JOURNAL
OF THE
Elisha Mitchell Scientific Society

Volume 65 June 1949 No. 1

MORPHOMETRY AND HYDROGRAPHY OF SOME NATURAL LAKES OF THE NORTH CAROLINA COASTAL PLAIN: THE BAY LAKE AS A MORPHOMETRIC TYPE

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INTRODUCTION

In the summer of 1947 under the sponsorship of the North Carolina Wildlife Resources Commission studies were begun on a number of natural lakes in Bladen and Columbus counties.[1] It was realized at the outset from the examination of airplane photographs of the region and from reading the theories by various geologists concerning the origin of the Carolina bays that these lakes probably were of the same origin. It was not entirely unanticipated, therefore, to discover that the lakes are surprisingly alike in many of their morphometrical, chemical, and even biological characteristics, enough so to warrant considering the Bay Lake as a morphometric type. The present paper is concerned primarily with the distinctly morphometrical features of the lakes and to a lesser extent with some of the chemical characteristics of their water. It presumes to furnish a basis for further hydrobiological studies.

In the Atlantic Coastal Plain from Virginia to Georgia there are thousands of shallow, elliptical or ovoid depressions known as "Carolina Bays" from their first having been studied in the Carolinas where they are most abundant, and from their containing the various species of bay trees—*Magnolia virginiana*, *Gordonia lasianthus*, *Persea borbonia*, and *Persea palustris*. Strangely enough there have been very few published studies on these bays aside from geological investigations to determine their origin and botanical studies on their vegetation; but judging from the findings of Buell (1946) on Jerome Bay and current

[1] Other persons participating in the collection of the data here reported were Edward E. Hueske and T. Stuart Critcher of the N. C. Wildlife Resources Commission and A. Carter Broad of the Fisheries Research Institute of Morehead City. The Wildlife Resources Commission has also assisted in the publication of this paper by furnishing the plates of the illustrations.

investigations by the author on others, it seems likely from the nature of the sediments that many of these basins, perhaps all of them, at one time contained lakes. Nearly all such bodies of water have been extinguished by processes of filling in and lowering of the water table attendant on the incision of streams into the Coastal Plain, leaving behind the oval-shaped swamps so prominent from the air. But in North Carolina a small number of bay lakes still exist, with the main concentration in Bladen County in the vicinity of Elizabethtown.

As soon as the Carolina Bays were recognized by the geomorphologists, a number of theories were advanced to account for their origin, of which two are held most widely at present. Melton and Schriever (1932) proposed that all these depressions were formed by the impact of meteorites in the unconsolidated sediments of the Coastal Plain. As evidence accumulated the theory was modified in various ways, until in its present form it conceives of a large shower of meteorites striking the earth obliquely from a northwest direction, excavating the depressions not so much by the impact of the meteorites themselves or by their explosions on striking the earth as by the shock waves preceding them. (This whole subject is reviewed by Johnson, 1942.) Opposed to this theory is that of Johnson (1942), who conceived of the Coastal Plain depressions as having arisen from a complex of natural forces resulting from ground water, artesian water, solution, and wind action. The present paper does not attempt to decide what the most likely origin of these basins is, but merely to describe the present configuration of some of those still containing lakes and to consider some of the forces which have been active in producing them.

METHODS

From aerial photographs of the region made under the direction of the U. S. Department of Agriculture in 1938, working outlines of the lakes were traced. Actual surveying of the lakes was then completed with a plane table and a non-telescopic alidade. Stations (frequently cypress trees in shallow water close to shore) were established at convenient distances and were then incorporated into a triangulation grid with the plane table. A base line distance between two stations was measured with a standard 100-foot steel surveyor's tape.

As an outboard motor boat was run along ranges at a suitable relationship to each plane table station, soundings were made at convenient intervals of approximately 250 to 1000 feet, with a standard stadia rod, to the bottom of which was securely fastened a small tin can to enable the depth of water to be more accurately determined and to enable a sample of the uppermost sediments to be raised to the boat for examination. Data on the depth of water to the nearest tenth of a foot and the character of the bottom sediments were recorded at each position, which, after a suitable exchange of flag signals between boat and shore, was sighted on the range line with the alidade.

It was soon discovered that the major portion of these lakes was relatively flat, with most of the contour lines crowded close to shore. In order, therefore, to determine the bottom configuration more exactly, soundings were taken at measured intervals of 50 or 100 feet, depending on the size of the lake, along numerous lines at right angles to the shore, extending from the edge of the water out to the central plain of the lake (Table 1).

In the laboratory the data from the field notebook were transferred to the plane table map, and contour lines at intervals of one foot were drawn by inspection. The areas of the lakes and of the various contour surfaces were measured with a K & E compensating planimeter. Volumes were then calculated by use of the established formula for this type of work, $V = \frac{h(a_1 + a_2 + \sqrt{a_1 \cdot a_2})}{3}$, where a_1 is the area of the upper contour surface, a_2 that of the lower, and h the vertical distance between them. For the lowermost portion, the formula for the volume of a cone was used, $V = \frac{h \cdot a}{3}$. Length of shoreline was determined with a standard map measurer. The shoreline development, which is the ratio of the actual length of the shoreline to that of the circumference of a circle with an area equal to that of the lake, denotes the irregularity of the shoreline and the departure of the lake from a circular shape. Volume development which is equal to $3 \times \frac{\text{mean depth}}{\text{maximum depth}}$ indicates the general configuration of the lake basin according to whether the ratio is greater than or less than unity.

TABLE 1

Number and intensity of soundings in each of the six bay lakes investigated

LAKE	NUMBER OF SOUNDINGS			
	From plane table	Measured from shore	Total	Per mi.² lake area
Jones	87	131	218	623
Salters	99	244	343	700
Singletary	119	324	443	498
White	274	266	540	323
Black	242	114	356	162
Waccamaw	257	245	502	36

Only three types of bottom sediments were found in contact with the water: 1) *sand*, usually fairly clean and coarse in shallow water, becoming finer and darker with organic matter away from shore, 2) *pulpy peat*, a soft homogeneous, black or slightly brownish organic sediment, often containing a very small proportion of sand, detectable by rubbing some of the material between the fingers, and 3) *fibrous peat*, a light yellowish-brown mass of softened and partially decomposed rootlets, twigs, and leaves, with larger pieces of wood mixed in. The boundary between sand and either of the two other types of deposits was fairly sharp. That between pulpy peat and fibrous peat was not always sharp, so that the arbitrary limits of these two deposits may be subject to some variation according to individual interpretation.

RELIABILITY OF RESULTS

Sometime after the summer of 1947 it was discovered that three of the lakes—White, Jones, and Salters—had been previously surveyed in the late twenties by Thorndike Saville, Chief Engineer of the Water Resources Division of the North Carolina Department of Conservation and Development. By means of standard traverse surveys outlines of the lakes were prepared from which the area and length of shoreline were determined. No hydrographic studies were made. A comparison of the results in Table 2 reveals a close correspondence between the two sets of surveys. With respect to area the maximum difference is just over two per cent, and with respect to length of shoreline four per cent. The similarity in the figures for White Lake is especially interesting, because the outline map of this lake had to be pieced together from two separate aerial photographs. Because of the greater ease in making a plane table survey based on an outline obtained from aerial photographs, it is gratifying to learn that

TABLE 2

Comparison of area and length of shoreline determinations in two separate surveys

LAKE	AREA			SHORELINE		
	1947 survey	Traverse survey	Difference	1947 survey	Traverse survey	Difference
	acres	*acres*	*per cent*	*miles*	*miles*	*per cent*
Jones	224	227	1.4	2.19	2.27	3.7
Salters	315	322	2.2	2.70	2.73	1.1
White	1068	1065	0.3	4.77	4.58	4.0

this type of survey can be quite reliable for fairly large lakes as well as for small lakes.

In 1935 the Resettlement Administration in the process of developing Singletary and Jones lakes for recreational purposes determined the elevations of the lake surfaces[2] and prepared rough hydrographic maps, which agree in general with the ones reported in this paper. The accuracy of the maps presented in this report depends on how nearly the boat was on the range being worked at the time each sounding was sighted from the plane table. Since readjustments were frequently made in the boat's direction to correct for drift, using the stadia rod as a sighting device for making these adjustments, it is believed that most soundings were taken within 25 feet of the line being run. Allowing for the most acute angles sighted, it is probable that the true locations of each sounding is within 40 feet of where its position is plotted on the map. This difference is of little importance in the flat central plain of the lakes. The contour lines along shore where the gradient is steepest were located more accurately by measurement from shore. Hence, it is believed that the volume determinations from the contour maps are at least as accurate as the outline maps of the lakes.

[2] Surface elevations: Singletary 63 ft., Jones 73 ft. The elevations of the other lakes are probably less than that of Jones because of the general seaward slope of the Coastal Plain terraces.

GENERAL CONSIDERATIONS OF THE INDIVIDUAL LAKES

Jones Lake[3]

The smallest of the lakes investigated is one of the most attractive. Its dark colored water is virtually free of suspended matter, enabling a number 20-mesh plankton net to be towed for long distances without any appreciable decrease in efficiency.

Towards the southeast end where a natural sand beach occurs is a Colored Recreation Area, operated by the Department of Conservation and Development. No other cultural developments occur on the lake.

Jones Lake, as is typical of all the bay lakes, gives clear evidence of considerable fluctuation of water level during the past few hundred years. Along the east shore just north of the outlet, for example, is a row of cypress trees about 50 feet from shore, exactly paralleling the shore with 3 scallops. This represents an old shoreline, since the cypresses must get started on dry land. These trees are at present in 16 inches of water, which means that the lake level must have been approximately 16 inches lower at the time the trees became established than it is now. Although the trees are not very large, cores taken with an increment borer indicate they are approximately 400 years old. Along the deeper northwest shore are a few large isolated trees occurring in even deeper water, and hence presumably older, although not necessarily so. They give evidence of a lower water level.

Salters Lake

The least accessible of the lakes, Salters, probably has least reason for the average person visiting it. Fishing is poor, the shores of the lake are crowded everywhere with a dense, all but impenetrable tangle of shrubs and trees, and there are no natural sand beaches. There are no developments of any kind on the lake, except for a few boats which the Forest Service maintains for the use of the infrequent fishermen. The shoreline gives considerable evidence of somewhat recent expansion of the lake area.

Singletary Lake

Singletary boasts a greater length of natural sand beach than any of the other lakes of Bladen County. At the east end of the lake just below the outlet is a development begun by the Resettlement Administration and now operated by the Department of Conservation and Development as a group recreation camp. This is the only development on the lake.

The Resettlement Administration dredged out a channel in the outlet creek and constructed a spillway dam 160 yards from the original shoreline in the region of the sand rim. This provides a convenient reference point for observing fluctuations in lake level. On July 14, 1947, the lake level was 10 inches

[3] The diagrams of hydrography and distribution of bottom deposits and the morphometrical data for each lake at the end of the paper (Figs. 6–11, and Tables 8–13) should be referred to.

below the crest of the spillway, and on November 16, 1947, it was 4 inches above, giving an observed fluctuation of 14 inches. According to reports this is fairly typical of annual fluctuations in water level of all the Bladen County lakes.

Singletary Lake exhibits more filling in of the bay along the sides than do the others, yielding a body of water more elongated in shape than is the usual condition. As a result the shoreline development of Singletary is the largest of any of the lakes. The deepest water found in any of the lakes was near the southeast end of Singletary. The water of this lake contains a large amount of organic detritus which quickly coats anything placed in the water and clogs even a number 10-mesh plankton net so that its filtering efficiency is greatly reduced.

White Lake

White Lake derives its name from the clarity of its water and almost complete absence of color, a characteristic not shared by any of the other lakes. A white secchi disc is readily visible on the bottom, even in the deepest part of the lake. This feature has made the lake most desirable from a recreational standpoint, and has resulted in a number of resorts and many cottages being located along its shores.

The most plausible explanation for the lack of color is that of drainage. All the lakes except White Lake have their outlets somewhere in the southeastern to southwestern section, so that rainwater leeching through the bay vegetation and peat deposits at the northwest end must flow through the lake to leave the basin. In White Lake, on the other hand, the outlet is at the northwest end almost in the middle of the filled in portion of the bay, and hence the dark colored water from this region is drained away from the lake rather than through it. On November 15, 1947, for instance, after a rather heavy rain, the color of the water immediately adjacent to the northwest shore was as usual less than 10 parts per million, as measured with a USGS color set, whereas that of the outlet creek at the road bridge just outside the edge of the bay was 440 parts per million. At this same time there was a zone of colored water up to 100 yds. wide along the entire shore except at the northwest. The color of this zone ranged from 32 to 55, being darkest immediately adjacent to the shore.

According to reports White Lake is spring fed. Offshore about the middle of the northeast side are a number of round clean areas in a region where the sand is thinly covered with fine dark detritus. Careful soundings of these areas showed the centers about 8 inches lower than the edges, but the bottoms were hard, no bubbling as reported by other visitors could be observed through a water glass, and there was no detectable chemical evidence of any volume of water entering the lake through these depressions. Earlier in the year at a time of higher lake level and more favorable ground water conditions there might be visible evidence of inflowing water.

There is also a belief that some springs at the base of a cliff along the Cape Fear River within 3 miles of the lake are the result of an underground outlet from the lake, but there is no concrete evidence in the matter. The only known outlet is the small surface creek at the northwest end of the lake, which flows except in extremely dry periods.

Black Lake

Black Lake differs from the others in the indefiniteness of the margin of the bay in which it is situated. The others all have a distinctly oval outline, but that of Black Lake is quite irregular and in places appears to merge indistinguishably with neighboring bays. There are no natural sand beaches on the lake except at two small places along the southwest shore where the basin of Black Lake has cut across the sand rim of a smaller bay during its period of enlargement. At the southeast end of Black Lake are many small irregularities in the shoreline, with adjacent small coves being separated by narrow peninsulas of land often only a few feet wide, covered with typical bay shrubs and trees. This condition seems to represent a fairly recent expansion of the lake area through erosional activities. This is a phenomenon apparent in several of the other lakes as well, particularly Salters and parts of Singletary.

Black Lake, although the largest natural lake in Bladen County, is likewise the shallowest, with the maximum depth of water being just over seven feet near the southeast end.

An unknown quantity of water drains into Black Lake bay through a small inlet towards the northeast end. This is not readily detectable from the lake, but is apparent at a nearby road bridge. The outlet from the lake at the south end has no definite channel but rather spreads somewhat diffusely over and through the surface of the ground, resulting in a slow unidirectional drift of water through swampy land.

Black Lake is accessible only with difficulty by road and there is no cultural development of the lake.

Lake Waccamaw

Waccamaw, the largest of the lakes studied, is nevertheless smaller than the dimensions of five by seven miles claimed by the nearby inhabitants. The lake is more nearly three by five miles. The erroneous conception as to size dates back at least to the time of John Bartram, who reported in the diary of his journey in 1765–66, "... Wocoma lake ... is 8 miles long & 5 broad & about 12 foot deep & very shoal toward ye borders in some places ..." (Harper, 1942). The exaggeration of the horizontal dimensions does not apply to the vertical, since the maximum depth of the lake reported is substantially correct.

Waccamaw is the only bay lake examined thus far with sand completely around the shore. This has been brought about by a sand bar working across the northwest end and isolating the peat-filled portion which had formerly been in direct contact with the open water, as it still is in the other bay lakes. A similar alteration, although to a lesser degree, occurred at the southeast end of the lake. As a result there are just two types of bottom deposits—sand and pulpy peat—at the surface of the present lake basin.

The dark colored water is probably derived from the extensive swamp to the northeast of the lake which drains into the lake through Big Creek. The color of the water in this creek is much darker than that in the lake itself, where it has been observed to fluctuate considerably from one year to another (See the data of Aug. 23, 1947, in Table 14). Hubbs and Raney (1946), for instance, reported that the lake when visited on March 30, 1941, had almost no perceptible color, yet a color averaging 160 ppm. was observed in the lake in 1947. These variations would considerably affect the rate of light penetration and the dependent photosynthesis. Fish from the creek are much darker in color than those from the lake, and the question arises as to whether or not there is a partial barrier here to the free exchange of individuals.

The greatest depth of water is not in the lake itself but in Big Creek within a relatively short distance of the lake. The creek bottom is separated from the lake by a sand bar sloping steeply on the creek side, covered by less than four feet of water at the deepest place. It is likely that the creek water below this sill can be effectively isolated from the lake, especially in spring and fall when its bottom temperature might be considerably below that of the lake.

At the outlet of Waccamaw is a low concrete spillway dam with a broad concrete apron, constructed some time ago to help regulate the water level of the lake. Several years ago when the dam washed out around the abutments, the lake level dropped approximately 2 feet, permitting the establishment of a new crop of cypresses in the shallow southeast shoals.

Except for a few widely scattered cottages, cultural development of the lake is confined to the high ground for several miles along the upper northeast side. At one low point in this region there is exposed an outcrop of the fossiliferous Duplin formation of Miocene age, overlying the dark phosphatic Cretaceous formation (Clark, 1912). Hence, one has here the somewhat novel experience of collecting tertiary marine fossils (corals, oysters, Crepidula, Pecten, Venus, sharks' teeth, etc.) from a fresh water lake. It is believed this calcareous Miocene formation plays a significant role in bringing the chemical reaction of Waccamaw water to neutrality, whereas in all the other lakes studied the water is very acid.

THE BAY LAKE AS A MORPHOMETRIC TYPE

A detailed comparison of the lakes and their respective bays reveals a number of interesting and significant similarities. Each lake is located in an oval area known as a "Carolina Bay," surrounded more or less by a rim of white sand which is most prominent towards the east and southeast sides. It is likely that these sharp outer limits of the bays represent the maximum size of the lakes at any time in their history. Furthermore, in all lakes except Black and Waccamaw the bay appears to be congruent with the drainage basin because of the lack of surface affluents. This means that except for an unknown quantity of water coming in below the surface of the ground, the water reaching the lake is largely that precipitated directly into the bay. The implications of this are a general scarcity of dissolved materials in the water, and, partly resulting from this low productivity and partly from a low level of allochthony, a very slow rate of sedimentation.

PATTERN OF FILLING IN

The areas of the bays vary from a minimun of 638 acres for Salters Lake to a maximum of 9801 acres for Wacamaw, but these acreages are no longer the areas of the present day lakes. There has been a considerable amount of lake obliteration by the accumulation of peat deposits. These, as Buell (1939) has already pointed out. are best developed towards the northwest end of the bay, so that as the basin increases in ecological age the lake becomes displaced progressively towards the southeast end of the bay.

Except for Black Lake (see Table 3) there is an inverse relationship between the present size of the lake and the percentage of the original bay area which has been filled in. Thus, Jones Lake, the smallest, now occupies only 34 per cent of its bay, whereas Waccamaw, the largest, still fills 91 per cent of the area of its bay. It appears, however, that the small lakes are being obliterated more rapidly because of their original smaller size rather than because of a faster rate of areal decrease. The absolute areas of the various bays filled in appear to fall

TABLE 3

Areas of the bays and their contained lakes in Bladen and Columbus counties, N. C.

The bay area in all cases was taken to the outside edge of the typical bay vegetation where it meets the surrounding sand rim. The bay area for each lake does not include that of any overlapping bays, as in the case of Salters, White, and Black (see Figures 1 and 2).

LAKE	AREA		PER CENT OF BAY OCCUPIED BY LAKE	ACRES OF BAY FILLED IN
	Bay	Lake		
	acres	*acres*		
Jones	667	224	33.6	443
Salters	638	315	49.4	323
Singletary	1022	569*	55.7	453
White	1496	1068	71.4	428
Black	2361	1418	60.0	943
Waccamaw	9801	8938	91.2	863

* The lake area does not include that of the artificial channel at the outlet.

readily into two groups. In the four smallest lakes (and likewise the four smallest bays)—Jones, Salters, Singletary, and White—slightly more than 400 acres of the original bays have been filled in. The figure for Salters Lake is less than this average by almost 100 acres, but at the time of the survey it was noted that Salters had more of an erosional than a depositional shoreline, indicating that perhaps the area of this lake has been enlarged from a previous minimum. The two largest lakes—Black and Waccamaw—have had twice as much of their original areas extinguished, but these figures are probably likewise misleading, in that there is evidence that both lakes have been enlarging their basins in recent time. One would ordinarily expect a larger lake, because of its greater length of shoreline and greater volume of shallow water, to exhibit a greater absolute areal decrease in unit time than a smaller lake.

The apparently constant rate of areal decrease in four of these lakes may be largely coincidental. There are many bays in the Coastal Plain (see Fig. 1) larger than those containing the lakes which have been completely filled with vegetation and peat deposits. Either the rate of filling in these bays has been considerably faster than in the lake bays, perhaps varying with the original depth of the basin, or the filled-in bays represent older basins. Studies to determine the ages of a number of these basins have not yet been completed.

As the basins have been filled in, the lakes have not only been displaced towards the southeast, but two other phenomena have taken place concurrently: 1) the general shape of the lake (except for Singletary) has tended to become

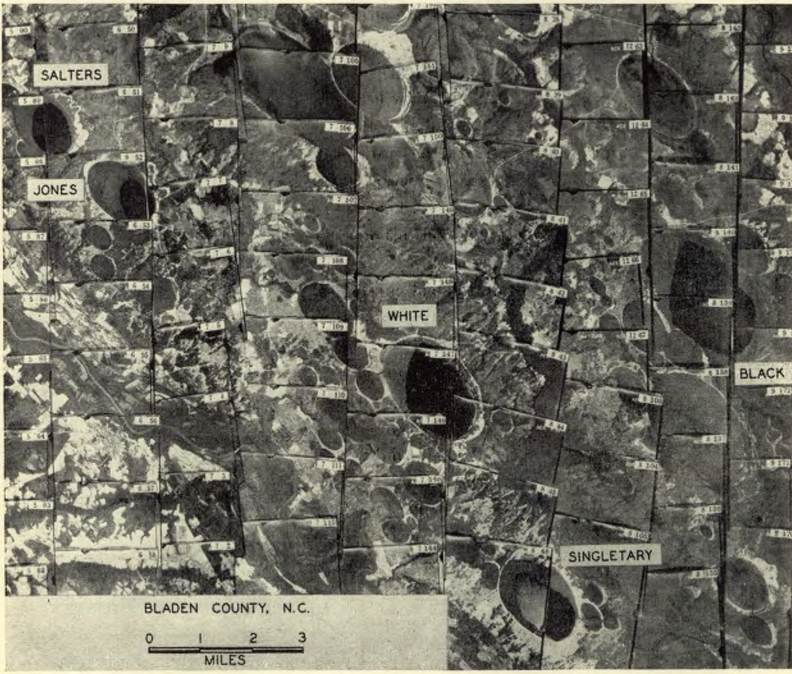

FIG. 1. Photographic mosaic of a portion of Bladen County, showing the location and general relationships of five bay lakes. (USDA, Production and Marketing Administration.)

more nearly equidimensional than the original bay, and 2) the axis of elongation of the lake has rotated clockwise with reference to that of the respective bay (see Figs. 1 and 2).

Table 4 shows that the length-width ratios of the lakes are in all cases except Singletary less than those of the respective bays. Singletary Lake is relatively more elongate than its containing bay, a condition which has been brought about by means of a relatively greater degree of areal decrease along the northeast and southwest sides than at the northwest end. The greatest change in relative

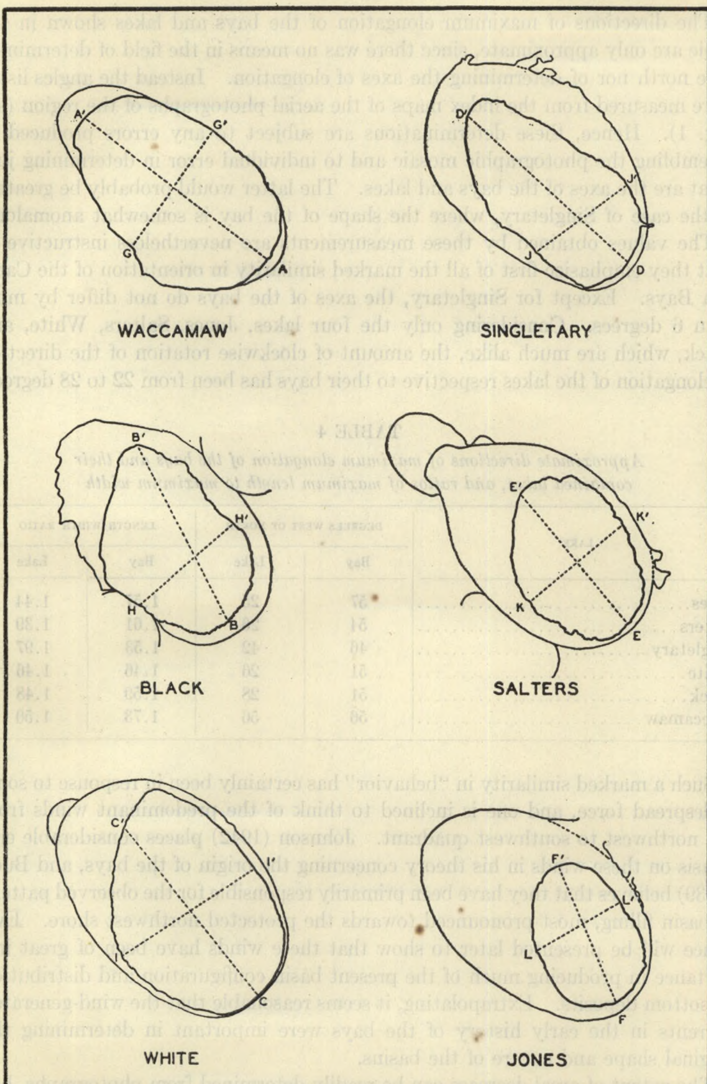

FIG. 2. Reduction of the bay lakes and their containing bays to the same absolute size to show the general pattern of orientation and filling in.

dimensions is in Waccamaw, where there has been filling in at both ends but none along the sides.

The directions of maximum elongation of the bays and lakes shown in the table are only approximate, since there was no means in the field of determining true north nor of determining the axes of elongation. Instead the angles listed were measured from the index maps of the aerial photographs of the region (see Fig. 1). Hence, these determinations are subject to any errors produced in assembling the photographic mosaic and to individual error in determining just what are the axes of the bays and lakes. The latter would probably be greatest in the case of Singletary, where the shape of the bay is somewhat anomalous.

The values obtained by these measurements are nevertheless instructive in that they emphasize first of all the marked similarity in orientation of the Carolina Bays. Except for Singletary, the axes of the bays do not differ by more than 6 degrees. Considering only the four lakes, Jones, Salters, White, and Black, which are much alike, the amount of clockwise rotation of the direction of elongation of the lakes respective to their bays has been from 22 to 28 degrees.

TABLE 4

Approximate directions of maximum elongation of the bays and their contained lakes, and ratios of maximum length to maximum width

LAKE	DEGREES WEST OF NORTH		LENGTH/WIDTH RATIO	
	Bay	Lake	Bay	Lake
Jones	57	25	1.57	1.44
Salters	54	26	1.61	1.39
Singletary	46	42	1.53	1.97
White	51	26	1.46	1.46
Black	51	28	1.59	1.48
Waccamaw	56	56	1.73	1.50

Such a marked similarity in "behavior" has certainly been in response to some widespread force, and one is inclined to think of the predominant winds from the northwest to southwest quadrant. Johnson (1942) places considerable emphasis on these winds in his theory concerning the origin of the bays, and Buell (1939) believes that they have been primarily responsible for the observed pattern of basin filling, most pronounced towards the protected northwest shore. Evidence will be presented later to show that these winds have been of great importance in producing much of the present basin configuration and distribution of bottom deposits. Extrapolating, it seems reasonable that the wind-generated currents in the early history of the bays were important in determining the original shape and nature of the basins.

The extent of areal decrease can be readily determined from photographs, but the extent of volume decrease can be determined only with great difficulty by borings taken along longitudinal and transverse ranges. It is not yet known, therefore, whether or not the largest lakes were also the deepest, nor is it known why lakes have persisted in these few bays but have completely disappeared in the surrounding bays, many of which have a greater surface area (see Fig. 1).

Whatever the original depths, the present lakes are all shallow. Waccamaw is not even a foot deeper than Salters, although its area is almost 30 times greater.

BOTTOM DEPOSITS

An ordinary survey can determine only the sediments at the surface of contact with the water, or those immediately beneath the surface. At the surface of these lakes are sand, a yellowish-brown fibrous peat, and a soft "greasy" pulpy peat (dygyttja?). Fibrous peat occurs only in a relatively narrow zone along the shore at the northwest end where the bays have been filling in most rapidly. Sand occurs elsewhere along the shore from the edge of the shore down the slope to the flat bottom of the lake. In Waccamaw, as previously stated, bars of sand have cut off the peat deposits at the northwest and southeast ends of the bay, resulting in sand all around the lake; no fibrous peat was found in the lake bottom. In all the other lakes except Jones the sand overlaps the fibrous peat offshore at the south end of the fibrous peat zone, and in White Lake at the north end as well (see Figs. 7b, 8b, 9b, and 10b). This makes it appear that either the sand is gradually working around the northwest shore and may eventually result in a condition like that in Waccamaw at the present time, or that the fibrous peat is a more recent deposit which has been laid down over the sand. The latter alternative is more likely, because in a number of instances only 0.1–0.2 foot of fibrous peat was found overlying sand.

The boundary between sand and pulpy peat is usually sharp and can readily be determined with a sounding pole. The sand, however, in some places extends beneath the pulpy peat, and can be felt beneath a thin layer of the softer material. The Black Creek formation, in which the Bladen County lakes are located, is predominantly sand, so that it is likely the bottoms of the original basins are sandy in nature. The boundary between fibrous peat and pulpy peat is to a certain extent a matter of individual opinion, since there is more or less of a gradual change from the greasy pulpy peat of the central plain to the yellowish fibrous peat at the northwest end.

A fourth deposit which appears to underlie the pulpy peat almost everywhere except immediately where it comes in contact with the sand is a light gray (sometimes brownish gray) silt or clay. This deposit was not found at the surface anywhere, although in White Lake it was at times covered by only a foot of organic sediments.

In Table 5 the percentage which each of the three surface sediments comprises of the total lake bottom as projected on the surface area of the lake is given. Since sand and pulpy peat are the two most extensive deposits, there is naturally an inverse relationship between them: when one declines in amount the other increases, and conversely. When the lakes are arranged in order of increasing size, a natural series appears to result. The largest lakes possess the greatest proportion of sand and the least of pulpy peat, whereas the smallest lakes have the least sand and the most pulpy peat. This results in direct relationships between the composition of the bottom sediments, the present size of the lakes, and the percentage of the original basins filled in by peat deposits.

As the lakes increase in ecological age (become smaller through filling in of their basins), the quantity of sand in the bottom decreases and of pulpy peat increases. When the lake area has been reduced to such an extent that wave action can no longer keep the shores towards the southeast end clear of the finer sediments, sand is then entirely eliminated from direct contact with the water. Such a condition was not observed in the lakes examined.

The fibrous peat along the protected northwest shore has probably resulted from the trunks, branches, and leaves of the vegetation growing near the shore and overhanging the water for distances up to 12 feet falling into the water and sinking to the bottom. The relative amount of this deposit in a lake may well be an indication as to the rate of filling in, inasmuch as areal decrease is most important at the northwest end.

TABLE 5

Percentage composition of the lake bottom deposits, measured in terms of the surface area of the lake

LAKE	PER CENT OF TOTAL		
	Sand	Pulpy peat	Fibrous peat
Jones	21	71	4
Salters	26	59	15
Singletary	43	49	8
White	44	52	4
Black	48	45	7
Waccamaw	64	36	0

MORPHOMETRY OF PRESENT LAKE BASINS

Although the configuration of the original lake basins cannot readily be determined, that of the portions still occupied by water can be ascertained by making a sufficient number of soundings. For any basin the existing configuration is the resultant of all the erosional and depositional processes which have been operating since the basin was formed.

The six lakes studied are similar in their morphometric characteristics, exhibiting progressive variations which appear to be a function of the size of the lake. The lakes are all somewhat saucer-shaped, with most of the contours being relatively close to shore, and the central plain being a remarkably flat area, sometimes varying not more than one-half foot in depth for 2000 yards or more. It is not surprising, therefore, to find that the volume development ratios are all greater than 2, except in the case of Singletary Lake, showing a wide departure from a conical shape.

It is impossible to ascertain without making detailed borings what the depths of the original basins were, but it is interesting that even with the different rates of sedimentation which have probably taken place, the present depths of the lakes are very much alike. The lakes are all shallow, with maximum depths ranging from 7.1 ft. in Black to 11.8 ft. in Singletary, and mean depths from 5.3 ft. in Black to 7.6 in Waccamaw. There is a tendency, best developed in Singletary, White, and Black lakes, for the deepest water to be located close to the southeast end of the lake (see Figs. 8a, 9a, and 10a).

When the longitudinal and transverse sections of the lakes are examined (Fig. 3) it is apparent that the lakes have mature profiles, at least along the southeast shore. In all the lakes within 50 feet of the shoreline there is an initial drop of from 1.1–2.0 ft. which is produced by the smaller abundant waves against the shore. Then there follows a wave-built terrace, whose width is roughly proportional to the length of the lake. In Waccamaw, for example, the southeast terrace extends almost 1500 ft. from shore, in Black Lake 400 ft., and so on down to Jones Lake, which has a gradual slope from the edge of the water to the central plain with no terrace at all. White Lake does not follow this relationship, in that on the basis of length of lake, its terrace should be midway in size between those of Black and Singletary, whereas it is actually only about 50 ft. wide.

The presence of these terraces indicates that the waves against the southeast shores are strong and have been in operation for considerable periods of time. But since the length of each terrace is related to the length of the lake rather than the length of the containing bay, it is also likely that the terraces are equilibrium phenomena, which are altered as the dimensions of the lake are altered.

At the northwest end of the lakes there are no terraces. Here, where the dense growth of bay vegetation comes to the edge of the water, there are depths up to 5 feet at the water's edge. No influence of the wind is evident along this shore. Of all the lakes Singletary shows the most gradual rise in the bottom from the deepest place at the southeast end to the northwest shore, as a consequence of which it has the smallest volume development ratio.

The southwest and northeast shores are somewhat similar in profile in the three largest lakes, but in the three smallest lakes there is a marked asymmetry, with the average slope of the southwest shore tending to be steeper than that of the northeast. Waccamaw shows two terraces along the southwest shore and one broad terrace along the northeast shore, which has a number of irregularities in it. Black Lake exhibits a small terrace towards the southwest, and what might be considered a rather extensive deep water terrace towards the northeast. Although the level of this latter terrace is little above that of the central plain of the lake, it is composed entirely of sand rather than of pulpy peat. White Lake, which has the most nearly regular basin of any of the lakes examined, cannot be said to have any lateral terraces. The three smallest lakes may or may not have traces of terraces at the southwest, but all of them—even Jones—have narrow terraces at various depths along the northeast shore. Thus for the particular places in the lakes where the profiles were made, in Singletary the terraces occur at depths of 2.7–3.4 ft., 4.0–4.4 ft., and 5.5–6.0 ft., in Salters from 3.0–3.4 ft., and in Jones from 3.6–4.1 ft. The transverse sections show that even in the two latter lakes there is a tendency towards development of multiple terraces.

In the only other published study on a Carolina Bay, Buell (1946) likewise observed the development of multiple terraces along the northeast and southeast sides in Jerome Bay, a completely filled-in bay in the northwest corner of Bladen County. With a Davis peat borer he penetrated the sediments of the

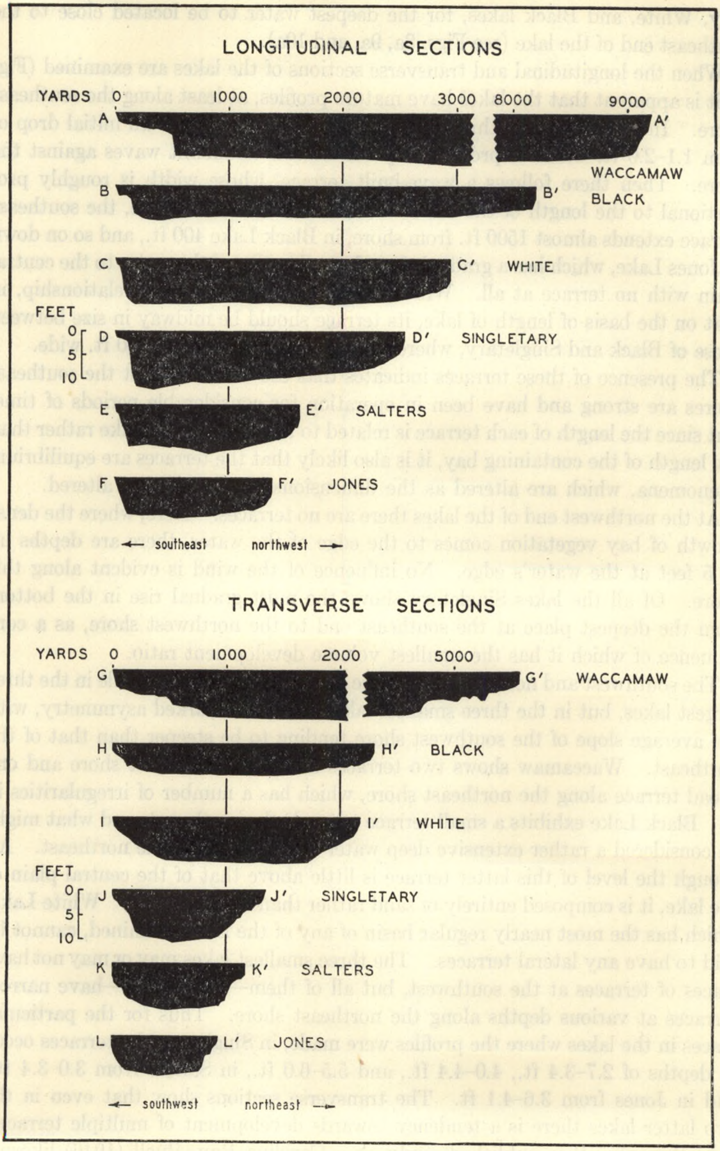

FIG. 3. Transverse and longitudinal profiles of the bay lakes. Note that the depths are greatly exaggerated with respect to the horizontal dimensions. The locations of these particular sections are shown in Fig. 2.

bay to the underlying sand, which was assumed to be the limits of the original lake basin. His study, however, is not strictly comparable to the present one, since from his profile diagrams it cannot be determined where the bottom was located at any particular stage of the lake, nor consequently how many of the terraces were exposed simultaneously.

It is difficult to conceive how along a single exposed shore a number of terraces might be formed simultaneously. Although the evidence from the terraces at the southeastern end is that these structures are in equilibrium with the wave action and hence can be modified in dimensions as the force of the wave action changes, it might nevertheless be true that the terraces along the northeast shore, not being subject to such strong waves, are more nearly permanent. They can possibly represent previous low water stages of the lakes. In each of the lakes, for example, there are cypress trees growing away from shore in water of varying depth, sometimes as deep as 4 feet. Whatever the depth at which these trees now occur, the lake bottom must have been exposed in order for the trees to get started, since cypress seeds cannot germinate and take root underneath the water. The fact that the terraces are best developed along the southeast and northeast shores indicates that the winds of greatest effect come from the northwest to southwest directions, as previously indicated.

At first consideration it seems anomalous that the rate of filling has been most rapid at the northwest end where the deepest water now occurs, and least of all at the southeast where the shallowest water of the entire lake is located. The northwest end of the original basin was undoubtedly shallow enough at one time so that vegetation could easily become established along this protected shore. Now, however, the water is so deep along this shore that only with extreme fluctuations in water level can new cypresses become rooted. The accumulation of fibrous peat offshore must be an extremely slow process.

New crops of cypresses do get started on the southeast and south shoals at the present time. A dense stand in White Lake in this region dates back about 130 years, presumably to the time when the lake level is reported to have been lowered about 2 feet by the operation of a sawmill at the east end, and in Waccamaw there is a more recent crop of new trees only a few years old, as previously indicated. No doubt there have been other similar stands in the long histories of these lakes, but for some reason—perhaps the strong wave action along this shore—the trees were eventually all killed without contributing materially to the advance of the shore into the lake. Thus the same forces which made the terraces and provided the best location for the establishment of new generations of trees are also responsible for keeping the trees off these shoal areas.

The aerial photographs of Lake Waccamaw are remarkable in that they were taken under conditions of water transparency and angle of sunlight enabling certain details of the terraces to be distinguished. The broad terrace at the southeast end is quite clearly visible, those to the northeast and southwest are a little less so, and each terrace has irregularities in it, which are in the nature of sand ridges formed by wave and current action.

At the southeast end of the lake for a distance of 6000 feet along shore are a series of small ridges paralleling the shore and extending offshore for a distance of 1000 feet. These sand waves average 45 feet from crest to crest, but they are largest and farthest apart closest to shore where the currents are strongest.

Extending along shore for 11,000 feet from this zone towards the outlet of the lake are a series of ridges projecting out from shore at an angle towards the northwest (Fig. 4). They are not strictly parallel, because their direction of elongation tends to shift clockwise with increasing distance from the southeast end. These ridges are visible up to 1500 feet offshore, and in the area just north of the

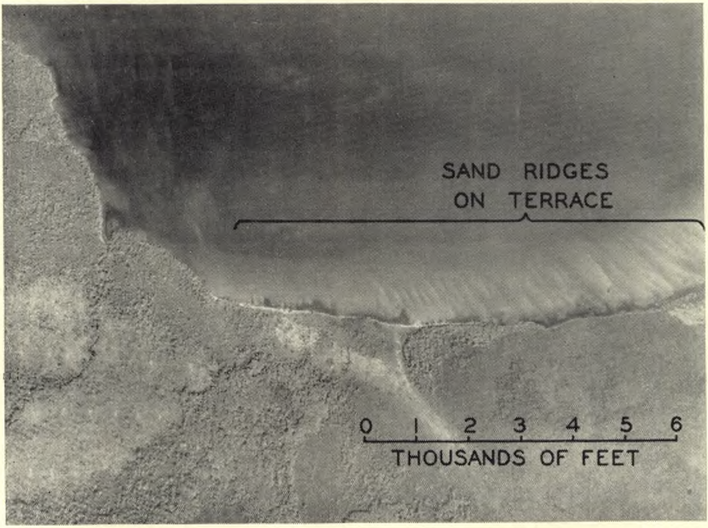

FIG. 4. Aerial photograph of a portion of the south end of Lake Waccamaw, showing the prominent sand ridges in the terrace along the shore. (USDA, Production and Marketing Administration.)

outlet there is another more diffuse and irregular group of similar ridges extending up to 2500 feet from shore.

Along the northeast side of the lake are other sand ridges, which are quite irregular in shape, and trend in a direction slightly east of south. They are visible on the photographs up to 2500 feet from shore. The irregularities in the northeast terrace of Lake Waccamaw shown in Fig. 3 undoubtedly are produced by some of these ridges. No attempt was made to chart any of these bars and ridges on the hydrographic map.

Such extensive irregularities in the sandy bottom of Waccamaw indicate the force of the currents which can be generated by the winds. The ridges parallel to shore at the southeast end seem to indicate that the winds of maximum effect are from the northwest. Westerly and northwesterly waves reflected from the northeast shore have built up the irregular ridges trending southward. The surface return of water at the southeast end appears to have been mainly clockwise, resulting in the extensive series of ridges along the south and southwest shore. If there is any general circulation of the lake generated by the winds, all evidence indicates that it is strongest in a clockwise direction. None of the

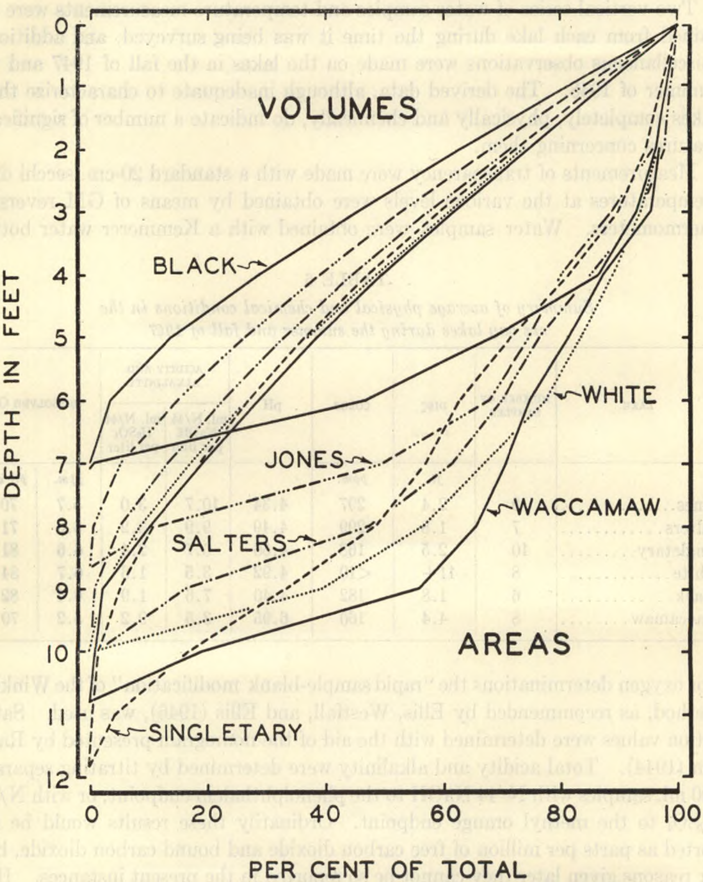

FIG. 5. Area and volume hypsographic curves for the bay lakes

other lakes, presumably because of their small size, exhibit similar sand bars, with the possible exception of Black Lake.

In biological studies on lakes it is frequently necessary to be able to determine the surface area at a particular depth, or the volume of water below a certain depth. Both of these types of data can be readily determined from the tables at the end of this report and from the area and volume hypsographic curves in Fig. 5. The area curves again emphasize the steep-sided, flat-bottomed shape of the basins, and also demonstrate how little a fluctuation in water level of a foot or two would change the surface area of the lakes.

CHEMISTRY AND PHYSICS OF THE LAKE WATERS

Two vertical series of water samples and temperature measurements were obtained from each lake during the time it was being surveyed, and additional miscellaneous observations were made on the lakes in the fall of 1947 and the summer of 1948. The derived data, although inadequate to characterize these lakes completely, physically and chemically, do indicate a number of significant features concerning them.

Measurements of transparency were made with a standard 20-cm. secchi disc. Temperatures at the various levels were obtained by means of GM reversing thermometers. Water samples were obtained with a Kemmerer water bottle.

TABLE 6

Summary of average physical and chemical conditions in the six bay lakes during the summer and fall of 1947

LAKE	NUMBER OF SAMPLES	DISC	COLOR	pH	ACIDITY AND ALKALINITY		DISSOLVED O_2	
					ml. N/44 NaOH per liter	ml. N/44 H_2SO_4 per liter		
		ft.	*ppm.*				*ppm.*	*per cent*
Jones	9	2.4	297	4.34	10.7	3.0	5.7	70
Salters	7	1.8	299	4.49	9.9	3.2	6.0	71
Singletary	10	2.5	168	4.50	6.7	2.4	6.6	81
White	8	11+	<10	4.92	3.5	1.6	6.7	84
Black	6	1.8	182	4.40	7.6	1.9	6.4	82
Waccamaw	8	4.4	160	6.95	3.5	9.2	5.2	70

For oxygen determinations the "rapid sample-blank modification" of the Winkler method, as recommended by Ellis, Westfall, and Ellis (1946), was used. Saturation values were determined with the aid of the nomogram presented by Rawson (1944). Total acidity and alkalinity were determined by titrating separate 100 ml. samples with N/44 NaOH to the phenolphthalein endpoint, or with N/44 H_2SO_4 to the methyl orange endpoint. Ordinarily these results would be reported as parts per million of free carbon dioxide and bound carbon dioxide, but for reasons given later they cannot be so reported in the present instances. Hydrogen ion concentration was measured with a Coleman pH electrometer, Model 3D, standardized against an Hydrion buffer of value 5.6 ± 0.05. Color, expressed as parts per million of potassium chloroplatinate, was measured by visual comparison with a standard U. S. Geological Survey color set.

Table 6 summarizes the physical and chemical conditions in the lakes during the brief periods of observation, and Table 14 at the end of the paper presents the results of the individual series of analyses. It is apparent from these data that the penetration of light into the water, as measured by a secchi disc, is rather low except in White Lake, where the disc was readily visible at the maximum depth.

One of the principal determinants of light penetration is the color of the water, which here varies from the almost colorless condition of White Lake to the strongly tea-colored water of Jones and Salters. The other three lakes exhibit an intermediate condition. Inspection of the table, however, shows that the correlation between color and transparency is only an approximate one, and the reason for this is that the amount of particulate matter (seston), both living and non-living, in the water, is the second important determinant of light penetration. Singletary, Black, and Salters lakes have greater quantities of non-living organic seston than the other lakes, which makes it possible, for example, for Jones and Singletary to have approximately the same transparency, even though the color of the former is almost twice as great. The evidence for the dark color being derived from the leaching of the vegetation and peat deposits around the margins of the lakes, and for the proposed explanation of the clarity of White Lake—that of drainage pattern—has already been discussed. Because of the pronounced color, all the lakes except White Lake would be considered dystrophic. Dissolved color accentuates biological and thermal stratification through its affect on light absorption, and these in turn tend to make the chemical stratification sharper than in a clear water lake.

The chemical reaction of most natural waters occurs within the pH range 6.0–8.5. If the acidity is great enough to lower the pH below 5.5, the acid condition can begin to affect biological processes and the lake is no longer harmonic: it is considered to be acidotrophic (Naumann, 1932). All the bay lakes here described, except Waccamaw, are strongly acidotrophic, with the average pH ranging from 4.34 in Jones to 4.92 in White. The higher pH (6.95) in Waccamaw is believed to result from the solution of lime and other minerals from the outcrops of the calcareous Duplin formation and of the older Cretaceous formation along the northeast shore (Clark, 1912).

Acidity in natural waters is usually caused by the carbon dioxide complex and/or organic acids such as humic acids dissolved in the water. Both of these can be eliminated as the primary cause of acidity in these lakes. If the pH of a fresh sample of water is determined, and then, after any free carbon dioxide present has been removed by thorough aeration, the pH is measured a second time, there is no consistent observable change in the pH value, showing that free carbon dioxide if present is not materially affecting the acidity. Even boiling a sample of water did not significantly alter the chemical reaction. That organic acids, likewise, are not the cause of the high acidity is demonstrated by the fact that the pH of White Lake is almost as low as that of the other Bladen County lakes, even though its color is very much less. Color of the type found in swampy lakes, it might be added, is primarily caused by these organic acids.

Table 6 demonstrates further that relatively small quantities of standard alkali are required to adjust the reaction of these lake waters to the phenolphthalein endpoint, and that likewise only small quantities of standard acid are needed to increase the acidity to the methyl orange endpoint. This indicates two conditions: 1) that the substances producing the acidity although rather intense in their activity are present only in small quantities, and 2) that there is relatively little buffer capacity in the water to resist changes in pH. In most natural waters the figures for N/44 NaOH in Table 6 would be listed as parts per million of free carbon dioxide, and half the values of the N/44 H_2SO_4 figures as bound carbon dioxide, the latter indicating roughly the total amount of calcium and magnesium present.

Frequently samples of bottom sediments brought to the surface had a faint odor of hydrogen sulphide, even though the water is apparently well aerated at all times. This suggested that perhaps free sulphuric acid might be the cause of the low pH, since it is known (see Ruttner, 1940, for example, or any textbook in bacteriology) that the colorless and red sulphur bacteria in lakes obtain their energy from hydrogen sulphide, with the ultimate release of sulphuric acid, which diffuses into the surrounding medium. Ordinarily this acid would react with various metallic ions in the water, but where the water is poor in dissolved minerals, some free acid might be expected.

Presumptive evidence that sulphuric acid produces the observed acidity is available from two sources. In the summer of 1947 Mr. Robert E. Short (1948) of North Carolina State College made chemical analyses on the bottom sediments of several lakes as part of a project supported by the North Carolina Wildlife Resources Commission. The materials to be analyzed were first extracted from the sample with a weak sodium acetate solution according to standardized procedures of soil chemistry. Then the approximate concentrations of sulphates were determined turbidimetrically, using barium chloride to precipitate the sulphate (Spurway, 1944). This method gives only the extractable sulphates rather than the total sulphates in the sediments.

According to these analyses the extractable sulphates in the bottom deposits of the four lakes investigated—Jones, Salters, Singletary, and White—are high, ranging up to 800 ppm. Only two samples out of the 22 analyzed contained less than 100 ppm., and the simple numerical average for all the samples was 360 ppm. Of the various ions tested for, sulphate was present in greatest concentration, and even allowing for considerable error in the method, there would still be an abundance of sulphates in the bottom deposits.

In the summer of 1948 Mr. Howard T. Odum ran some analyses on bottom sediments from Singletary Lake and water samples from several of the lakes.[4] The sulphate content of the water in White, Jones, Salters, and Waccamaw varied from 6.1 ppm. in Waccamaw to 7.9 ppm. in White. Because of certain errors which developed in the benzidine method employed, it is felt these results are only approximate, although of the correct general magnitude. Assuming that these results are substantially correct, that all the sulphate present is in the form of sulphuric acid, and that the acid is completely dissociated, the pH of a solution with 7 ppm. of sulphate would be 3.8, which is reasonable considering

[4] The work of H. T. Odum here reported was sponsored by a research grant to the author in 1948, Project C-50, from the Carnegie Foundation for the Advancement of Teaching.

the fact that the other substances present in the water would modify the chemical reaction.

Instances of low pH resulting from free sulphuric acid are reported in the literature. Yoshimura (1934) investigating Kata-numa with a minimum pH of 1.4 found 474 milligrams per liter of sulphate ions. Ohle (1934) reported that the Tonteich at Reinbeck contains significant quantities of sulphuric acid, but pointed out that an unusually high sulphate concentration is not necessary in a minerogenous acidotrophic lake, for example Pinnsee. Uéno (1934) reported that Onuma-ike had pH values of 2.8 to 3.8 over a five-year period. At one time he found the water contained 92 milligrams of sulphuric acid per liter.

These instances all occur either in regions of volcanic activity or in regions of iron pyrites oxidation. The North Carolina Coastal Plain is negative in both these respects. If the acidotrophy of this region is shown by additional work to result from sulphuric acid, it is likely that biological activity will have been the source.

The dissolved oxygen content of the lake waters never approached saturation, even in the surface waters. The particular analyses made showed White, Singletary, and Black lakes forming one group with approximately 80 per cent of saturation, the other three a second group at approximately 70 per cent. On the basis of biological productivity it was surprising for Waccamaw to have a lower average oxygen content than Black Lake, for example. The reasons for this are not known, since many factors would have to be studied concurrently to determine the controls of the oxygen levels at any particular time.

With the lakes as shallow as they are there is, of course, no permanent summer stratification. The chemical conditions from top to bottom may change over relatively short periods of time, depending on rainfall, photosynthesis, wind action, etc. Yet during bright, calm days steep microthermoclines can develop at the surface, temporarily cutting off the lower water from contact with the air. Such stratification, however, can be quite readily dispelled by the violent convectional squalls which often follow such conditions in the summer. In Black Lake on September 4, 1947, for example, the surface water temperature was 34.9°C, at one foot almost the same, and at 2 feet 31.0°C. A temperature difference of 5.5 degrees existed at this time between the surface and three feet. Surface conditions in Waccamaw on August 18 were almost as severe, with the temperature at the surface being 34.0° and at 3 feet 29.5°. The greatest temperature gradient found was in Salters Lake on June 30, 1947, with a temperature change of 5.7° over a vertical distance of 19 inches. The surface temperature at this time was 35.0°C. The examples quoted represent extreme conditions. Usually the temperature differences between surface and bottom were less than one degree centigrade.

Of the several chemical substances analyzed, only oxygen showed any consistent stratification. The tendency was for the per cent saturation to decline slightly with increasing depth, indicating that maximum oxygen addition through photosynthesis and agitation was occurring at or near the surface. In White Lake, however, the greatest concentrations of oxygen were in the bottom water, which may well have resulted from photosynthesis by the higher plants growing on the bottom. White Lake was the only lake with rooted aquatics in deep water.

A few analyses were made by Odum on the amount of CaO in the lake waters, the total dissolved substances, and the loss on ignition. These data, summarized in Table 7, are subject to rather large errors and hence are only preliminary. The analysis of dissolved matter, for example, was made on 200 ml. samples, whereas with such small quantities of dissolved matter much larger samples should be used to reduce the relative magnitude of instrument errors. Calcium determinations were likewise made on 200 ml. samples, but here the quantities present are so small that errors up to several hundred per cent would not appreciably change the relative magnitude of the results. The general reliability of the latter results is evidenced by the small quantities of standard acid required to bring the reaction of these waters to the methyl orange end-point (Table 6).

TABLE 7

Analysis of calcium and dissolved matter in the water of four bay lakes

LAKE	CaO	DISSOLVED MATTER		
		Total solids	Loss on ignition	Inorganic residue
	ppm.	*ppm.*	*ppm.*	*ppm.*
White	1.8	34.0	14.0	20.0
Jones	1.8	55.5	41.0	14.5
Singletary	2.1	53.5	39.0	14.5
Waccamaw	4.1	90.5	36.0	64.5

The quantities of calcium found in these lakes are very small. According to the system established by Naumann (1932) the lakes would be considered strongly oligotypic for calcium. In a study of 358 lakes in northern Wisconsin, Juday, Birge, and Meloche (1938) found that 21 per cent had a calcium content of less than 1 mg./l., and another 15 per cent 1.0–1.9 mg./l. This latter group would correspond to the North Carolina lakes, except for Waccamaw, which has a somewhat higher calcium content of 2.9 mg./l. To a considerable extent dystrophy develops only in regions low in calcium and magnesium, because these ions when abundant precipitate out the humic acids as humates, thereby preventing the accumulation of excessive color.

Loss on ignition, representing the dissolved organic matter, shows an expected correlation with the colors of the lake listed in Table 6. The inorganic residue in White, Jones, and Singletary is 20 parts per million or less, that in Waccamaw is three to four times greater. This agrees with the finding of a higher pH and a greater titratable alkalinity to methyl orange in Waccamaw than in the other lakes.

BIOTA

A separate report on the biota of these lakes will be presented later. Preliminary reports on the fishes (Hueske, 1948) and the benthos of Waccamaw (Frey, 1948b) have already appeared. A brief summary of these shows that in spite of the rather high acidity there is a rather good representation of organisms in the lakes. A total of 27 species of fishes were collected from the lakes. Waccamaw with 23 species had the greatest individual total, then followed White with 16, Jones with 13, Salters and Singletary with 12 each, and Black with 10 species. The lists contain a high proportion of predacious species, which, according to Hubbs and Raney (1946), explains the high rate of endemism in Waccamaw, where there were found three new species of *Fundulus*, *Boleosoma*, and *Menidia*, and possibly a new species of *Notropis* (described by Fowler). The fishes from the other lakes have not yet been sufficiently studied to determine whether or not evolution had proceeded along parallel lines in them.

The preliminary report on the benthos of Waccamaw showed an average of 579 organisms per square meter of bottom. The three groups of organisms most abundant were molluscs, 208 per square meter; two species of Tubificidae and one of Lumbriculidae, 179; and insects, 160, with *Hexagenia* nymphs being most abundant. The more acid lakes have smaller numbers of bottom organisms, particularly mollusca. In fact the only mollusc occurring in the acid Bladen County lakes is *Ferrissia hendersoni* Walker.

All lakes, except White, have a fairly good representation in the zooplankton of cladocera, copepods, and rotifers, but generally very little phytoplankton, as is to be expected in dystrophic lakes. Coker (1938) has already called attention to the fact that the plankton of White Lake is lacking in cladocera. Salters Lake was the only one with significant quantities of phytoplankton. Both in the summers of 1947 and 1948 *Asterionella* was abundant.

SUMMARY

The six lakes studied in the North Carolina Coastal Plain all conform to a common pattern, with differences resulting chiefly from differences in size of the basins. The lakes are saucer-shaped with regular outlines. Their single-depression basins are nowhere more than 12 feet deep, and the average depth varies from 5.3 to 7.6 feet.

Evidence from the pattern of filling, the profiles of slopes along the various shores, particularly the well developed terrace at the southeast end and the less well developed terraces along the northeast shore, the pattern of surface irregularities in the Waccamaw terraces, and the distribution of the bottom deposits all substantiate the marked influence of the westerly winds in controlling the morphometry and hydrography of the present basins, and presumably helping to shape the original basins.

The lakes tend to be dystrophic because of the swampy and peaty nature of their surroundings, but White Lake is colorless as a result of a difference in drainage pattern. The lakes tend to be strongly acidotrophic, with available evidence indicating that sulphuric acid is very likely responsible for the low pH. The water of Waccamaw comes in contact with geological formations other than clean sand, from which it dissolves sufficient materials to raise its chemical reaction to neutrality. All the lakes are strongly oligotypic for calcium and have only small quantities of materials in solution. Presumably the basic pattern of production is oligotrophy, although no analyses on phosphorus and nitrogen are here reported.

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TABLE 8

JONES LAKE

Bladen County, N. C. 36°41'N, 78°36'W.

Area.............. 224 acres
Volume............ 707,100 yd.³
Maximum depth.... 8.7 ft.
Mean depth........ 6.1 ft.

Maximum length........... 1420 yd., 0.80 mi.
Length shoreline............ 3860 yd., 2.19 mi.
Shoreline development....... 1.05
Volume development......... 2.10
Number of soundings........ 218

DEPTH	AREA		STRATUM	VOLUME	
	Acres	Per cent of total		Yd.³ × 10⁶	Per cent of total
feet			*feet*		
0	224	100.0	0–2	0.71	32.0
2	214	95.5	2–3	0.33	15.1
3	198	88.4	3–4	0.31	13.9
4	181	80.8	4–5	0.28	12.7
5	167	74.5	5–6	0.26	11.7
6	152	67.8	6–7	0.21	9.6
7	111	49.5	7–8	0.10	4.7
8	26	11.6	8–8.7	0.01	0.4
Total........				2.21	100.1

TABLE 9

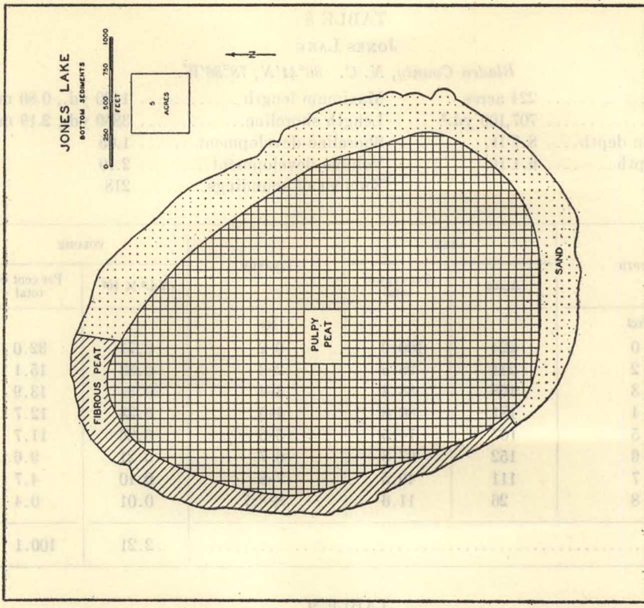
SALTERS LAKE

Bladen County, N. C. 36°42'N, 78°38'W.

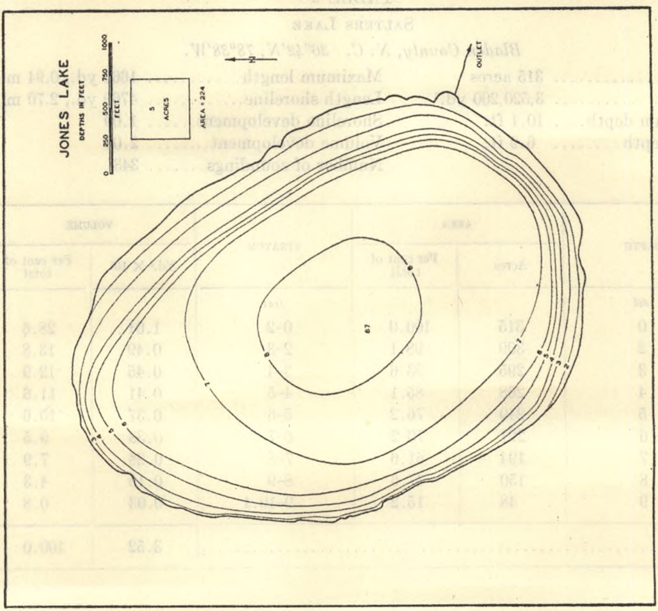
Area.............. 315 acres
Volume............ 3,520,200 yd.³
Maximum depth.... 10.1 ft.
Mean depth........ 6.9 ft.

Maximum length........... 1660 yd., 0.94 mi.
Length shoreline............ 4760 yd., 2.70 mi.
Shoreline development....... 1.09
Volume development......... 2.05
Number of soundings....... 343

DEPTH	AREA		STRATUM	VOLUME	
	Acres	Per cent of total		Yd.³ × 10⁶	Per cent of total
eet			*feet*		
0	315	100.0	0–2	1.01	28.6
2	309	98.1	2–3	0.49	13.8
3	295	93.6	3–4	0.45	12.9
4	268	85.1	4–5	0.41	11.6
5	240	76.2	5–6	0.37	10.6
6	221	70.2	6–7	0.33	9.5
7	194	61.6	7–8	0.28	7.9
8	150	47.6	8–9	0.15	4.3
9	48	15.2	9–10.1	0.03	0.8
Total........				3.52	100.0



6b



6a

FIG. 6a and 6b. JONES LAKE. Hydrographic chart and distribution of bottom sediments.

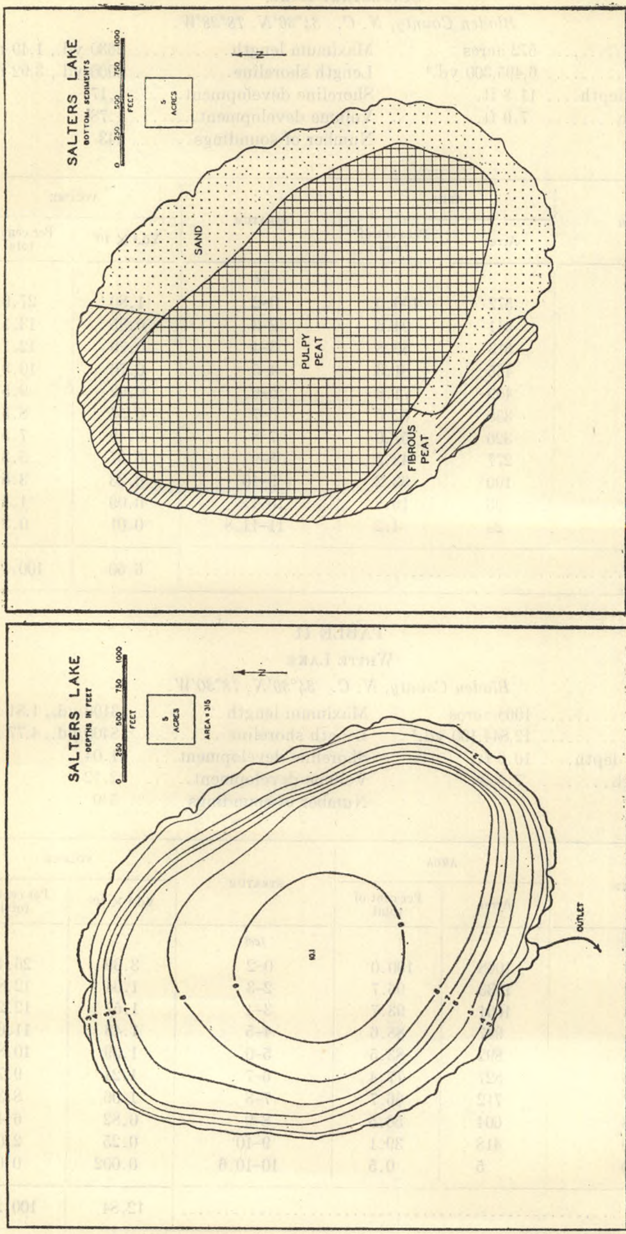


FIG. 7a and 7b. SALTERS LAKE. Hydrographic chart and distribution of bottom sediments.

TABLE 10

SINGLETARY LAKE

Bladen County, N. C. 34°36'N, 78°28'W.

Area	572 acres	Maximum length	2630 yd., 1.49 mi.
Volume	6,495,300 yd.³	Length shoreline	6900 yd., 3.92 mi.
Maximum depth	11.8 ft.	Shoreline development	1.17
Mean depth	7.0 ft.	Volume development	1.78
		Number of soundings	443

DEPTH	AREA		STRATUM	VOLUME	
	Acres	Per cent of total		Yd.³ × 10⁶	Per cent of total
feet			*feet*		
0	572	100.0	0–2	1.80	27.6
2	541	94.6	2–3	0.85	13.1
3	513	89.8	3–4	0.79	12.1
4	465	81.3	4–5	0.70	10.9
5	409	71.6	5–6	0.62	9.5
6	358	62.6	6–7	0.55	8.5
7	326	57.0	7–8	0.49	7.5
8	277	48.5	8–9	0.37	5.8
9	190	33.2	9–10	0.23	3.5
10	96	16.8	10–11	0.09	1.4
11	24	4.2	11–11.8	0.01	0.2
Total				6.50	100.1

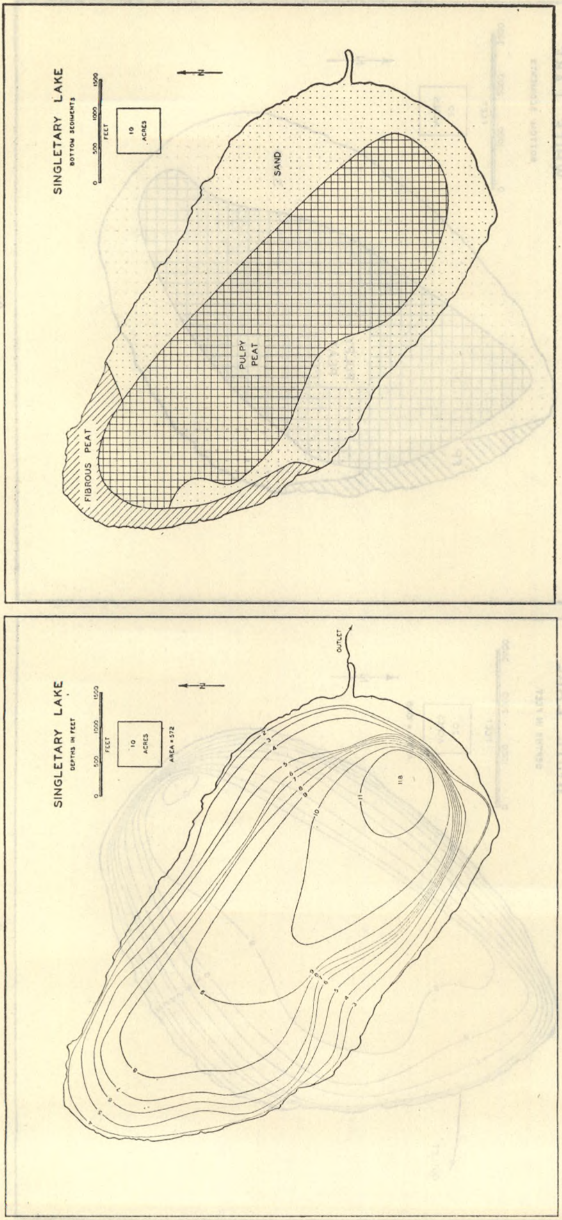
TABLE 11

WHITE LAKE

Bladen County, N. C. 34°39'N, 78°30'W.

Area	1068 acres	Maximum length	3190 yd., 1.81 mi.
Volume	12,844,100 yd.³	Length shoreline	8400 yd., 4.77 mi.
Maximum depth	10.6 ft.	Shoreline development	1.04
Mean depth	7.5 ft.	Volume development	2.12
		Number of soundings	540

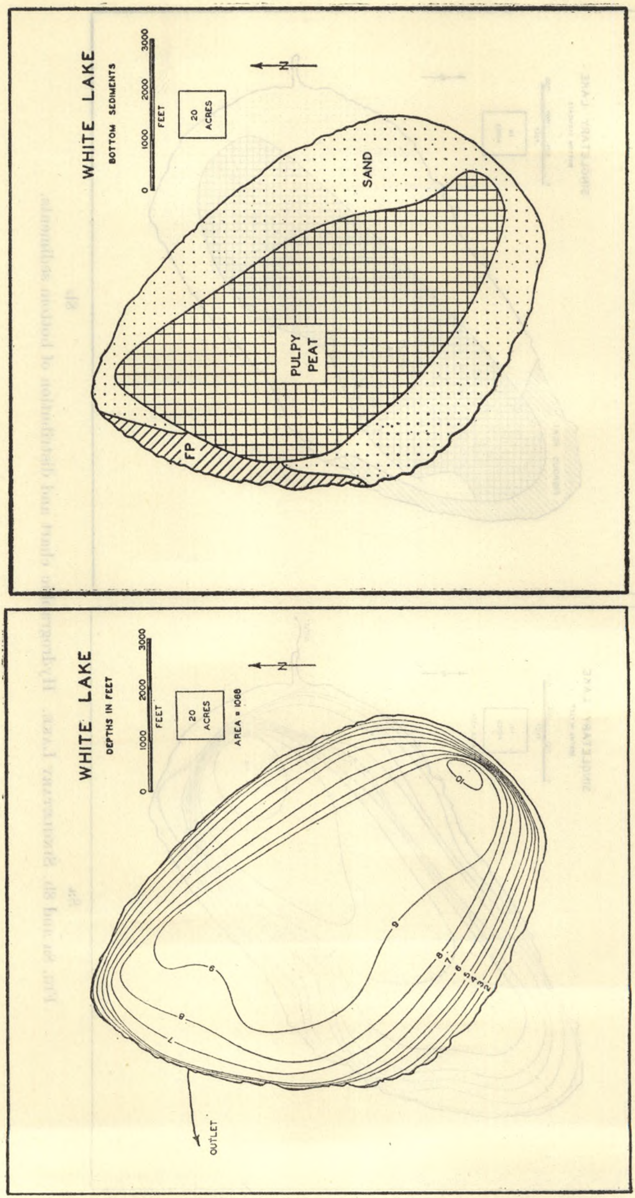
DEPTH	AREA		STRATUM	VOLUME	
	Acres	Per cent of total		Yd.³ × 10⁶	Per cent of total
feet			*feet*		
0	1068	100.0	0–2	3.39	26.4
2	1033	96.7	2–3	1.64	12.8
3	1001	93.7	3–4	1.57	12.2
4	947	88.6	4–5	1.48	11.6
5	892	83.5	5–6	1.39	10.8
6	827	77.4	6–7	1.24	9.7
7	712	66.7	7–8	1.06	8.3
8	604	56.5	8–9	0.82	6.4
9	418	39.1	9–10	0.25	2.0
10	5	0.5	10–10.6	0.002	0.01
Total				12.84	100.2



8b

8a

FIG. 8a and 8b. SINGLETARY LAKE. Hydrographic chart and distribution of bottom sediments.



9b

9a

FIG. 9a and 9b. WHITE LAKE. Hydrographic chart and distribution of bottom sediments.

TABLE 12

BLACK LAKE

Bladen County, N. C. 34°40'N, 78°25'W.

Area	1418 acres	Maximum length	3720 yd., 2.11 mi.
Volume	12,197,700 yd.^{3}	Length shoreline	10,400 yd., 5.91 mi.
Maximum depth	7.1 ft.	Shoreline development	1.12
Mean depth	5.3 ft.	Volume development	2.24
		Number of soundings	356

DEPTH	AREA		STRATUM	VOLUME	
	Acres	Per cent of total		Yd.^{3} × 10^6	Per cent of total
feet			*feet*		
0	1418	100.0	0–2	4.50	36.9
2	1369	96.5	2–3	2.17	17.8
3	1318	93.0	3–4	2.05	16.8
4	1224	86.3	4–5	1.76	14.5
5	970	68.4	5–6	1.31	10.7
6	664	46.8	6–7	0.41	3.3
7	10	0.7	7–7.1	+	0.004
Total				12.20	100.0

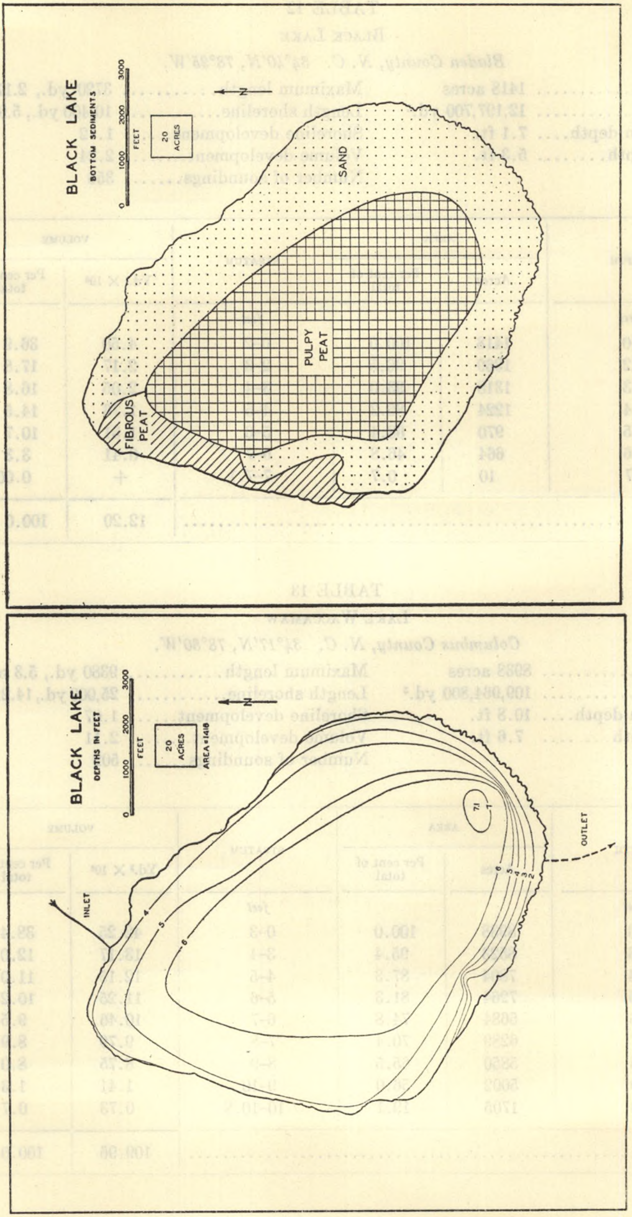
TABLE 13

LAKE WACCAMAW

Columbus County, N. C. 34°17'N, 78°30'W.

Area	8938 acres	Maximum length	9380 yd., 5.3 mi.
Volume	109,964,800 yd.^{3}	Length shoreline	25,000 yd., 14.21 mi.
Maximum depth	10.8 ft.	Shoreline development	1.07
Mean depth	7.6 ft.	Volume development	2.11
		Number of soundings	502

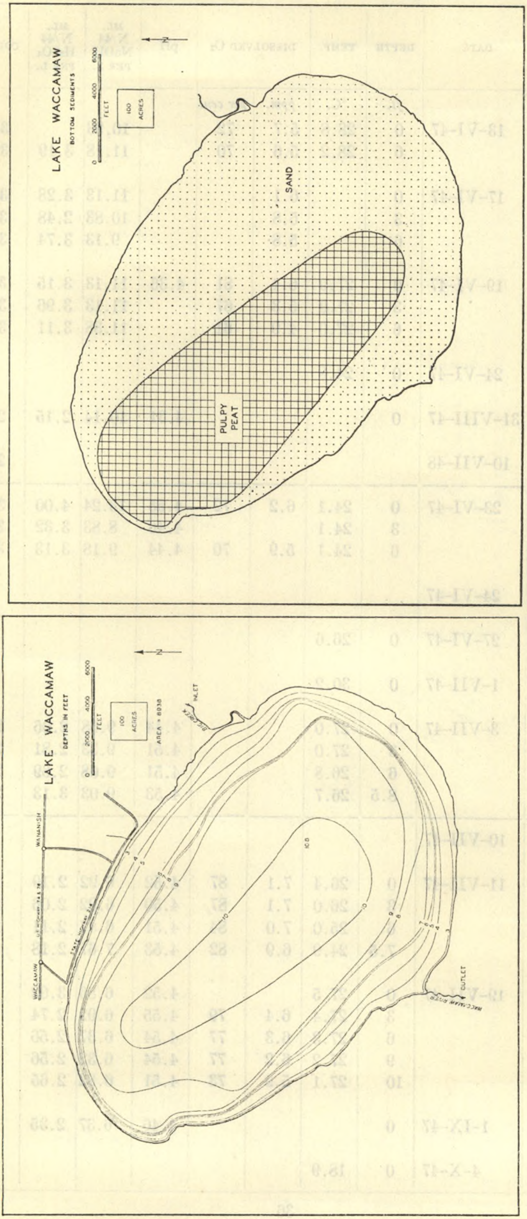
DEPTH	AREA		STRATUM	VOLUME	
	Acres	Per cent of total		Yd.^{3} × 10^6	Per cent of total
feet			*feet*		
0	8938	100.0	0–3	42.25	38.4
3	8523	95.4	3–4	13.17	12.0
4	7804	87.3	4–5	12.15	11.0
5	7264	81.3	5–6	11.25	10.2
6	6684	74.8	6–7	10.46	9.5
7	6289	70.4	7–8	9.79	8.9
8	5850	65.5	8–9	8.75	8.0
9	5002	56.0	9–10	1.41	1.3
10	1705	19.1	10–10.8	0.73	0.7
Total				109.96	100.0



10b

10a

FIG. 10a and 10b. BLACK LAKE. Hydrographic chart and distribution of bottom sediments.



11b

11a

FIG. 11a and 11b. LAKE WACCAMAW. Hydrographic chart and distribution of bottom sediments.

TABLE 14

Chemical and physical observations on the Carolina bay lakes

LAKE	DATE	DEPTH	TEMP.	DISSOLVED O_2		pH	ML. N/44 NaOH PER L.	ML. N/44 H_2SO_4 PER L.	COLOR	DISC
		ft.	°C.	*ppm.*	*per cent*					*ft.*
Jones	13–VI–47	0	28.8	5.7	72		10.93		352	
		6	28.2	5.6	70		11.18	3.19	340	
	17–VI–47	0		6.1			11.13	3.28	340	2.3
		3		5.8			10.83	2.48	340	
		6		5.8			9.13	3.74	340	
	19–VI–47	0	27.9	6.4	81	4.36	11.13	3.15	340	2.1
		3	27.9	5.3	67		11.13	3.96	340	
		6	27.0	4.9	61		11.38	3.11	340	
	24–VI–47	0	24.8							2.3
	31–VIII–47	0				4.31	10.14	2.15	240	2.7
	10–VII–48								260	
Salters	23–VI–47	0	24.1	6.2	72	4.55	13.24	4.00	320	1.8
		3	24.1			4.46	8.83	3.32	352	
		6	24.1	5.9	70	4.44	9.18	3.13	340	
	24–VI–47									1.7
	27–VI–47	0	26.6							2.0
	1–VII–47	0	30.2							1.8
	3–VII–47	0	27.0			4.44	9.68	2.06	280	1.8
		3	27.0			4.51	9.33	2.81	280	
		6	26.8			4.51	9.08	2.69	280	
		8.5	26.7			4.53	9.03	3.13	280	
Singletary	10–VII–47									2.2
	11–VII–47	0	26.4	7.1	87	4.52	6.92	2.19	185	2.3
		3	26.0	7.1	87	4.50	6.92	2.06	180	
		6	25.0	7.0	84	4.51	6.87	2.11	180	
		7.5	24.9	6.9	82	4.53	7.67	2.18	180	
	19–VII–47	0	27.5			4.52	6.86	3.62	170	2.3
		3	27.4	6.4	79	4.55	6.92	2.74	170	
		6	27.3	6.3	77	4.54	6.37	2.56	170	
		9	27.2	6.2	77	4.54	6.32	2.56	170	
		10	27.1	5.9	73	4.51	6.82	2.65	185	
	1–IX–47	0				4.46	6.37	2.35	140	2.9
	4–X–47	0	18.9							2.6

TABLE 14—*Continued*

LAKE	DATE	DEPTH	TEMP.	DISSOLVED O_2		pH	ML. N/44 NaOH PER L.	ML. N/44 H_2SO_4 PER L.	COLOR	DISC
		ft.	°C.	*ppm.*	*per cent*					*ft.*
Singletary *Cont.*	5-X-47	0	19.4							2.9
	16-XI-47								170	
	10-VII-48								160	
White	26-VII-47	0	26.2	6.7	82	4.92	3.26	1.90	12	9
		3	26.2	7.1	86	4.90	3.76	1.85		
		6	26.2	7.1	86	4.95	3.51	1.60		
		7.5	26.2	7.3	88	4.97	3.26	1.69		
	2-VIII-47	0	29.5	6.3	81	4.90	3.71	1.69	<10	9
		3	29.1	6.4	82	4.94	3.36	1.39		
		6	29.0	6.4	82	4.87	3.46	1.43		
		8	29.0	6.5	83	4.91	3.41	1.39	<10	
	10-VII-48								<10	
Black	30-VIII-47	0	27.8	6.3	78	4.43	7.47	2.39	180	1.8
		3	27.5	6.5	80	4.41	7.17	1.98	170	
		6	27.2	6.6	82	4.46	7.47	1.99	175	
	4-IX-47	0	34.9	6.5	92	4.35	7.47	1.60	180	1.8
		1	34.4							
		2	31.0							
		3	29.5	6.6	85	4.38	7.78	1.47	190	
		6	26.6	5.9	72	4.39	7.98	1.68	190	
Waccamaw	15-VIII-47									4.5
	18-VIII-47	0	34.0	5.3	74	7.03	2.66	9.78	140	4.4
		2	30.2							
		3	29.5	5.0	64	6.95	2.66	9.33		
		6	28.6	4.8	61	6.95	3.01	9.28		
		9	28.3	4.6	58	6.92	3.31	9.04	140	
	23-VIII-47	0	30.1	6.1	80	6.91	3.87	8.74	160	4.8
		3	28.8	6.1	77	7.00	4.22	8.53		
		6	28.7	5.8	73	6.93	4.02	8.83		
		9	28.6	5.7	73	6.87	3.92	8.66	170	
	16-XI-47	0	13.2						175	3.8
Big Creek Inlet	23-VIII-47	0	24.0			5.42	24.40	6.89	360	
		0	24.4			5.22	25.45	4.45	400	