THE DISTRIBUTION, CHARACTER, AND ABUNDANCE OF SEDIMENTS IN A 3000-ACRE IMPOUNDMENT IN PAYNE COUNTY, OKLAHOMA

By

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IN PAYNE COUNTY, OKLAHOMA

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PREFACE

The objectives of this study were to: (1) test the hypothesis that the abundance and distribution of certain benthic dwelling invertebrates in the reservoir are related to one or more of several sediment characteristics; (2) evaluate loss on ignition method for determination of organic content of sediment.

Dr. R. C. Summerfelt served as Committee Chairman and directed the research. Dr. T. C. Dorris served on the advisory committee, and provided research facilities in the early part of the study. Dr. L. W. Reed, the third member of the advisory committee, suggested sediment analysis techniques. Mrs. N. Norton aided in the writing of computer programs for the sediment analysis and the statistical analyses.

Thanks are given to the personnel of the Oklahoma Cooperative Fishery Unit, especially Messrs. Daniel Templeton, Stanley Smith, and Ronald Hover, for the collection of samples and assistance in the laboratory work. I am grateful to my wife, Nancy, for typing the manuscript.

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CHAPTER I

INTRODUCTION

Population growth and success, measured in terms of abundance and distribution of a species, is determined by a set of environmental factors, any one of which may become limiting (Reid, 1961). Organisms exist only where abiotic factors, either through scarcity or overabundance, do not become limiting to their existence. Likewise, organisms increase mumerically when food and basic habitat requirements are abailable.

Benthic macroinvertebrates are presumably responsive to one or more sediment characteristics which provide food, shelter or material for case building. The importance of organism-substrate relationships in lotic environments has been stressed in a recent review by Cummins (1964). Amounts of organic matter of the sediment may be too small to provide adequate nutrition for certain burrowing benthos. Likewise, organic matter may accumulate too rapidly and cause anerobiosis destroying many aerobic benthos. Certain intertidal invertebrates are limited in distribution by the particle size composition of the beaches (Weiser, 1958). Flocculent substrate has limited the burrowing of the mayfly *Hexagenia limbata* (Hunt, 1953).

The objective of this study was to test the hypothesis that the abundance of certain benthic dwelling invertebrates in a reservoir is related to one or more of several sediment characteristics.

Sediment parameters analyzed were sediment depth, particle size distribution, organic content, and hydrogen ion concentration. An understanding of this relationship will aid in determining the distribution of the fish that feed on the benthos.

CHAPTER II

LITERATURE REVIEW

Since the turn of the century, there have been many studies directed at the substrate as an integral part of the aquatic environment. Early studies, such as Baker (1918), were based on the visual appearance of the substrate rather than an analysis of characteristics such as particle size, organic content, or hydrogen ion concentration. Well defined analytical methods in sediment studies were not widely used until later investigations, such as Henson (1962).

Using descriptive methods, Baker (1918) classified Lake Oneida substrate types as clay, mud, sand, gravel, and boulder. Members of the family Tubificidae and the genus *Chironomus* (Culicidae) were found in all substrate types to a depth of 3.9 and 5 meters (13 and 15 feet), respectively. *Hexagenia* (Ephemeridae) was found on sand, gravel, and mud substrates, and was restricted to depths between one and five meters (3 and 16 feet). There was no quantitative measurement of other environmental variables. Krecker and Lancaster (1933) classified photographed substrates from the littoral zone of western Lake Erie, as clay, sand, gravel, flat rubble, angular rubble, and shelving rock. Chironomid larvae were found on all substrate types to the maximum depth studies, two meters (6 feet). *Hexagenia* (Ephemeridae) was limited to a depth of .46 meters (18 inches) on a substrate called flat rubble. Environmental factors such as temperature, oxygen, carbon dioxide and pH were uniform throughout the study area and were not regarded as influential to the distribution of the benthos.

Milne (1943) regarded the distribution of caddis fly larvae in Waskesiu Lake, Saskatchewan, to be limited by wave action and water depth. Interaction of these two factors determined the substrate type thereby influencing the availability of casebuilding materials for larval caddis flies. Based on descriptive substrate classification, the greatest number of larvae were found associated with sand and submerged vegetation and the least number of larvae on the mud substrate. While no other environmental variables were measured, Milne suggested that other interactions may also have affected the distribution of the larvae.

Hunt (1953) concluded that nymphs of Hexagenia limbata could not burrow in fine sand unless it was mixed with a significant amount of marl and mud. Hunt graded natural sediments in laboratory experiments with standard seives. Lyman (1955), working with members of the same genus, states that Hexagenia nymphs were sensitive to decreasing concentrations of dissolved oxygen and were intolerant to sediment with high sand content. Cole (1953) decided that oxygen depletion below the upper centimeter of lake sediment in Douglas Lake, Michigan, limited the vertical distribution of microbenthos in the sediment.

The lack of standardization in sediment descriptors in early works make comparison of published works difficult. This difficulty was compounded by a lack of discrimination between the effects of the substrate on macrobenthos distribution patterns and the effect of other environmental variables such as wave action, temperature, and dissolved oxygen concentration. More recent works have followed well defined methods of analysis and have included consideration of other environmental variables.

Sublette (1957) gave an analytical description of the sediment cenoses found in Denison Reservoir, Oklahoma and Texas, and stated habitat preferences for annelids (soft mud), Hexagenia (sand and mud), Chaoborinae (soft sediments). Many species of Tendipedidae (= Chironomidae) were collected, each with particular habitat preferences, lending a ubiquitous distribution to the family as a whole. Hensen (1962) related the distribution of tubificids collected in the Mackinac straits area of the Great Lakes to the median phi (negative logarithm to base 2 of median particle diameter) of the sediment. Greatest numbers of tubificids were found in sediments with a median phi around 3.9 (fine to very fine sand on the Wentworth scale). Swanson (1967) studied the environmental factors influencing the distribution and abundance of Hexagenia in a mainstream impoundment on the Missouri River, and found that with the exception of isolated areas of sand, most of the substrate was suitable for burrowing nymphs. Swanson also found that depth, dissolved oxygen concentration, molar action, and water levels were also limiting to the distribution of Hexagenia.

CHAPTER III

DESCRIPTION OF LAKE CARL BLACKWELL

Lake Carl Blackwell (Figure 1) is located 11 kilometers (7 miles) west of Stillwater, Oklahoma, on State Highway 51C. Reservoir construction began in 1936 as a project of the Works Progress Administration, and was completed in 1938. The initial function of the reservoir was to provide a recreational facility, though it now serves as a water supply for the city of Stillwater.

Maximum surface area of approximately 1500 hectares (3700 acres) was attained at spillway elevation (283.2 m, m.s.l.) in 1945 with an approximate capacity of 80 million cubic meters (65,000 acre-feet) (Table I). The lake level decreased during the study from about 280.8 m to about 279.2 m (m.s.l.). The mean lake elevation 280 meters (933.4 feet) above mean sea level was used in all figures and the following computations.

The lower water level during this study compared to spillway elevation reduced the surface area and the shoreline length by 40% or more. The reduction in shoreline length was sufficient to cause a 50% decrease in shoreline development index (Hutchinson, 1957). The mean depth was decreased by nearly one-third. The watershed to surface area ratio at spillway elevation is insufficient to maintain water level at spillway elevation except during years of above average rainfall. The watershed to surface area ratio at an elevation of

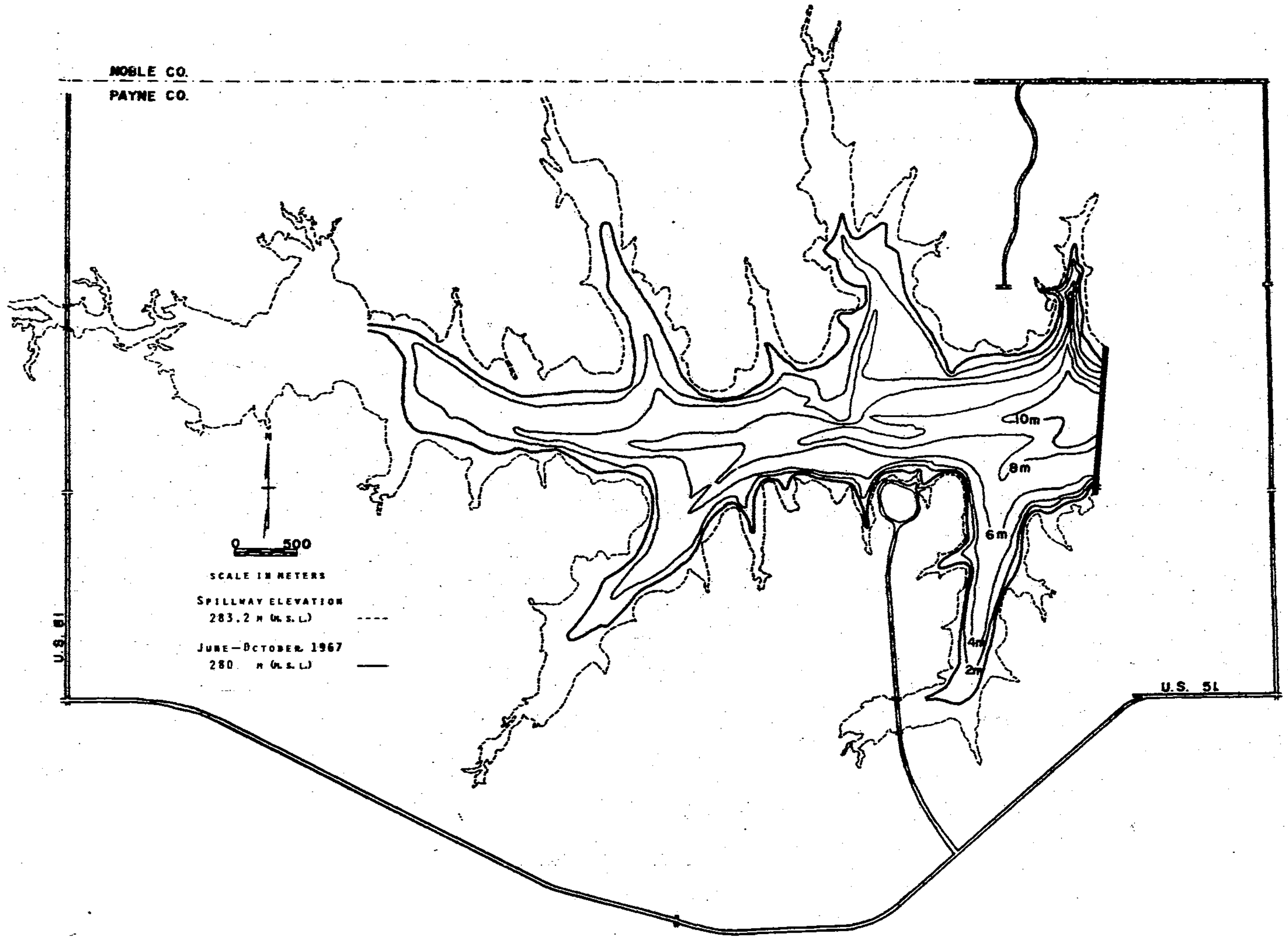

Figure 1. Map of Lake Carl Blackwell with 2 Meter Depth Contours

TABLE I

LAKE CARL BLACKWELL MORPHOMETRIC CHARACTERISTICS AT SPILLWAY (283.3 M) ELEVATION AND MEAN ELEVATION (280.0 M) DURING THE PERIOD OF STUDY, JUNE THROUGH SEPTEMBER, 1967

Elevation (mean sea level)	Shoreline length (km)	Surface area (hectare)	Volume (million m^3)	Mean depth (m)	Watershed area (sq km)	Watershed to surface area ratio	Shoreline development
283.3 m	71.6	1486	79.9	2.94	172.7	11.6 to 1	5.24
280.0 m	42.5	856	33.9	2.00	173.3	20.2 to 1	2.42

280 meters (m.s.l.) is probably sufficient to maintain water level even during years of below average rainfall.

CHAPTER IV

EXPERIMENTAL DESIGN

Thirty range lines were established between prominent points around the reservoir (Figure 2). The location of these transects were chosen to correspond to those of an earlier sediment study in the reservoir by Schrieber (1959). Schrieber's transects were used to provide a bases for measuring changing rates of sedimentation and stability of sediment patterns. However, samples during the study were only collected from setes along 23 range lines because of the lower water level. There were 109 sampling sites located at the midpoints of 75 meter (250 feet) intervals along each transect.

In June and October, 1967, ooze samples, benthos samples, and turbidity samples were collected and depth of sediment, surface and bottom water temperature, surface and bottom dissolved oxygen, and pH were measured. During the months of August and September, three replicate samples of the same parameters were taken from randomly selected areas along Transects 1, 3, 5, 7, 18, and 22 to obtain a measure of variation within the sample sites.

Relationships between the various parameters were explored by means of a multiple linear regression analysis. The data from each sampling period was analyzed separately, using biomass (wet weight) of the total benthos and biomass (wet weight) of each of the four major families (Chironomidae, Tubificidae, Ephemeridae, and Culicidae) as the

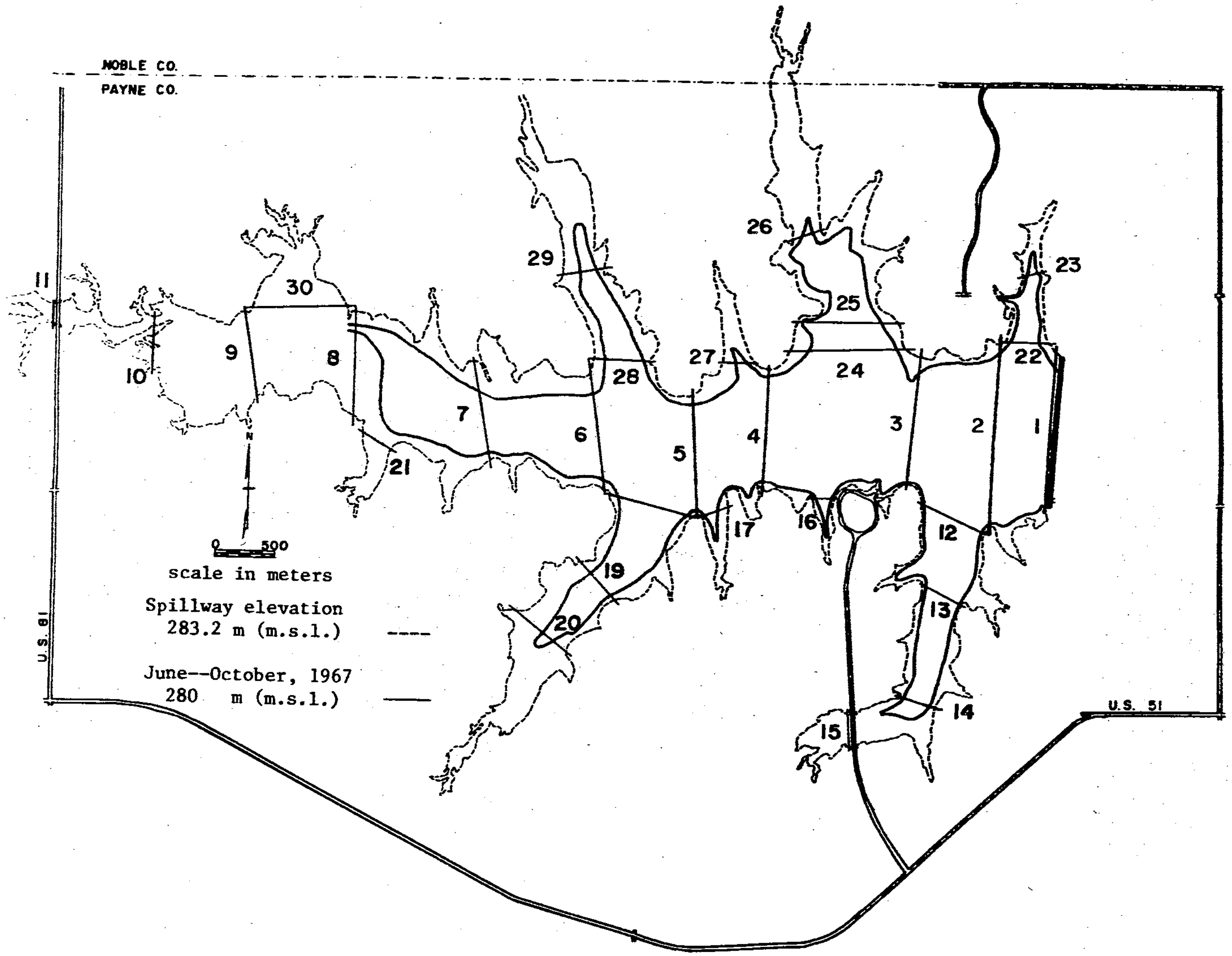

Figure 2. Map of Lake Carl Blackwell with Sampling Transects

dependent variables and the sediment parameters (sediment depth, particle size distribution, organic content, and hydrogen ion concentration) as independent variables. Each regression could be expressed as:

$$Y = a + b_1x_1 + . . . + b_ix_i$$

where Y is the biomass estimation of the macroinvertebrates, a is the Y intercept, b_i is the ith regression coefficient and x_i is the ith independent variables. The significance of the regression analysis was determined by an F test while the significance of individual independent variables, in terms of contribution to the regression analysis, was determined by a t test (Steel and Torrie, 1960:288). The coefficient of determination, defined as the percent of variation in the dependent variables attributable to the combined effect of the independent variables, was also calculated (Steel and Torrie, 1960:288). The triplicate samples of the summer period were analyzed by an hierarchical analysis of variance to estimate the amount of within-sample variance of the parameters (Appendix A). These analyses show that variation of replicate samples within 75 meter sample sites was not statistically significant.

Statistical analyses were performed on an IBM-7040 computer, with 32K memory, using a program adapted from the IBM Scientific Subroutine Package. Additional statistical analyses, computations, and transformations were run on an IBM-7040 computer using programs written by the author and/or personnel of the University Computer Center, Oklahoma State University. These programs are given in Appendix B.

CHAPTER V

METHODS

Physicochemical

Dissolved oxygen and temperature were measured at the surface and near the bottom when sediment and macroinvertebrates were collected. All oxygen and temperature determinations were made with a galvanic cell oxygen analyzer[1]. Surface water samples were taken at the sampling stations to determine turbidity and pH. Field measurements of pH were made using a Hellige pH comparator[2]. Turbidity measurements were made according to standard methods (APHA, 1965) using a Jackson candle turbidimeter.

Sediment Collection

The ooze sucker was chosen rather than the core sampler for collection of sediment samples. The former collects sediment at the sediment-water interface, a zone regarded by the author as more important to the distribution of benthic invertebrates than deposits some distance below the sediment-water interface.

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[1]Precision Scientific Co., Chicago, Illinois, 60647.

[2]Hach Chemical Co., Des Moines, Iowa.

Hunt (1953) states that even large individuals of Hexagenia sp. would not burrow deeper than 5 cm (2 inches).

In operation, the sampler is lowered to the bottom and tripped by a messenger, allowing a squeeze bulb to suck up the sediment from the sediment-water interface (Welch, 1948). The ooze samples were placed in quart jars and cooled in an ice chest until they could be taken to the laboratory. The ooze sucker was rinsed thoroughly before reuse. At the laboratory, each sample was centrifuged for one hour at 2000 rpm. The water was decanted from the sediment and each sediment sample was placed in a plastic bag and frozen.

Particle Size Diameter of Sediment

The hydrometer method (Bouyoucos, 1927) was used to determine the particle size distribution of the samples. The density of a suspension is a function of the amount of suspended matter. Therefore, measurements of the density of suspension at intervals following mixing allows calculation of the percentage by weight of soil particles remaining in suspension at the measured depth. The diameter of the particles that have reached the measured depth in their fall from the surface of the suspension were computed from Stoke's formula (below). Particles of greater diameter, or particles not starting at the surface of the suspension, are below the measured depth at the time the reading is taken. Since Stoke's law is stated in terms of a single spherical particle, the diameters calculated by use of the formula are those of spheres which will have the same settling velocity as the sediment particles.

The procedure used to determine particle size diameter is modified from that given by ASTM (1958). A 10-50 gm sample was thoroughly mixed with distilled water and a dispersing agent (sodium carbonate) to form a suspension totaling 1000 ml. Particles began to settle immediately after mixing ceased and the first hydrometer reading was made after 30 seconds. The second reading was made at the end of 1 minute and subsequent readings were taken at 3, 10, 30, and 90 minutes, 4, 8, 12, and 24 hours. The grams per liter of sediment remaining in suspension was read directly from the hydrometer, and the effective diameter calculated from the formula (Bauer, 1937):

$$D = \sqrt{\frac{30}{980} \cdot \frac{N}{G - G_1} \cdot \frac{L}{T}}$$

In the formula, D equals the diameter of the particles in millimeters, G equals the specific gravity of the sediment, G_1 equals the specific gravity of the liquid, N equals the viscosity of the liquid, and L equals the distance in centimeters through which the particles of diameter D have fallen. T, is the time in minutes from the start to the time the observation was made.

Calculations of particle diameter were made by use of an IBM-7040 computer. The output included a listing of input data, the percent of sample in suspension for each reading, the effective particle diameter for each reading, a listing by particle size group of the percentage in each group, the median phi value, and the median particle diameter (Figure 3). By use of a plotting subroutine, a semi-logarithmic plot was obtained of particle diameter (log scale), X axis, and, on the Y axis, the percent of

BLACKWELL 6-III
SAMPLE NO. 82

TOTAL SAMPLE WEIGHT = 18.6
HYDROMETER NO. 8
SPECIFIC GRAVITY = 1.76

READING NO.	TIME ELAPSED	READING	PERCENT OF SAMPLE	PARTICLE DIAMETER
1	0.5	18.5	99.46	0.10516
2	1.0	18.5	99.46	0.07436
3	4.0	18.0	96.77	0.03726
4	10.0	16.2	87.10	0.02375
5	40.0	13.5	72.58	0.01201
6	60.0	11.4	61.29	0.00989
7	90.0	7.9	42.47	0.00818
8	650.0	1.8	9.68	0.00312
9	1390.0	1.1	5.91	0.00214

COARSE SAND	0.45
FINE SAND	0.95
COARSE SILT	22.32
FINE SILT	60.89
COARSE CLAY	12.63
FINE CLAY	1.38
VERY FINE CLAY	1.38

MEDIAN PARTICLE DIAMETER	0.04906
MEDIAN PHI	4.34933

Figure 3. Computer Output of Particle Size Calculations

the sample finer than a given diameter (Figure 4). The particle size group percentages, the median phi value, and the median particle diameter were also obtained as punched card output for use in the subsequent regression analyses.

As Bouyoucos (1929) pointed out, the results of the hydrometer method agree with those obtained by the pipette method, though the latter is still considered as the only standard method by investigators in some fields.

In accordance with the recommendations stated by Cummins (1962), the results were reported in terms of median phi values, phi being the negative logarithm to the base 2 of the particle diameter. The median phi value has been used in benthos studies as an index to the particle size distribution in a sample. In the statistical analyses, the median particle diameter was used to avoid the combination of both arithmetic and logarithmic values in the calculations.

Organic Content of the Sediment

There is no single method which can be considered as the "standard" for determination of organic content of soils or sediment. The wet oxidation has many advantages, among which are simplicity and low cost. For these reasons, the procedure which was used in this investigation was a modification of the Allison-Deturk chromic acid oxidation method (Melsted, 1954). Cummins (1962) stated that the loss of weight on ignition method is acceptable for samples with low clay content. This method was evaluated for comparison to the chromic acid oxidation and was found to be greatly in error, presumably because of high clay content.

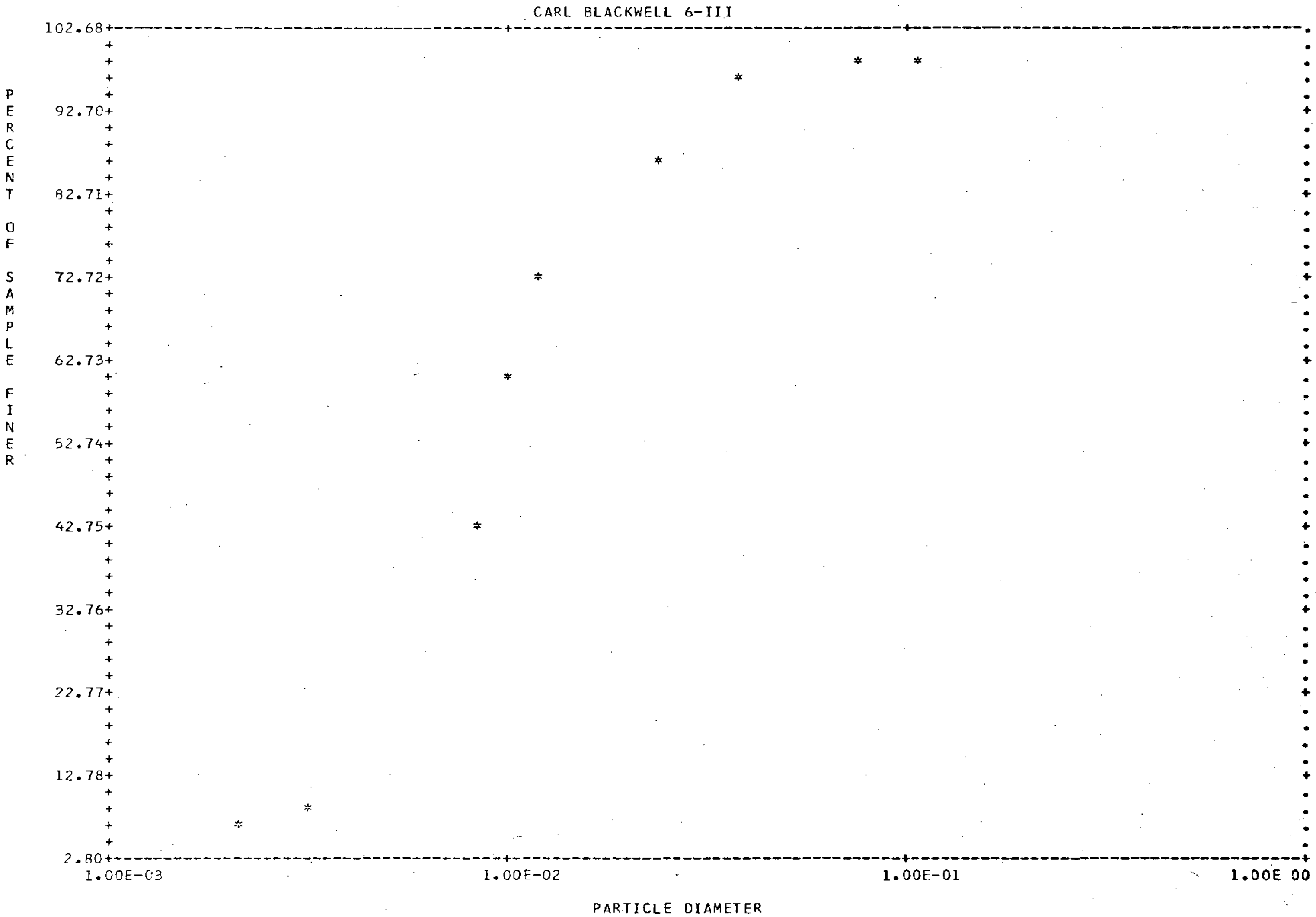

Figure 4. Computer Output Plot Showing the Percent of Sediment Sample Finer than a Given Particle Diameter

The loss of weight on ignition procedure consists of drying the sediment sample to constant weight, heating in a muffle furnace to oxidize the carbon present and subsequent gravimetric determination of weight loss. Although still widely used because of its simplicity and convenience (Schnitzer, et al., 1959) the procedures used are highly variable and the method has been considered of questionable value in many instances. Utilizing pyrolysis curves developed by use of thermogravimetric procedures, Schnitzer, et al. (1959), reported the loss of all hygroscopic moisture by heating to a temperature of 150 to 190 C. Organic constituents began decomposition at 210 and 240 C and were usually completely combusted upon heating to 500 C; lattice held moisture was released after reaching a temperature of 550 C. Sources of error in the loss in ignition procedures result from the choice of drying or ignition temperatures. Heating to a constant weight at 100 C might not eliminate all hygroscopically bound moisture.

Moisture retained after drying would be driven off upon ignition and would constitute a positive error giving higher apparent values for organic content. On the other hand, ignition temperatures above 500 C risks disrupting the clay lattice and release of lattice moisture which would produce a positive error in the organic content determinations. Until recently, therefore, inadequate knowledge of proper drying or ignition temperatures resulted in highly variable and questionable results.

However, the report by Schnitzer, et al. (1959), provided a sound basis for application of the correct drying and ignition temperature which should make the loss of weight upon ignition an effective, as well as accurate, procedure. The loss of weight on ignition procedure, using drying temperatures of 150 C followed by ignition at 500 C for two hours, was evaluated for sediment subsamples taken from Lake Carl Blackwell by comparison with the chromic acid oxidation procedure. Twenty-two sediment samples from Lake Carl Blackwell were subdivided and analyzed for organic content by the loss of weight on ignition method and the chromic acid oxidation method.

The loss of weight on ignition method gave values higher and more variable than those given by the chromic acid oxidation method (Table II). A paired t test (Steel and Torrie, 1960: 78) was performed on the data from Lake Carl Blackwell and it was determined that the two methods were statistically different (Table II).

On the basis of the results in Table II, the null hypothesis of no difference between the methods would be rejected. It would seem that the loss of weight on ignition method for determining the organic content of sediments as described in this study does not yield acceptable results when compared to the chromic acid oxidation. The organic content of Lake Carl Blackwell sediment samples was similar to a shallow, turbid reservoir in southern Illinois described by Larson, et al. (1951).

pH of Sediment

The measurement of pH was made following standard procedures as outlined by Jackson (1958). Electrometric measurement of pH

TABLE II

A STATISTICAL COMPARISON OF THE LOSS ON IGNITION METHOD WITH THE CHROMIC ACID OXIDATION METHOD IN LAKE CARL BLACKWELL AND A COMPARISON OF ORGANIC CONTENT IN LAKE CARL BLACKWELL, OKLAHOMA WITH CARBONDALE RESERVOIR, ILLINOIS

	Lake Carl Blackwell		Carbondale Reservoir[1]
Statistic	Loss on Ignition	Wet Oxidation	Wet Oxidation
Mean	6.20%	1.01%	0.72%
Maximum	9.60%	1.27%	1.12%
Minimum	1.00%	0.32%	0.32%
Standard deviation	2.20%	0.25%	0.24%
Coefficient of variability	35.97%	24.00%	33.00%
$t_{\bar{d}} = 11.06$	$t_{.01,\ 21\ df} = 2.831$		

[1]Statistics computed from data given by Larson, et al., 1951.

was made with a glass electrode pH meter[3] using a sample of 1:1 ratio of sediment and distilled water. A high flow reference electrode[4] was used to overcome the high viscosity of the samples. A regular reference electrode was first used but it became clogged with the sediment and gave highly erratic results. The pH of the raw ooze samples was also measured as they arrived at the laboratory as an estimate of the sediment pH at the sediment-water interface. The pH values were converted to hydrogen ion concentration for all computations and statistical analyses.

Specific Gravity

Specific gravity was measured by the procedure modified from ASTM (1959). A known weight of dry sediment, approximately 0.5 gm, which passed a #20 seive was placed in a 50 ml volumetric flask and covered with about 40 ml of distilled water. The sample was aspirated to remove air entrapped in the sample and distilled water was used to fill the flask. The bottle was weighed on an analytical balance.

Benthic Macroinvertebrates

Benthic macroinvertebrates were collected from 109 sample sites in June and October from 23 transects at 75 meter (250 feet) intervals. Through the months of July and September, triplicate samples were taken in randomly selected sampling areas

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[3]Beckman Instrument Co.

[4]Beckman catalogue number: 40463.

on transects 1, 3, 5, 18, and 22. All samples were taken with a 38.7 cm (6 inch) square Eckman dredge and screened through a #30 seive. Screened samples were preserved in 10% formalin in the field and sorted in the laboratory. Benthic invertebrates were keyed to family, counted, and estimates of total wet and total dry weight were obtained for each of the four major families, Ephemeridae, Culicidae, Tubificidae, and Chironomidae. Dry weight was obtained by drying preserved specimens at 105 C to constant weight.

Depth of Sediment

The depth of sediment was measured with the spud bar (Figure 5). The spud bar, dropped from the boat, would penetrate the sediment to the original lake floor. Upon retrieval, the depth of sediment was measured to the nearest .03 meters (.1 feet) by visually examining differences in texture and color of the material adhering to the bar.

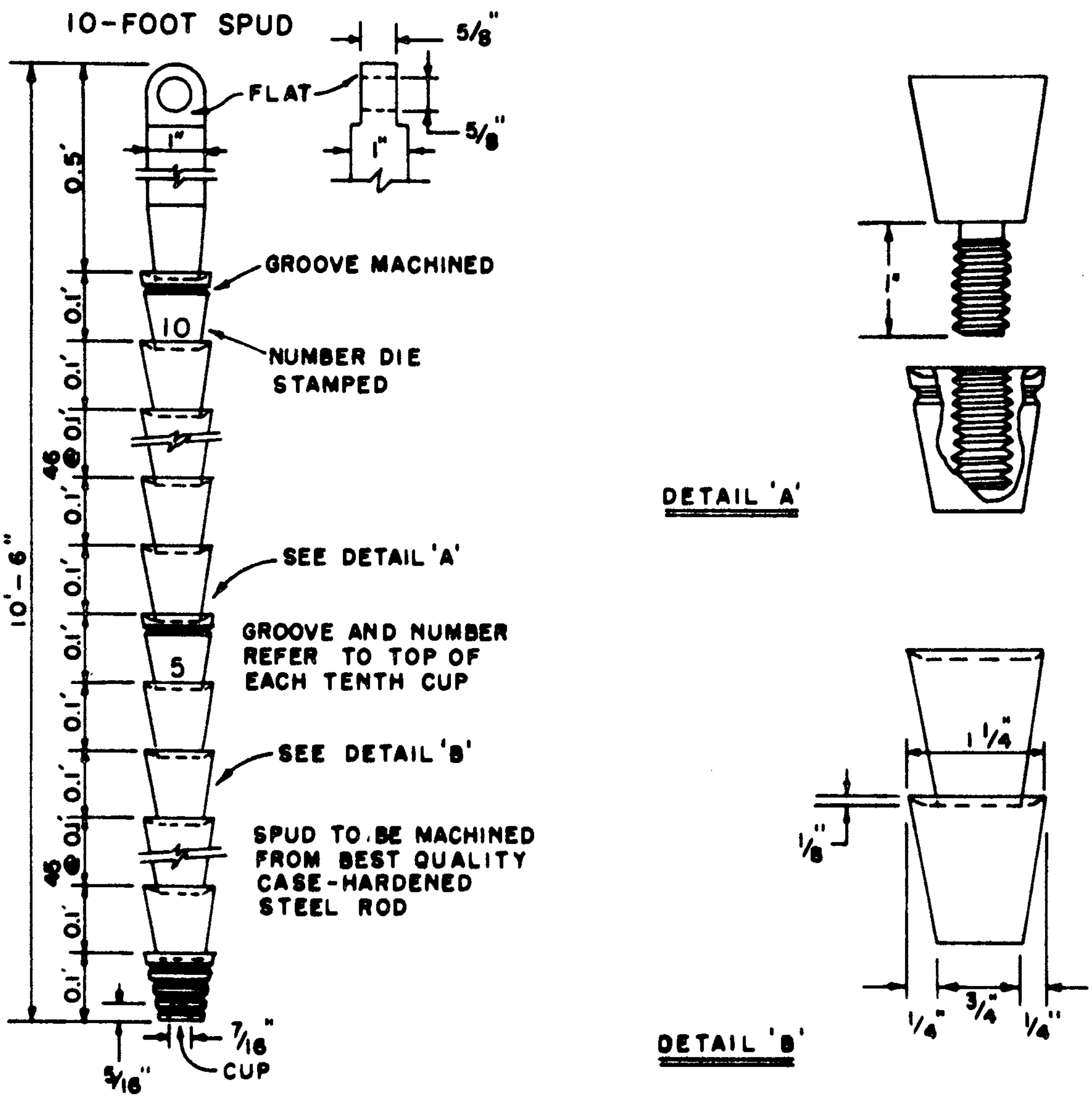

Figure 5. Diagrammatic Representation of the Spud Bar Used for Measuring Depth of Reservoir Sediment

CHAPTER VI

ENVIRONMENTAL CONDITIONS

A multiple correlation analysis between organic content of the sediment and the particle size divisions showed that the percent of organic material was at all times positively correlated to the fine silts and clays and negatively correlated to the coarse silt and sands. Because these correlations indicate a definite break in substrate characteristics (about phi = 6) the sediment was divided into 2 groups: 1) coarse sand and fine silt and 2) fine silt and clays. The dichotomy occured between phi values of 6 (sands and coarse silt) and 7 (fine silt and clays). A multiple correlation analysis indicated that the distribution of these particle classes was correlated to the depth of water. This statistical analysis was substantiated by visual inspection of iso-organic contours (Figures 10 and 11). The coarser sediments (phi values of 6 or larger) are in shallow water. Table III gives the percentages of total area covered by each particle size group.

Coarser particles are deposited soon after they enter the reservoir whether they are transported by streams or slope runoff, while the finer particles which tend to remain in suspension longer are deposited in deeper water. Wave action also inhibits permanent deposition of finer sediments in shallow waters. Minimum median phi values of 4 were recorded in near shore areas in October.

TABLE III

PERCENTAGE OF LAKE AREA COVERED BY THE TWO SEDIMENT SIZE GROUPS AT LAKE ELEVATIONS OF 280 METERS (m.s.l.) AND AT SPILLWAY ELEVATION (283.2 METERS, m.s.l.)

	June		October	
Phi value	283.2 m	280 m	283.2 m	280 m
Less than 6	31.8	58.8	25.2	46.6
6 or larger	22.3	41.1	28.8	53.3

At the same time, maximum values of 9 were found in deeper water areas on Transects 2 and 4. Phi values from various transects from the October sampling period (Figure 6) support the conclusions made from the June samples (Figure 7), that is, coarser particles were most abundant in near shore areas, and finer particles in the deeper water portions of the transect.

The amount of sample composing each particle size group was fairly constant during the June samples. This constant distribution gave a less variable median phi value (Table IV). On the other hand, during the October samples, the maximum median phi value (indicating finest sediments) and the minimum median phi value (indicating the coarsest sediments) were found in deep and shallow water respectively, indicating that some degree of sediment particle size grading may have taken place.

Depth of Sediment and Sediment Cycling

One of the aims of this study was to compare long term rates of sedimentation with an earlier sediment study on Lake Carl Blackwell (Schrieber, 1958). However, comparison with Schrieber's work was not possible because of the large difference in lake levels between the two studies. Sediment in over 40% of the lake could not be measured in this study due to the low water level. Calculation of long term sedimentation rates since the construction of the dam were likewise meaningless because much of the lake could not be measured.

A short term comparison of sediment depth is possible between the June and October samples. There was little runoff during the

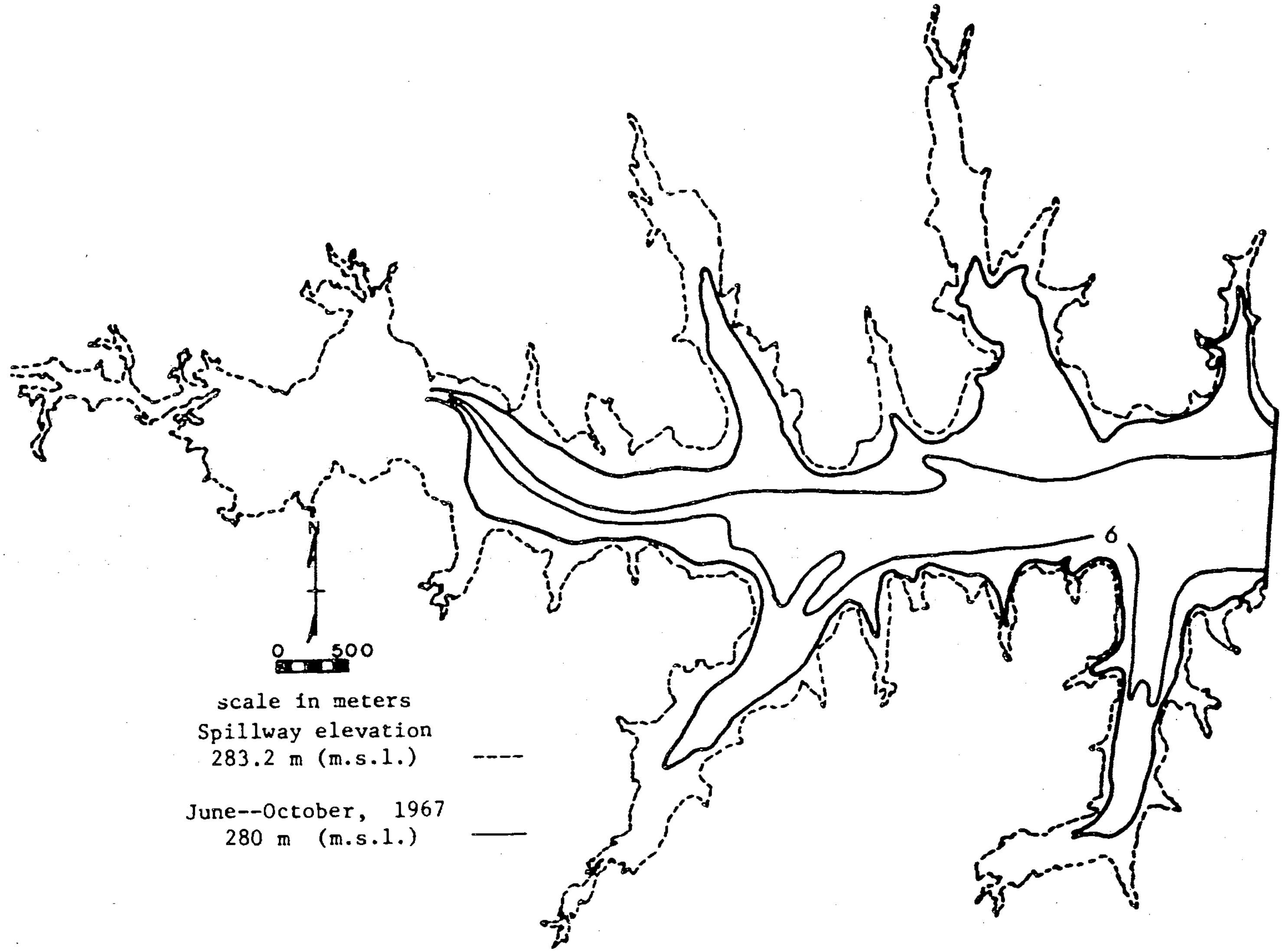

Figure 6. Map Showing Contour of Sediments with Median Phi Equal to 6 for October Samples

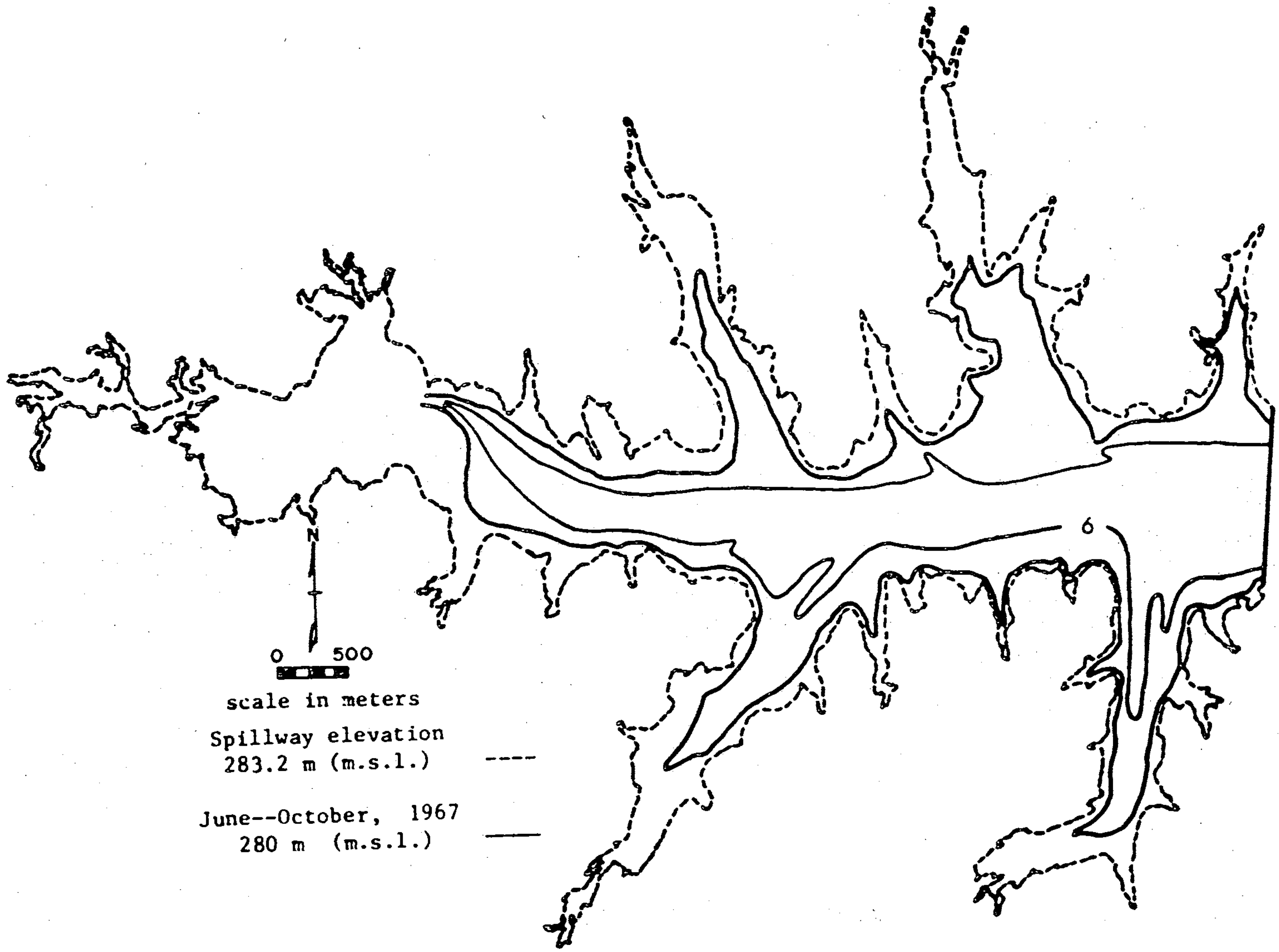

Figure 7. Map Showing Contour of Sediments with Median Phi Equal to 6 for June Samples

TABLE IV

MEANS AND STANDARD DEVIATIONS OF THE MEDIAN PARTICLE DIAMETERS FOR THE JUNE AND OCTOBER SAMPLES

Statistic	June	October
Median particle diameter (mm)	0.046	0.028
Standard deviation	0.031	0.069

study, yet the amount of sediment varied nearly 1.5 million cubic meters (about 700 acre-feet) (Table V). There was variation in the location of contours of equal sediment depth, although the general pattern was evident (Figures 8 and 9).

During the sampling period which extended from June to October, wave action appeared to cause suspension of near shore sediments and deposition in deeper water. Turbidity and depth of sediment measurements support this conclusion. For example, on Transect 2, several centimeters of near shore sediments present in June were absent in October. There was, however, a significant increase in the depth of sediment at some distance from the shore. Comparison of the depth of sediment for some of the major transects between June and October shows more sediment present in October (Figure 8) than in June (Figure 9), at least in the deeper water portions of the transects. Transect 5 was the only exception to this generalization. The first sample site was always on the north side of the lake and was therefore exposed to wide expanses of open water resulting in heavy wave action from the prevailing southwest winds. Reid (1961) describes a similar phenomenon causing formation of a littoral shelf by suspension of small particles from beaches by wave action in a period of high wave activity and deposition offshore in areas of less turbulence.

A second type of sediment redistribution may occur when flocculent sediments suspended by wave action at the western end of the reservoir are moved by wind-created currents toward the eastern end of the reservoir. Sediment resuspension was described by Jackson and Starrett (1959) for Lake Chautauqua, Illinois.

TABLE V

PERCENT OF TOTAL AREA AND ACRE-FEET OF SEDIMENT IN EACH DEPTH OF SEDIMENT CONTOUR: ALL CALCULATIONS ARE BASED ON MEAN WATER LEVEL DURING THE STUDY (280 m, m.s.l.)

	June 1967		October 1967	
Contour (feet)	Percent	Acre-feet	Percent	Acre-feet
1	63.0	666.8	76.5	1828.6
2	22.8	1203.4	19.5	412.2
3	9.8	724.4	3.1	65.5
4	4.2	308.5	0.4	8.5
5	1.8	171.0	0.5	47.7
Total (Acre-feet)		3074.1		2362.5
Total (Cubic meters x 10^6)		3.6		2.2

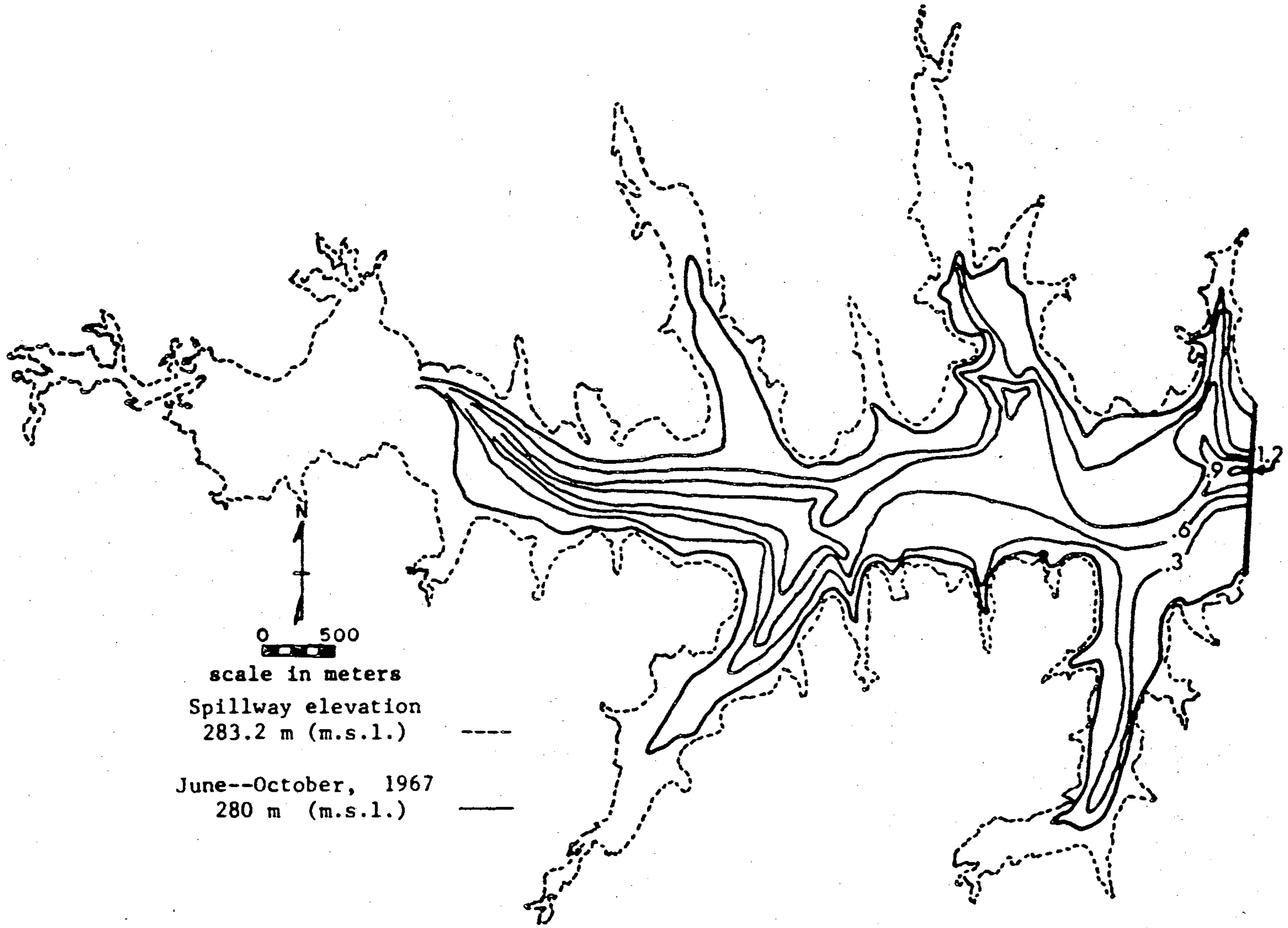

Figure 8. Lake Carl Blackwell Sediment Depth Contours (Meters) During October, 1967

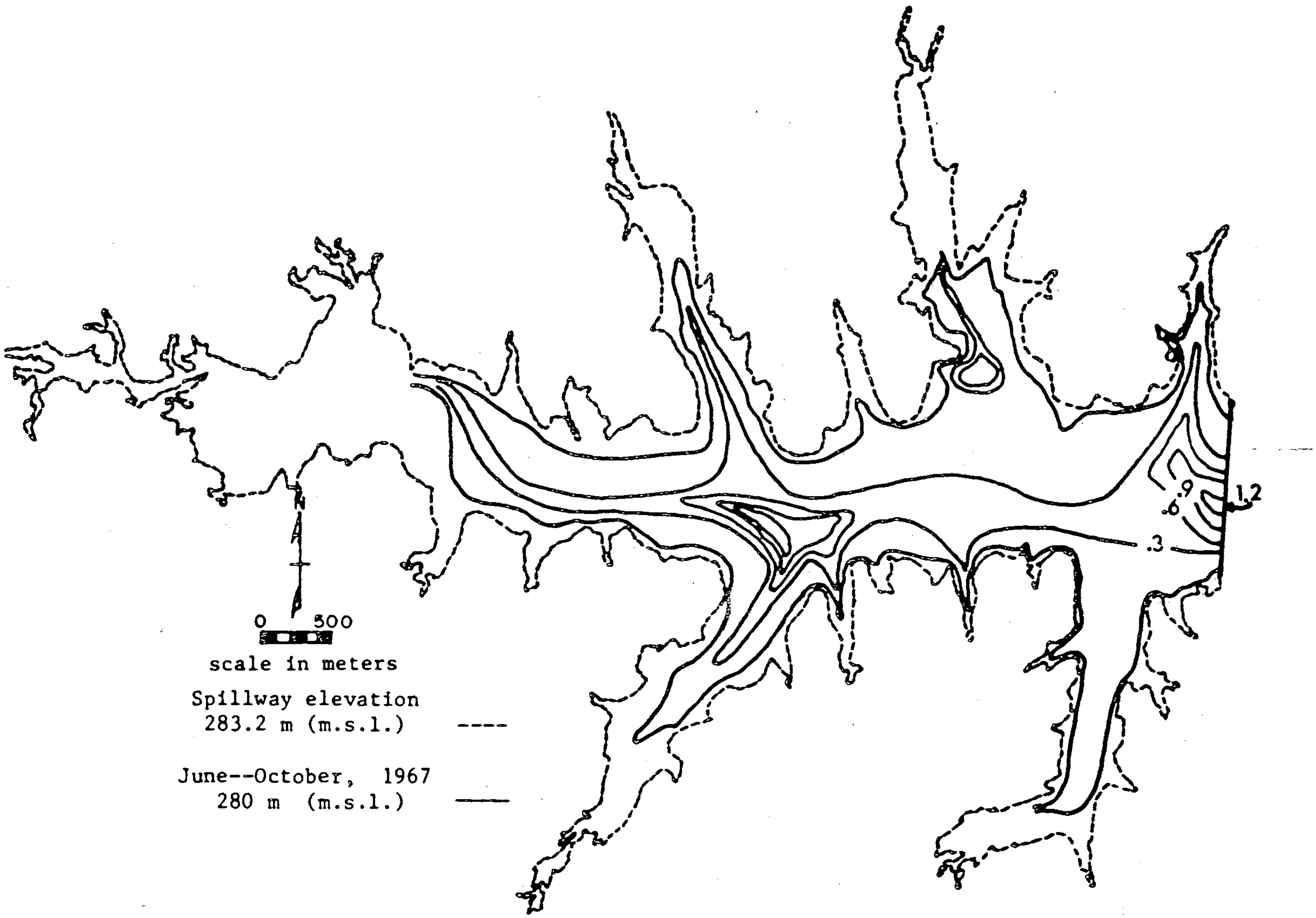

Figure 9. Lake Carl Blackwell Sediment Depth Contours (Meters) During June, 1967

Return currents, moving from east to west along the bottom of the reservoir, may be strong enough to resuspend light flocculent material from the sediment-water interface. Further investigation would be necessary to determine the actual resuspension mechanisms.

Organic Content of Sediment

Values obtained for the organic content of the sediment ranged from 2.5% on Transect 1 in June to 0.6% on Transect 26 in October (Figures 10 and 11). The largest concentrations of profundal organic matter were associated with deeper water collection sites. The overall mean organic content was 1.22% in June and 1.94% in October. The increase between June and October amounted to 59% of the organic material present in June. The difference between the two means was tested with a "t test" for unpaired observations (Steel and Torrie, 1960: 72) and was determined to be statistically different ($t_{\bar{d}} = 12.66$, $t_{.001,\ 89\ df} = 3.420$).

Sediment in Lake Carl Blackwell can be considered average in organic content when compared to the results of other investigators using chromic acid oxidation procedures in midwestern reservoirs (Table VI).

Both allochthonous and autochthonous material were present in June; the autochthonous material which was not yet decomposed, and allochthonous material which was washed into the lake by spring rains prior to the study. Minimal runoff between June and October prevented further introduction of allochthonous materials, but autochthonous materials would have been produced at a high rate during the same interval. Catabolism and decomposition of

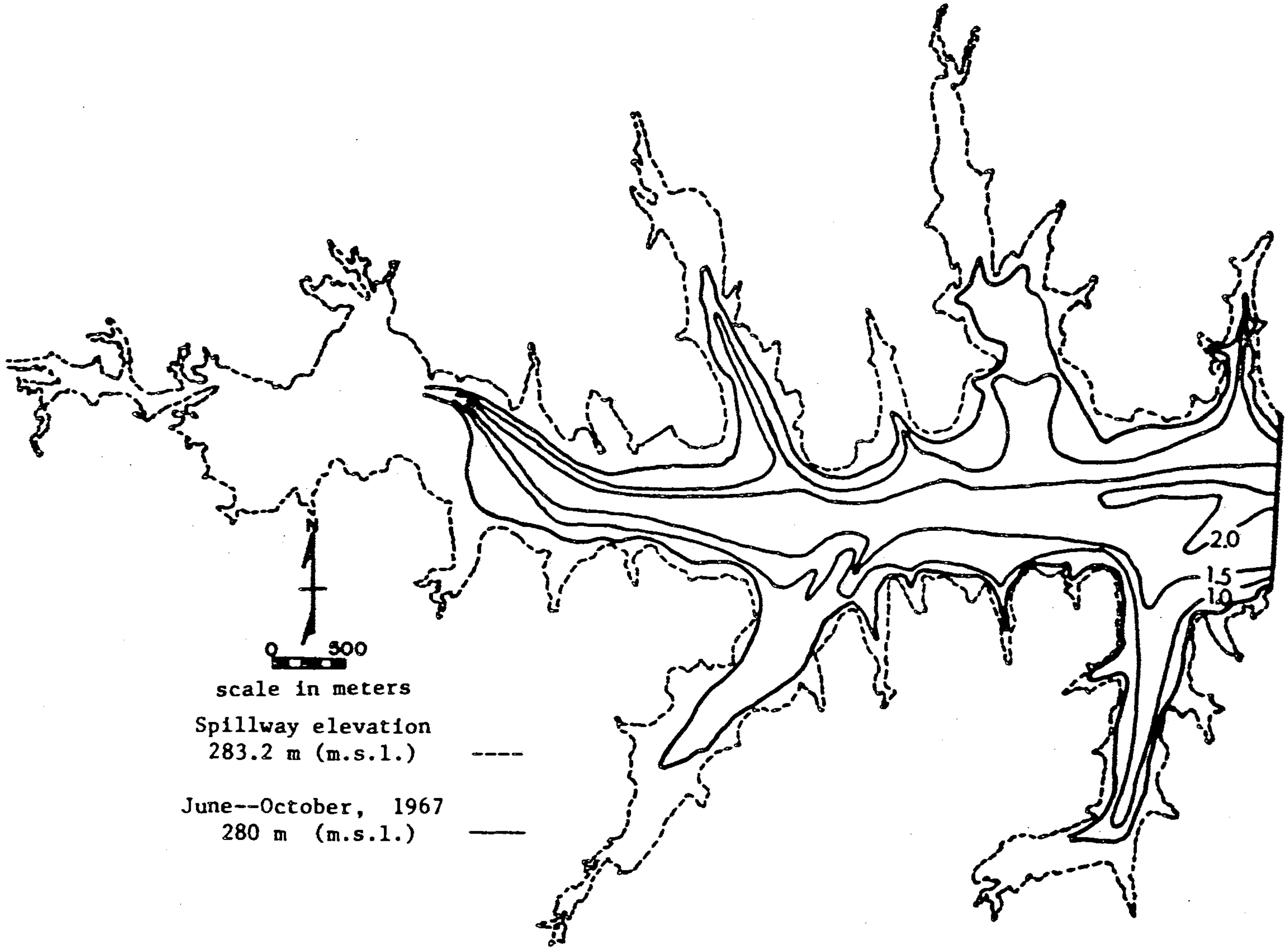

Figure 10. Iso-organic Contours (Percent) for the June Samples

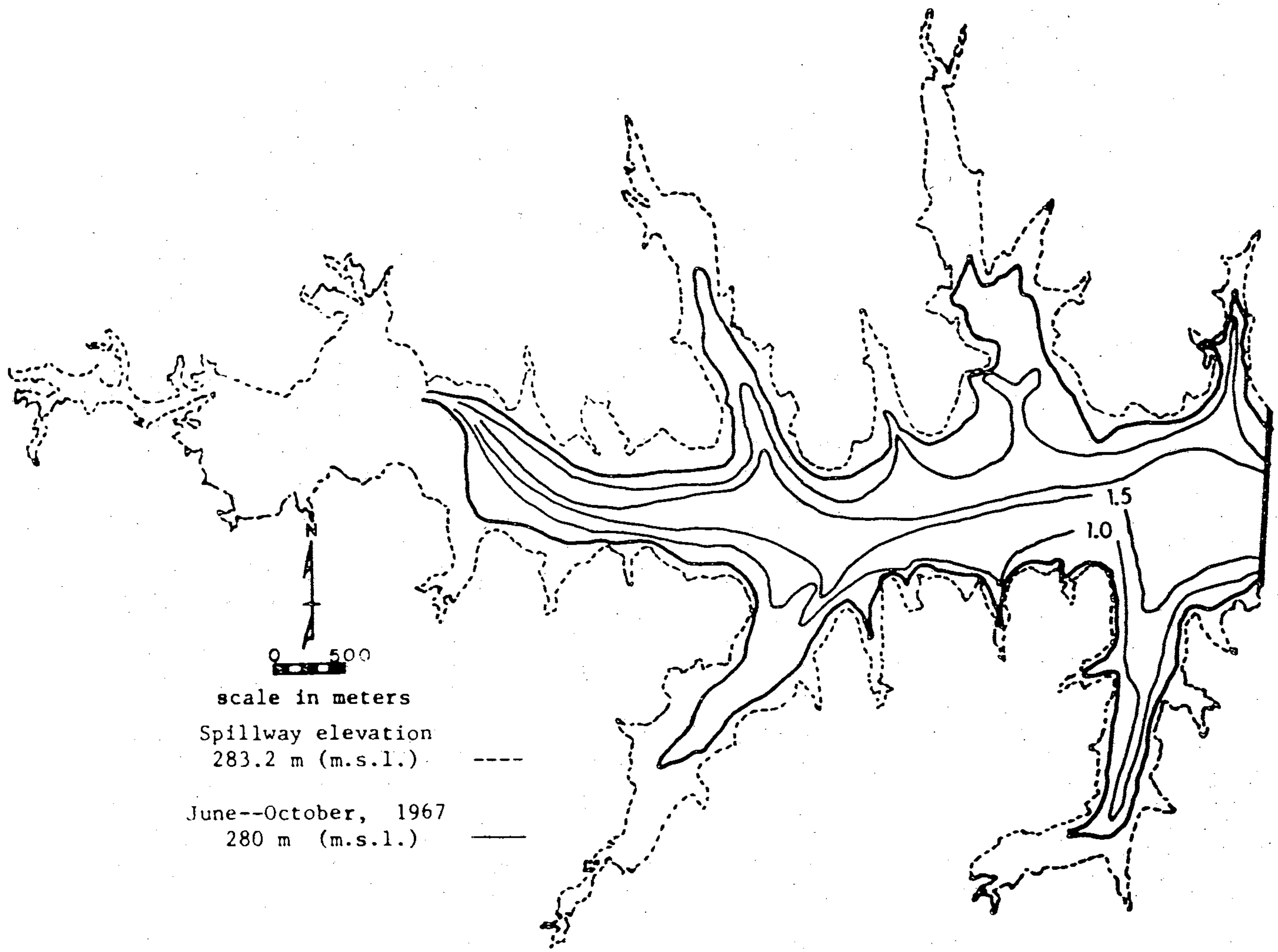

Figure 11. Iso-organic Contours (Percent) for the October Samples

TABLE VI

A COMPARISON OF CHROMIC ACID DETERMINATIONS OF MEAN ORGANIC CONTENT OF MIDWESTERN RESERVOIRS

Investigators	Reservoir	Mean Organic Content (%)
Larson, et al., 1951	Carbondale Res., Ill.	0.79
Stall, et al., 1954	Crab Orchard Lake, Ill.	1.08
Stall, et al., 1951	West Frankfort Res., Ill.	1.29
Stall, et al., 1953	L. Carthage, Ill.	1.86
Stall, et al., 1952	L. Calhoun, Ill.	2.01
Larson, et al., 1951	L. Bracken, Ill.	2.37
Brown, et al., 1947	L. Decatur, Ill.	2.67
Stall and Melsted, 1951	L. Chautauqua, Ill.	3.05
Present Study--June	L. Carl Blackwell, Okla.	1.23
Present Study--October	L. Carl Blackwell, Okla.	1.94

organic material did not equal the high rate of production during this period and the accumulation of material was seen as an increase in the mean organic content of the sediment.

pH of the Sediment

The pH of the sediment varied independently of the pH of the surface water. The surface water pH remained at 8.4 throughout the duration of the study while the pH of the sediment was inversely correlated with the depth of the water.

The maximum sediment pH value obtained in the spring samples was 8.48 (Transect 8, Area 1, depth of 1.25 m), and the minimum value was 6.92 (Transect 18, Area 7, depth of 3.3 m). Considerable variation occured both along transects and between transects, though the lower values were usually found in deeper water. In the fall samples, the maximum was 8.35 for a sample taken from Area 3, Transect 1 in 4.3 m of water while the minimum pH of 6.18 (Transect 6, Area 3) was found in 6.0 m of water. Once again, the lower pH values were found for deeper water areas.

Factors affecting the pH of the sediment would be the type of sediment, the amount of organic matter in the sediment, and the amount of dissolved oxygen present to allow aerobic decomposition of the sediment. The greater amount of organic matter in the deeper water could supply sufficient oxygen demand at the sediment-water interface to create anoxic conditions and increase the hydrogen ion concentration of the sediment by production of acidic end-products. Evidence for this is given by a highly significant positive correlation between hydrogen ion concentration and the organic content. Highly significant negative correlations were found between hydrogen ion concentrations and each of the particle size fractions of coarse sand, fine sand, and coarse silt. Highly significant positive correlations were found for the finer particle size fractions and the hydrogen ion concentration of the sediment. If the hydrogen ion concentration is determined in part by the organic matter, then the particle size correlation is not related to particle size *per se* but rather to organic matter which is found in the smaller particles.

Turbidity

Turbidity concentrations varied along the transects and along the east-west axis of the lake. These variations seem to be related to the depth of water and degree of exposure to wave action. A maximum turbidity of 180 was measured on Transect 8 in one-half meter of water during the October sampling period. Other high turbidity readings were obtained from shallow exposed wind-swept areas (Table VII).

As there was little runoff during the study, most of the turbidity in the surface waters was due to wind induced currents and shoreline erosion. Jackson and Starrett (1959) reported that turbidity over 150 ppm on Lake Chautauqua, Illinois was largely attributable to particulate matter resuspended by strong winds. Lake Chautauqua, as it was described by Jackson and Starrett (1959), is similar to a portion of the western end of Lake Carl Blackwell, where a large area was less than one meter in depth.

TABLE VII

TURBIDITY OF LAKE CARL BLACKWELL, JUNE AND OCTOBER, 1967

Transect	Number	June Maximum	June Minimum	June Mean	October Maximum	October Minimum	October Mean
1	14	20	20	20	60	40	49
2	14	35	20	26	51	28	35
3	8	20	20	20	40	26	35
4	9	20	20	20	48	29	38
5	5	38	25	31	42	20	30
6	8	52	28	44	50	32	40
7	5	115	99	106	100	90	92
8	1	--	--	122	--	--	180
12	6	30	20	24	50	28	44
13	3	35	20	26	48	36	41
14	1	--	--	45	--	--	47
16	1	--	--	25	--	--	20
17	1	--	--	30	--	--	38
18	8	32	20	28	50	30	35
22	2	27	26	26	38	31	34
23	1	--	--	30	--	--	78
24	5	42	40	41	40	30	36
25	7	47	20	27	38	20	31
26	1	--	--	50	--	--	31
27	1	--	--	41	--	--	30
28	2	55	51	53	70	70	70
29	2	68	48	58	80	80	80

According to Jackson and Starrett (1959), the bottom of Lake Chautauqua was covered by a loose flocculent "false bottom" which was easily placed in suspension by a slight disturbance. In three of four sediment samples analyzed by Stall and Melsted (Jackson and Starrett, 1959) particles of less than 20 microns composed about 80% of the samples. In the majority of samples collected in the study on Lake Carl Blackwell, 50% or more of each sample was composed of particles 20 microns in diameter or smaller. On Transect 8, when the maximum turbidity was recorded, 82% of the particles in the sediment-water interface were finer than 20 microns.

Dissolved Oxygen

Dissolved oxygen was plentiful in all parts of the lake at all depths during June (Table VIII). The lake stratified for about a week in late July, and depletion of oxygen occured below 7 meters. This temporary stratification is attributed to the absence of strong winds which are generally prevalent in the summer season. Though this condition persisted for only a short time, large areas of the reservoir were affected. During September and October, oxygen was again abundant in the deeper water and bottom oxygen levels were above 3.3 ppm (Table IX).

It is pointed out by Fremling (1960) that there is often an oxygen depletion at the sediment-water interface in the micro-habitat of benthic macroinvertebrates which would affect the distribution of some benthic organisms. Such oxygen depletion would probably not be detected by the method being used. This type of oxygen depletion would be attributed to the oxidation of

TABLE VIII

SURFACE AND BOTTOM DISSOLVED OXYGEN CONCENTRATIONS OF LAKE CARL BLACKWELL, JUNE, 1967

Transect	Number	Surface Maximum	Surface Minimum	Surface Mean	Bottom Maximum	Bottom Minimum	Bottom Mean
1	14	6.5	2.1	3.6	4.8	2.4	3.2
2	14	9.4	8.1	8.8	8.6	6.2	7.1
3	8	11.1	10.1	10.5	10.7	3.3	5.7
4	9	11.1	9.9	10.4	10.4	2.5	5.5
5	5	5.0	2.0	3.1	3.8	2.1	3.0
6	7	10.1	9.3	9.8	10.1	5.0	6.8
7	5	10.4	9.7	10.0	10.2	5.0	9.9
8	1	--	--	9.4	--	--	9.4
12	6	9.6	9.4	9.5	9.0	6.1	8.2
13	3	10.3	10.1	10.2	9.4	7.8	8.4
14	1	--	--	8.9	--	--	8.9
16	1	--	--	8.7	--	--	7.7
17	1	--	--	8.6	--	--	8.6
18	8	11.5	9.4	10.0	9.2	4.2	7.6
22	2	3.5	2.8	3.1	3.9	1.5	2.7
23	1	--	--	6.6	--	--	3.9
24	5	9.2	8.8	9.0	9.1	3.0	8.2
25	7	9.2	3.7	6.2	9.3	3.0	6.1
26	1	--	--	2.8	--	--	2.6
27	1	--	--	9.2	--	--	9.2
28	2	8.8	8.7	8.7	8.5	8.3	8.4
29	2	9.2	8.8	9.0	8.4	7.8	8.1

TABLE IX

DISSOLVED OXYGEN CONCENTRATIONS MEASURED FOR ALL TRANSECTS IN OCTOBER

Transect	Number	Surface Maximum	Surface Minimum	Surface Mean	Bottom Maximum	Bottom Minimum	Bottom Mean
1	14	8.1	7.5	7.8	8.0	7.1	6.7
2	14	12.8	5.8	10.8	12.0	6.4	10.6
3	8	14.6	11.9	14.0	14.6	11.9	13.9
4	9	14.9	14.1	14.7	14.4	13.8	14.1
5	5	7.5	6.3	7.2	7.6	6.1	7.2
6	7	16.5	14.6	15.1	15.1	14.1	14.6
7	5	7.4	7.0	7.2	7.4	7.2	7.3
8	1	--	--	7.1	--	--	7.1
12	6	12.4	11.7	12.0	12.2	12.0	12.1
13	3	13.6	13.6	13.6	13.6	13.6	13.6
14	1	--	--	3.5	--	--	3.5
16	1	--	--	3.8	--	--	3.8
17	1	--	--	3.6	--	--	3.3
18	8	16.1	15.2	15.6	16.1	15.5	15.7
22	2	3.5	3.5	3.5	3.6	3.5	3.6
23	1	--	--	3.6	--	--	3.5
24	5	15.8	15.5	15.6	15.8	15.5	15.6
25	7	15.9	15.2	15.5	15.8	15.2	15.6
26	1	--	--	15.2	--	--	15.2
27	1	--	--	8.0	--	--	8.0
28	2	7.5	7.4	7.4	7.5	7.4	7.4
29	2	7.6	7.6	7.6	7.6	7.6	7.6

organic materials in the sediment, in areas where currents or turbulence could not replenish the oxygen supply.

CHAPTER VII

MACROINVERTEBRATES

A total of 301 benthic samples were collected during the study. Thirteen families were collected, but Ephemeridae (Ephemeroptera), Chironomidae (Diptera), Tubificidae (Annelida), and Culicidae (Diptera), composed 99.35% of the total number and therefore most of the biomass. Other families collected were Sphaeriidae (Mollusca), Unionicolidae (Mollusca), Poduridae (Collembola), Hydracnidae (Hydracarina), Arachnidae (Hydracarina), Diplodontidae (Hydracarina), Tabanidae (Diptera), Tipulidae (Diptera), and Perlidae (Plecoptera). The four most abundant families were chosen for comparison with the sediment parameters. Mean dry weight for each taxa was determined from wet weight to dry weight conversion factors from three samples of 10 individuals from each taxon (Table X).

In June a maximum number of 1976 individuals per square meter (all families included) was collected on Transect 4, in Area 4 (Table XI). In October, the maximum number per square meter, 7318 individuals, was found on Transect 1 in Area 5 (Table XII).

In June, Transect 7 had the highest mean number of individuals per square meter, 660 individuals, while in October, the maximum mean value of 3186 individuals per square meter per transect was found on Transect 22 (Table XII).

TABLE X

BIOMASS DETERMINATION AND WET WEIGHT-DRY WEIGHT CONVERSION FACTORS FOR THE FOUR COMMON FAMILIES OF MACROBENTHOS

Family	Average wet weight (mg) per individual	Average dry weight (mg) per individual	Conversion factor wet to dry weight
Chironomidae	1.7	0.1	0.059
Tubificidae	0.8	0.1	0.125
Ephemeridae	18.8	1.8	0.096
Culicidae	1.6	0.1	0.062

TABLE XI

MEANS AND RANGES OF NUMBERS OF INDIVIDUALS COLLECTED PER METER SQUARE ON EACH TRANSECT IN JUNE

Transect	Area	Total	Chironomidae	Culicidae	Ephemeridae	Tubificidae
1	14	387 (43- 818)	194 (43- 474)	55 (0- 215)	43 (0- 215)	95 (0- 301)
2	14	415 (172- 904)	234 (86- 517)	18 (0- 129)	28 (0- 215)	135 (0- 387)
3	8	592 (258- 947)	307 (86- 646)	38 (0- 129)	11 (0- 86)	237 (43- 431)
4	9	592 (258-1076)	196 (43- 387)	110 (70- 560	33 (0- 86)	254 (86- 603)
5	5	517 (215- 732)	112 (86- 129)	26 (0- 86)	78 (43- 129)	301 (86- 473)
6	7	341 (129- 603)	175 (0- 301)	37 (0- 86)	80 (0- 129)	49 (0- 215)
7	5	660 (387- 775)	215 (172- 258)	26 (0- 86)	266 (172- 431)	26 (0- 129)
8	1	517	172	43	215	86
12	6	524 (129-1205)	230 (43- 517)	7 (0- 43)	14 (0- 86)	273 (43- 689)
13	3	416 (172- 732)	230 (86- 301)	14 (0- 43)	14 (0- 43)	158 (43- 431)
14	1	646	517	0	129	0
16	1	646	431	0	43	172
18	8	334 (258- 603)	161 (86- 344)	0	65 (43- 172)	108 (0- 387)
22	2	280 (86- 474)	43	215 (0- 430)	0	22 (0- 43)
23	1	129	86	0	0	43
24	5	293 (129- 689)	164 (43- 430)	34 (0- 129)	26 (0- 43)	9 (0- 172)
25	7	337 (215- 474)	143 (0- 387)	29 (0- 129)	86 (0- 215)	79 (0- 215)
26	1	172	43	0	86	43
27	1	43	43	0	0	0
28	2	280 (258- 301)	151 (1129- 172)	0	108 (86- 129)	22 (0- 43)
29	2	387 (301- 474)	237 (172- 301)	0	129 (86- 172)	22 (0- 43)

TABLE XII

MEANS AND RANGES OF NUMBERS OF INDIVIDUALS COLLECTED PER METER SQUARE ON EACH TRANSECT IN OCTOBER

Transect	Area	Total	Chironomidae	Culicidae	Ephemeridae	Tubificidae
1	14	1921 (29-2041)	120 (0- 430)	1638 (0-7232)	62 (0- 129)	101 (0- 215)
2	14	1935 (215-5080)	207 (0- 560)	1581 (43-4649)	3 (0- 43)	144 (0- 258)
3	8	2618 (1507-3961)	572 (301- 818)	1759 (1076-3057)	22 (0- 129)	265 (86- 603)
4	9	1162 (258-2497)	201 (0- 517)	751 (0-2454)	19 (0- 86)	191 (0- 603)
5	5	1291 (48-2109)	121 (0- 258)	1061 (43-1851)	26 (0- 86)	138 (0- 301)
6	7	2433 (603-3788)	194 (43- 517)	1342 (43-3100)	136 (43- 215)	161 (43- 215)
7	5	990 (646-1722)	121 (0- 258)	431 (86- 818)	318 (129- 516)	121 (0- 344)
8	1	1461	215	517	258	474
12	5	930 (172-2325)	215 (0- 732)	551 (86-1378)	52 (0- 86)	112 (0- 258)
13	3	818 (387-1636)	273 (172- 387)	688 (86-1076)	72 (0- 129)	115 (0- 215)
14	1	947	172	172	387	215
16	1	947	172	387	86	301
17	1	818	215	0	474	129
18	8	1178 (344-2325)	188 (0- 517)	630 (0-1636)	161 (43- 215)	199 (0- 689)
22	2	3186 (430-5941)	194 (86- 301)	2949 (258-5640)	43 (0- 86)	0
23	1	301	0	0	43	258
24	5	1313 (129-4563)	265 (43- 603)	964 (0-3918)	43 (0- 172)	100 (0- 387)
25	7	434 (86- 646)	62 (0- 129)	133 (0- 431)	105 (0- 215)	135 (0- 301)
26	1	344	129	86	43	86
28	2	732 (646- 818)	151 (129- 172)	280 (129- 430)	151 (129- 172)	151 (86- 215)
29	1	129	0	0	129	0

The mean number per square meter for the entire reservoir in June was 83 individuals, while in October, the mean number per square meter was 256. Tables XI and XII give the means and ranges of numbers per square meter for each transect. Craven (1967) found about 700 individuals per square meter in June and about 1000 individuals per square meter in October in Boomer Lake.

The June samples were dominated by the abundance of Chironomidae ($\bar{x}$ = 211 individuals/square meter) and Tubificidae ($\bar{x}$ = 135 individuals/square meter) (Table XIII). The population structure changed in October when Culicidae ($\bar{x}$ = 1029 individuals/square meter) were the major component. At all times, Ephemeridae constituted a small percent of numbers, though they were of major significance in terms of biomass.

Chironomidae

In the June samples, the family Chironomidae was by far the most abundant family collected (Table XI). The highest average number per square meter, 517 individuals, per transect was found on Transect 14 in shallow (1.1 m) water. The greatest number of individuals per square meter was found on Transect 3, where 646 individuals were collected from Area 4.

The October sampling resembles the June samples in both the number and distribution of Chironomidae. This similarity would indicate that the population of Chironomidae in Lake Carl Blackwell is relatively stable. The average number per square meter for the entire reservoir in June was 194, while in October, the number was 180.

TABLE XIII

PERCENT OF TOTAL NUMBER CONTRIBUTED BY EACH TAXON

Sampling Period	Chironomidae	Culicidae	Tubificidae	Ephemeridae	Total
June	47.9	7.6	27.1	17.0	99.6
October	14.3	60.5	15.1	10.0	99.9

Tubificidae

Tubificids were abundant in the deeper water transects such as Transects 2, 3, 4, and 5 with the highest average number per square meter of 301 individuals being found on Transect 5. Shallow water transects such as Transects 27 and 14 produced no individuals. Many transects included sampling areas which were void of members of this family.

The numbers of individuals, all transects combined, increased from 110 individuals per square meter in June to 190 individuals per square meter in October. The maximum transect average was found on Transect 8 where 474 individuals per square meter were collected. Transect 22, a deep water transect, and Transect 29, a shallow water transect, had no tubificids. These transects are in arms leading into the lake, and there is a possibility of some type of substrate interaction which would preclude the presence of Tubificidae.

Ephemeridae

In the June samples, the ephemerids were definitely in a minority in terms of numbers, composing only 17% of the total (Table XIII). The maximum mean number per square meter per transect was 266 individuals per square meter (Transect 7). Typically, deep water transects were void of individuals and the ephemerids tended to be located in shallow water.

The overall mean number of individuals per meter square is higher in October than in June. There was one observed emergence of mayfly adults in the latter part of July. Craven (1967) found that the population numbers of Ephemeridae in Boomer Lake (approximately 16 kilometers east of Lake Carl Blackwell) in October were greater than the population estimated in June, though the relationship was the opposite for biomass estimates. Therefore, after the emergence, the smaller individuals were more abundant while in the spring, there were fewer large individuals. The decline in numbers was caused by natural mortality and predation.

Culicidae

The majority of the Culicidae were Chaoborus sp. The distribution of the individuals collected was consistently limited to deeper water. The maximum mean number per square meter found in June samples was 266 individuals (Transect 7). No individuals were found on Transect 18 and several transects had one or more samples which were void of culicids.

In the October samples, the culicids were the dominant family in terms of numbers. The maximum mean number per square meter per transect of 2949 individuals was found on Transect 22 in deep water. The maximum number per square meter for any one family was 7232 culicids on Transect 1 in Area 5.

CHAPTER VIII

ORGANISM-SUBSTRATE RELATIONSHIPS

Depth of Sediment

The presence of a habitable substrate is undoubtedly a significant factor influencing the distribution of macroinvertebrates. For many organisms, especially the burrowing forms, there must exist a minimal amount of suitable substrate to provide food and cover. Hunt (1953) pointed out that Hexagenia would not burrow in artificial substrates, presumably because the substrates were too coarse. Similarly, Pennak (1953) stated that acquatic oligochaetes, including Tubificidae, feed on and burrow in bottom mud.

The concept of minimum substrate requirement was tested in this study, but the results were not conclusive. A scattergram (Figure 12) of numbers of individuals collected at various sediment depths does not demonstrate the minimum value concept. A probable explanation is that the sampling technique was not sufficiently accurate to measure sediment depths less than 3 cm (0.1 feet). A method for measuring sediment less than 3 cm (0.1 feet) in depth would be essential to evaluate the minimum substrate hypothesis.

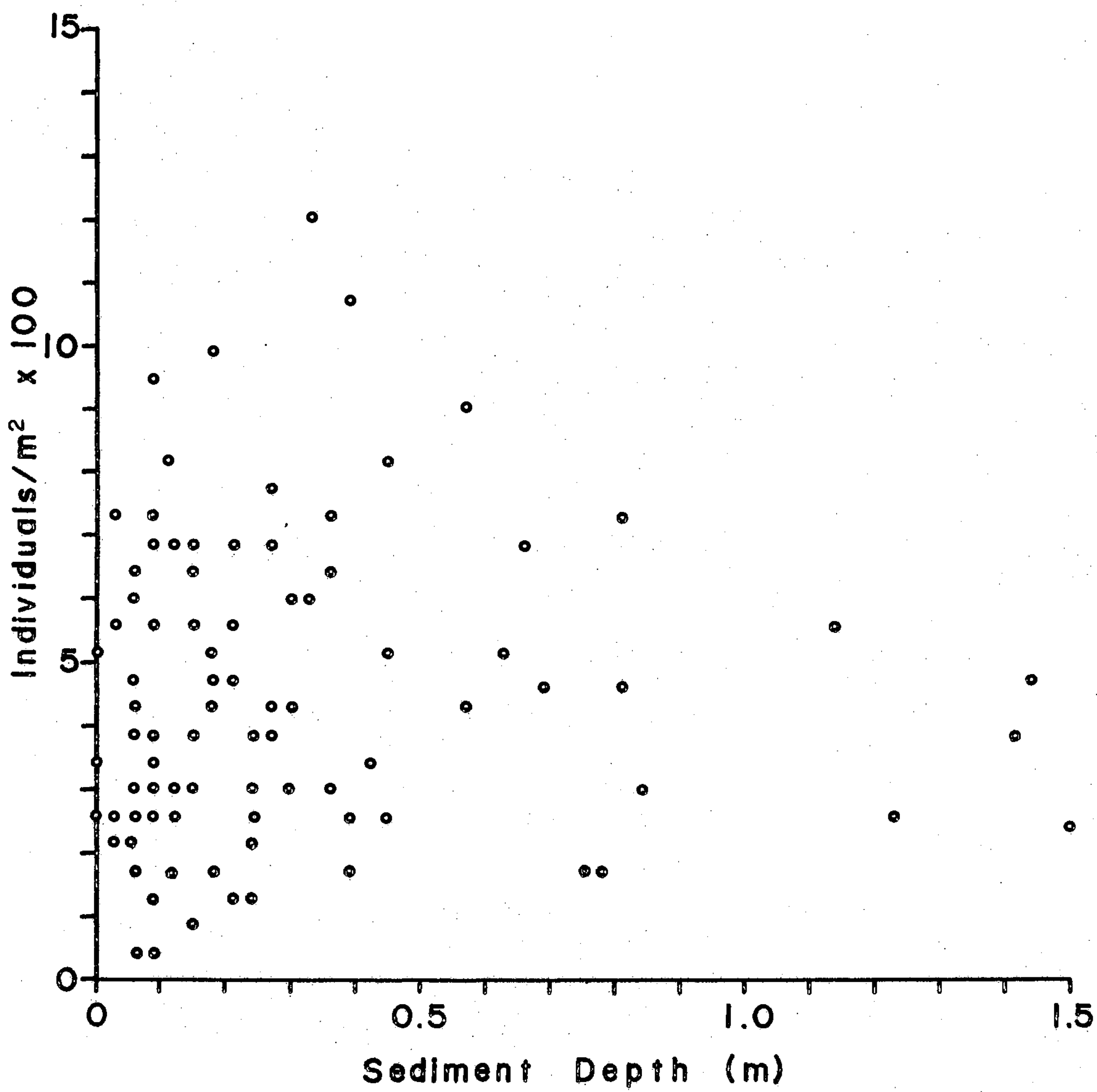

Figure 12. Scattergram of Numbers of Total Macrobenthos Versus Depth of Sediment

Total Biomass

During the June sampling, about 30% of the variability of the total biomass could be explained by variation in six independent variables (Table XIV). Water depth, hydrogen ion concentration, and organic content of the sediment, made highly significant contributions to the regression analysis (t greater than $t_{.01,\ 84\ df}$). This relationship can be expressed in a regression equation in the following form:

$$Y = 2.64 - 0.29x_1 + 1.08x_2 - 14.62x_3$$

where Y is the biomass estimate, and 2.64 is the Y axis intercept. The numbers, -0.29, 1.08, and -14.62 are regression slopes and x_1, x_2, and x_3 are the independent variables, water depth, organic content, and hydrogen ion concentration. Particle diameter, depth of sediment and specific gravity were not statistically significant (t less than $t_{.05,\ 84\ df}$).

The sign and magnitude of the correlation coefficients yield some insight into the relationship of these independent variables with the biomass of macrobenthos. Both the water depth and hydrogen ion concentration gave significant negative correlations, while the organic content was positively correlated with the biomass of invertebrates. This would indicate that the total biomass in the spring could be described as a decreasing function of water depth and hydrogen ion concentration and simultaneously as an increasing function of the organic content of the sediment. These relationships occured in spite of the significant positive relationship between water depth and organic content.

In the summer samples, neither the regression analysis nor correlation coefficients demonstrated significant relationships between total biomass and the independent variables, as was found for the spring samples. The possibility of an increase in the variability in the biomass (dependent variable) can be rejected as the coefficient of variability (Steel and Torrie, 1960: 179) was less in the summer samples than in the spring samples (Table XIV). The standard error of estimate of the regression (Steel and Torrie, 1960: 278) was greater in the summer samples than in the spring samples, indicating an increase in the variability of the independent variables.

In the fall, the independent variables were again able to account for a significant amount of the variation of total biomass of macroinvertebrates (Table XIV). However, depth of sediment was the only independent variable which made statistically significant (t greater than $t_{.01,\ 83\ df}$) contributions to the regression equation, although the median particle diameter approached significance at the 10% level.

Ephemeridae

Craven (1967) gave evidence that Hexagenia in Boomer Lake followed a one year life cycle. If this hypothesis is true, the mayfly naiads collected in the spring sampling period from Lake Carl Blackwell hatched in the preceding summer. The large, pre-emergent naiads require large burrows, and hence a slightly different substrate than the smaller individuals of the late summer and early fall. Statistical analysis revealed a positive relationship between biomass of these individuals and the organic content of the sediment, and

TABLE XIV

MULTIPLE CORRELATION BETWEEN TOTAL BIOMASS OF PRINCIPLE MACROBENTHOS (DEPENDENT VARIABLE) AND SIX SEDIMENT PARAMETERS[1] (INDEPENDENT VARIABLES), AND CORRELATION BETWEEN BIOMASS OF PRINCIPLE TAXA AND THE SAME SEDIMENT PARAMETERS

Dependent Variables	F	Statistic R	Coefficient of Determination
SPRING			
Total biomass	6.060**[2]	.550	30.2%
Chironomidae	1.795	.337	11.3%
Tubificidae	.457	.177	3.1%
Ephemeridae	1.887	.345	11.9%
Culicidae	.597	.202	4.0%
SUMMER			
Total biomass	1.654	.338	11.4%
Chironomidae	.843	.248	12.2%
Tubificidae	.373	.168	1.4%
Ephemeridae	3.847**	.480	23.1%
Culicidae	1.278	.301	9.1%
FALL			
Total biomass	4.572**	.501	25.0%
Chironomidae	.392	.167	2.9%
Tubificidae	.393	.167	72.1%
Ephemeridae	6.457**	.566	33.2%
Culicidae	1.475	.312	9.7%

[1]Independent variables were median particle diameter, organic content, hydrogen ion concentration, depth of water, depth of sediment, and specific gravity.

[2]** indicate statistical significance at the .01 level with appropriate degress of freedom.

negative relationships between the depth of water, and the specific gravity of the sediment. The negative correlations with depth of water and specific gravity of the sediment suggests a preference of the larger individuals for the larger particles for burrow construction. The larger particles were principally found in the shallower areas of the lake (Figures 6 and 7). However, shallow water sediments also have higher concentrations of oxygen at the sediment-water interface than the deeper waters which upon stratification, quickly manifest oxygen depletion.

The genus Hexagenia sp. was described by Hunt (1953) as "mud eaters". Hunt (1953) also suggests that Hexagenia derive nourishment from organic material which is ingested with the mud. The positive correlation obtained between biomass of Hexagenia and organic content lend statistical evidence to support speculation about the dependence of mayflies on an organic substrate.

Summer samples show strongly negative relationships between the biomass of mayflies and the three independent variables, water depth, specific gravity, and hydrogen ion concentration of the sediment. The strength of these relationships may indicate an active avoidance of deeper water or decreased survival in deep water. Hydrogen ion concentration and specific gravity increased with increasing water depth. Hunt (1953) states than Hexagenia limbata was not adversely affected by water pH ranging from 7.4 to 9.6. Any avoidance of profundal sediments in Lake Carl Blackwell was due to anoxic conditions developed at the sediment-water interface. Oxygen depletion near the bottom was noted during July for one week.

The high hydrogen ion concentration indicates a high respiration rate associated with the oxygen depletion.

According to findings of Craven (1967) on Boomer Lake, the population of Ephemeridae samples in the fall samples would be only young individuals. The mean biomass per sample was equivalent to that of the spring samples, but the numbers of individuals per sample was larger indicating smaller body size. In the fall, the major environmental factors to which the biomass of Ephemeridae was related were the depth of water, specific gravity, and median particle diameter of the sediment. The positive relationship to the median particle diameter complements findings of a negative correlation of biomass of mayflies to the water depth and specific gravity of the sediment. These results would again indicate that the naiads were located in the shallower waters where the sediment particles have a larger median diameter.

Chironomidae

Chironomid larvae build tubes in "soft, mucky" substrates and feed on organic detritus (Usinger, 1963). In June, organic content was the single environmental variable which was significant in explaining the variation in chironomid biomass. During the summer and fall, however, the distribution of the Chironomidae was statistically random with respect to the sediment parameters (Table XIV). Habitat preferences of the diverse genera impart an ubiquitous distribution to the family when considered as a whole.

Culicidae and Tubificidae

The distribution of biomass of Culicidae larvae, and aquatic oligochaetes of the family Tubificidae, was statistically random with respect to the sediment parameters studied. This observation supports previous findings by Baker (1918) that these forms have non-specific habitat requirements. The tolerance of a wide range of substrate and compounding environmental variables associated with substrate characteristics indicates a large ecological valence (Allee and Schmidt, 1951: 26). In fact, this large valence and independence of substrate characteristics undoubtedly accounts for their ubiquitous occurrence in profundal sediments.

CHAPTER IX

CONCLUSIONS

The loss on ignition method for determination of organic content of sediment was inaccurate due to a high clay content, which loses hygroscopic moisture upon heating. The loss on ignition method gave highly variable results which did not represent the organic content of Lake Carl Blackwell sediments as measured by the chromic acid oxidation method.

The organic content of sediment from Lake Carl Blackwell was greater in October than in June, 1967. During the five month period studied, when autochthonous organic inflow was very low, autochthonous material was apparently produced at a rate significantly higher than the rate of respiration because of significant increase in organic material in October as compared to June samples.

The accumulation of organic matter during the summer produced a high rate of respiration at the sediment-water interface in deep water as noted by the low sediment pH values. Moreover, while moderate amounts of dissolved oxygen were found near the interface, a short period of thermal stratification which occured in July was quickly followed by complete exhaustion of hypolimnetic oxygen. High hydrogen ion concentrations in the sediment-water interface probably result from acidic end-products of respiration. A high correlation was found between the organic content of the sediment and the associated hydrogen ion concentration.

It was hypothesized that a minimum depth of substrate must be present to provide a suitable habitat for burrowing forms. This relationship could not be demonstrated. The smallest amount of sediment which could be measured with the spud bar (0.1 feet) was considered too gross a measurement to test the hypothesis.

Two types of sediment cycling processes are in progress in the lake. Resuspension of shallow sediment by wave action occurs in the western end of the lake, and the sediment is moved to the eastern end of the lake by wind-blown currents. In one instance, the author observed a distinct band of sediment-laden water in the area of Transect 6 which was visibly moving eastward. In addition, there was a greater mean depth of sediment on Transect 7 in October than in June. This area would receive sediment from the large shallow area immediately to the west. There is a great deal of similarity between the particle size composition of the sediment between Lake Carl Blackwell and Lake Chautauqua, Illinois, where sediment cycling has been reported. A second type of sediment cycling process resulted from resuspension of sediments in nearshore areas and movement to deeper water by the wave action. Turbidity was often higher in wind-swept shore areas, where sediment was being resuspended by wave action. Wave built terraces, as indicated by the depth of sediment measurements, were present in October on Transects 2 and 7 along the north shore.

The mean median particle diameter of the sediment was larger in June than October. It was assumed that this was due to wind-caused turbulence in the water which would tend to maintain the finer particles in suspension. However, mean turbidity values were found to be greater in October than in June.

Turbulence and resuspension of the lake sediments was at a peak in the fall and lowest in June. This can be inferred from the amount of sediment present in June and October (Table V). In addition, the percent of total area represented by a phi value less than six (large particles) was greater in June than in October (Table III). The standard deviation for the median phi value was smaller in June than in October, indicating that the particle size composition was more constant in June than in October. Variation in particle size composition could be caused by the grading action of waves, which would remove small particles from shallow areas, thereby causing a lower median phi value.

The distribution of benthic macroinvertebrates could be determined, at least in part, by three of six substrate or environmental characteristics. During the June samples, depth of water, organic content of sediment and hydrogen ion concentration contributed significantly to the explanation of the variation of total biomass of benthic macroinvertebrates. During the fall, however, the variation of the total benthic biomass was significantly related to only one variable, the depth of sediment. However, median particle diameter approached significance at the 10% level.

Ephemerids were found primarily in the shallow water areas. Typically deep water transects were void of individuals, while the majority were collected from shallow water areas. The distribution of the family Ephemeridae was correlated to the substrate and environmental characteristics. Statistically significant positive relationships were found between the biomass of mayflies and the organic content of the sediment, the depth of water, and the specific gravity. It has been previously suggested that mayflies derive nourishment from the organic material in the mud they ingest and that they avoid anoxic deeper water areas.

The distribution of chironomid larvae was affected by the organic content of the sediment in which they burrow. In June, the organic content of the sediment was the only environmental variable which contributed significantly to the distribution of the biomass of chironomid larvae.

The distribution of Culicidae and Tubificidae was found to be statistically random with respect to the sediment parameters studied. Their large ecological valence for substrate and other habitat characteristics helps account for their wide distribution.

The chironomid population at Lake Carl Blackwell is relatively stable. The distribution and number of individuals collected is similar in both the June and October samples. The culicids were found primarily in deep water.

The tubificids are found in deep water profundal sediments in the main body of the lake. Deep water transects generally yielded the highest average number of individuals per square meter.

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APPENDIX A

ANALYSIS OF VARIANCE OF INDEPENDENT AND DEPENDENT VARIABLES WITHIN SAMPLE SITES

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
		Coarse Sand		
Between samples	2	0.863	.432	0.003
Within samples	81	10071.438	124.339	
Total	83	10072.301		
		Fine Sand		
Between samples	2	124.214	62.107	0.605
Within samples	81	8303.974	102.518	
Total	83	8428.188		
		Coarse Silt		
Between samples	2	134.791	67.396	0.435
Within samples	81	12540.976	154.827	
Total	83	12675.766		
		Fine Silt		
Between samples	2	110.643	55.321	0.185
Within samples	81	24247.687	299.354	
Total	83	24358.330		
		Coarse Clay		
Between samples	2	22.371	11.186	
Within samples	81	2770.673	34.206	
Total	83	2793.045		
		Fine Clay		
Between samples	2	2.349	1.174	0.769
Within samples	81	123.695	1.527	
Total	83	126.043		

APPENDIX A (Continued)

Very Fine Clay

Between samples	2	1.154	0.577	0.401
Within samples	81	116.464	1.438	
Total	83	117.619		

Specific Gravity

Between samples	2	0.187	0.093	2.004
Within samples	81	3.779	0.047	
Total	83	3.966		

Chironomidae--Biomass Wet Weight

Between samples	2	97.648	48.824	0.163
Within samples	81	24259.147	299.496	
Total	83	24356.795		

Tubificidae--Biomass Wet Weight

Between samples	2	184.249	92.125	0.351
Within samples	81	21265.677	262.539	
Total	83	21449.926		

Ephemeridae--Biomass Wet Weight

Between samples	2	21.597	10.798	0.008
Within samples	81	113692.004	1403.605	
Total	83	113713.601		

Culicidae--Biomass Wet Weight

Between samples	2	764.736	382.368	0.266
Within samples	81	116293.074	1435.717	
Total	83	117057.810		

Total Biomass Wet Weight

Between samples	2	0.741	0.370	0.142
Within samples	81	211.369	2.609	
Total	83	212.110		

Chironomidae--Biomass Dry Weight

Between samples	2	101.562	50.781	0.198
Within samples	81	20722.986	255.839	
Total	83	20824.549		

APPENDIX A (Continued)

Tubificidae--Biomass Dry Weight

Between samples	2	134.282	67.141	0.184
Within samples	81	29542.855	364.727	
Total	83	29677.137		

Ephemeridae--Biomass Dry Weight

Between samples	2	10.583	5.291	0.003
Within samples	81	129411.588	1597.674	
Total	83	129422.172		

Culicidae--Biomass Dry Weight

Between samples	2	670.574	335.287	0.228
Within samples	81	119182.166	1471.385	
Total	83	119852.740		

Total Biomass Dry Weight

Between samples	2	0.008	0.004	0.190
Within samples	81	1.711	0.021	
Total	83	1.719		

Depth of Water

Between samples	2	3.001	1.500	0.259
Within samples	81	469.374	5.795	
Total	83	472.376		

Surface Temperature

Between samples	2	0.723	0.362	0.091
Within samples	81	321.533	3.970	
Total	83	322.256		

Bottom Temperature

Between samples	2	0.230	0.115	0.029
Within samples	81	319.018	3.938	
Total	83	319.248		

Surface Oxygen

Between samples	2	0.187	0.093	0.011
Within samples	81	664.750	8.207	
Total	83	664.937		

APPENDIX A (Continued)

		Bottom Oxygen		
Between samples	2	0.368	0.184	0.018
Within samples	81	808.685	9.984	
Total	83	809.053		
		Turbidity		
Between samples	2	0.002	0.001	0.013
Within samples	81	0.628	0.008	
Total	83	0.630		
		Depth of Sediment		
Between samples	2	0.268	0.134	0.779
Within samples	81	13.956	0.172	
Total	83	14.224		
		Percent of Organic Matter		
Between samples	2	0.009	0.004	0.030
Within samples	81	10.922	0.135	
Total	83	10.931		

$F_{.05;\ 81,2\ df} = 3.10$; $F_{.01;\ 81,2\ df} = 4.90$

APPENDIX B

```
NANCY NORTON                              FORTRAN SOURCE LIST                              06/07/68
    ISN       SOURCE STATEMENT

      0 $IBFTC MAIN
      1       COMMON/END/IVAR1,IVAR2
      2       ASSIGN 5000 TO IVAR1
      3       IVAR2=1
      4       TPER=0
      5       KNT=0
      6       DIMENSION TIME(20),READ(20),SCALE(7),PERCNT(20),DIA(20),Z(20)
      7       DIMENSION XPER(20),XDIA(20),CON(8),PERNEW(7),IPERNW(7)
     10       DIMENSION PERDIV(20),PERD(20)
     11       DIMENSION PER(7),CON2(6)
     12       DATA CON2/1.,.5,.0625,.0382,.0039,.001/
     13       DATA CON/2.0,0.42,0.0625,0.015,0.004,0.001,0.0005,0.0/
     14       READ (5,10) (SCALE(I), I=1,7)
     21    10 FORMAT (7F5.2)
     22    11 WRITE (6,12)
     23    12 FORMAT (1H1)
     24    15 DO 96000 IIII=1,20
     25       PERDIV(IIII)=0.0
     26 96000 PERD(IIII)=0.0
     30       READ (5,20) NO,NAME1,NAME2,NAME3,NOR,WT,IHYD,DENSTY
     37    20 FORMAT (I3,1X,3A6,I2,F3.1,I1,F3.2)
     40       WRITE (6,30) NAME1,NAME2,NAME3
     41    30 FORMAT (1H0,3A6)
     42       WRITE (6,31) NO
     43    31 FORMAT (1H ,11HSAMPLE NO. ,I3)
     44       WRITE (6,35) WT
     45    35 FORMAT (1H0,22HTOTAL SAMPLE WEIGHT = ,F4.1)
     46       WRITE (6,40) IHYD
     47    40 FORMAT (1H ,15HHYDROMETER NO. ,I1)
     50       WRITE (6,41) DENSTY
     51    41 FORMAT (1H ,19HSPECIFIC GRAVITY = ,F5.2)
     52       WRITE (6,42)
     53    42OFORMAT (1H0,11X,11HREADING NO.,11X,12HTIME ELAPSED,11X,7HREADING,
             111X,17HPERCENT OF SAMPLE,11X,17HPARTICLE DIAMETER)
     54       READ (5,45) (TIME(I),READ(I), I=1,NOR)
     61    45 FORMAT (4X,F5.1,F3.1,F5.1,F3.1,F5.1,F3.1,F5.1,F3.1,F5.1,F3.1,F5.1,
            1F3.1,F5.1,F3.1,F5.1,F3.1,F5.1,F3.1)
     62       DO 130 I=1,NOR
     63       PERCNT(I)=(READ(I)/WT)*100.0
     64       XPER(I)=PERCNT(I)
     65       IF(READ(I).LT.10.0) GO TO 50
     70       IF(READ(I).LT.20.0) GO TO 60
     73       IF(READ(I).LT.30.0) GO TO 70
     76       IF(READ(I).LT.40.0) GO TO 80
    101       IF(READ(I).LT.50.0) GO TO 90
    104       IF(READ(I).LT.60.0) GO TO 100
    107    50 XL=SCALE(1)-((READ(I)-0.0)*((SCALE(1)-SCALE(2))/10.0))
    110       GO TO 105
    111    60 XL=SCALE(2)-((READ(I)-10.0)*((SCALE(2)-SCALE(3))/10.0))
    112       GO TO 105
    113    70 XL=SCALE(3)-((READ(I)-20.0)*((SCALE(3)-SCALE(4))/10.0))
    114       GO TO 105
    115    80 XL=SCALE(4)-((READ(I)-30.0)*((SCALE(4)-SCALE(5))/10.0))
    116       GO TO 105
    117    90 XL=SCALE(5)-((READ(I)-40.0)*((SCALE(5)-SCALE(6))/10.0))
```

```
  ISN      SOURCE STATEMENT

  120           GO TO 105
  121      100 XL=SCALE(6)-((READ(I)-50.0)*((SCALF(6)-SCALE(7))/10.0))
  122      105 X=(.000216/(DENSTY-.99371))*((XL+12.255)/TIMF(I))
  123           DIA(I)=SQRT(X)
  124           XDIA(I)=DIA(I)
  125      110 WRITE (6,120) I,TIME(I),READ(I),PERCNT(I),DIA(I)
  126      120 FORMAT (1H ,15X,I2,19X,F6.1,15X,F4.1,17X,F7.2,21X,F8.5)
  127      130 CONTINUE
  131           DO 131 I=1,NOR
  132      131 IF(PERCNT(I).GT.100.) PERCNT(I)=100.
  136           DO 133 I=1,NOR
  137           IF(I.GE.2) GO TO 132
  142           PERD(I)=100.-PERCNT(I)
  143           GO TO 133
  144      132 J=I-1
  145           PERD(I)=PERCNT(J)-PERCNT(I)
  146      133 CONTINUE
  150           PERD(NOR+1)=PERCNT(NOR)
  151           DIA(NOR+1)=0.0
  152           DO 135 I=1,8
  153           II=I
  154           IF(DIA(1).GE.CON(I)) GO TO 136
  157      135 CONTINUE
  161           GO TO 90000
  162      136 IP=II-1
  163           DO 137 I=1,IP
  164           IF(I.EQ.IP) GO TO 138
  167           PERDIV(I)=((CON(I)-CON(I+1))/(CON(1)-DIA(1)))*PFRD(1)
  170           GO TO 137
  171      138 PERDIV(I)=((CON(I)-DIA(1))/(CON(1)-DIA(1)))*PERD(1)
  172      137 CONTINUE
  174           NOR1=NOR+1
  175           DO 200 I=2,NOR1
  176           IF(DIA(I).LT.CON(II)) GO TO 139
  201           PERDIV(IP)=PERDIV(IP)+PERD(I)
  202           GO TO 200
  203      139 K=II+1
  204           DO 210 J=K,8
  205           II2=J
  206           IF(DIA(I).LT.CON(J)) GO TO 210
  211           GO TO 211
  212      210 CONTINUE
  214           GO TO 95000
  215      211 IP2=II2-1
  216           DENOM=DIA(I-1)-DIA(I)
  217           PERDIV(IP)=PERDIV(IP)+((DIA(I-1)-CON(II))/DENOM)*PERD(I)
  220           DO 220 J=II,IP2
  221           IF(J.EQ.IP2) GO TO 300
  224           PERDIV(J)=((CON(J)-CON(J+1))/DENOM)*PERD(I)
  225           GO TO 220
  226      300 PERDIV(J)=((CON(J)-DIA(I))/DENOM)*PERD(I)
  227      220 CONTINUE
  231           II=II2
  232           IP=IP2
  233      200 CONTINUE
```

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ISN SOURCE STATEMENT

```
506 WRITE (6,510) PERDIV(1)
510 FORMAT (1HL,54X,11HCOARSE SAND,13X,F7.2)
    WRITE (6,520) PERDIV(2)
520 FORMAT (1H ,55X,9HFINE SAND,14X,F7.2)
    WRITE (6,530) PERDIV(3)
530 FORMAT(1H ,54X,11HCOARSE SILT,13X,F7.2)
    WRITE (6,540) PERDIV(4)
540 FORMAT(1H ,55X,9HFINE SILT,14X,F7.2)
    WRITE (6,550) PERDIV(5)
550 FORMAT(1H ,54X,11HCOARSE CLAY,13X,F7.2)
    WRITE (6,560) PERDIV(6)
560 FORMAT(1H ,55X,9HFINE CLAY,14X,F7.2)
    WRITE (6,570) PERDIV(7)
570 FORMAT(1H ,52X,14HVERY FINE CLAY,12X,F7.2//)
    DO 601 I=1,7
601 PER(I)=PERDIV(I)
    IF(PER(1) - 50.) 610,610,620
620 DIFF1 = 100. - 50.
    DIFF2 = CON2(1)-CON2(2)
    DIFF3 = PER(1) - 50.
    X = DIFF3 * DIFF2/DIFF1
    XMED = X + CON2(2)
    GO TO 611
610 PERA = PER(1) + PER(2)
    IF(PERA - 50.) 612,612,621
621 DIFF4 = 100. - PER(1)
    DIFF1 = DIFF4 - 50.
    DIFF2 = CON2(2) - CON2(3)
    DIFF3 = PERA - 50.
    X = DIFF3 * DIFF2/DIFF1
    XMED = CON2(3) + X
    GO TO 611
612 PERB = PERA + PER(3)
    IF(PERB - 50.) 613,613,622
622 DIFF4 = 100. - PERA
    DIFF1 = DIFF4 - 50.
    DIFF2 = CON2(3) - CON2(4)
    DIFF3 = PERB - 50.
    X = DIFF3 * DIFF2/DIFF1
    XMED = CON2(4) + X
    GO TO 611
613 PERC = PERB + PER(4)
    IF(PERC - 50.)614,614,623
623 DIFF4 = 100. -PERB
    DIFF1 = DIFF4 - 50.
    DIFF2 = CON2(4) - CON2(5)
    DIFF3 = PERC - 50.
    X = DIFF3*DIFF2/DIFF1
    XMED = CON2(5) + X
    GO TO 611
614 PERF = PERC + PER(5)
    IF(PERF - 50.) 615,615,624
624 DIFF4 = 100. - PERC
    DIFF1 = DIFF4 - 50.
    DIFF2 = CON2(5) - CON2(6)
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NANCY NORTON                                 FORTRAN SOURCE LIST MAIN                          06/07/68
    ISN         SOURCE STATEMENT

    325         DIFF3 = PERF - 50.
    326         X = DIFF3 * DIFF2/DIFF1
    327         XMED = CON2(6) + X
    330         GO TO 611
    331     615 PERF = PERF + PER(6)
    332         IF (PERE - 50.) 616,616,625
    333     625 DIFF4 = 100. - PERF
    334         DIFF1 = DIFF4 - 50.
    335         DIFF2 = CON2(5) - CON2(6)
    336         DIFF3 = PFRE - 50.
    337         X = DIFF3 * DIFF2/DIFF1
    340         GO TO 611
    341     616 PERG = PERE + PER(7)
    342         IF (PERE - 50.) 617,617,626
    343     626 DIFF4 = 100. - PERE
    344         DIFF1 = DIFF4 - 50.
    345         DIFF2 = CON2(5) - CON2(6)
    346         DIFF3 = PERG - 50.
    347         X = DIFF3 * DIFF2/DIFF1
    350         GO TO 611
    351     617 WRITE (6,600) NO
    352     600 FORMAT(1X,I3,41HTOTAL OF PERCENTAGES NOT GREATER THAN 50.)
    353     611 PHI = -(ALOG10(XMED)/ALOG10(2.))
    354         WRITE (6,630) XMED,PHI
    355     630 FORMAT (1H ,47X,24HMEDIAN PARTICLE DIAMETER,7X,F10.5/1H ,54X,10HME
               1DIAN PHI,14X,F10.5)
    356         CALL XLOT (DIA,3,PERCNT,0,Z,0,NOR,1,1,3,2,0,1)
    357         GO TO 11
    360 90000 WRITE(6,90001)
    361 90001 FORMAT(8H1ERROR 1)
    362         GO TO 15
    363 95000 WRITE(6,95001)
    364 95001 FORMAT(8H1ERROR 2)
    365         GO TO 15
    366    5000 CALL EXIT
    367         END
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VITA

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Master of Science

Thesis: THE DISTRIBUTION, CHARACTER, AND ABUNDANCE OF SEDIMENTS IN A 3000-ACRE IMPOUNDMENT IN PAYNE COUNTY, OKLAHOMA

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