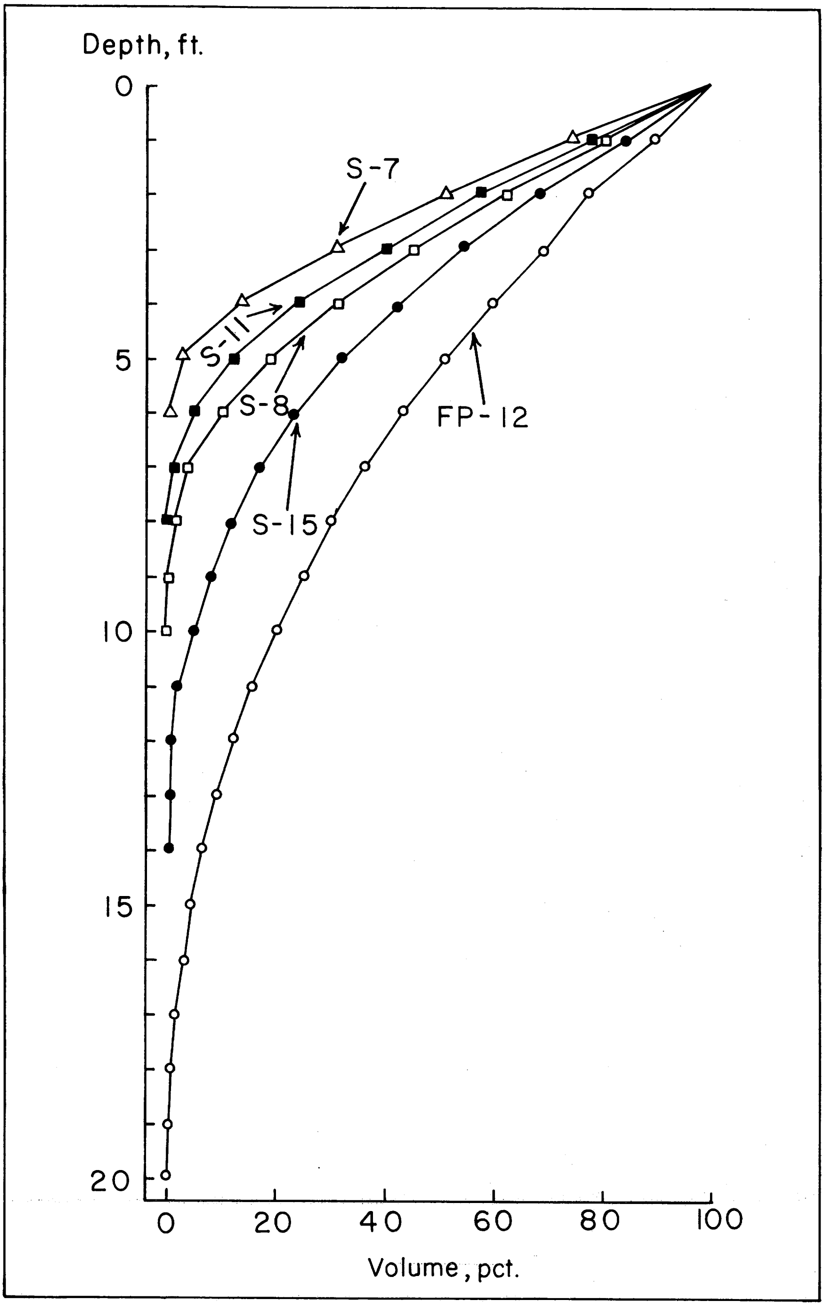

FIG. 5. Depth-volume relationships for five ponds on the Auburn University Fisheries Research Unit.

for five typical ponds are provided in figure 5. Deep areas of the ponds contributed relatively little to total volume.

The form of the basin of a water body may be expressed as an index known as the volume development *(23)*. This expression represents the ratio of the total volume of a water body to the volume of a cone whose base area is equal to the surface area of the water body and whose height is equal to the maximum depth. When the value of volume development approaches unity, the basin is close to the shape of the cone described above; the volume development value is less than unity when the basin walls are essentially convex towards the water; when the basin walls are concave towards the water, the index will be greater than unit. All but two ponds had volume development values greater than 1.0, Appendix table 2; the average was 1.30 (standard error = 0.028). Thus, most ponds had basin walls that were concave towards the water.

Degree of regularity or irregularity of shoreline is expressed as an index figure called the shore development *(23)*. Shore development refers to the ratio of the actual length of shoreline to the length of the circumference of a circle the area of which is equal to that of the water body. If the shoreline formed a circle, shore development would be 1.0. The greater the shore development value, the more irregular the shoreline. Ponds on the large pond research area had shore development values between 1.03 and 1.86, and all but four ponds had values of 1.50 or less, Appendix table 2. The average was 1.30 (standard error = 0.032). Hence, ponds had quite regular shorelines. Many larger lakes and reservoirs have shore development values of 5 or more. The natural productivity of water bodies is considered to increase with greater shore development *(22)*. However, application of fertilizers to fish ponds will increase natural productivity regardless of shore development.

SUMMARY

The large pond research area on the Auburn University Fisheries Research Unit contains 36 ponds which have a total area of 199 acres and a combined volume of 1,156 acre-feet. These ponds are located on a 2,310-acre hydrologic unit. During a 12-month period, when rainfall totaled 61.33 inches, calculated storm runoff was 7.9 inches. The majority of storm runoff occurred between November and March. Seepage out of ponds ranged from 0.02 inch per day in February to 0.21 inch per day in September; seepage often exceeded evaporation. Ponds that depended entirely on storm runoff and rainfall as water sources had marked declines in water levels during summer and fall—1.5 to 3 feet. Ponds receiving seepage from other ponds, and ponds into which springs or streams discharged, had more stable water levels. Ponds did not drastically reduce the volume of storm runoff available from the hydrologic unit because storm runoff in late fall quickly filled ponds and runoff entering ponds during winter and early spring flowed through spillways. Nevertheless, a large volume of water was held in storage by the ponds throughout the year.

The small pond research area consists of 26.8 acres of small ponds with average depths of about 3 feet. Water is confined by embankments built above ground level. Hence, ponds are filled and maintained by rainfall and inflow from a water supply pond. Seepage rates were quite high (annual average = 0.20 inch per day), and did not vary greatly with season. Ponds are normally drained and refilled once each year. The total volume of water required from storage is 176 acre-feet—provided no water is wasted and no ponds are drained and refilled more than once in a year. Of this total, 77.4 acre-feet must be supplied between March 1 and October 31 when storm runoff does not replenish the water supply pond.

Observations on water budgets for ponds were for a wetter than average year. Water levels in large ponds would decline more and the amount of water withdrawn from storage to maintain small ponds would increase during drier than average years.

The large ponds varied greatly in average depth. Bottoms were regularly sloped toward deepest points, and the basin walls were concave towards the water (volume development averaged 1.30). Ponds had considerable areas less than 2 feet deep (average = 17 percent), and an average of 55 percent of the pond was covered by water less than 5 feet deep. Most water storage (average = 75 percent) was above 5-foot contours. Shorelines were quite regular; shore development averaged 1.30 as compared to 1.0 for a circular body of water.

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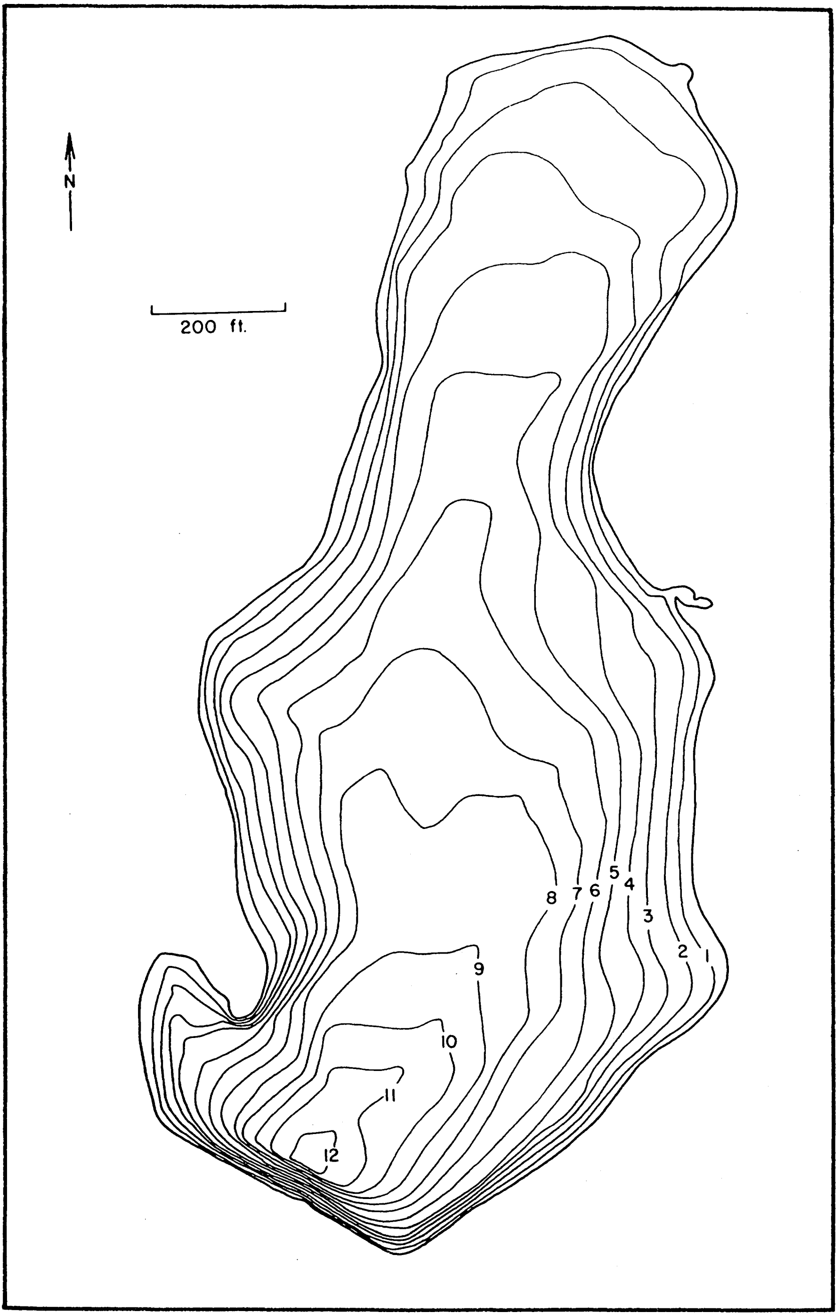
APPENDIX

APPENDIX TABLE 1. AREAS AND VOLUMES OF PONDS ON THE LARGE POND RESEARCH AREA OF THE AUBURN UNIVERSITY FISHERIES RESEARCH UNIT

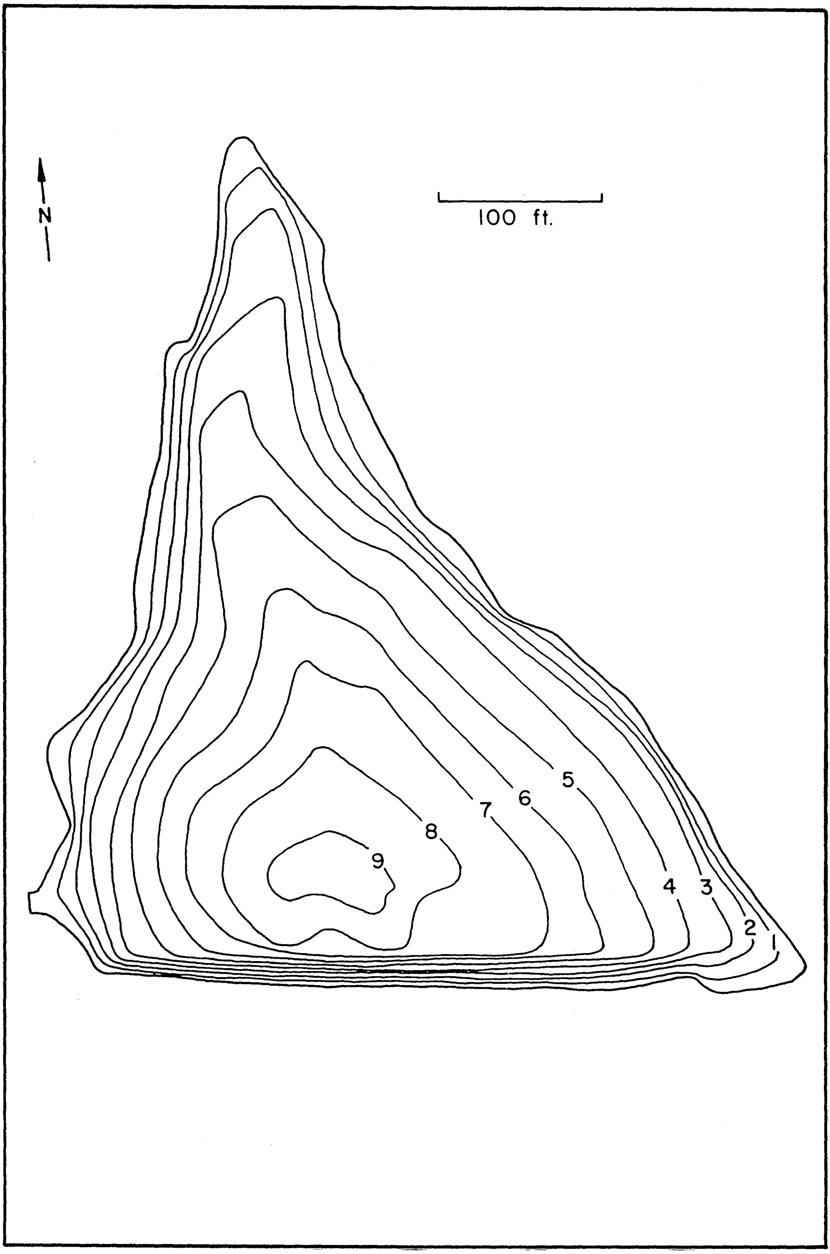
Pond	Area	Volume	Pond	Area	Volume
	Acres	*Acre-ft.*		*Acres*	*Acre-ft.*
S-1	22.6	113.9	S-23	2.32	8.6
S-2	2.75	12.9	S-24	2.22	10.2
S-3	9.49	53.3	S-25	1.03	2.8
S-4	1.42	7.6	S-26	1.00	4.8
S-5	1.82	9.6	S-27	.72	2.3
S-6	26.0	193.2	S-28	4.74	25.5
S-7	2.56	9.4	S-29	7.23	51.8
S-8	11.1	54.1	S-30	13.2	72.1
S-9	3.72	19.0	AE-1	4.04	33.1
S-10	3.27	18.5	AE-2	3.40	16.0
S-11	2.83	12.7	AE-3	3.25	15.0
S-12	2.27	10.7	BC-1	1.01	4.2
S-13	2.08	6.8	FP-6	2.22	7.9
S-14	12.9	72.2	FP-8	1.94	9.8
S-15	5.70	33.2	FP-9	1.26	5.0
S-16	2.48	6.2	FP-10	4.75	26.3
S-19	1.70	6.1	FP-11	20.1	140.6
S-22	2.15	12.7	FP-12	7.90	68.2

APPENDIX TABLE 2. SHORE AND VOLUME DEVELOPMENT VALUES FOR PONDS ON THE LARGE POND RESEARCH AREA OF THE AUBURN UNIVERSITY FISHERIES RESEARCH UNIT

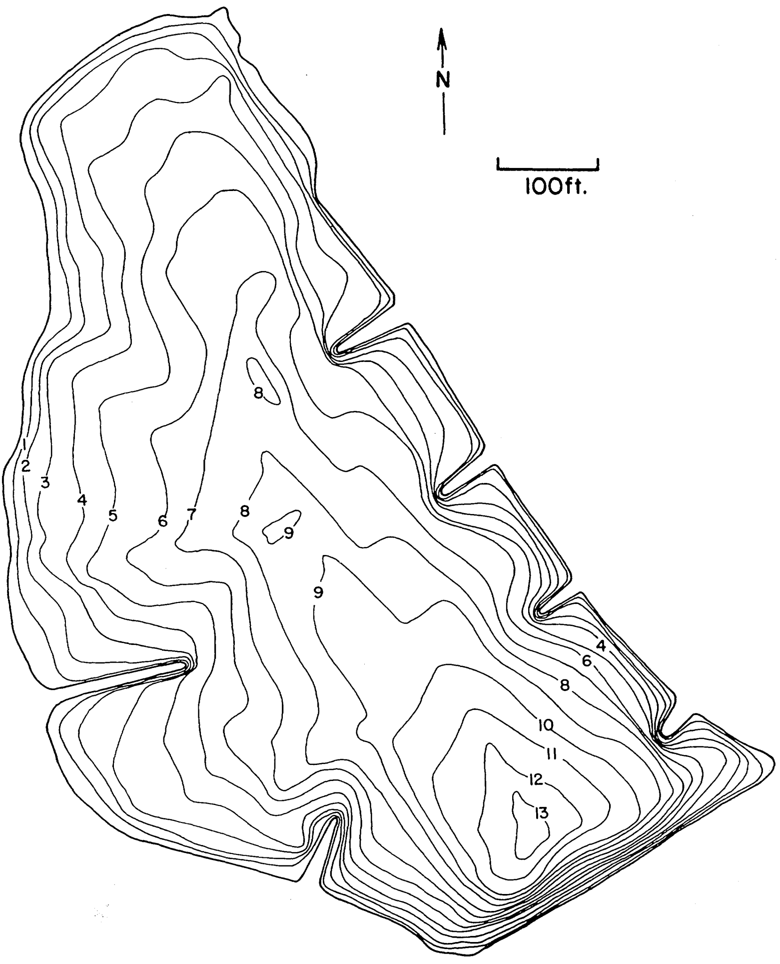
Pond	Shore development	Volume development	Pond	Shore development	Volume development
S-1	1.45	1.16	S-23	1.16	1.39
S-2	1.41	1.41	S-24	1.25	1.37
S-3	1.61	1.20	S-25	1.11	1.34
S-4	1.12	1.23	S-26	1.11	1.61
S-5	1.20	1.31	S-27	1.13	1.59
S-6	1.86	1.39	S-28	1.48	1.07
S-7	1.17	1.58	S-29	1.05	1.02
S-8	1.64	1.33	S-30	1.44	1.17
S-9	1.28	1.54	AE-1	1.33	1.44
S-10	1.18	1.42	AE-2	1.50	1.41
S-11	1.03	1.49	AE-3	1.30	.99
S-12	1.15	1.42	BC-1	1.18	1.25
S-13	1.16	1.22	FP-6	1.17	1.19
S-14	1.49	1.29	FP-8	1.31	1.27
S-15	1.11	1.16	FP-9	1.35	1.19
S-16	1.26	1.26	FP-10	1.49	.92
S-19	1.20	1.34	FP-11	1.51	1.31
S-22	1.29	1.47	FP-12	1.49	1.23



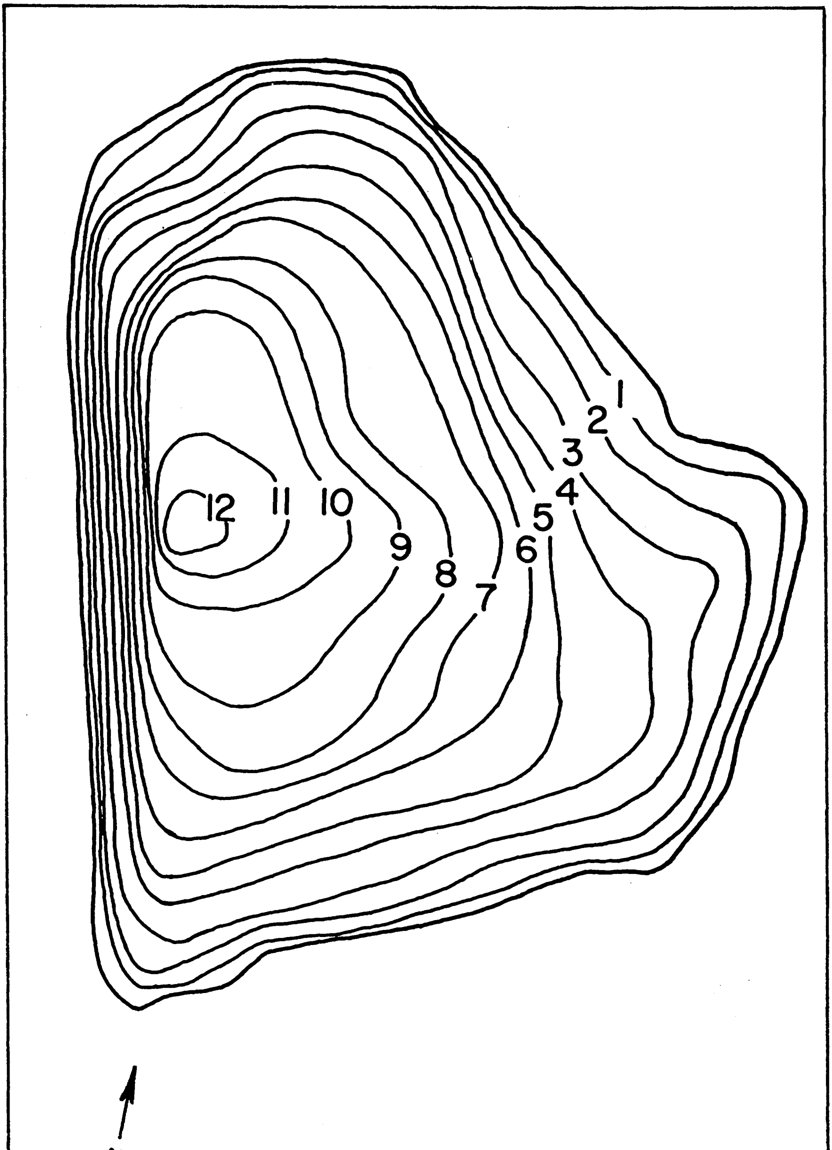
APPENDIX FIG. 1. Pond S-1.



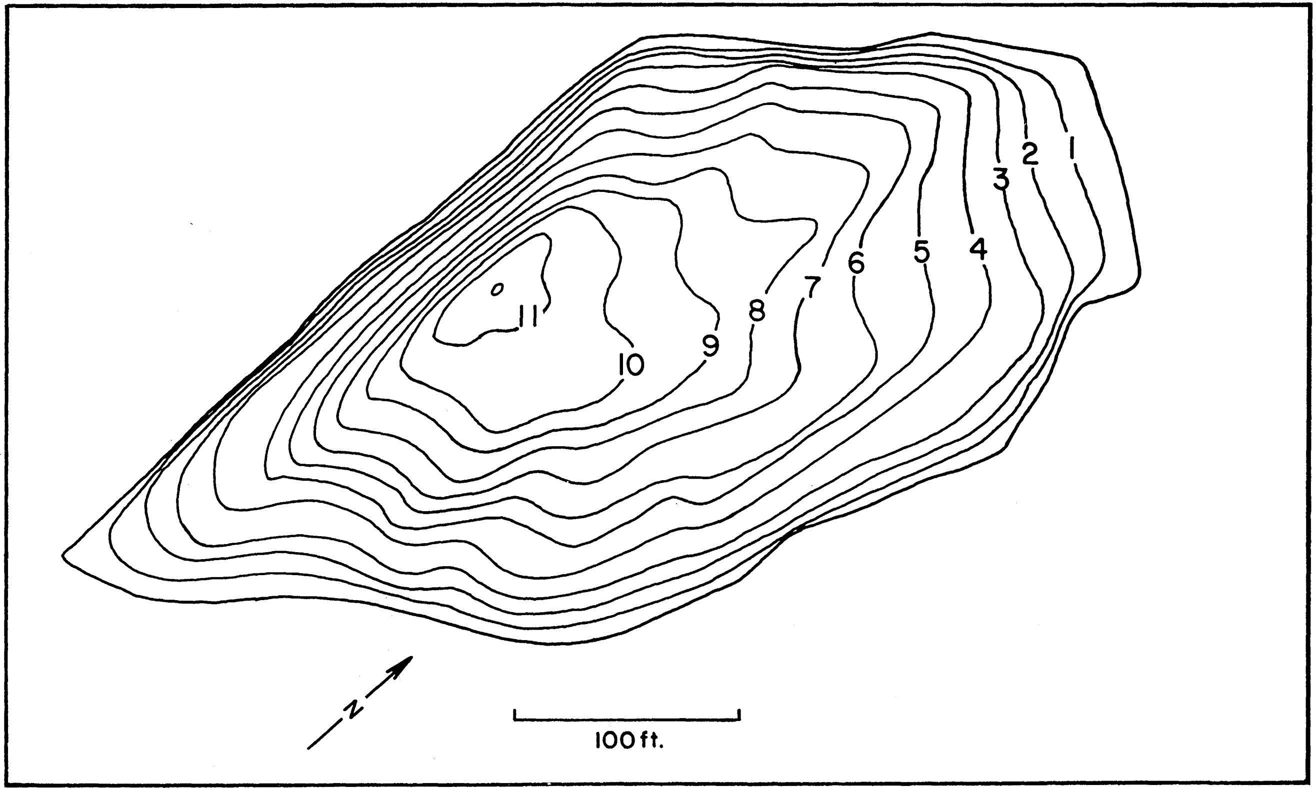
APPENDIX FIG. 2. Pond S-2.



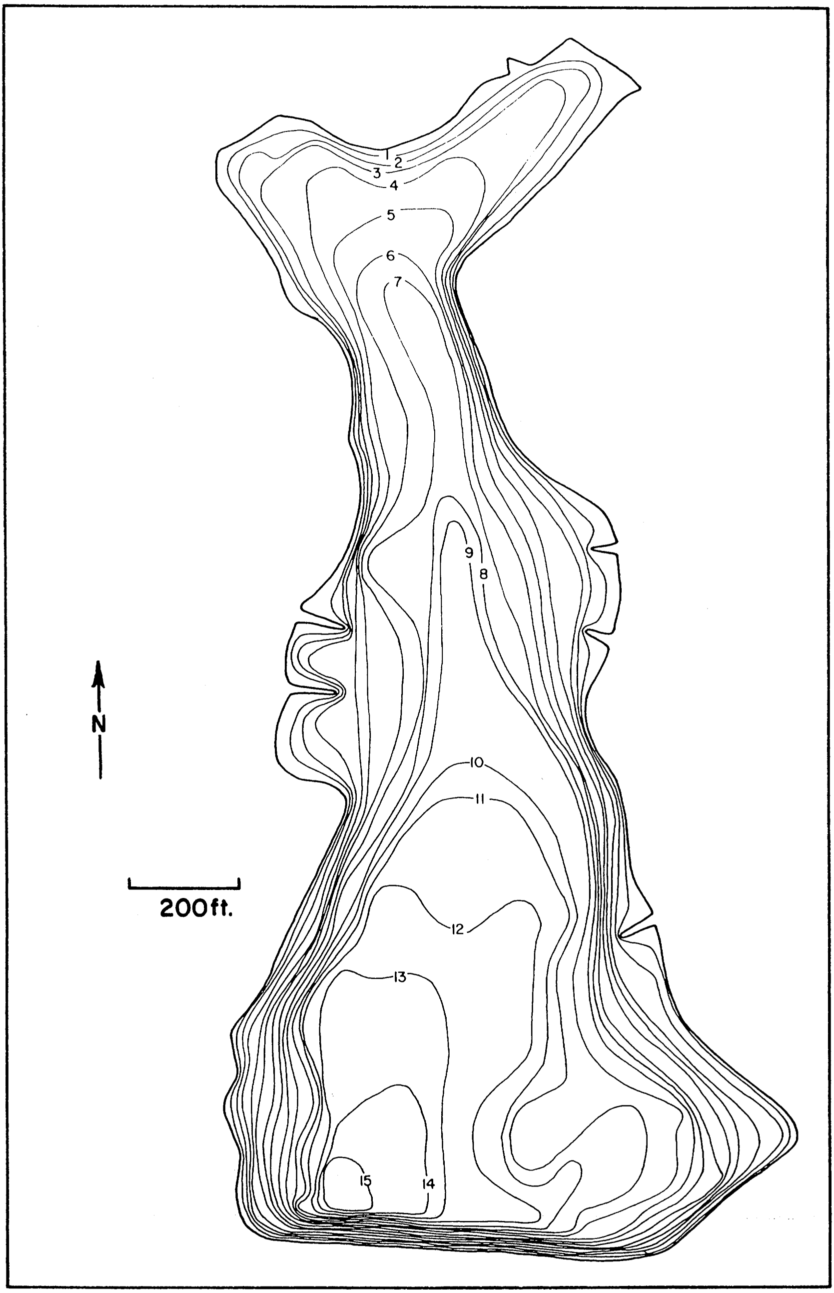
APPENDIX FIG. 3. Pond S-3.



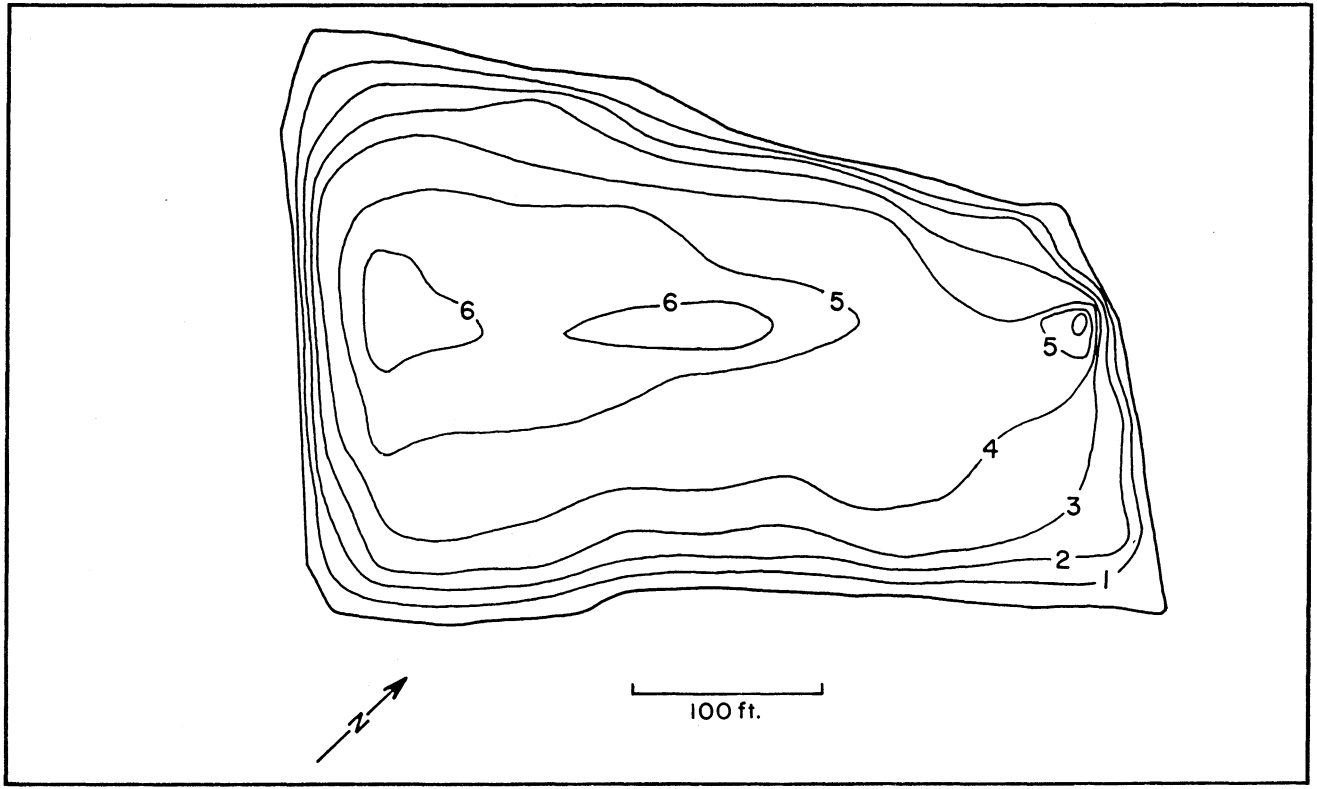
APPENDIX FIG. 4. Pond S-4.



APPENDIX FIG. 5. Pond S-5.



APPENDIX FIG. 6. Pond S-6.



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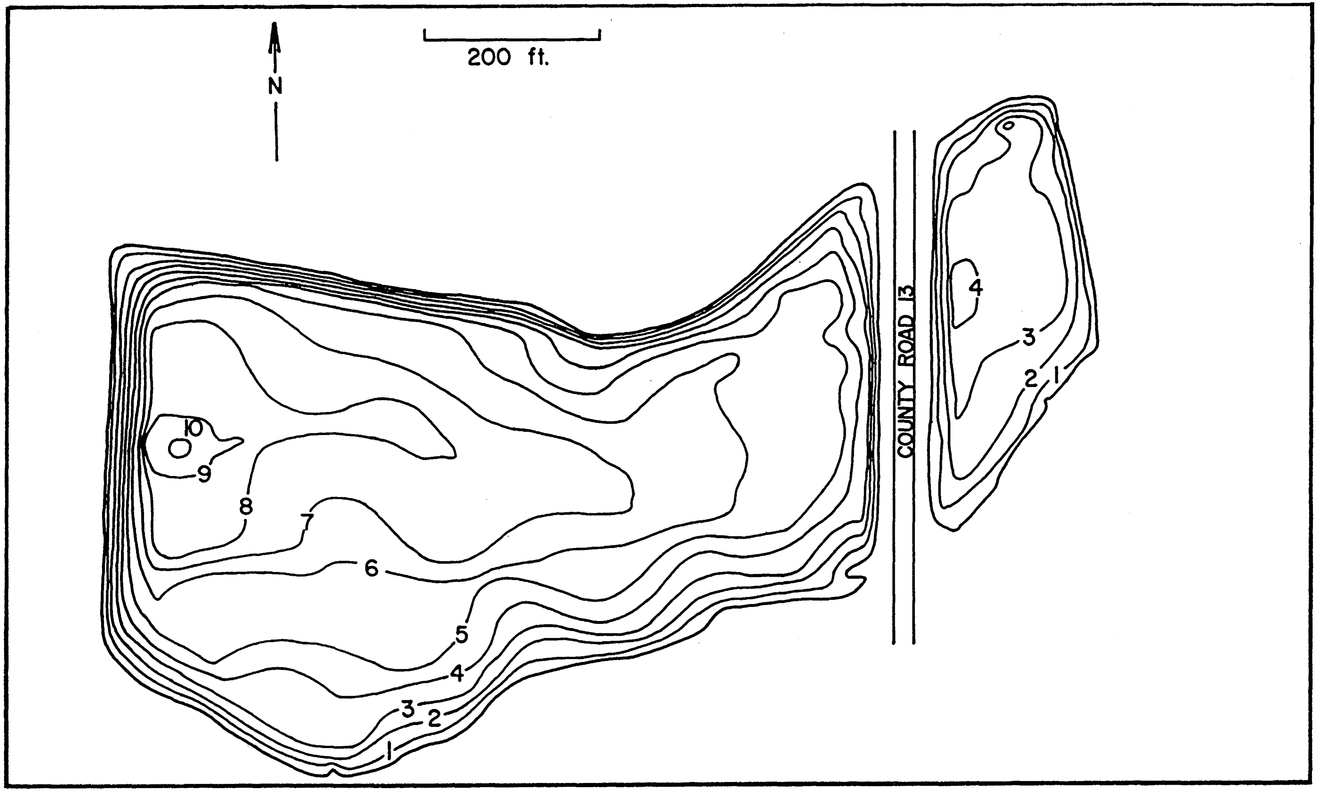
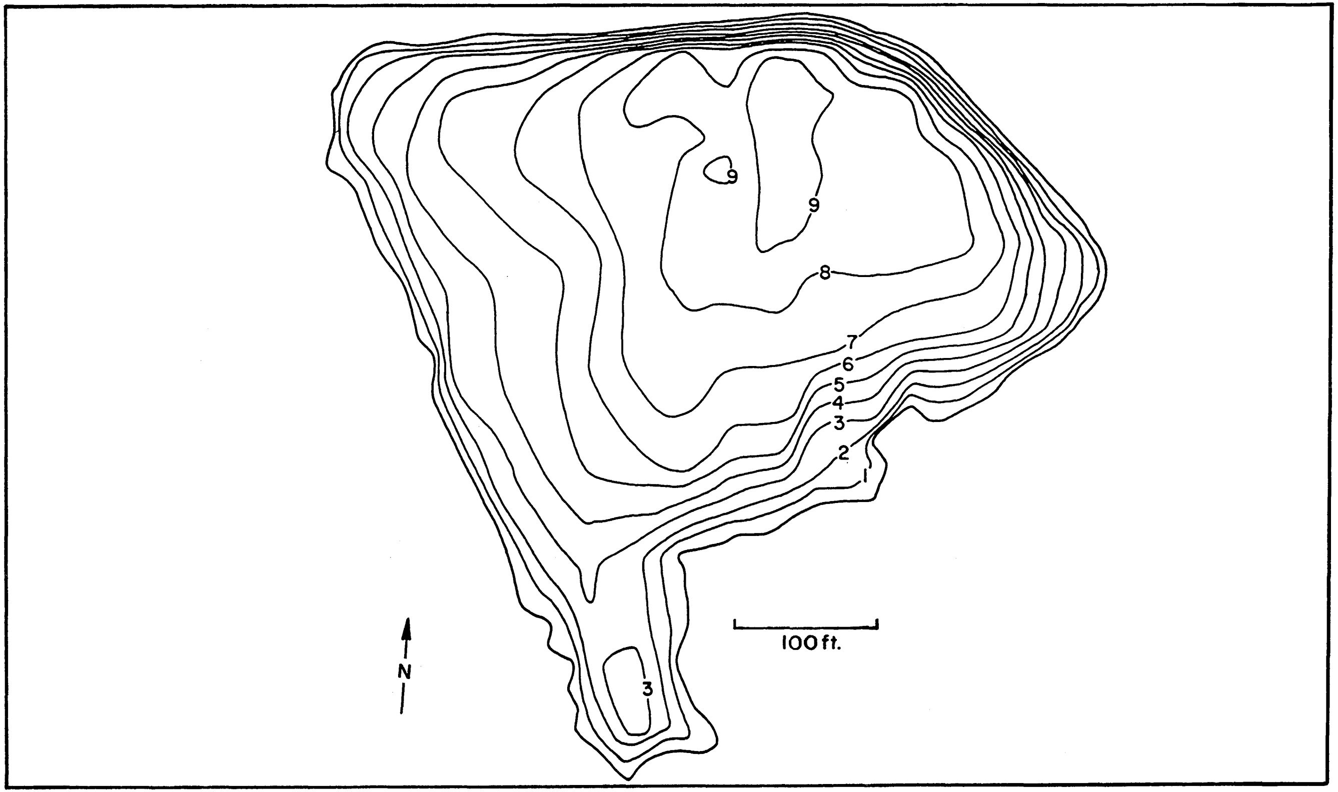
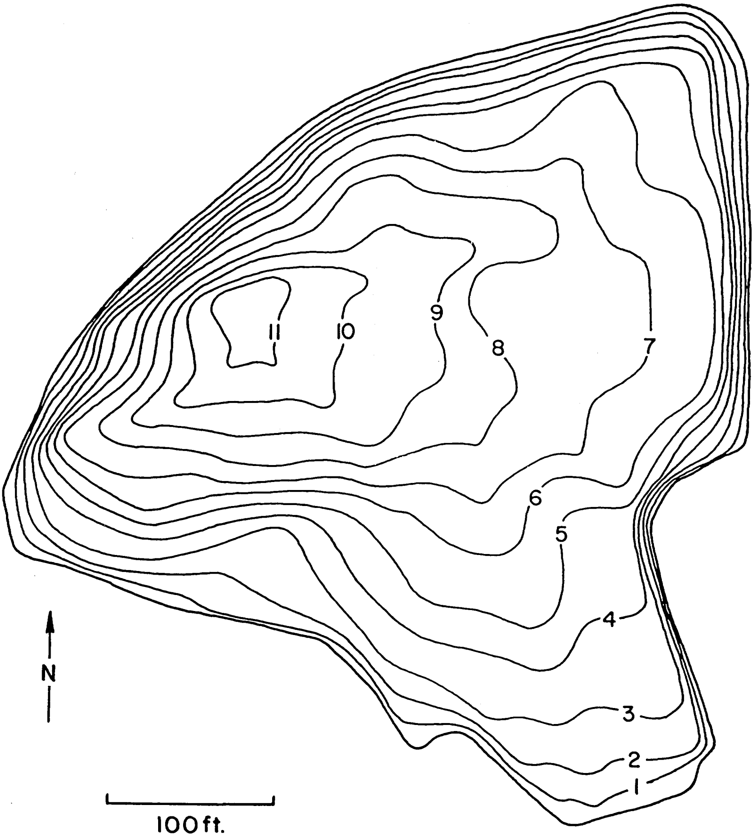


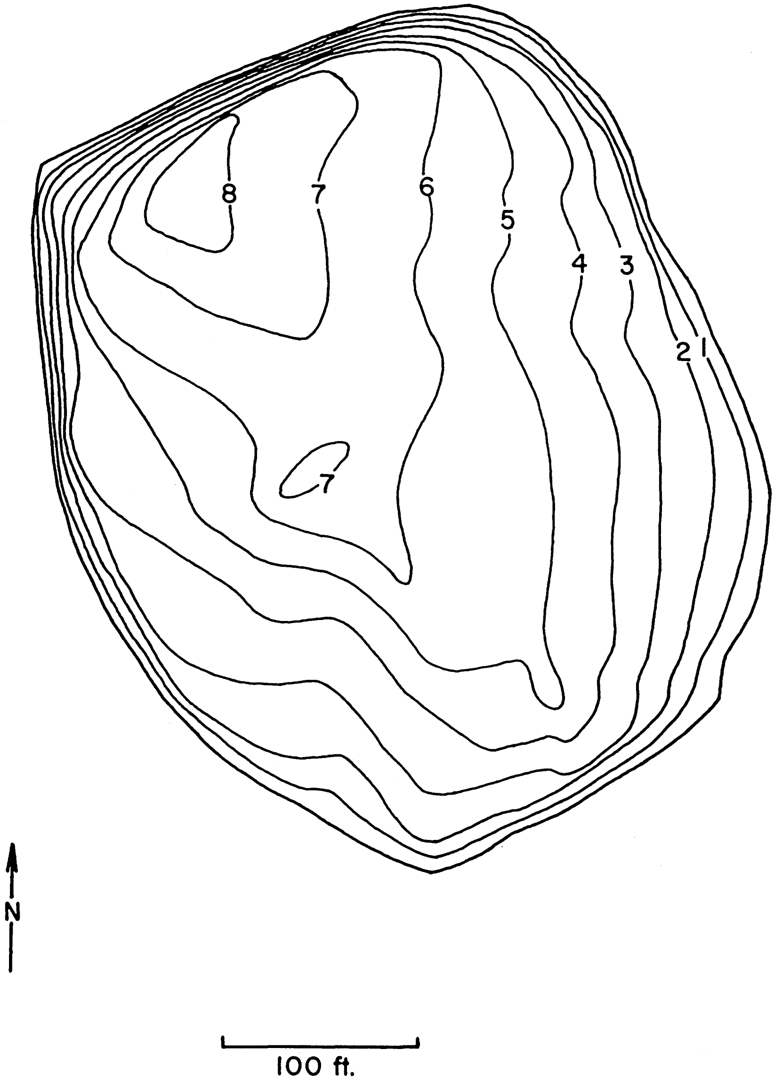
APPENDIX FIG. 8. Pond S-8.



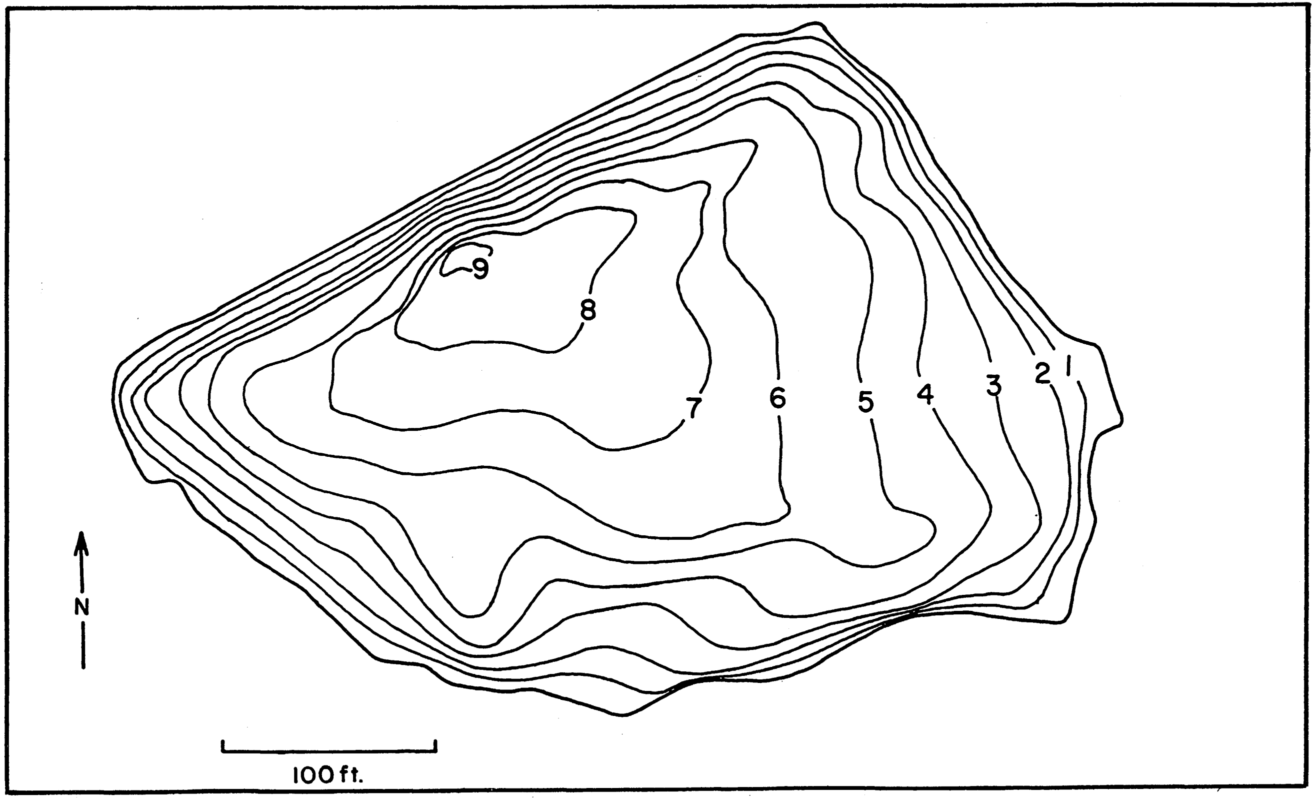
APPENDIX FIG. 9. Pond S-9.



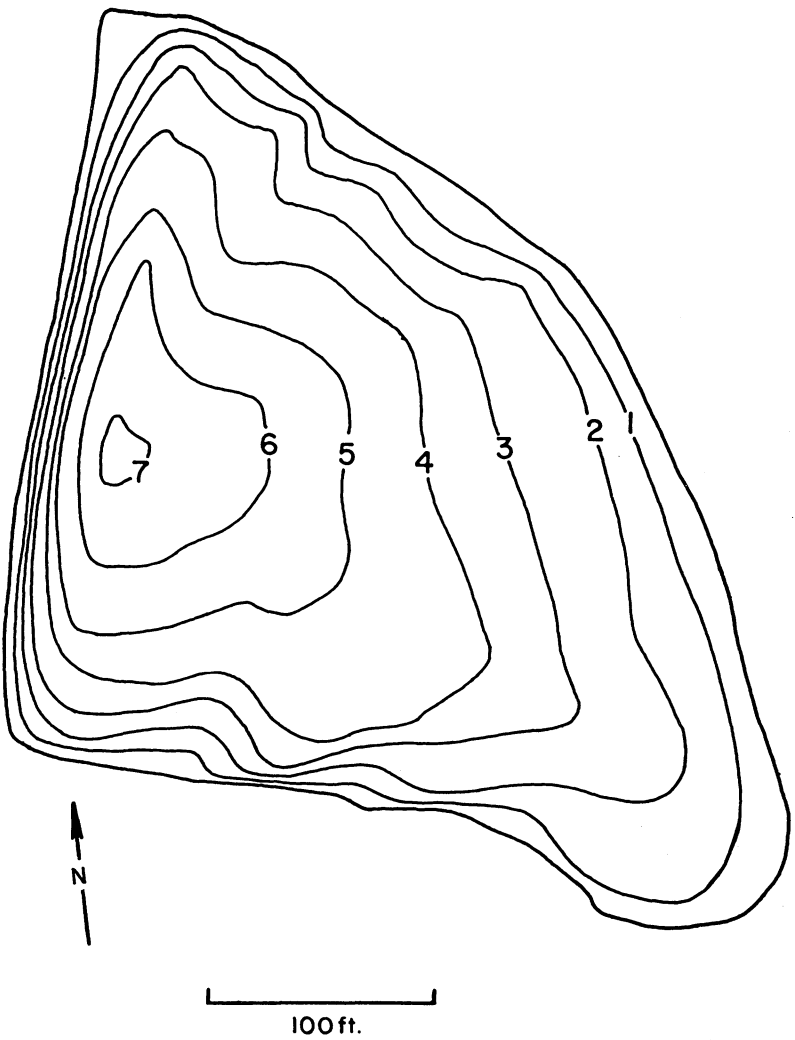
APPENDIX FIG. 10. Pond S-10.



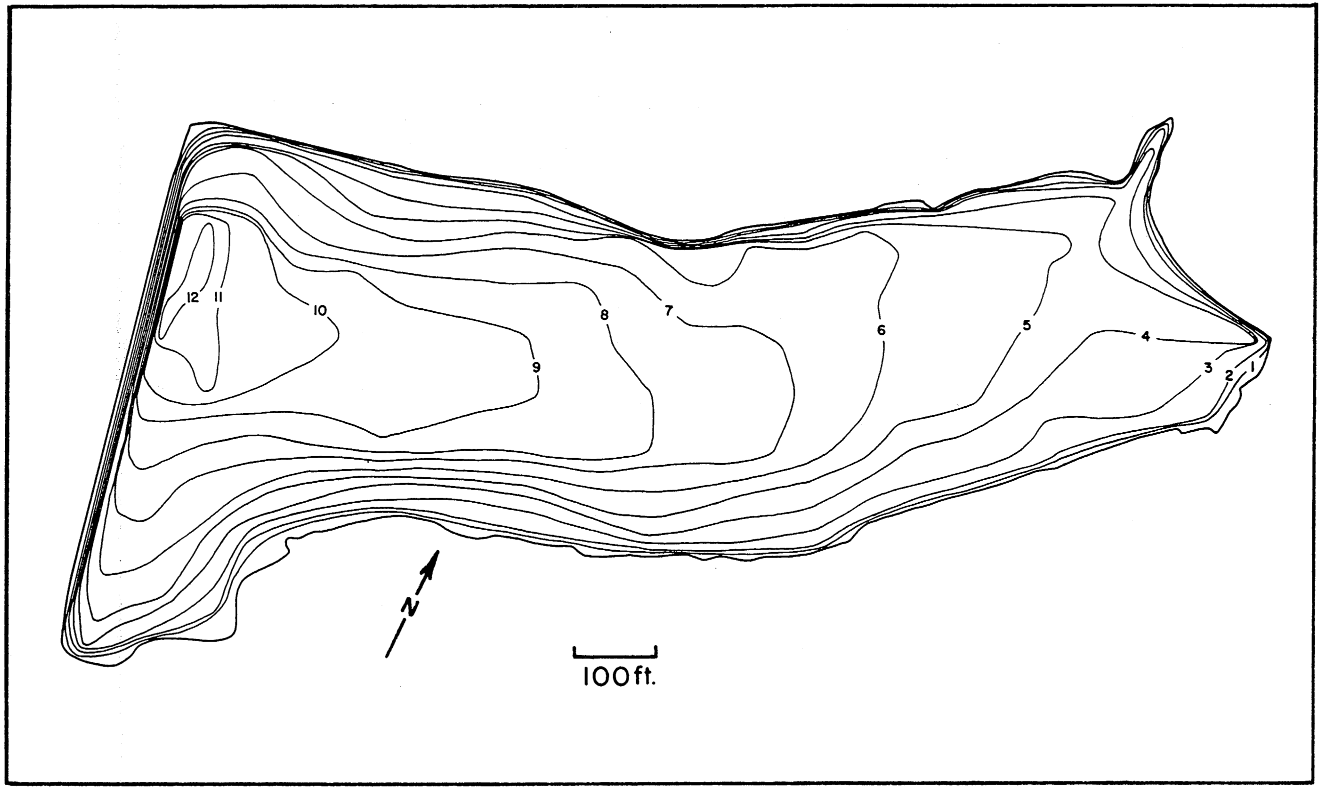
APPENDIX FIG. 11. Pond S-11.



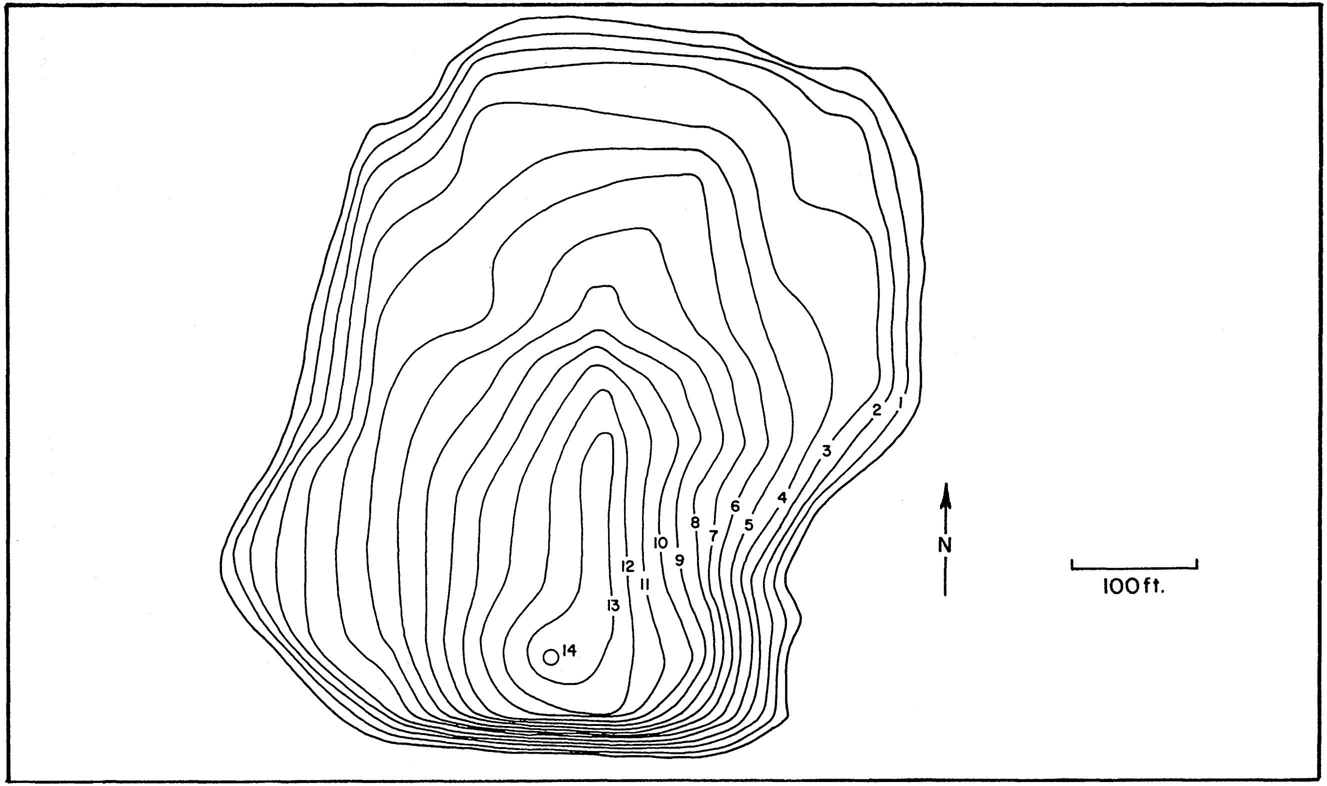
APPENDIX FIG. 12. Pond S-12.



APPENDIX FIG. 13. Pond S-13.



APPENDIX FIG. 14. Pond S-14.



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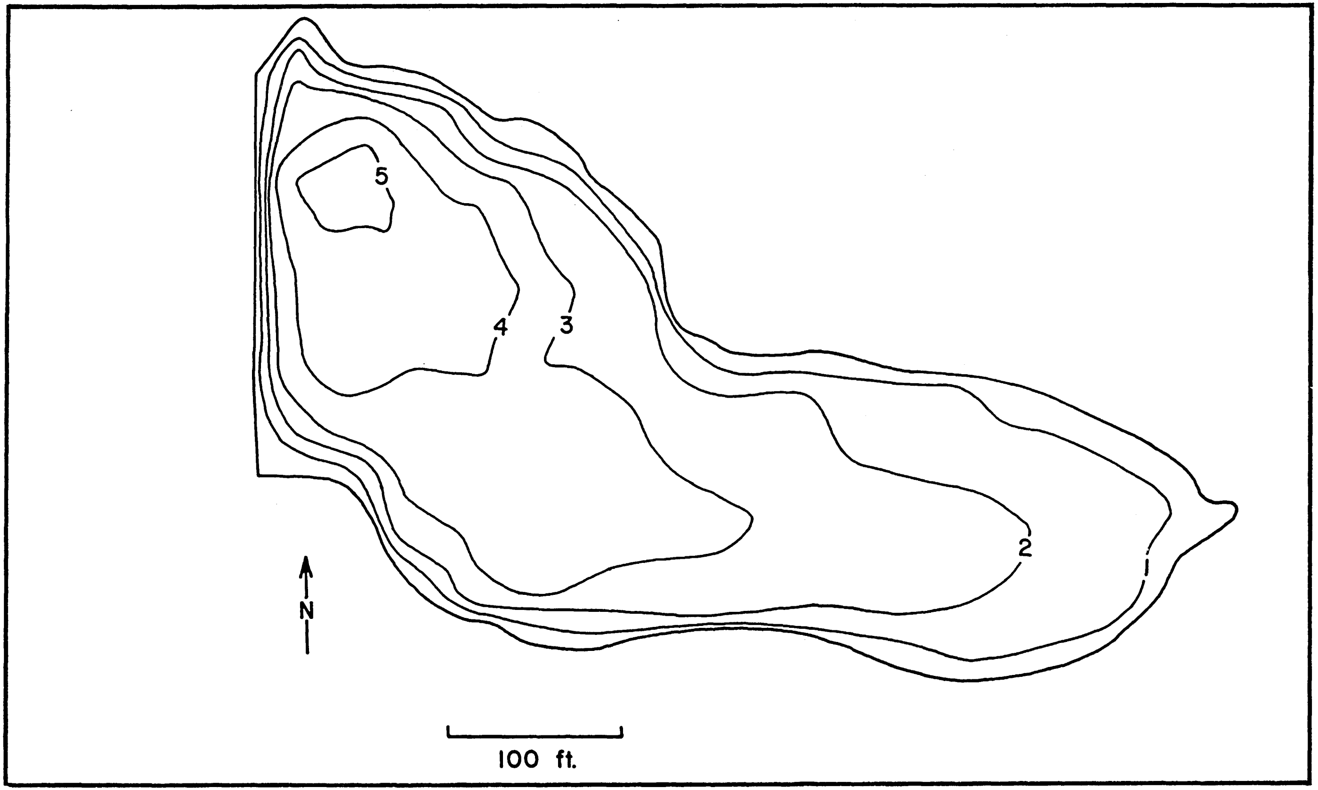

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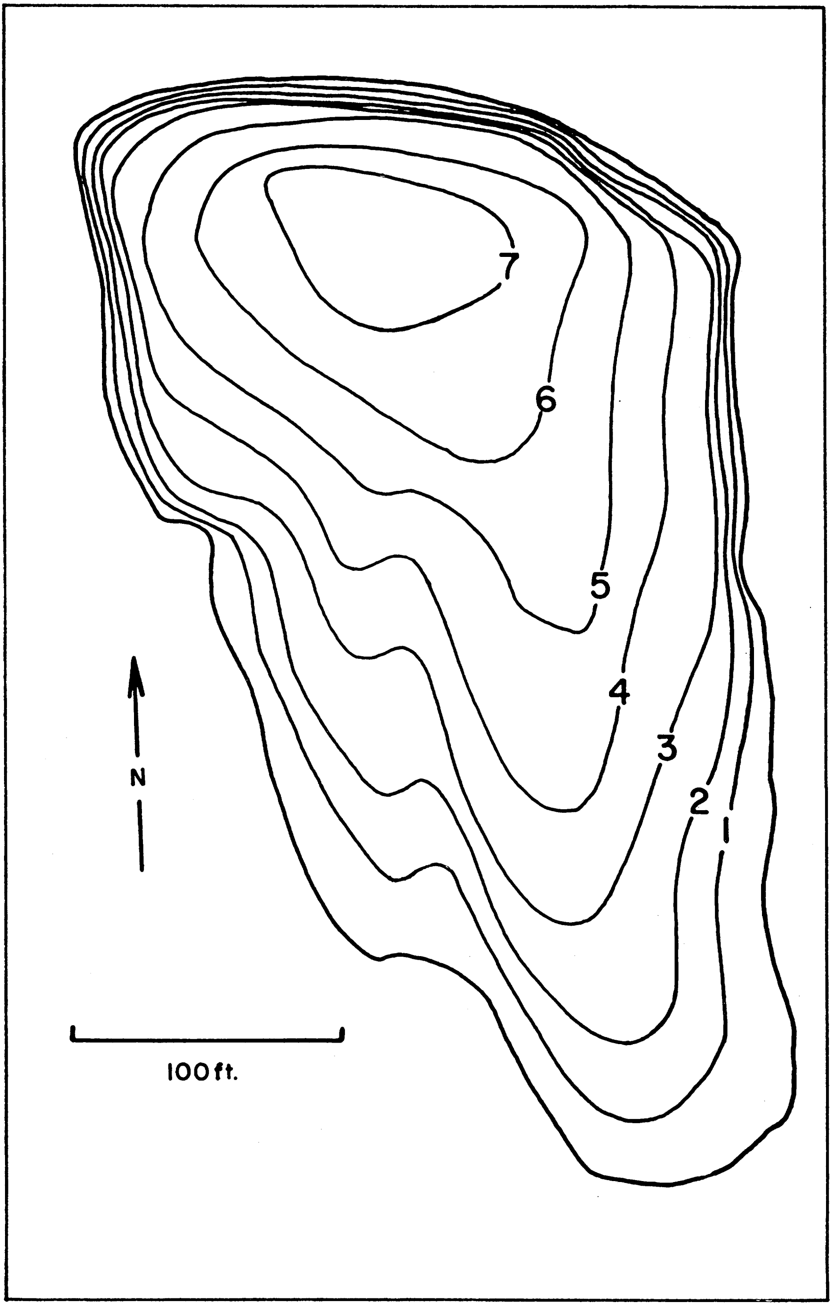
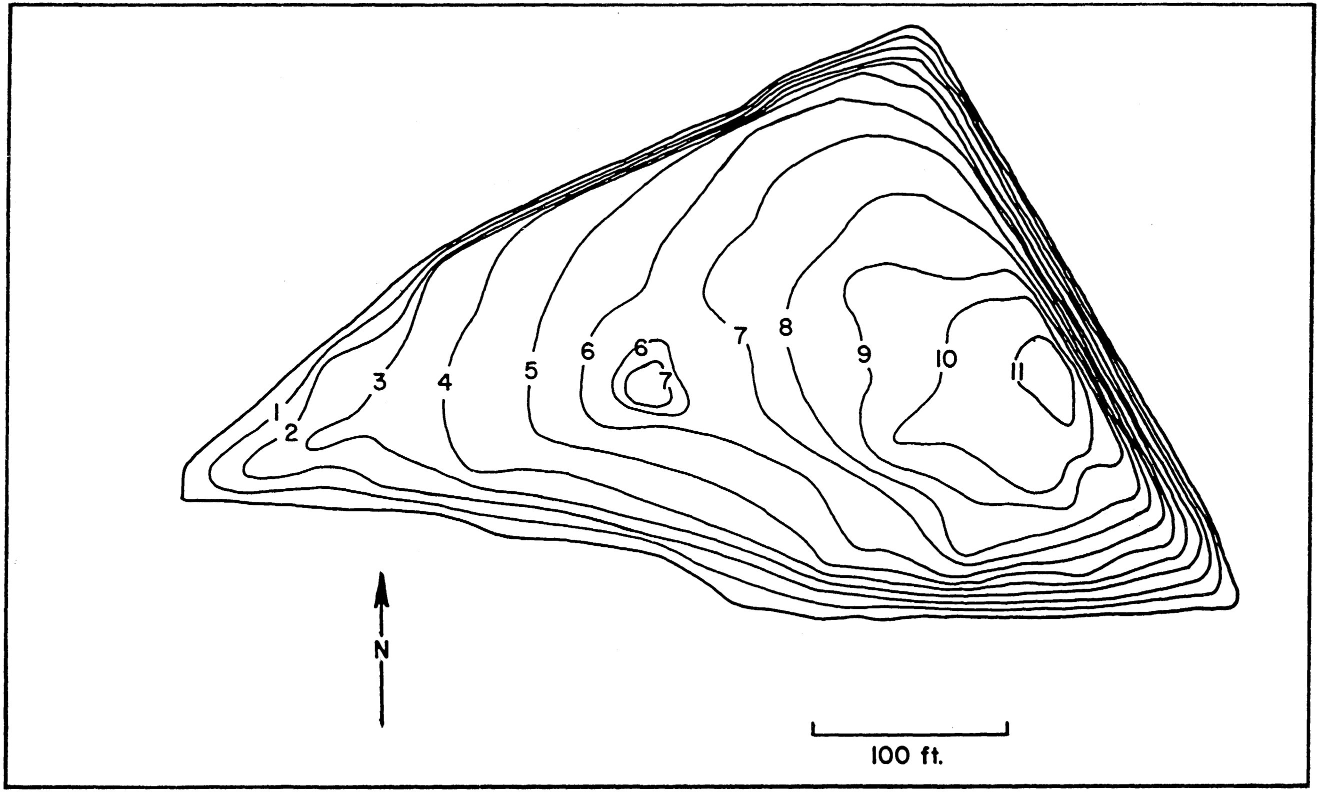
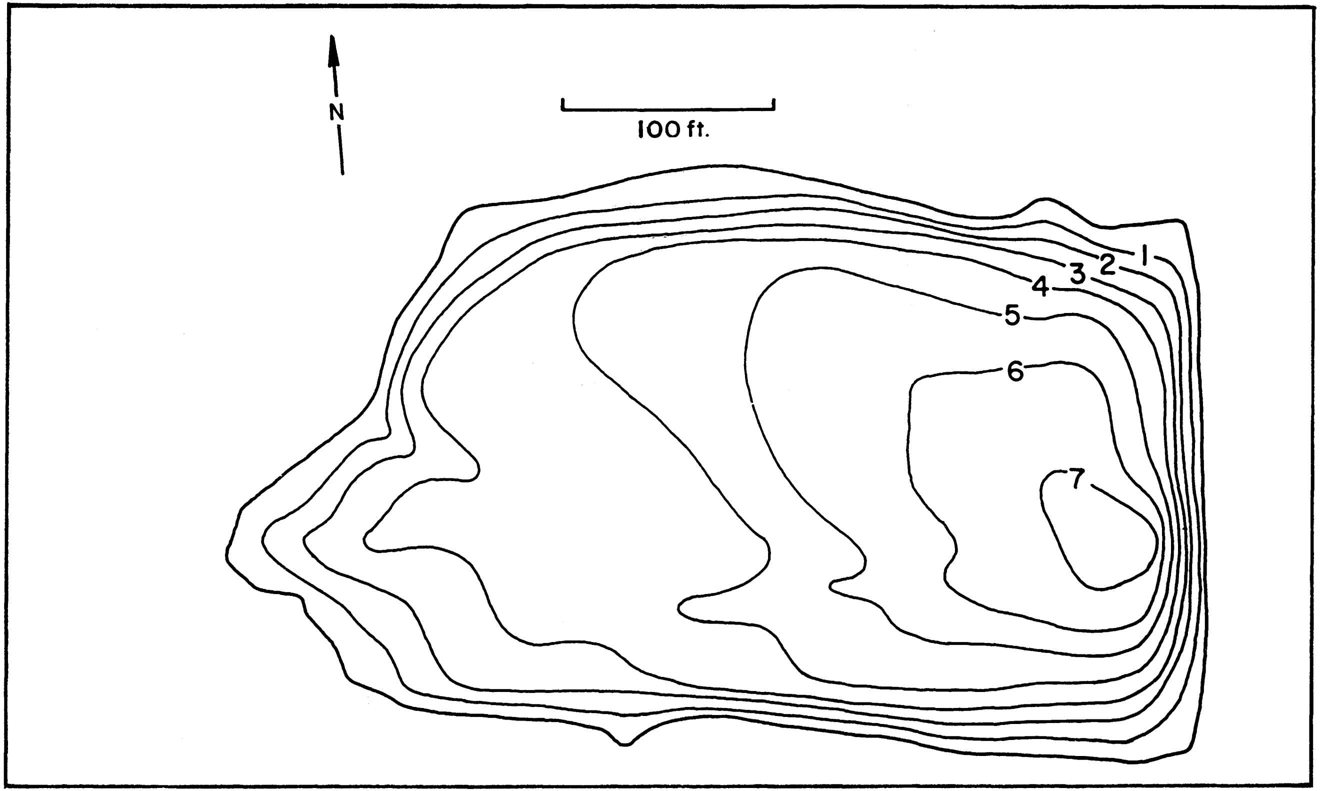


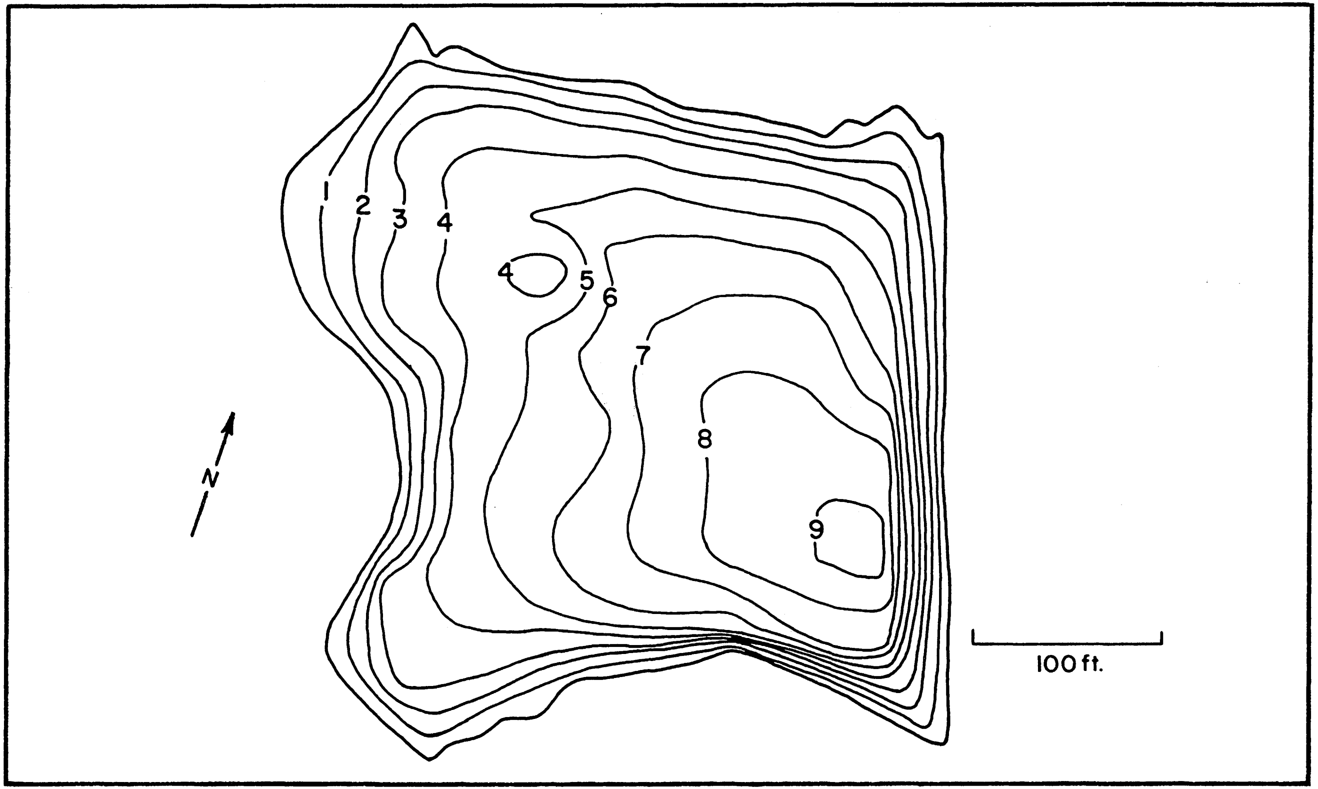
APPENDIX FIG. 17. Pond S-19.



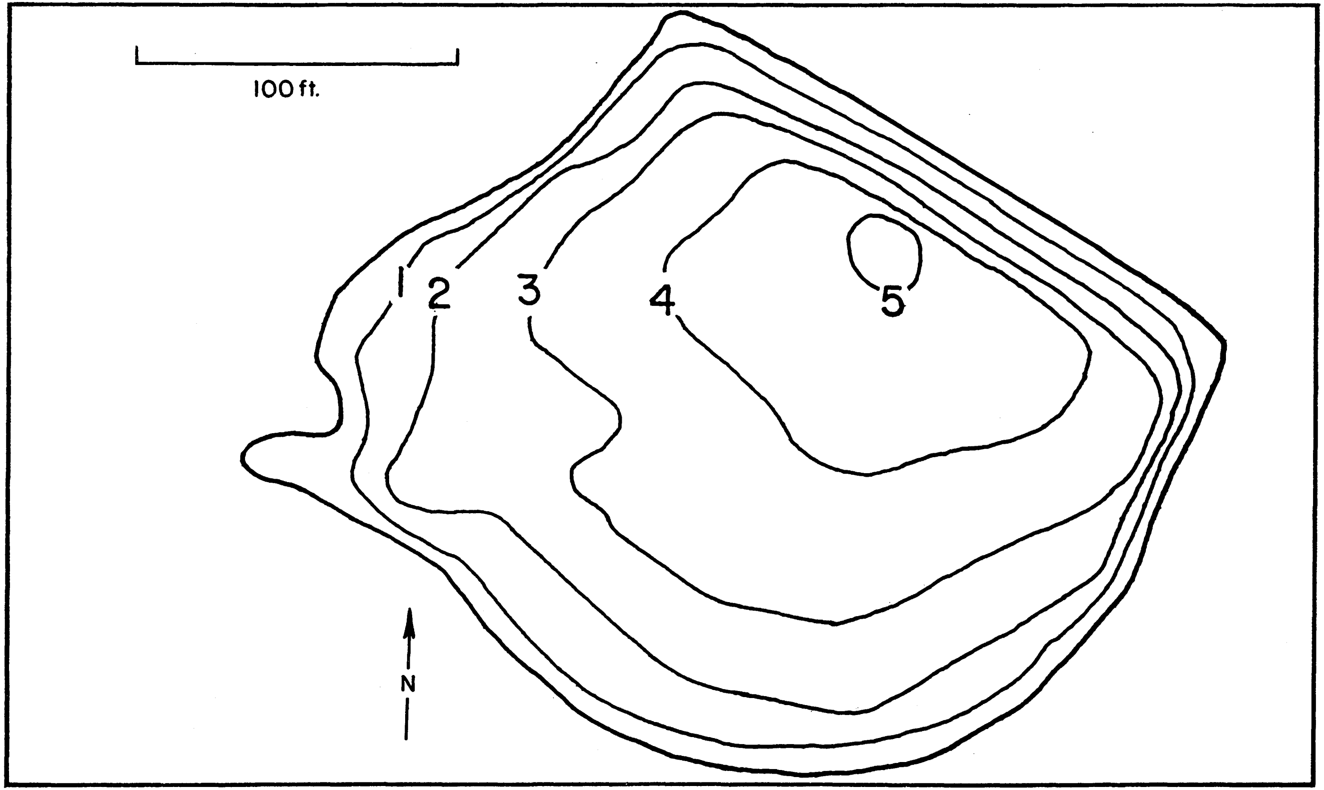
APPENDIX FIG. 18. Pond S-22.



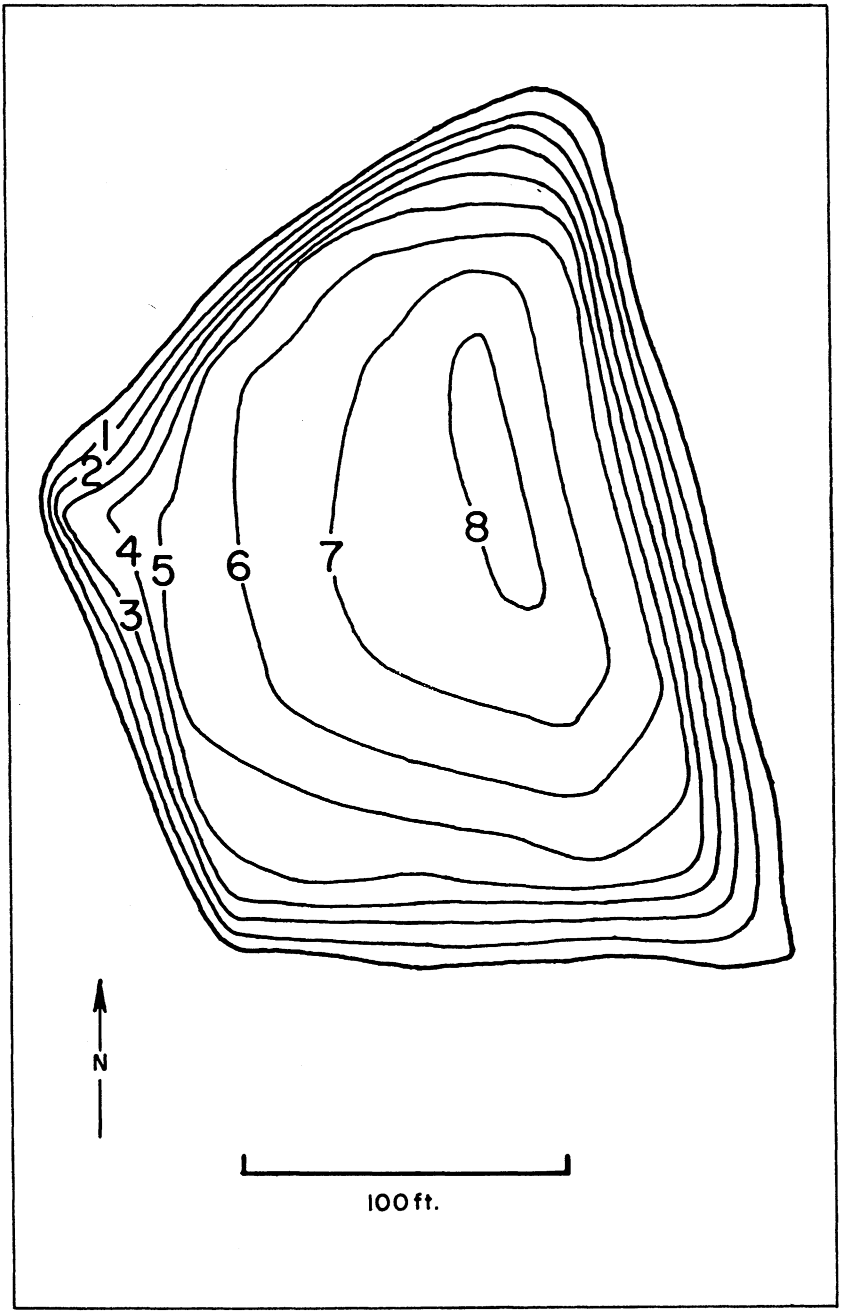
APPENDIX FIG. 19. Pond S-23.



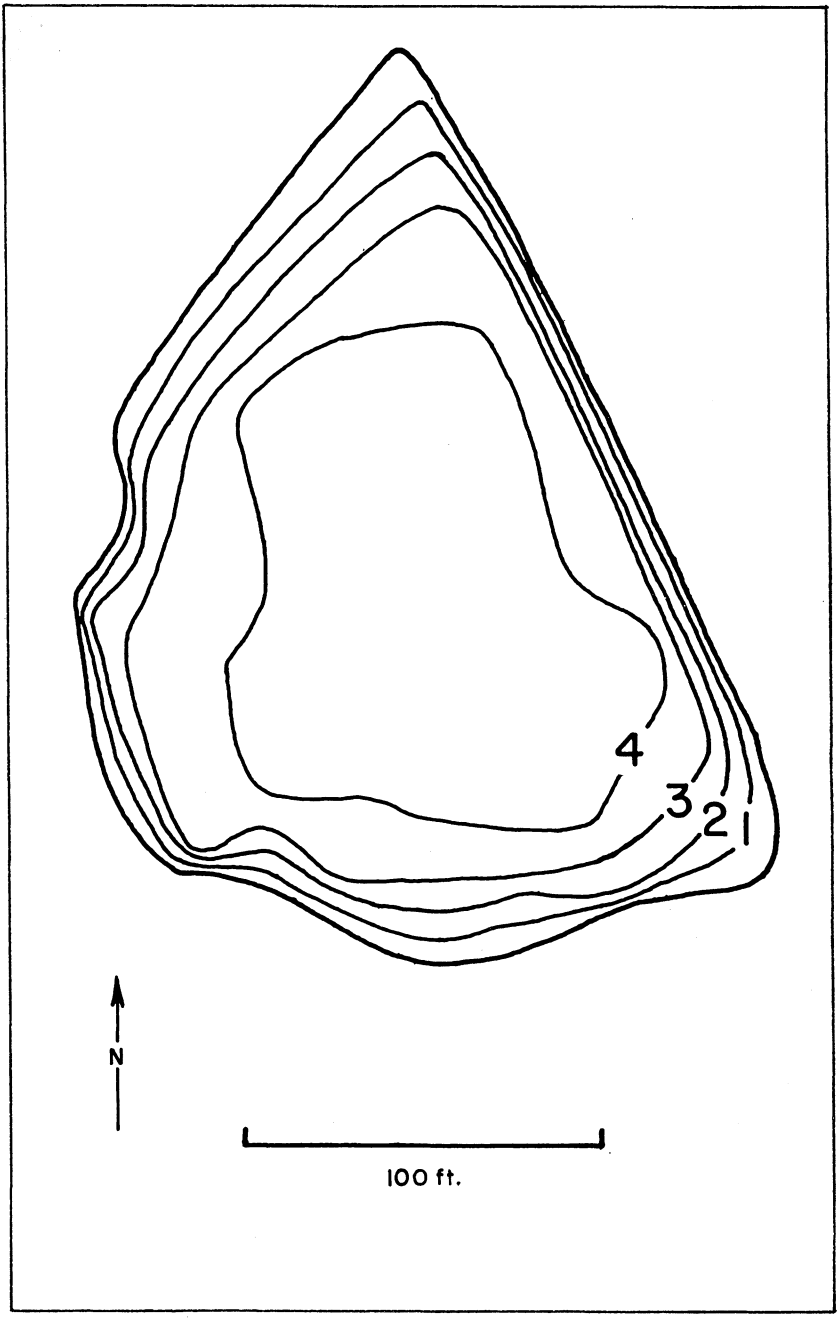
APPENDIX FIG. 20. Pond S-24.



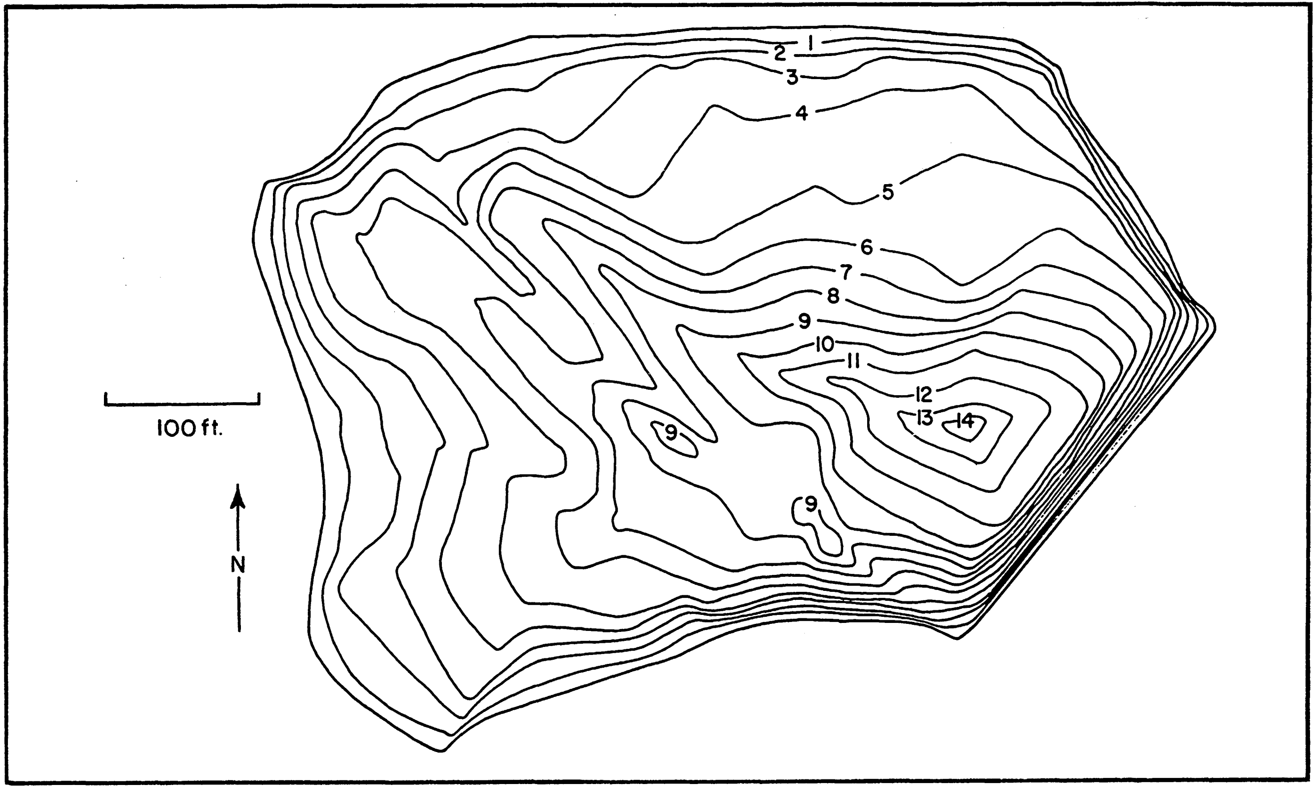
APPENDIX FIG. 21. Pond S-25.



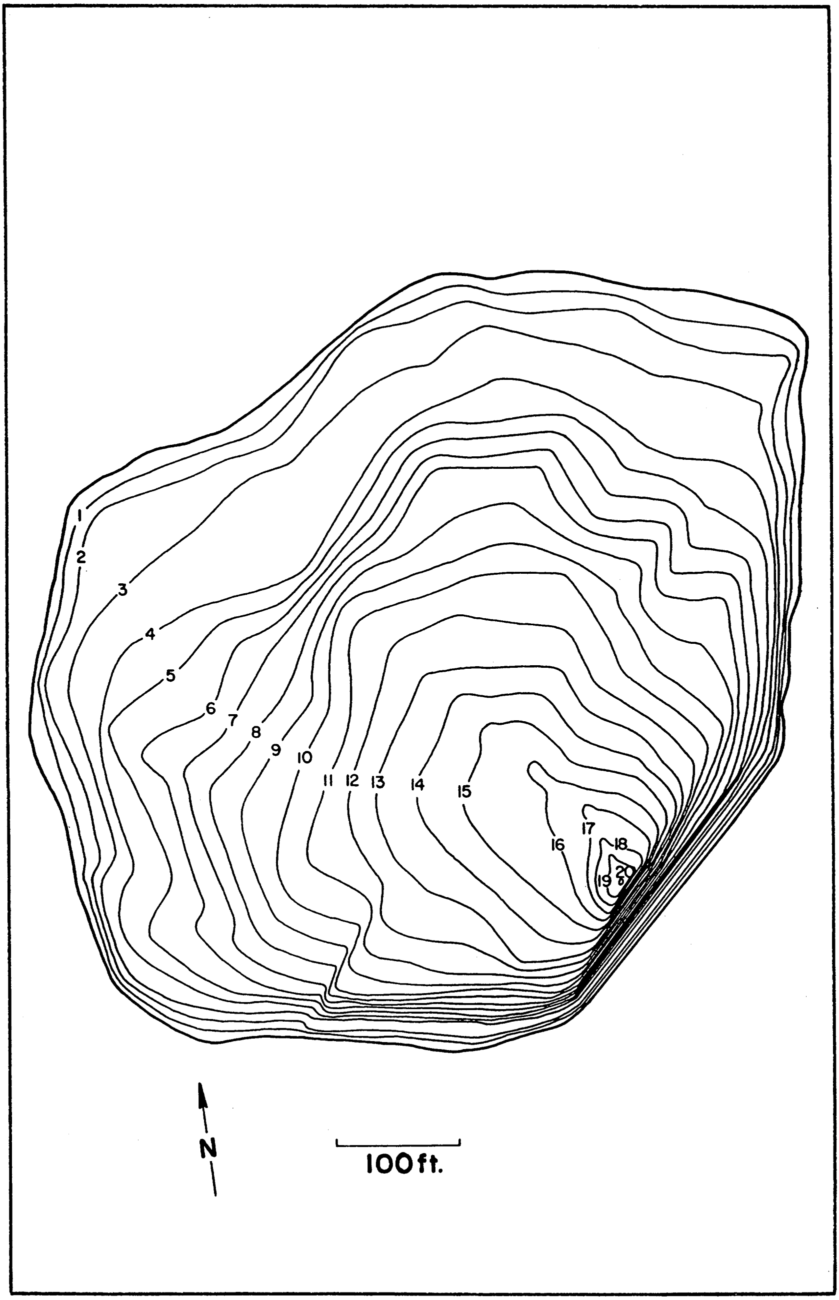
APPENDIX FIG. 22. Pond S-26.



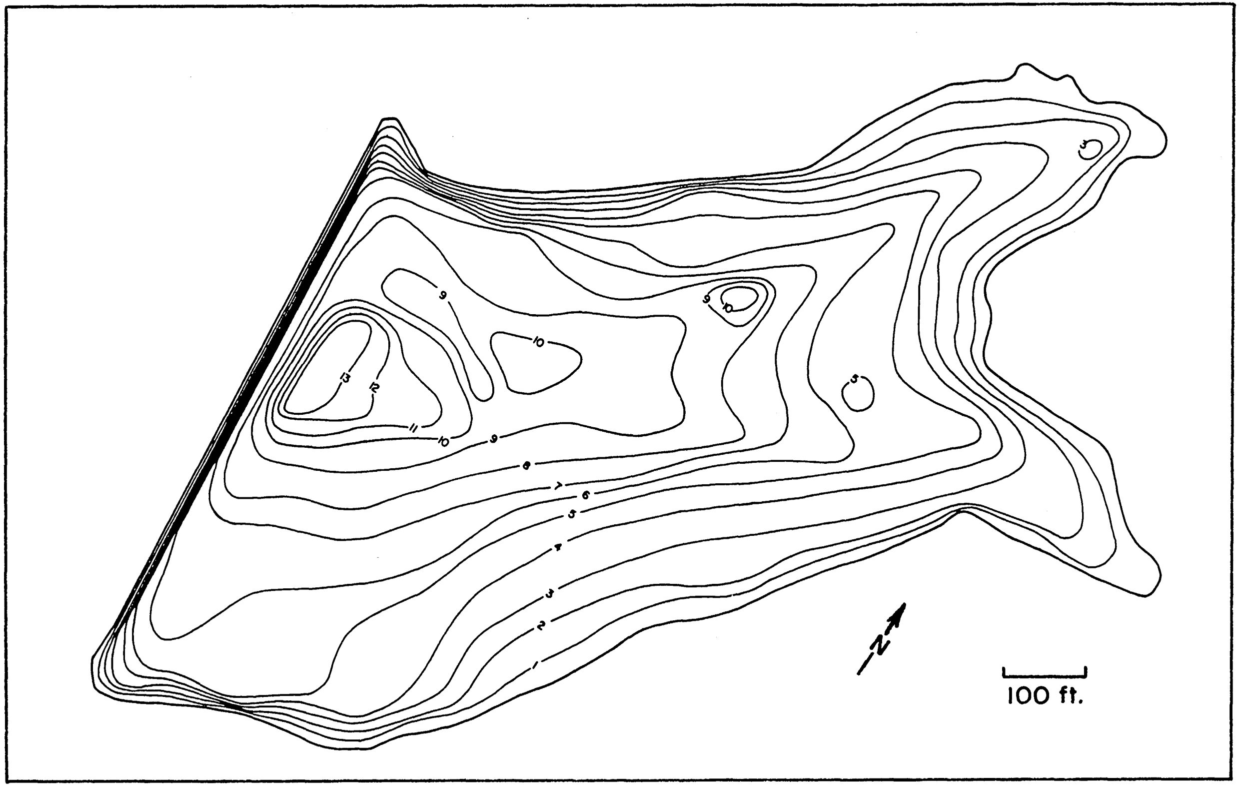
APPENDIX FIG. 23. Pond S-27.



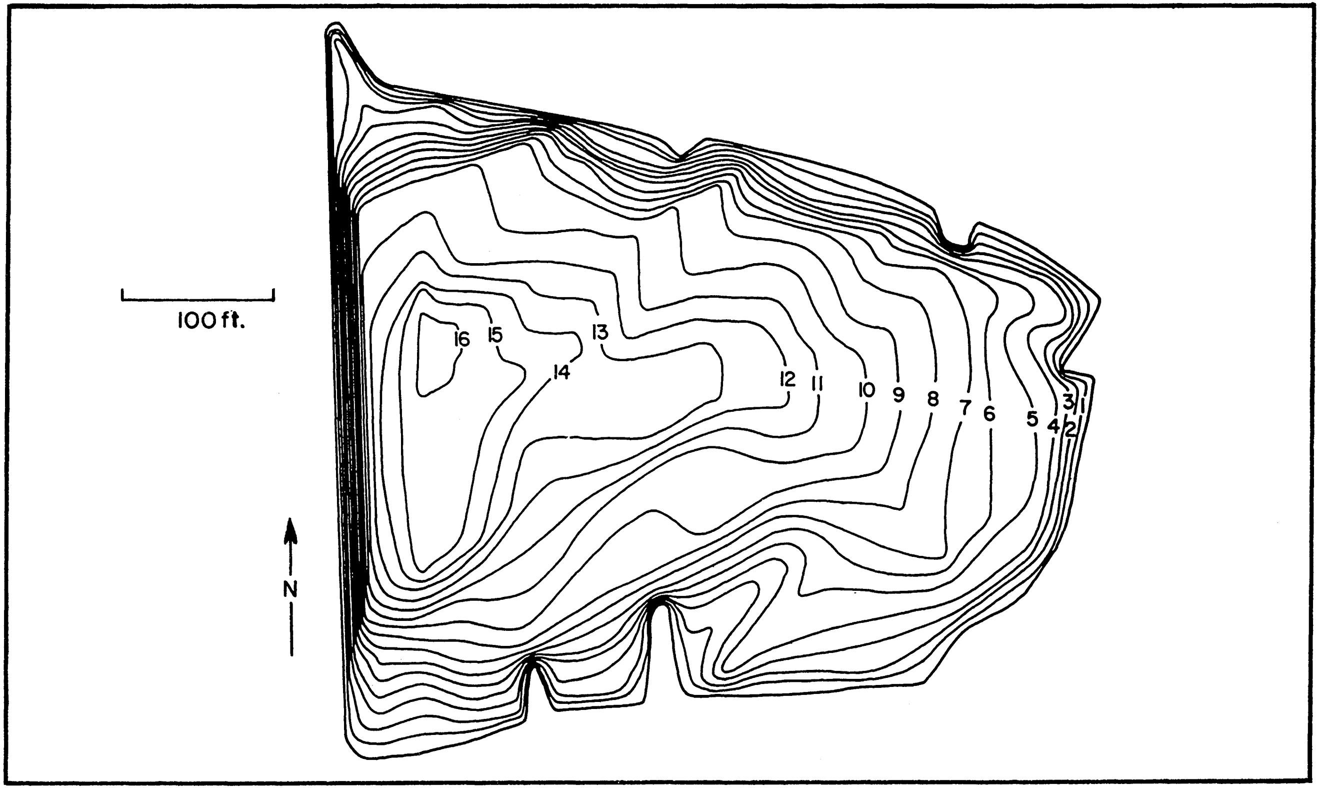
APPENDIX FIG. 24. Pond S-28.



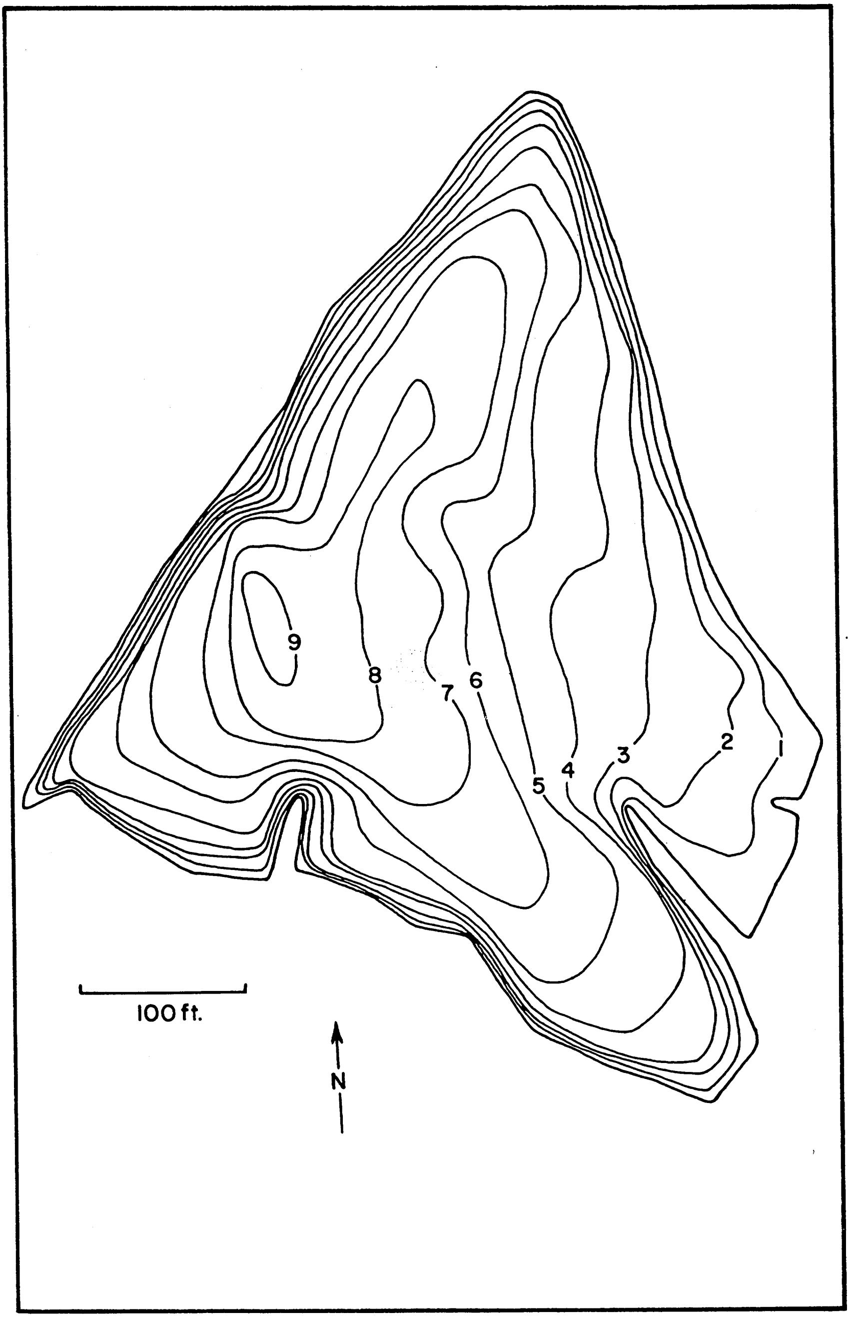
APPENDIX FIG. 25. Pond S-29.



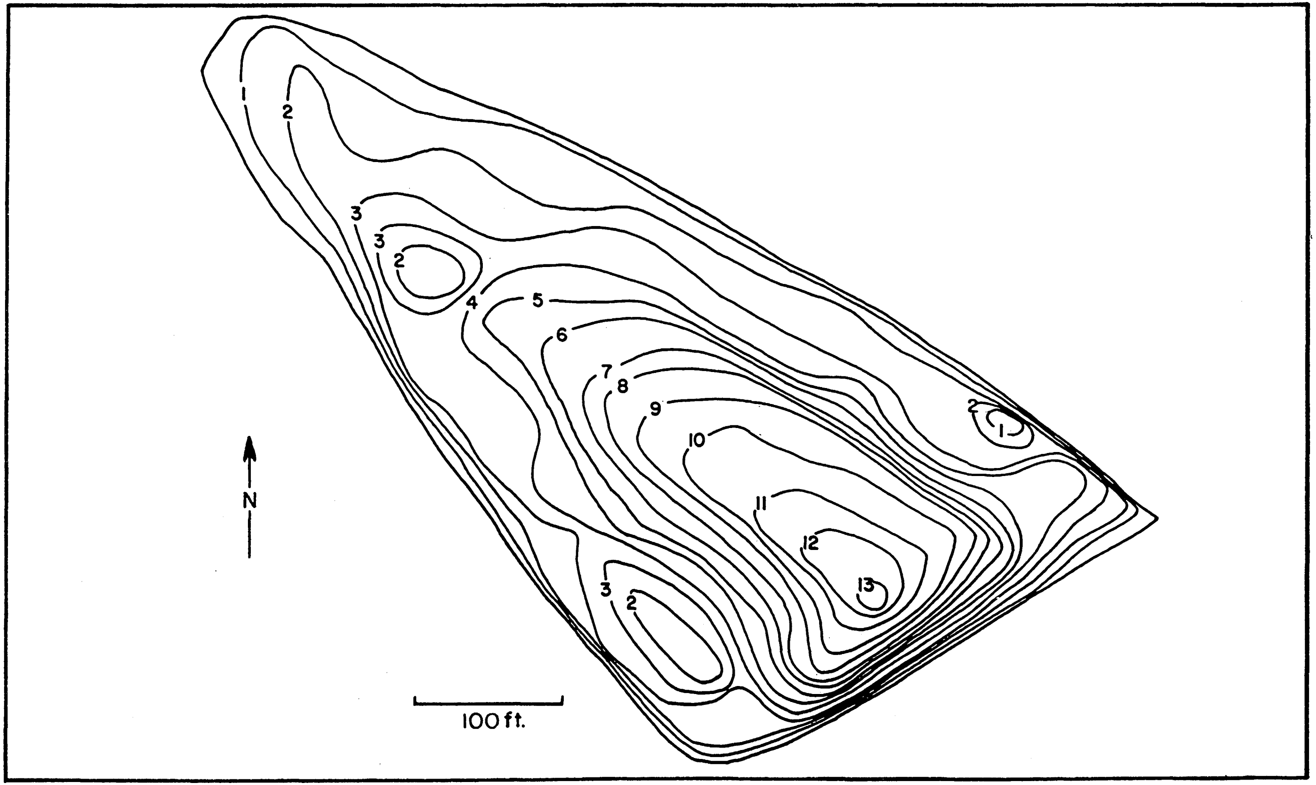
APPENDIX FIG. 26. Pond S-30.



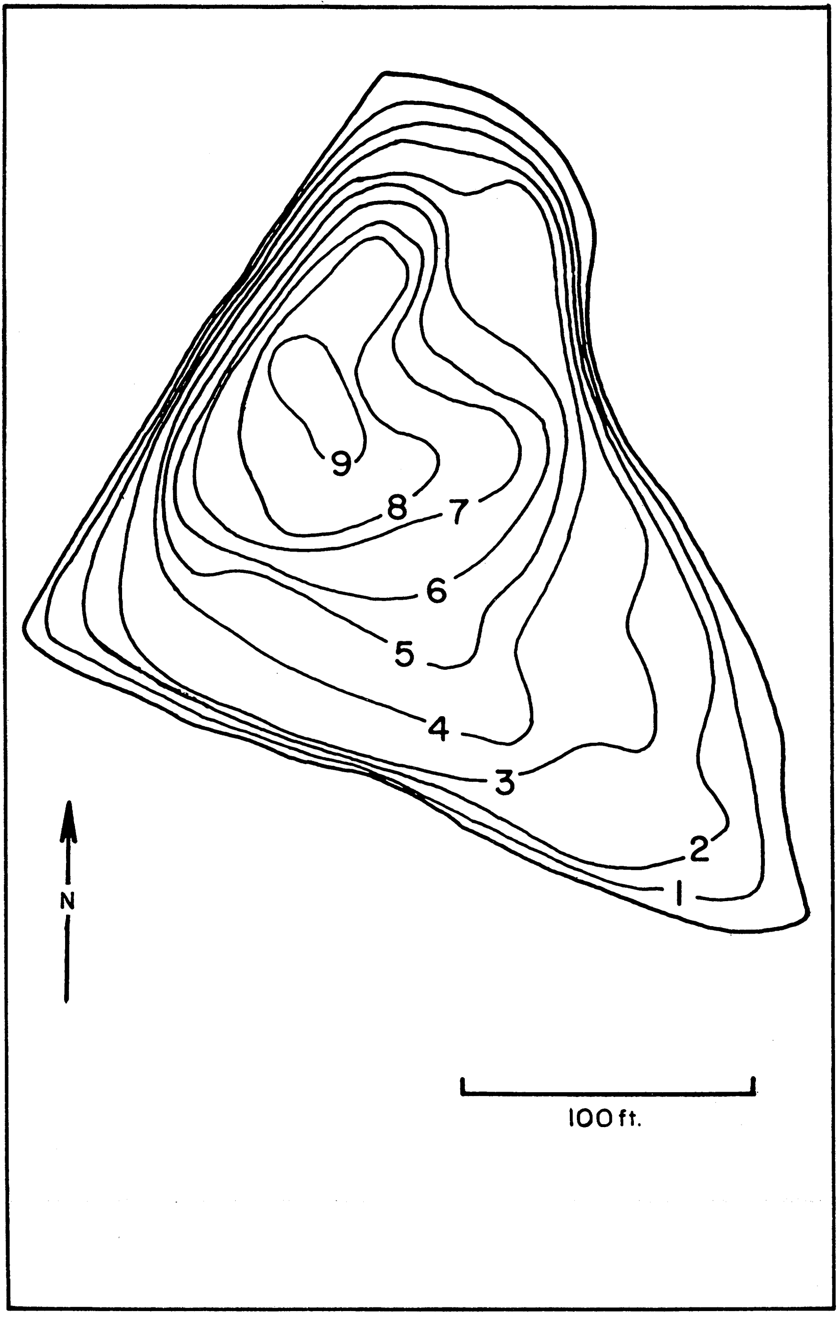
APPENDIX FIG. 27. Pond AE-1.



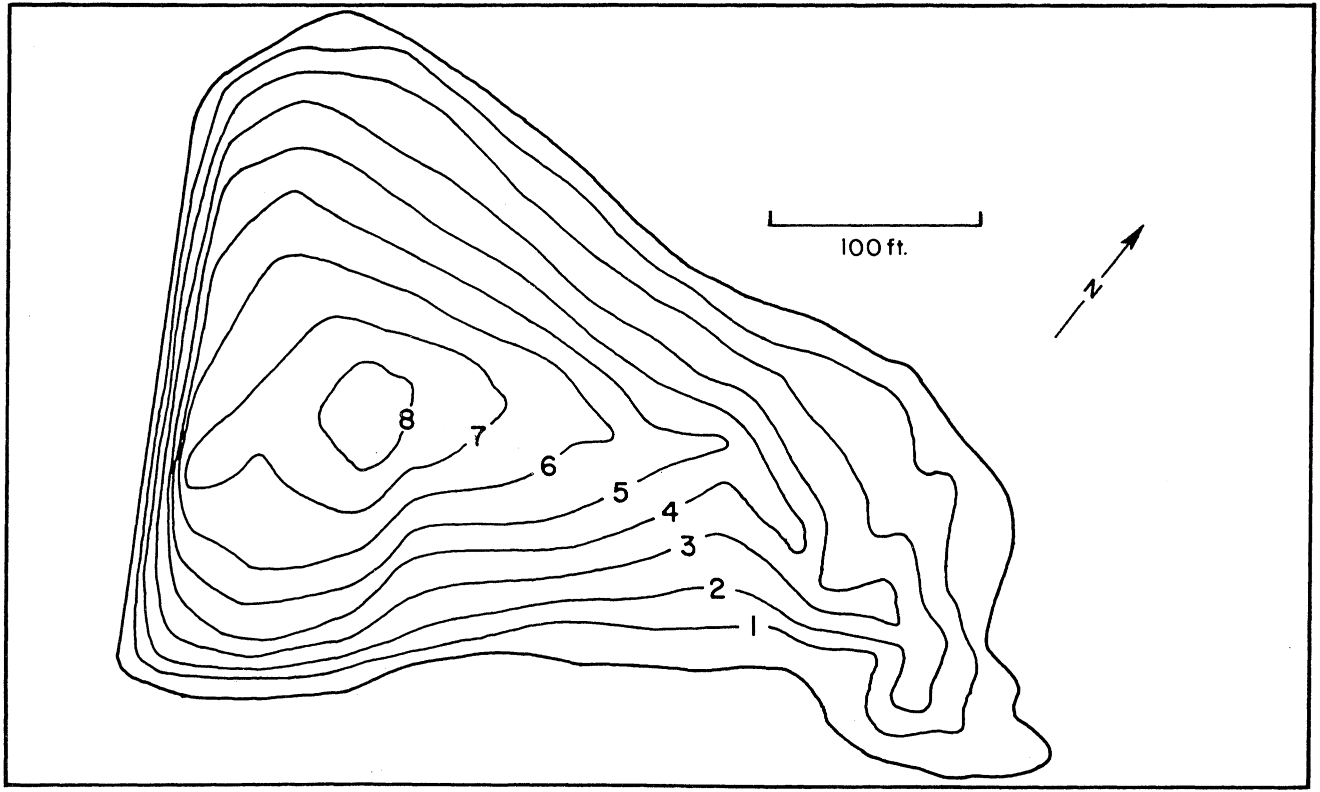
APPENDIX FIG. 28. Pond AE-2.



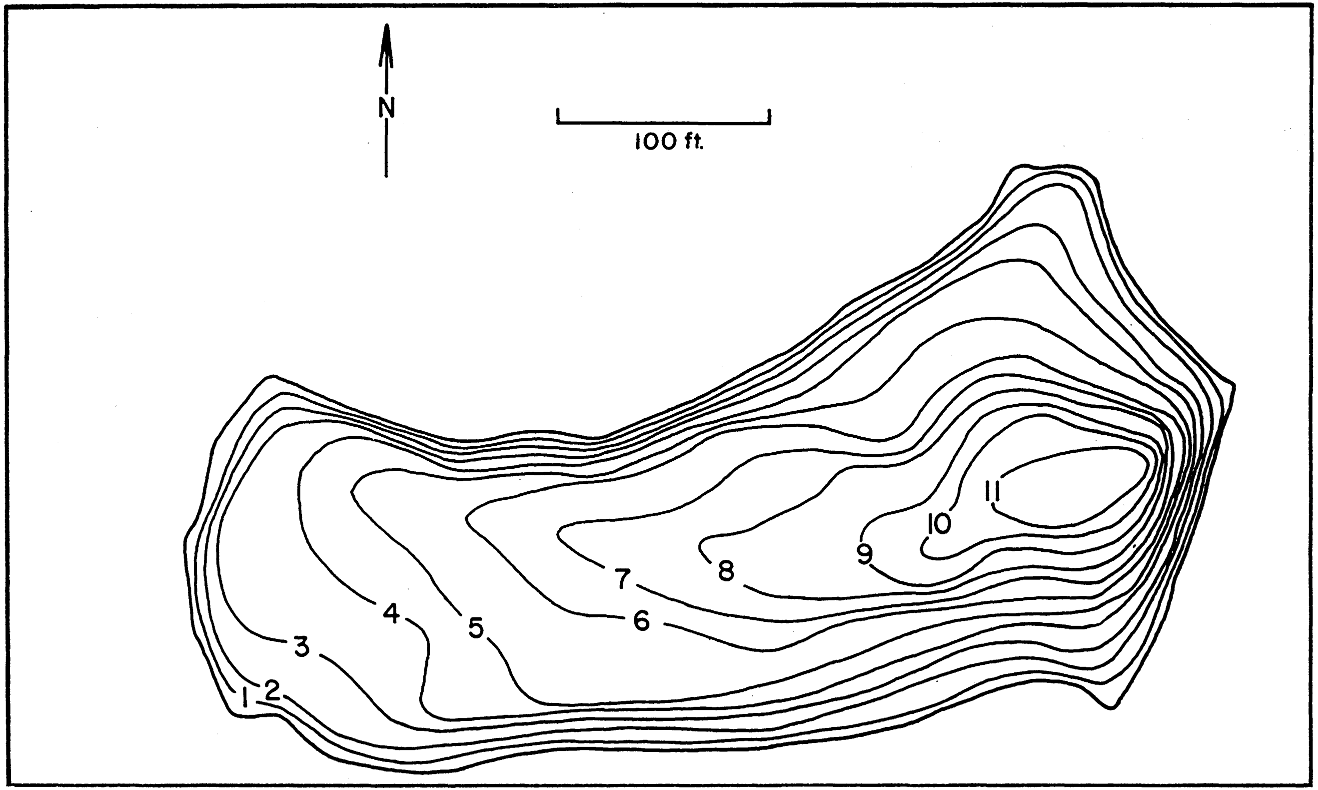
APPENDIX FIG. 29. Pond AE-3.



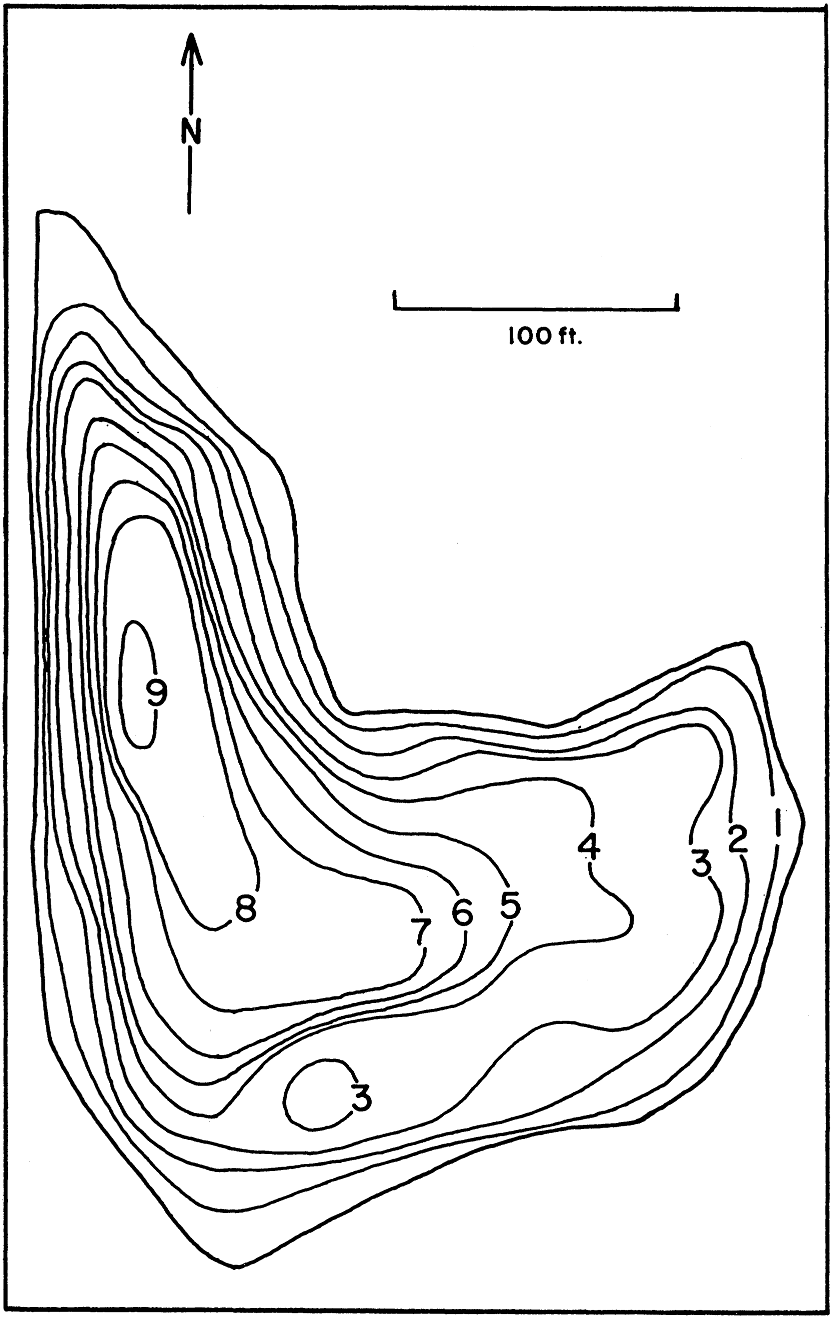
APPENDIX FIG. 30. Pond BC-1.



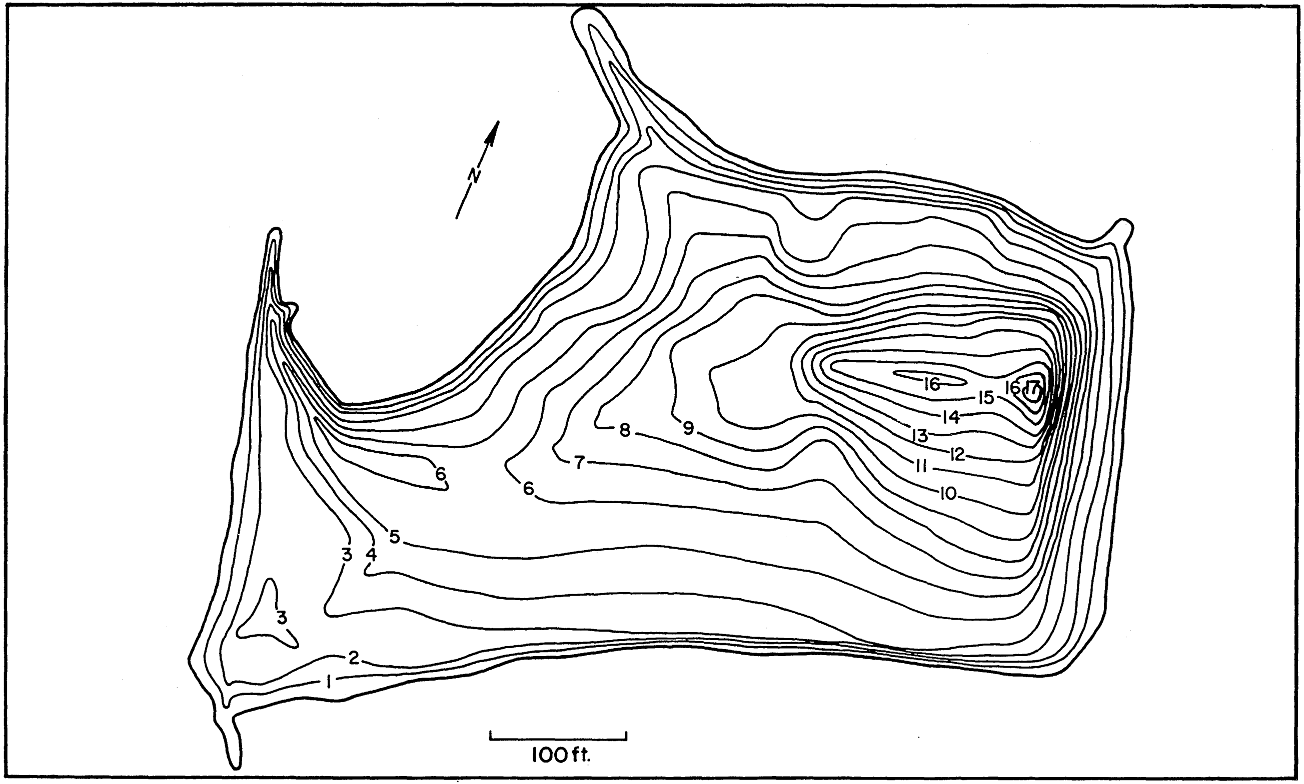
APPENDIX FIG. 31. Pond FP-6.



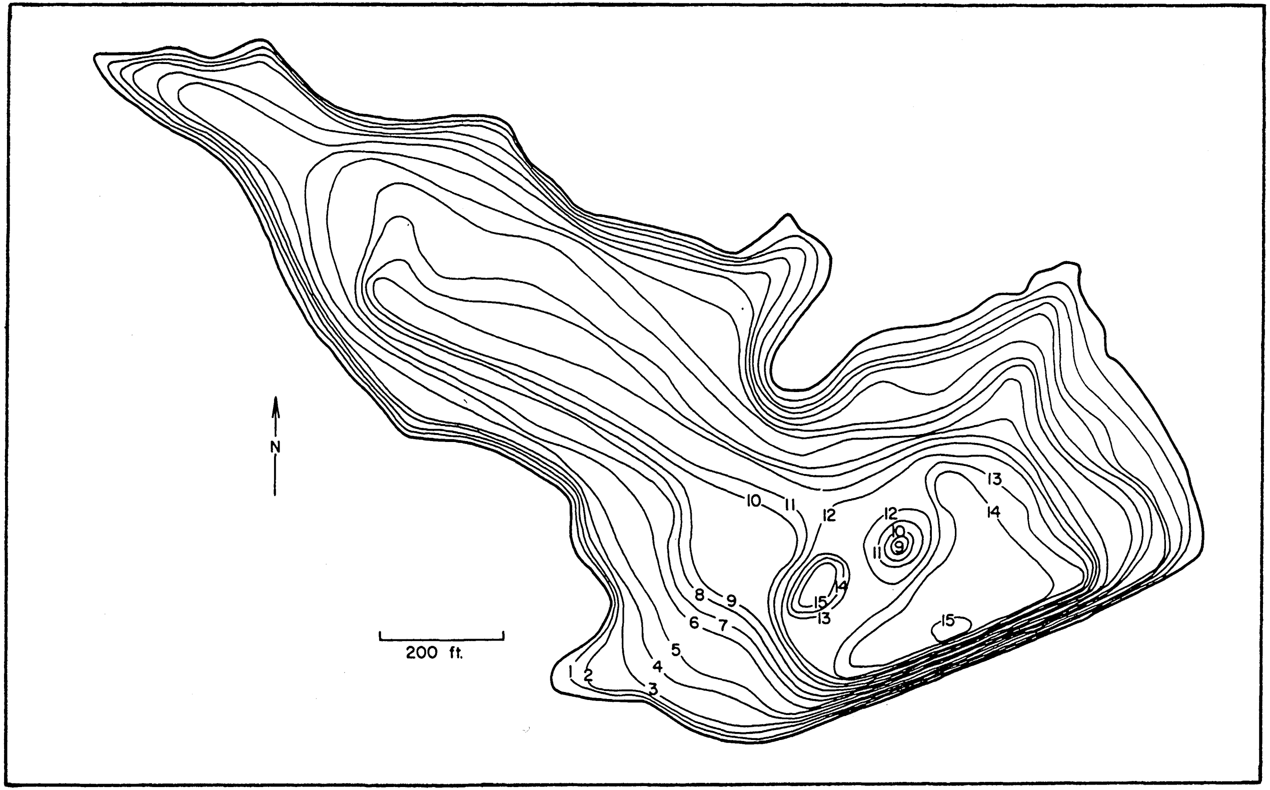
APPENDIX FIG. 32. Pond FP-8.



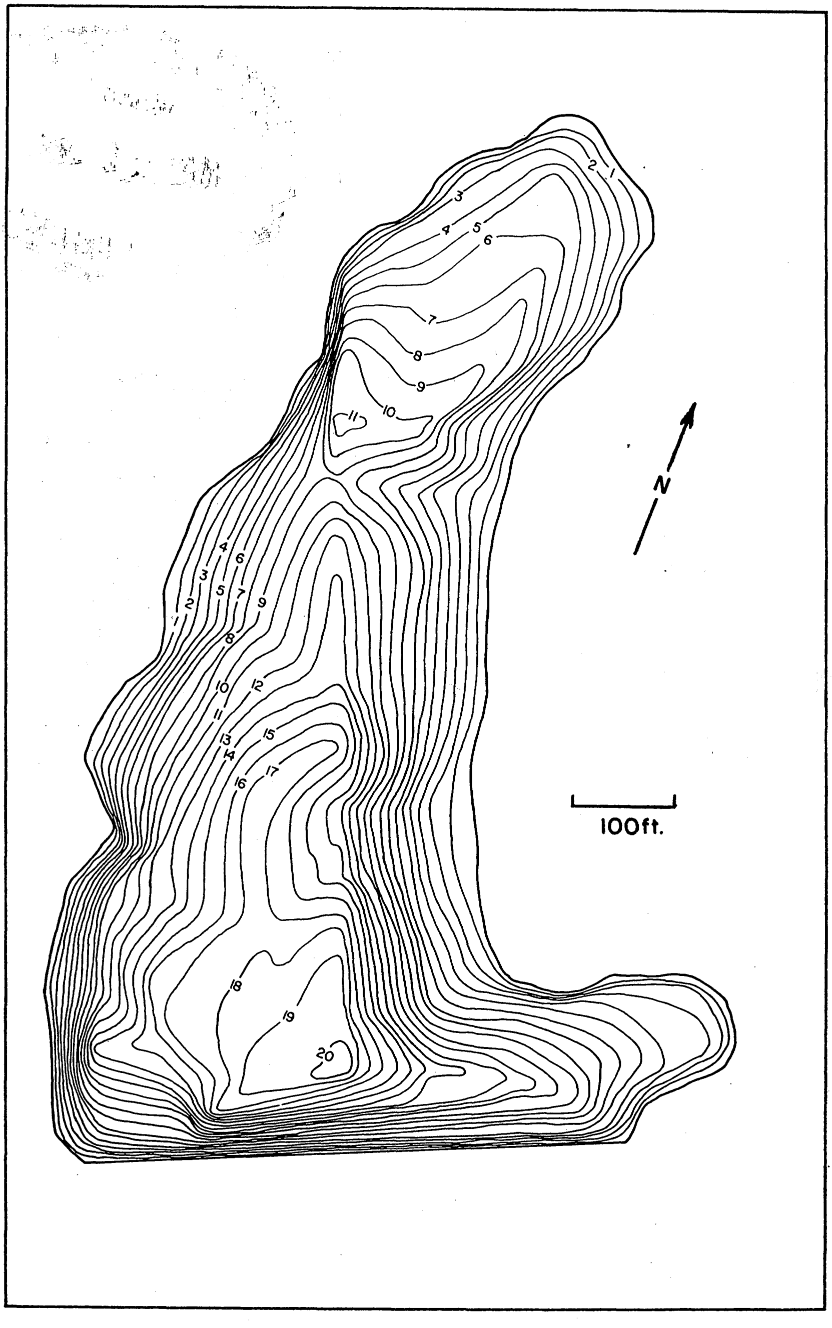
APPENDIX FIG. 33. Pond FP-9.



APPENDIX FIG. 34. Pond FP-10.



APPENDIX FIG. 35. Pond FP-11.



APPENDIX FIG. 36. Pond FP-12.