Sedimentation in Lake Lemon Monroe County, Indiana

By EDWIN J. HARTKE *and* JOHN R. HILL

DEPARTMENT OF NATURAL RESOURCES
GEOLOGICAL SURVEY OCCASIONAL PAPER 9

ENVIRONMENTAL STUDY 3

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Introduction

Lake Lemon was constructed during 1953 in a hilly (average relief of about 100 feet), heavily wooded drainage basin. Considerable lakeside development has taken place after impoundment, and as a result concern has arisen about the sedimentation rate in the lake. This study was undertaken to determine the sedimentologic conditions and the total sediment accumulation in the lake and to relate these determinations to the geology of the drainage basin.

Lake Lemon is on the boundary between Monroe and Brown Counties about 9 miles northeast of Bloomington (fig. 1). The lake is used presently for flood control, low-flow augmentation, and recreation. It was used for water supply and is being considered as a future auxiliary and emergency supply for Bloomington.

The reservoir has a surface area of 1,440 acres at the spillway (crest) elevation of 630 feet above sea level. The original lake volume at that level, as computed by the U.S. Geological Survey and verified by this study, was 14,400 acre-feet. Because of the siltation during the past 20 years, the present lake volume corresponding to the 630-foot pool is 13,920 acre-feet, which represents an approximate 3½-percent decrease in reservoir volume.

The average annual precipitation of about 43 inches in the area exceeds the annual evaporation rate by a small margin. Rainfall was well below average for the 3-month period of August through October 1973. The total precipitation for the period, 5.40 inches, was 4.46 inches below the normal average. The lake level, however, which is controlled by a spillway and a 42-inch-diameter outflow gate, was relatively high during the study because of an unusually wet spring and early summer season which had maintained the lake at spillway level until the end of July. Lake level was 628.6 feet above mean sea level at the beginning of the study and 628.2 feet at the completion. Lake Lemon is recharged primarily by Beanblossom Creek, which drains the major part of the 70.2-square-mile watershed of the lake. Supplementary recharge is received directly from the immediately surrounding forested ridges.

Comprehensive treatment of the extremely complex erosion-sedimentation cycle is beyond the scope of this study. Some of the more important factors affecting this cycle, however, should be mentioned. The rate of erosion, and therefore the lake sedimentation rate within a given drainage basin, are determined by various factors. The more important of these are: the nature of the geologic materials (fig. 2), topography, precipitation (intensity and duration), climate, vegetative cover, and degree and type of human-related development. Interrelated factors affecting lake sedimentation rates are: flow velocity within the lake, water depth, turbulence, wave action, flow through time, and water temperature.

The sediments deposited in Lake Lemon are derived from various sources. The unconsolidated surficial materials that supply sediment are residual soil derived from weathered bedrock of the Borden Group (Mississippian), loess-derived silts, and some clayey silts derived from Illinoian glacial till in the Beanblossom drainage basin. The wide variation in soil types within the Lake Lemon drainage complex is a direct reflection of the different types of parent materials. Owing to the texture of these varied soil sources, the most common size fraction of material delivered to the lake is silt. Streams tributary to Beanblossom Creek have downcut into the materials over which they flow and consequently flow primarily on their own bedload or on bedrock. In upland areas, where these feeder streams originate, they may flow over loess, till, and residual soil as mentioned above. The rate of erosion within the watershed has averaged about 400 tons per square mile per year during the 20-year life of the lake.

The major part of sediment load in the lake and in Beanblossom Creek is derived by sheet erosion in late fall or early spring when vegetative cover is at a minimum and the ground is not frozen. Winter rains immediately following thaws also produce marked erosion and consequent lake sedimentation. Heavy rains quickly strip large volumes of soil materials from unprotected slopes, carrying these sediments in suspension by tributaries and open sheet wash to the Beanblossom valley and finally to the lake. A study of Big Raccoon Creek near Fincastle, Ind. (Johnson, 1971, p. 9), showed that about 90 percent of the total annual suspended sediment discharge was transported during 10 percent of the time (36 days).

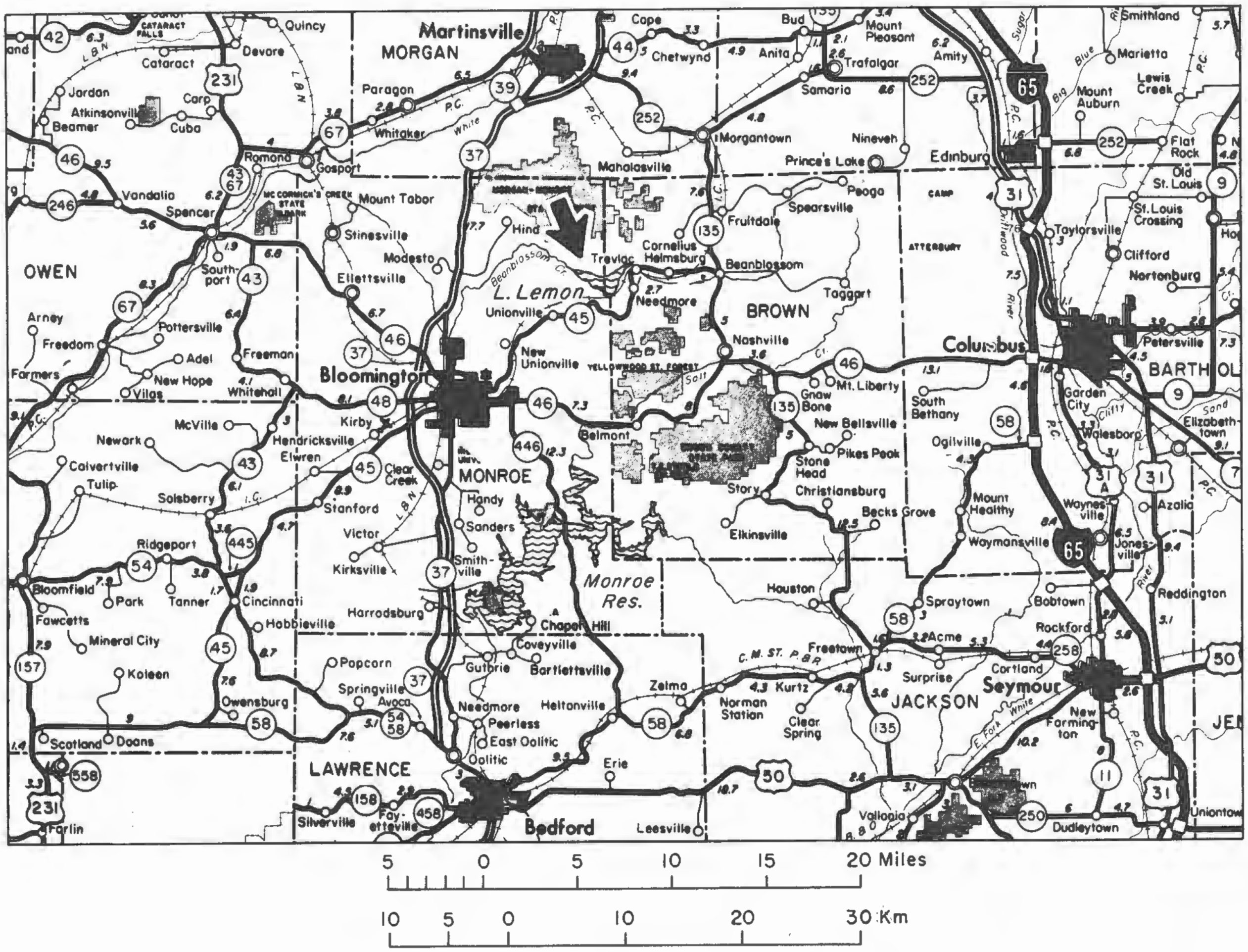

Figure 1. Map showing the location of Lake Lemon with respect to Monroe and Brown Counties.

The lake appears to be quite turbid even during conditions that are ideal for settling of suspended solids. The water is tealike in appearance, with strictly limited light transmittal and visibility. This situation leads the casual observer to believe that the lake may be filling rapidly with sediment or that the sediment is being carried directly through the lake and into Beanblossom Creek below the dam. Neither was found to be the case, however.

Sampling Techniques

Eight north-south oriented sample lines (fig. 3) were surveyed in and along the length of the lake to provide a base for a sampling grid. Markers delineating these range lines were placed on the north and south shores of the lake. One hundred and twelve samples were taken at regular intervals ranging from 50 to 400 feet along the range lines by use of a fixed-axis and triangulation surveying technique. The distance between sample stations depended on the variability of sediment thickness. An additional 13 samples were taken at random from the east end of the lake (fig. 2) to bring the total number of samples to 125.

The bottom samples were taken with a 1½-inch-diameter piston core sampler that was pushed manually into the bottom sediments. A 24-foot flat-bottom inboard motor boat provided a stable but mobile work platform. Each core sample was immediately examined to ascertain the thickness and texture of sediment that had accumulated since the lake was impounded. The samples were then labeled and packaged for further analysis in the Indiana Geological Survey laboratories.

Lake bottom topography was determined with a recording fathometer calibrated to within plus or minus 0.5-foot accuracy. To insure the kind of detail needed to profile the lake bottom, four additional range lines (fig. 3, A-D) were added to those used in the sediment-sampling phase of the study. Surface and near-bottom water samples were taken at strategic locations within the lake to determine suspended sediment load in the lake under conditions prevailing during the bottom-sampling study.

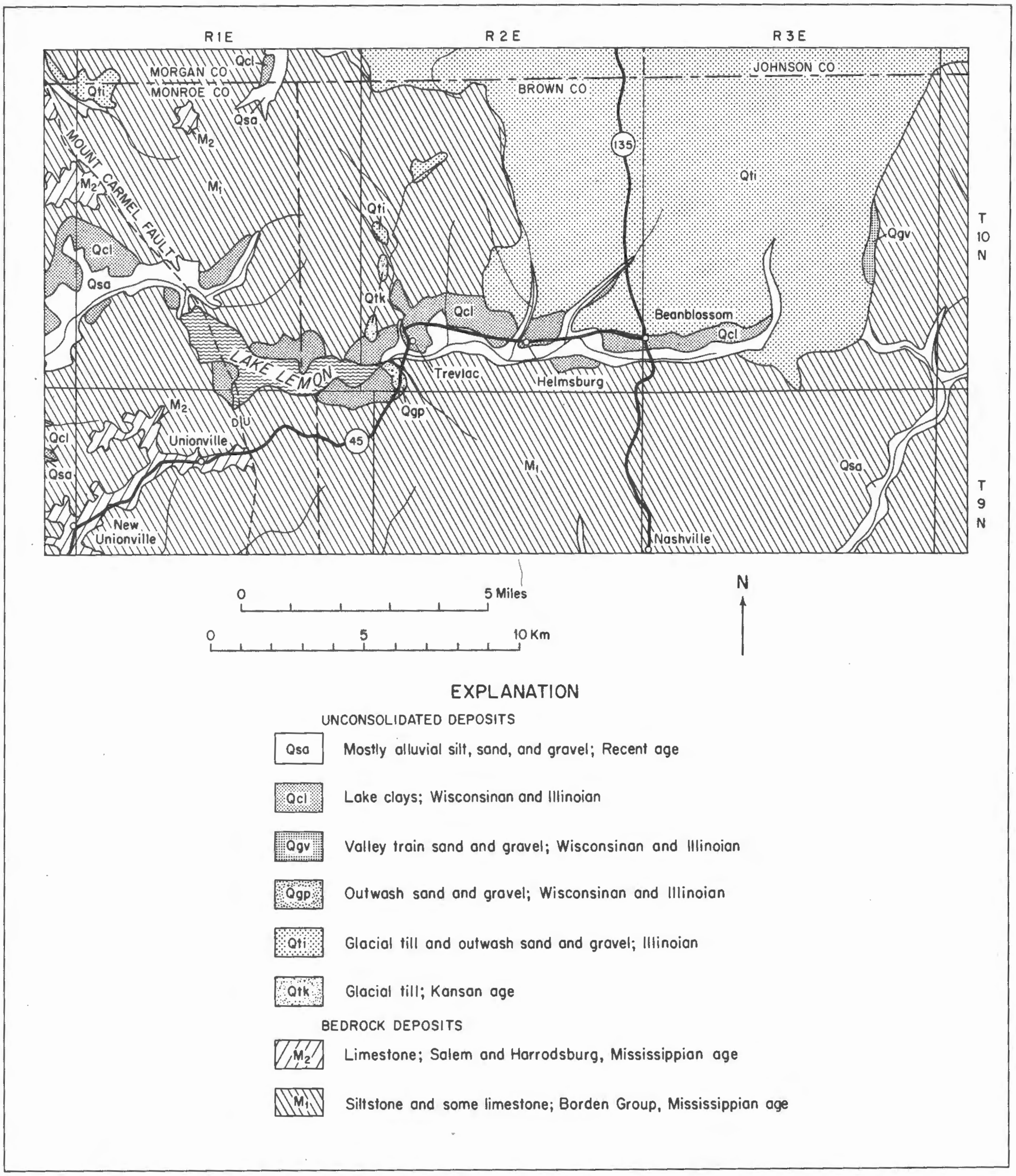

Figure 2. Geologic map of the Lake Lemon area including the upper Beanblossom drainage basin. From Wier and Gray, 1961.

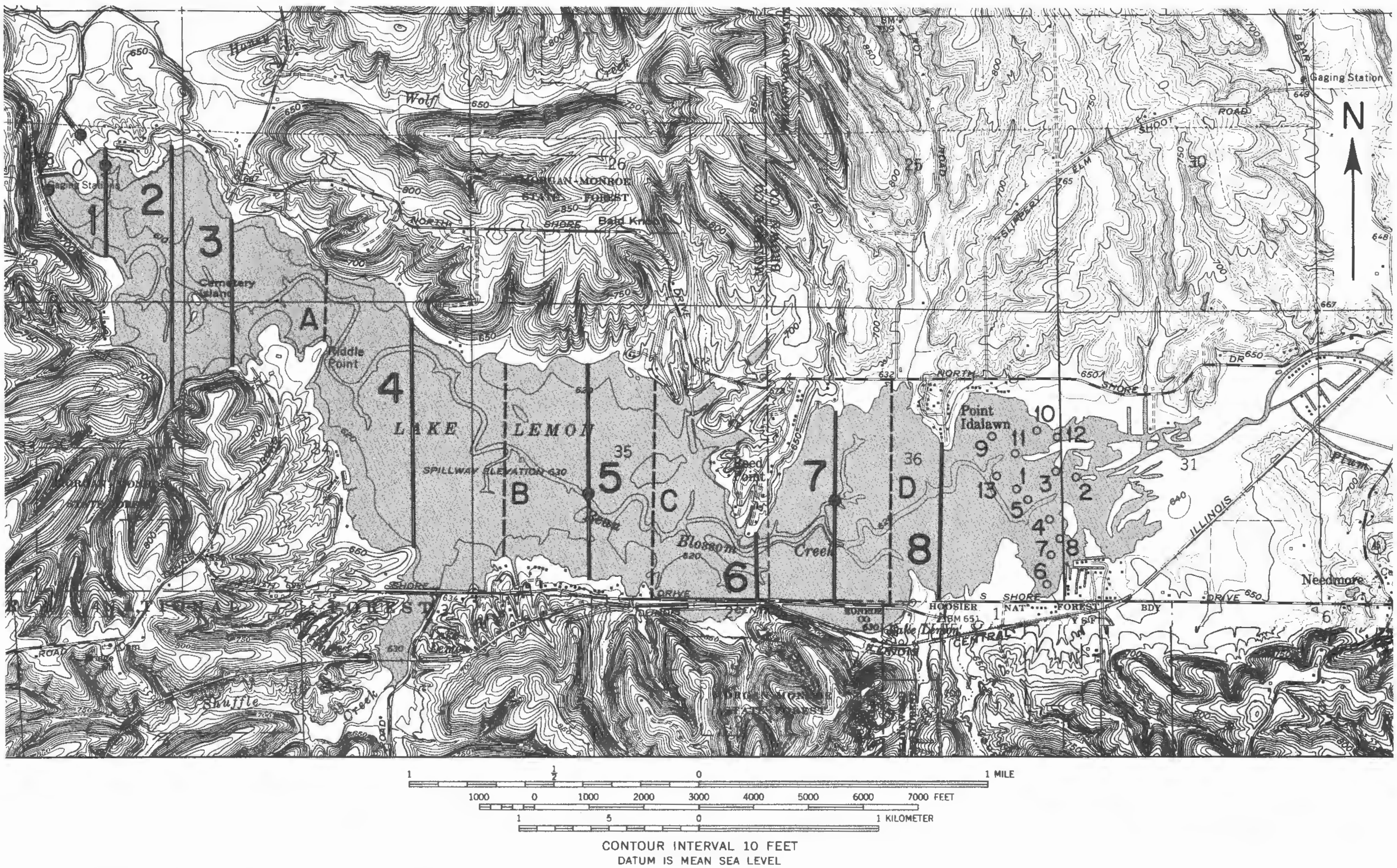

Figure 3. Map of Lake Lemon showing the location of eight range lines used in collecting samples and of random sample points at the east end of the lake. Letters A through D indicate additional range lines used in water depth survey. Circles indicate water sample sites. Base detail from U.S. Geological Survey maps, 7½-minute series, of the Unionville, Belmont, Hindustan, and Morgantown Quadrangles.

Laboratory analyses were made of the 125 samples to determine texture, carbonate content, bulk density, organic clay content, and clay mineral composition. For this report, only the bulk density and texture have been tabulated and are discussed.

Watershed Hydrology

Lake Lemon, an artificial lake fed by surface water, is maintained by runoff from precipitation within its 70.2-square-mile watershed. The local climate is such that average annual precipitation exceeds evaporation on a yearly basis. Therefore, in a year with normal precipitation, the lake level is readily maintained reasonably near spillway elevation, even though a constant release rate is maintained through the 42-inch-diameter outflow gate at the dam.

The erosion, transport, and sedimentation processes evaluated in this report are directly controlled by the hydrologic cycle (precipitation, infiltration and surface runoff, ground-water flow, collection, evaporation and transpiration, and finally condensation). There is minimal infiltration and ground-water flow in the watershed, so that only surface flow needs to be considered here.

The erosion-sedimentation process, which results from surface flow, is initiated with the precipitation phase. It is in this stage that the water, in the form of droplets, has its greatest amount of energy. The water droplets disturb the surface soils, particularly unprotected soils, thus producing sheet erosion. The eroded material is carried in sheet and rivulet flow into gullies and streams, where some bank erosion may take place. Beanblossom Creek is the primary collection and transportation route for the eroded material (suspended sediment) on its journey to Lake Lemon. About five-sixths of the watershed is drained by Beanblossom Creek, and the rest is drained directly into the lake. The water confined by the Beanblossom stream channel maintains a high-energy state, thus allowing it to carry its load of suspended sediment until it reaches the lake. On reaching the lake the channel flow abruptly changes to a broad, much slower area flow and loses most of its energy. It is in this upper area of the lake that the heavier, coarse material settles out of suspension and the greatest amount of filling takes place. The finer clays that settle more slowly are carried farther into the lake.

It is apparent from the sediment distribution pattern in the lake, however, that not all the energy is lost as the creek enters the lake. A small part of the flow is likely vectored into the old channel and other subsidiary troughs as shown in the water depth map (fig. 4). This in-lake flow could explain the high sediment concentrations in the troughs at the east end of the lake. The subsidiary troughs are depicted on the water depth contour map by the flow-line arrows. The channels can also be seen on the profile maps discussed in the following section. Additional explanation of the sediment distribution in these channels and in the lake in general is provided in the section on sedimentation in this report.

Beanblossom Creek drains about five-sixths of this physiographically and vegetatively uniform watershed and is, as indicated by the sediment distribution pattern, the transport medium for most of the sediment that enters the lake. The rest of the sediment is supplied from the ridges and valleys directly surrounding the lake.

Lake Volume and Water Capacity Computations

After collection of the field data, the original cross-sectional areas of the reservoir and the cross-sectional area of sediment at each range line were determined for use in computing present capacity and sediment volume. The process involved a combination of arithmetic computation and planimetric techniques.

The computation method (Soil Conservation Service, 1968) is based on the determination of individual trapezoidal areas which are increments of the total cross-sectional area of each range line. Since sample points were unevenly spaced, the following equation was used:

$$E_{1,2} = \frac{D}{2}(d_1 + d_2)$$

Where: E_1 = area of trapezoid in square feet (cross-sectional area of lake),

E_2 = area of trapezoid in square feet (cross-sectional area of sediment),

D = distance between soundings in feet,

d_1 = depth below reservoir crest at first sample point in feet or (thickness of sediment at first sample point in feet), and

d_2 = depth below reservoir crest at second sample point in feet or (thickness of sediment at second sample point in feet).

The summation of the trapezoidal areas gives the original total cross-sectional area of the lake and the total cross-sectional area of sediment. Above-crest sediments were not considered in this study because they are minimal and do not directly affect reservoir capacity.

Because the original volume of the lake has been computed by the U.S. Geological Survey, the average percentage of change in area within the range lines can be interpolated to give the overall percentage of reduction in lake volume. The total volume also was determined, however, by the following method (Soil Conservation Service, 1968):

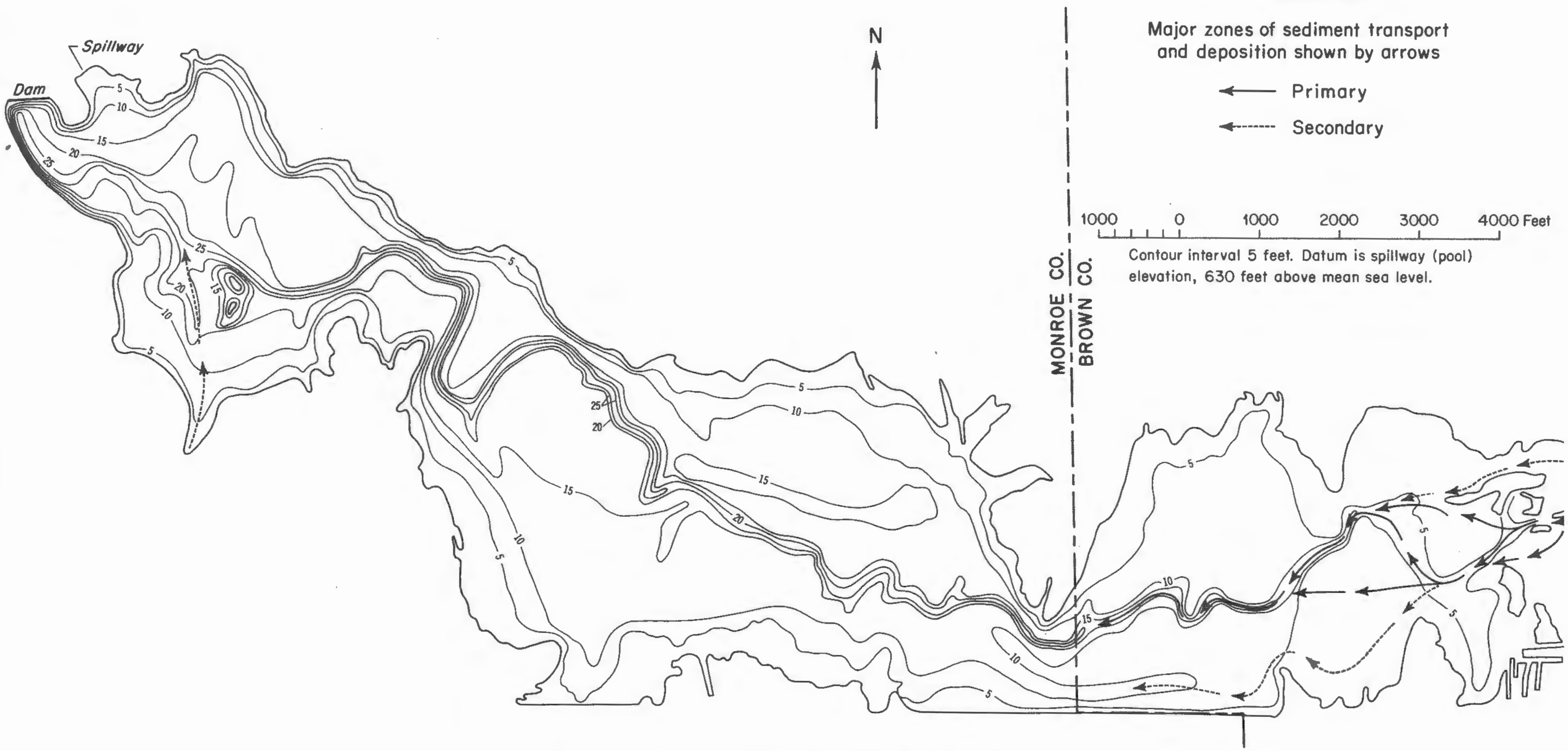

Figure 4. Map of Lake Lemon showing water depth.

The original water capacity and current total sediment volume were determined by establishing the water surface area and the quadrilateral area for each segment. A segment is bounded by two consecutive range lines and the two connecting shore lines at pool or crest elevation. The water surface area for each segment was determined by planimetering, but the quadrilateral areas were determined by computation.

The original capacity and sediment volume were determined by the Dobson prismoidal formula:

$$V = \frac{A^1}{3}\left(\frac{E_1 + E_2}{W_1 + W_2}\right) + \frac{A}{3}\left(\frac{E_1 + E_2}{W_1 + W_2}\right), \text{ in which}$$

V = total original reservoir capacity or sediment volume in acre-feet,
A = planimetered area of each segment,
A^1 = computed quadrilateral area of each segment,
E = cross-sectional area of water and sediment along range in square feet, and
W = length of bounding range at crest elevation.

Next to the dam the original capacity and sediment volume between the dam and first range line were computed by the formula:

$$V = A\left(\frac{E}{W}\right) - V_o, \text{ in which}$$

V_o = volume displaced by the upstream face of the dam.

The summation of the segment volumes plus the dam segment volume produced the total original volume for the lake of about 14,400 acre-feet. The total present sediment volume is about 500 acre-feet.

Sedimentation

SOURCES OF SEDIMENT

As discussed earlier, the three major sources of sediments available for deposition in Lake Lemon are till, loess, and bedrock residuum. The till, of Illinoian glacial origin, is a patchy deposit ranging from a few inches to more than 10 feet in thickness. It is distributed northeast of the lake in a broad area that includes much of the upper Beanblossom Creek drainage basin. This glacial deposit probably contributes most of the clay-size fraction carried in suspension by Beanblossom Creek. Loess deposits, which consist primarily of silt-size sediments, are common throughout both Monroe and Brown Counties, and they range in thickness from only a few inches to as much as 15 feet. The average thickness of loess, however, is generally between 1 and 3 feet. This loess, which is abundant on the uplands within and adjacent to the Lake Lemon-Beanblossom Creek drainage area, forms a ready source of silt that is deposited in Lake Lemon. Some clay also comes to the system from the B-horizon of the loess soils. And weathered siltstones of the Borden Group provide abundant silt-size sediments to both Beanblossom Creek and Lake Lemon directly. More specifically, these weathered bedrock sediments were derived from the Borden Group, which underlies all the till and loess deposits in the area and which is exposed in many areas throughout the drainage complex.

Thus the most common size fraction available for transport by running water is silt. Because nearly all the silt in this area is eroded from soils of one variety or another, soil maps serve well to delineate the source areas for these materials. The Soil Conservation Service (Rogers and others, 1946) has mapped a wide variety of silt-loam soils, the most common of which include Cincinnati, Muskingum, Wellston, and Zanesville silt loams.

(The Huntington fine sandy loam is the major sand-bearing soil in the area forming atop alluvial deposits on the Beanblossom flood plain and presently underlies a part of the western one-third of Lake Lemon. We believe that the Huntington may be the source of the sand deposits observed during the survey.)

SEDIMENT ACCUMULATION AND DISTRIBUTION

The cross sections (figs. 5-12) below are diagrammatic illustrations of the data gathered along the eight range lines discussed in the introduction.

Depressions on the lake bottom topography are the most common sites of sediment thickening. This is anticipated because wave-induced current activity is

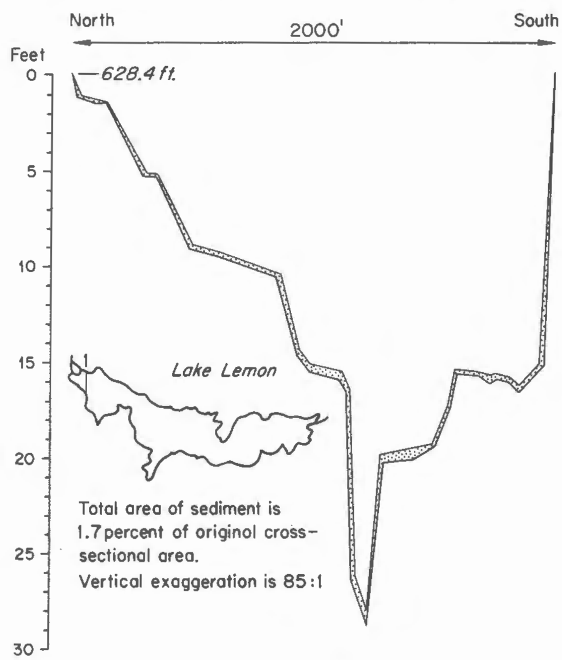

Figure 5. Cross section showing lake bottom configuration and sediment thickness for range line 1. Line thickness is indicative of sediment thickness at the scale shown.

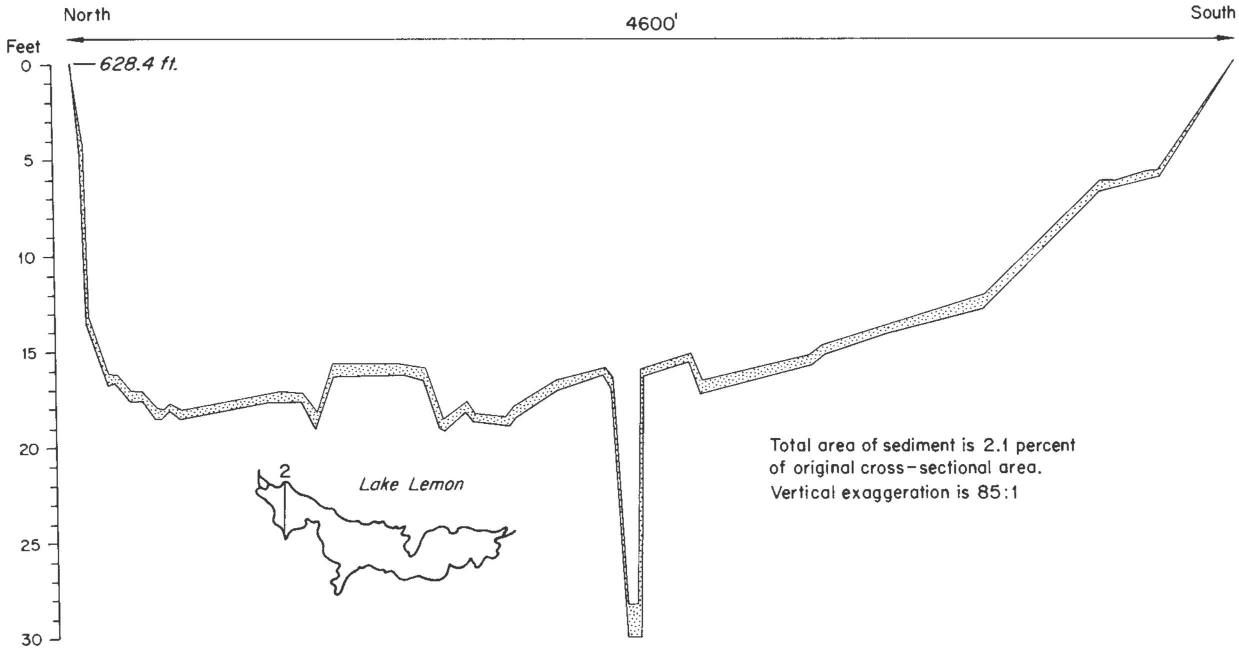

Figure 6. Cross section showing lake bottom configuration and sediment thickness for range line 2.

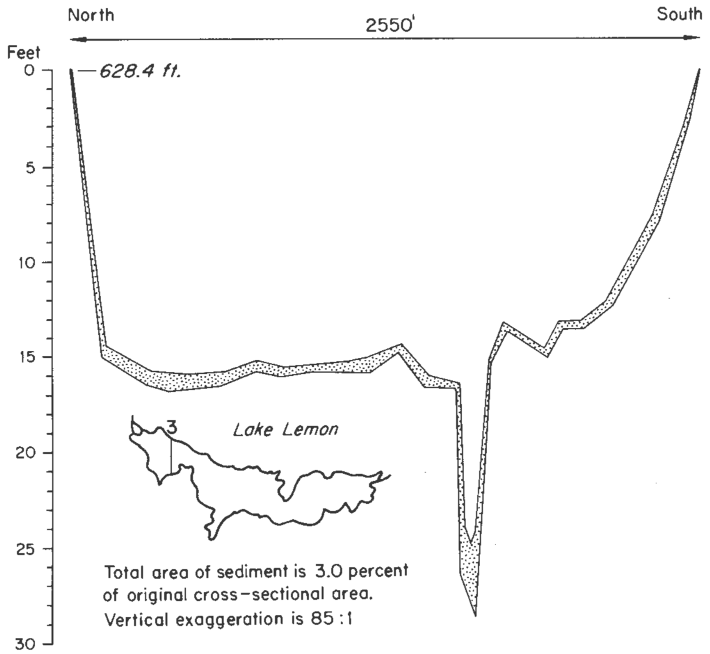

Figure 7. Cross section showing lake bottom configuration and sediment thickness for range line 3.

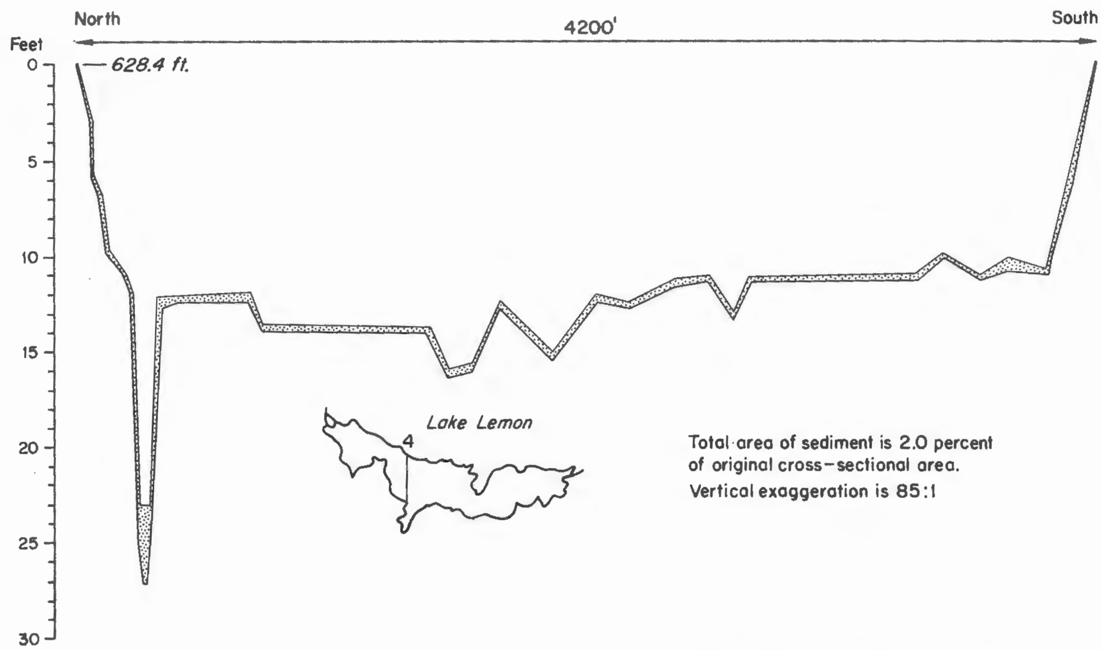

Figure 8. Cross section showing lake bottom configuration and sediment thickness for range line 4.

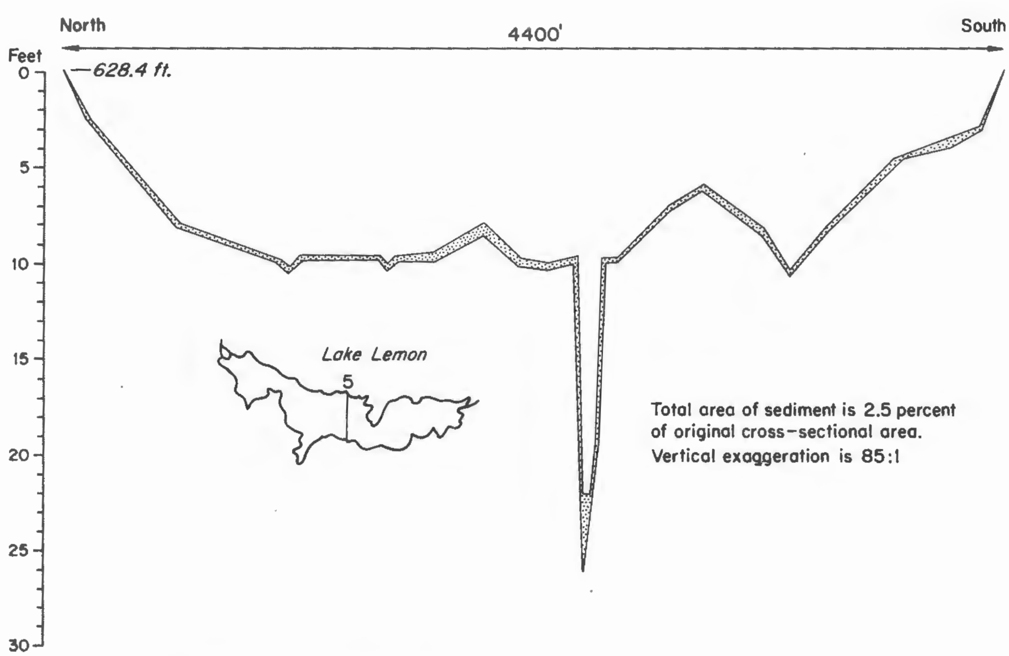

Figure 9. Cross section showing lake bottom configuration and sediment thickness for range line 5.

Table 1. Water depth and sediment thickness at sample locations in Lake Lemon
[in inches]

Sample location	Water depth			Sediment thickness		
	Average	Maximum	Minimum	Average	Maximum	Minimum
RL-1	91.2	222.0	36.0	3.8	14.0	1.0
2	168.0	216.0	33.6	5.1	22.0	1.0
3	182.4	220.8	36.0	6.8	16.0	2.0
4	153.6	174.0	96.0	4.3	12.0	2.0
5	88.8	240.0	33.6	4.8	18.0	1.0
6	136.8	235.2	96.0	8.9	22.0	1.0
7	87.6	180.0	27.6	6.6	16.0	2.0
8	39.6	66.0	30.0	7.7	24.0	2.0
Ra, east end	20.4	39.6	8.4	15.8	26.0	3.0

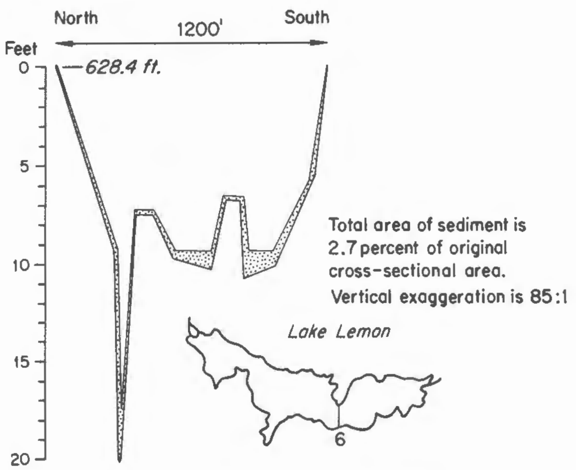

Figure 10. Cross section showing lake bottom configuration and sediment thickness for range line 6.

usually restricted to the shallow areas. Figures 7, 10, and 12 illustrate this assumption. The remaining cross sections, however, show degrees of variance in this anticipated pattern, especially the cross section of figure 9, which illustrates sediment accumulation in the shallower areas. Here sediments have their greatest accumulation along an elevated bottom plateau, probably in response to the current and to the subsequent energy patterns discussed on page 5. The old Beanblossom Creek channel, now inundated, affords the best example of sediment accumulation in a depression. We believe that currents induced by wave action and streamflow may act along the old channel, thus distributing sediments along its entire length. Truncation of the old channel at both the east and west ends of the lake makes escape of the channel bottom sediments unlikely there, and the steep sides of the channel itself prevent sediment scour transverse to the channel. The existence of such a current in a lake bottom channel has not, as yet, been documented.

From data on sediment thicknesses (table 1; fig. 3), it is apparent that the greatest accumulation of sediments is at the east end of the lake (figs. 13 and 14) near the ingress of Beanblossom Creek. The reasons for this relatively higher sediment accumulation have been discussed on page 5; but primarily the sudden loss of energy in Beanblossom Creek as it enters the reservoir accounts for deposition of most sediment in that area. The lesser factor is the sediment provided by the erosion of soils on the uplands adjacent to this area.

From the map (fig. 13) showing areal distribution of sediments and their corresponding thicknesses, it is evident that the greatest thicknesses occur in the channel and that progressive thinning takes place toward the shorelines. Anomalous patches of thicker accumulations are present throughout the lake and no doubt are a function of several potential variables. Although explanation of most of the thicker patches would be conjectural, one of the dominant causes in the eastern two-thirds of the lake is wind-generated wave action. Owing to the shallowness of the eastern part of the lake, wave-induced bottom currents are able to stir the bottom sediments and to bring about their selective redistribution. Another factor resulting in uneven sediment accumulation is the configuration of the shorelines. Projections, such as Reed and Riddle Points, create a venturi effect in the lake that modifies current patterns and velocities. Finally, drainage reentrants, such as Shuffle Creek, supply additional sediments in places to the lake from the adjacent uplands.

The accumulation of sediments in Lake Lemon during the past 20 years is only 3.4 percent of the original lake basin volume, which must be considered low. Most of the factors contributing to this condition cannot be quantified with the existing data. But in a qualitative sense three of the more important factors, all interrelated, appear to be: (1) dense vegetation throughout the drainage complex, which thus provides

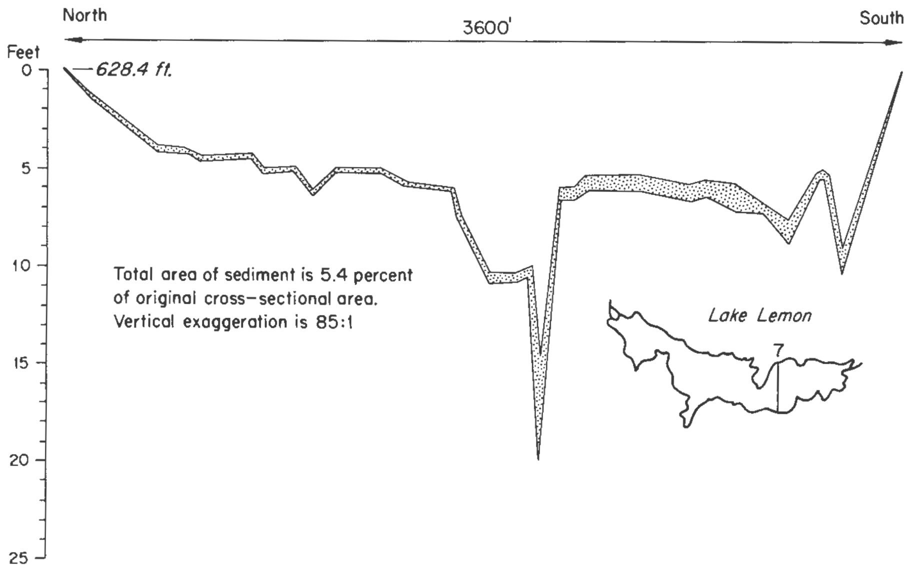

Figure 11. Cross section showing lake bottom configuration and sediment thickness for range line 7.

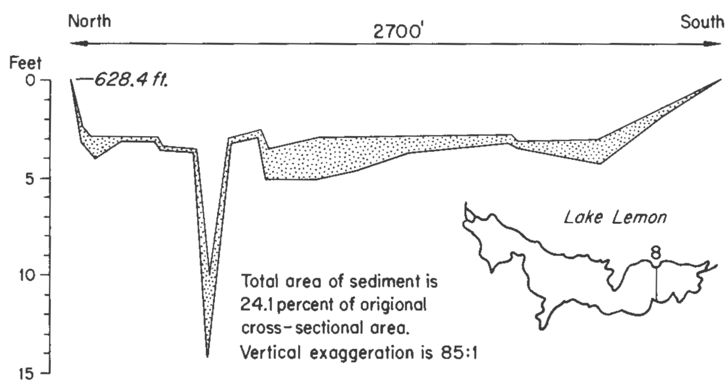

Figure 12. Cross section showing lake bottom configuration and sediment thickness for range line 8.

protection against fluvial and sheet wash erosion; (2) Beanblossom Creek has relatively low discharge and low energy and therefore does not transport large quantities of sediment, particularly not much coarse sediment; and (3) shoreline erosion. Although of minor significance, the erosion of shore materials by wave action does generate small amounts of sediments in the near-shore areas. Shoreline erosion is only of recognizable importance during storms when waves of relatively high intensity are produced.

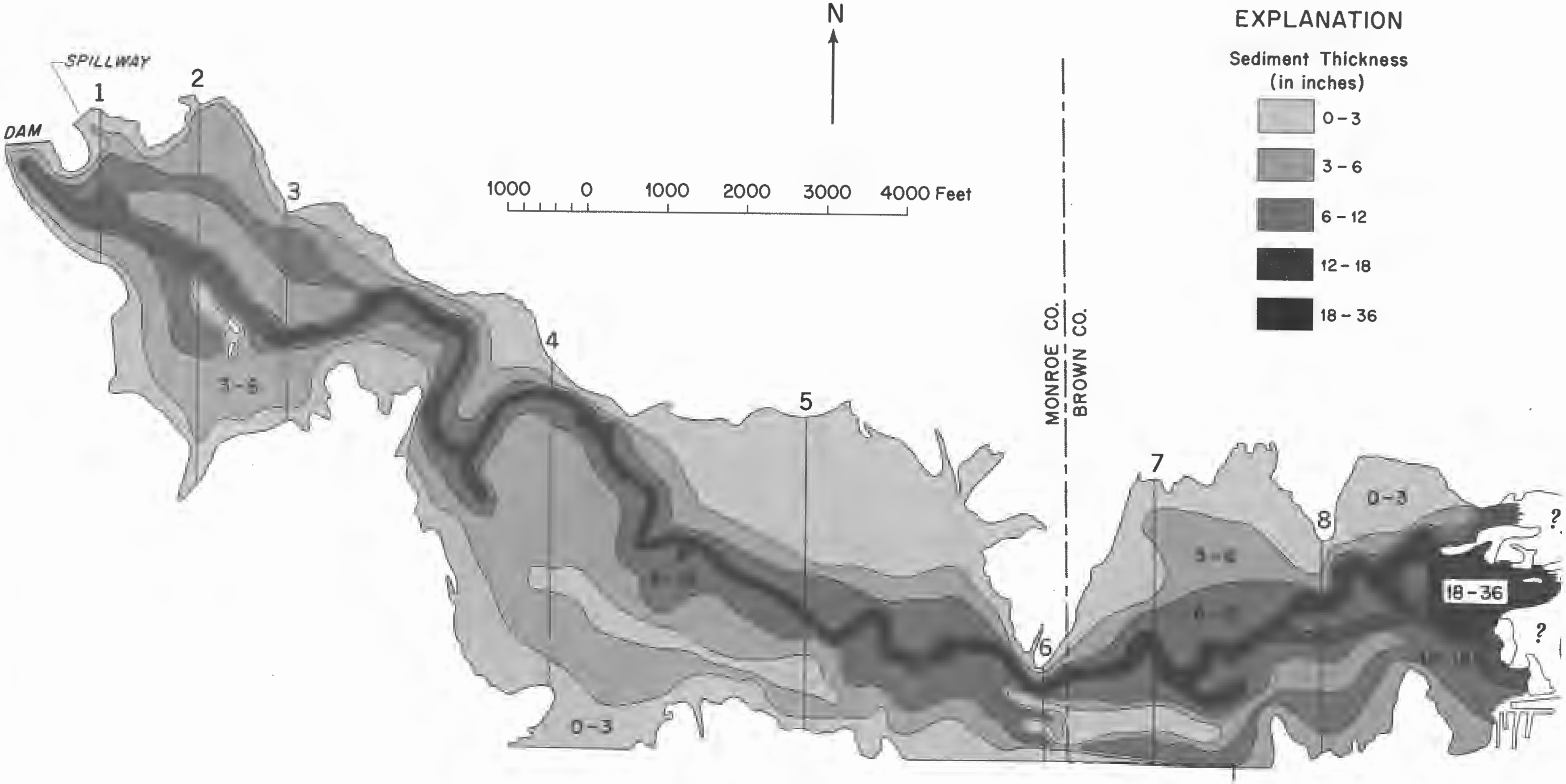

Figure 13. Map of Lake Lemon showing thickness of sediments.

Figure 14. Aerial photograph of the eastern one-third of Lake Lemon showing the distribution of bottom sediments.

Laboratory Analyses of Sediment Samples

BULK DENSITY

Only the laboratory results for bulk density and textural analyses are presented in this report. (Carbonate content and clay mineralogy data on these sediments are on file at the Indiana Geological Survey.) Bulk density, which is the weight of soil based on a definite volume that includes its natural pore space, is used as a measure of porosity and structural condition of soils. Bulk density was used to determine the degree of compaction of the samples taken in this survey. The different degrees of compaction enabled a pick to be made of the contact between the original bottom material and the new sediment entering the lake. The relative compactions also afford an idea of the amount of settling that might eventually occur within the new sediment. At each sample location, the new sediment has a lower bulk density (table 2) than the original bottom material. Because the original bottom was farmland, much of it shows the results of plowing and subsequent continued saturation in its relatively low bulk density values. (Bulk density for average soils generally ranges between 1.1 and 1.8 g per cm^3.) As additional sediments accumulate and weight is added, some additional compaction of the older sediments can be expected to occur, thereby effectively lowering the apparent present volumetric sedimentation rate and extending the life of the lake.

Table 2. Bulk densities of sediment samples from Lake Lemon[1]
[in grams per cubic centimeter]

Sample[2]		Bulk density[3]
No.	Location	
1	Ra-3 top	0.81
2	Ra-3 bottom	1.01
3	RL-3D top	0.76
4	RL-3D bottom	1.01
5	RL-3F top	0.69
6	RL-3F bottom	1.03
7	RL-3E top	0.67
8	RL-3I top	0.61
9	RL-3I bottom	0.99
10	RL-5G top	0.98
11	RL-5K top	0.97
12	RL-5K bottom	1.00
13	RL-5L reworked shoreline	0.83
14	RL-6F bottom	0.97
15	RL-7B top	0.68
16	RL-7F top	0.75
17	RL-7R bottom	0.95
18	RL-7G top	0.85
19	RL-8I top	0.91
20	RL-8I bottom	0.98
21	RL-8J top	0.83
22	RL-8J bottom	0.92

[1]Refer to figure 3 for location of range lines and random samples.

[2]Ra refers to random samples; RL refers to range line samples.

[3]Bulk density of water is $\frac{0.999\ g}{cm^3}$. Average bulk density of any soil is $\frac{1.1 \text{ to } 1.8\ g}{cm^3}$ in place. Particle density is $\frac{2.65\ g}{cm^3}$.

SUSPENDED SEDIMENT

To present a general picture of suspended sediment distribution and flow, a limited number of water samples was taken during varying stages of flow from within the lake and at inflow and outflow points (fig. 3). An additional sample site was selected downstream at the old Griffy water plant intake on Beanblossom Creek. This latter site was chosen to determine the effect of terrain and land use on sediment loads in Beanblossom Creek. The samples were taken both during and following the study in the autumn of 1973, when the lake was at a relatively low stage, and in the spring of 1974, when the lake was at spillway level. Concentrations of suspended sediment were determined in the laboratory by filtering the samples through a 0.45-micron Millipore filter.

Comparison of suspended sediment loads (table 3) indicates that the lake is in effect an active settling basin for Beanblossom Creek. The sediment load is dropped rapidly as the flow enters the lake and loses energy. Concentrations appear to vary erratically through the lake but are generally lower near the dam. This is particularly true during periods of high flow. A more detailed analysis is desirable but beyond the scope and intent of this study. Comparison of sediment loads above Lake Lemon in Beanblossom Creek and at the Griffy intake downstream shows a marked increase where the drainage area is largely agricultural rather than woodland, even though the stream gradient is less. The gradient is greater than 10 feet per mile above the lake and is less than 5 feet per mile below the lake.

TEXTURE

Of the several kinds of sediment analyses that were made, texture, or particle size of the materials, is one of the more important determinations because it can be related to the source area of the sediments as well as to their distribution throughout the lake. Table 4 summarizes the textures of 56 of the original 125 samples; the remaining 69 samples have too little recent sediment to yield reliable texture data. The table has data for at least four representative samples from each

Table 3. Suspended sediment of water samples taken during three distinctly different runoff regimes from nine sites in the Lake Lemon-Beanblossom Creek watershed

Sample location	Sample depth	Suspended sediment in milligrams per liter		
		Autumn 1973 (low stage)	Spring 1974 (high stage)	Spring 1974 (high stage)
1. Beanblossom Creek[1]	I[2]	——	7.6	31.0
2. Bear Creek[3]	I	——	3.8	20.0
3. Range line 7[4]	T[5]	2.6	2.4	16.0
	B[6]	6.3	7.8	33.0
4. Range line 5	T	0.8	3.1	13.0
	B	——	7.9	24.0
5. Range line 1	T	5.8	4.4	11.0
	B	7.2	5.6	19.0
6. Lake Lemon (near dam)	T	6.3	1.6	12.0
	B	11.0	6.8	19.0
7. Outflow (below dam)	I	——	4.6	22.0
8. Outflow (below spillway)	I	——	4.5	18.0
9. Beanblossom Creek[7]	I	19.0	14.0	29.0

[1]A mile from mouth at Lake Lemon.
[2]Indicates sample was integrated through entire depth.
[3]At entry into Beanblossom Creek.
[4]For range line location see figure 3.
[5]T indicates sample was taken 1 foot below surface.
[6]B indicates sample was taken 1 foot above lake bottom.
[7]At intake for old Griffy water plant.

of the sample range lines and good representation of the random samples taken at the east end of the lake (fig. 3).

The four defined particle sizes discussed in this section are granule, sand, silt, and clay. The Wentworth scale of diameters for these sizes is:

Granule . . . . . . 4 to 2 mm in diameter
Sand . . . . 2 to 1/16 mm
Silt . . . . 1/16 to 1/256 mm
Clay . . . . 1/256 to 1/2048 mm

Only sand, silt, and clay fractions were present in significant amounts. (Granules generally are present in amounts less than 2 percent by total weight.)

From the data in part B of table 4, it is clear that silt is the most abundant fraction and is followed by clay and sand in that order. Overall averages for the entire lake are 61.3 percent silt, 23.5 percent clay, and 3.9 percent sand. Although such averages can be misleading, the relatively high volume of silt in the sediments of Lake Lemon clearly reflects the abundance of that particle size in the soils and rock materials within the drainage complex.

A further point to note is that at the east end of the lake, where the Beanblossom enters, silt is highly concentrated. (See data for the random samples and range line 8.) The decrease in silt concentration especially west of range line 8 is due, as was explained on page 5, to the sudden loss of sediment-carrying capacity of the Beanblossom as it enters Lake Lemon. The heaviest particles drop out first, and the lightest fraction, clay, is held in suspension until very quiet water is reached. This principle is further borne out by the fact that the heavier sand particles tend to be deposited before the silt, as can be seen from samples 38 and 40 (table 4, part A).

Some anomalously high and low values of sand, silt, and clay, which do not fit the general observation of larger, heavier particle-size sediments at the east end of the lake and smaller, lighter particle-size sediments at the west end, have been obtained, however. For example, sample 32 from range 5 has 41 percent sand, a value much higher than generally expected for that middle reach of the lake. Also, sample 5 from range 2—a sample taken from an area of relatively low current energy near the west end of the lake—shows a rather high value of 18.6 percent sand. These anomalies

Table 4. Weight percentages of four size grades of 56 sediment samples from Lake Lemon

Part A. Raw data

Sample		Size grades[1]			
No.	Location	Granule	Sand	Silt	Clay
1	RL-2	0.0	5.5	72.3	22.3
2	do.	0.0	2.8	72.8	24.4
3	do.	0.0	0.7	69.5	29.8
4	do.	0.0	0.4	41.8	57.8
5	do.	0.0	18.6	64.2	17.2
6	do.	0.0	1.0	74.1	24.9
7	do.	0.0	3.8	81.1	15.1
8	RL-3	0.0	2.8	64.7	32.6
9	do.	0.0	7.3	65.4	27.3
10	do.	0.0	1.5	67.0	31.5
11	do.	0.0	2.8	59.5	37.7
12	do.	0.0	1.5	70.8	27.7
13	do.	0.0	0.7	73.9	25.4
14	do.	0.0	5.3	73.7	21.1
15	do.	0.0	1.8	71.5	26.7
16	do.	0.0	3.0	53.9	43.1
17	RL-4	0.0	3.0	68.2	28.8
18	do.	0.0	2.0	72.7	25.3
19	do.	0.0	2.8	68.3	28.3
20	do.	0.0	0.6	76.8	22.6
21	do.	0.0	1.3	78.3	20.4
22	do.	0.0	1.2	74.5	24.4
23	do.	0.0	2.5	77.2	20.4
24	do.	0.0	3.5	51.2	45.3
25	do.	0.0	17.0	59.3	23.8
26	do.	0.0	6.9	70.0	23.0
27	RL-5	0.0	4.8	75.6	19.6
28	do.	0.0	5.1	65.2	29.7
29	do.	0.0	3.0	76.9	20.1
30	do.	0.0	2.1	67.2	30.7
31	do.	0.0	1.9	67.4	30.7
32	do.	0.0	41.3	30.1	28.6
33	RL-6	0.0	7.5	73.0	19.5
34	do.	0.0	0.8	55.4	43.8
35	do.	0.0	0.6	55.1	44.3
36	do.	0.0	0.4	61.7	37.9
37	RL-7	0.0	1.3	62.7	35.9
38	do.	0.0	1.1	82.3	16.6
39	do.	0.0	10.1	70.3	19.6
40	do.	0.0	0.6	67.2	32.2
41	RL-8	0.0	1.2	82.3	16.5
42	do.	1.0	5.4	74.2	20.4
43	do.	0.0	0.4	81.3	18.2
44	do.	0.2	0.8	80.1	19.1
45	do.	0.0	1.3	81.4	17.3
46	do.	0.0	1.3	81.4	17.3
47	do.	0.0	2.8	75.3	21.9
48	do.	0.0	1.1	73.7	25.2
49	Ra-2	0.0	25.5	60.1	14.4
50	Ra-4	0.0	2.7	90.3	6.9
51	Ra-5	0.0	12.7	73.4	14.1
52	Ra-6	0.0	1.4	68.2	30.4
53	Ra-7	0.0	1.8	72.0	26.2
54	Ra-11	0.0	1.9	81.3	16.8
55	Ra-12	0.0	2.8	78.3	19.0
56	Ra-13	—	—	—	—

[1]Size grades are defined in accord with Wentworth scale.

Table 4. Weight percentages of four size grades of 56 sediment samples from Lake Lemon—Continued

Part B. Means and extremes of data

Sample location	Size grade								
	Sand			Silt			Clay		
	Mean	High	Low	Mean	High	Low	Mean	High	Low
RL-2	4.5	18.6	0.4	67.6	81.1	41.8	28.0	57.8	17.2
RL-3	2.8	7.3	0.7	66.0	73.9	53.9	30.1	43.1	21.1
RL-4	3.8	17.0	0.6	69.9	78.3	51.2	26.6	45.3	20.4
RL-5	9.3	41.3	1.9	64.6	76.9	30.1	26.1	30.7	19.6
RL-6	2.3	7.5	0.4	61.3	73.0	55.1	36.4	44.3	19.5
RL-7	3.27	10.1	0.6	70.6	82.3	62.7	26.1	35.9	16.6
RL-8	2.6	7.9	0.4	77.3	82.3	70.3	20.1	25.2	16.5
(all)	6.9	25.5	1.5	74.8	90.3	60.1	18.3	30.4	6.9
Entire lake	3.9	41.3	0.4	61.3	90.3	30.1	23.5	57.8	6.9

greatly alter average values for the sample series of which they are members. They probably should be ignored in this study because the high sand values very likely result from the mixing of the new lake sediments with sand deposits that predate the Lake Lemon materials and are not a part of the present regimen.

Generally speaking, the complexity of the textural data reflects the combined influence of wave-generated currents, stream currents, and sediment supply from the uplands adjacent to the lake. The textural data, taken together with information concerning suspended sediments, provide a good idea of the general manner in which the lake performs as a sediment trap and of the sources of sediment. From these observations, Beanblossom Creek is shown to be the dominant source of sediments in Lake Lemon, and the immediately adjacent uplands are shown to supply only minor amounts of materials. Careful observations during several years, however, could modify this view of the relative importance of the different sources and of the several interrelated distributional factors.

Conclusions

The sedimentation rate in Lake Lemon is a relatively low 0.17 percent per year. This is much lower than would be expected from a visual inspection of the lake. The water is murky brown and has a low vertical visibility of 6 to 12 inches in sunlight. If the lake water had proved to be as turbid as it appeared, the sediment load suspended in it would have been quite high. Such a circumstance would have been accompanied either by a very high sedimentation rate or by a high sediment flow. Suspended sediment was analyzed, however, and was found to be too low (0.8 to 7.2 mg per l) near the surface to cause the turbid appearance. Thus we believe that the turbid appearance is more likely caused by decay of the abundant forest litter that yields tannic acid, by other organic substances that discolor the water, and perhaps by the algae that feed on the organic matter.

The relatively low sedimentation rate, which has resulted in a reduction of 3.4 percent of the total lake volume, is due primarily to the considerable forest cover in the watershed. Urban development, except on the immediate shoreline, has been minimal, and little farming is carried on within the watershed. Each of these factors is variable, however, and if any of them is altered toward greater intensity, the sedimentation rate could be drastically increased and thus could shorten the effective life of the lake.

Projecting the present sedimentation rate of 0.17 percent (annual decrease in lake volume) into the future indicates that the capacity of the lake would be reduced by half in about 290 years. In all probability, however, the useful life, depending on water requirements, will be considerably less than the half life of the lake. Sediment infilling will effectively reduce the storage capacity and, consequently, the maximum sustained yield or maximum dependable water supply.

Weather, in addition to land use, is a variable condition that directly affects erosion and resultant sedimentation. A great part of the annual sediment load is directly related to the magnitude of stream discharge and to the duration of particularly high discharges, which are in turn related to precipitation. Because erosion is affected so greatly by rainfall, future increases (collectively or individually) in the amount of rainfall, in the intensity of rainfall, and in the cyclicity of rainfall could increase the sedimentation rate.

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