1-1-1981

Preliminary investigation of sedimentation in Lake Panorama, Iowa

Vernon Ray Schaefer
Iowa State University

Recommended Citation

Schaefer, Vernon Ray, "Preliminary investigation of sedimentation in Lake Panorama, Iowa" (1981). *Retrospective Theses and Dissertations*. 18633.
https://lib.dr.iastate.edu/rtd/18633

Preliminary investigation of sedimentation in Lake Panorama, Iowa

by

Vernon Ray Schaefer

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

Department: Civil Engineering
Major: Geotechnical Engineering

Approved:

Iowa State University
Ames, Iowa
1981

TABLE OF CONTENTS

INTRODUCTION

Erosion, transportation, and deposition of sediment are natural processes that have been occurring throughout time. With the construction of a dam across a waterway, it is inevitable that sedimentation will occur in the reservoir behind the dam. The extent of sedimentation is a function of many natural conditions occurring in the watershed above the dam. No matter what the intended use of the reservoir, the primary concern is the rate at which the sediment will accumulate and therefore the length of time during which adequate water storage will be available to the users of the reservoir.

Such a problem exists in connection with Lake Panorama, located in Guthrie County, Iowa. The location of the lake is shown in Figure 1. The reservoir, designed as a recreational and housing development, was developed privately, with planning beginning in the early 1960s by the Guthrie County Land Development Co. (Fruhling, 1979). The lake was formed by damming a segment of the Middle Raccoon River. The dam was completed in the summer of 1970 and the reservoir filled in August of that year.

The sale of property around the lake was to provide the source of income to fund the project. Money problems developed and bankruptcy of two development companies ensued. In 1976, one of the bankruptcy trustees suggested draining the lake and returning the area to agricultural production (Fruhling, 1979). Instead, the trustee arranged the sale of the property to Central Iowa Escrow, a subsidiary of Central

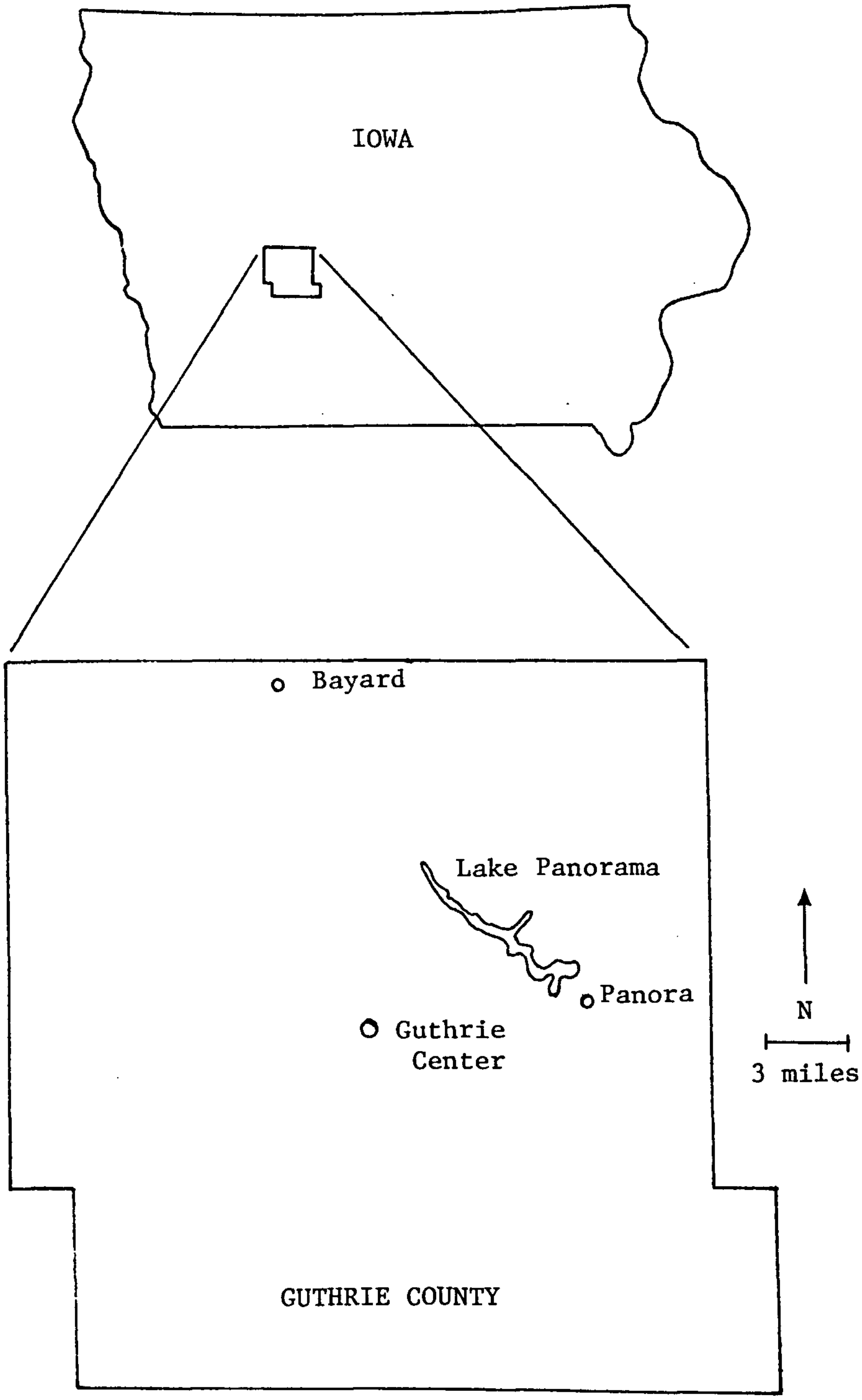


Figure 1. Location of Lake Panorama

Iowa Power Cooperative (CIPCO). The Central Iowa Energy Cooperative (CIECO) was then formed to manage the lake. The recreational facilities were sold to a new Lake Panorama Association, CIECO retaining water rights and some 1400 acres around the lake.

The watershed of the lake is situated in an area of intense cultivation and in geologic areas that produce high sediment yields. In the planning stages, the problems associated with sedimentation were recognized and recommendations such as silt traps above tributary coves were made. Within a few years of impoundment, sediment deposits formed in tributary coves and the upper reaches of the reservoir. Unfortunately, the companies operating the lake facilities could not afford the sediment abatement program recommended in the planning stages. With no provisions for reducing the sediment inflows to the lake, the problem continued, particularly in the upper reaches of the lake.

In the spring of 1977, CIECO engaged Shive-Hattery and Associates and Bechtel Associates Professional Corporation as consultants to evaluate the feasibility of using Lake Panorama as a source of cooling water for a coal fired power plant. The subsequent study identified sediment problems occurring at the lake and the report by Bechtel Assoc. (1977) estimated the rate of sedimentation in Lake Panorama. Three approaches were used in estimating the sedimentation rate: 1) a reservoir survey, 2) results of sediment gaging measurements, and 3) a regional analysis. This work produced a best estimate of 286 acre-ft/yr of sediment accumulation in Lake Panorama.

In an attempt to develop a sediment management plan, CIECO arranged to have Iowa State University and the U.S. Geological Survey do a more detailed analysis of the problem. In order to establish a sediment management program, estimates of sediment accumulation rate, water storage capacity, sediment unit weight, and sediment source areas need to be determined. This thesis is a part of that study.

LITERATURE REVIEW

Sources of Reservoir Sediment

The sources of sediment which deposit in a reservoir are in the lands of the watershed above the dam. The sediment delivered to the reservoir is generally from two broad classes of erosion sources (Foster and Meyer, 1977). The first is sheet and rill erosion, which is primarily an upland source. The second is channel erosion, resulting from a concentrated flow of water, and includes gully erosion, streambed, and streambank erosion. Glymph (1951) has introduced the term accelerated erosion to describe increased erosion and sedimentation due to man's activities. Indeed, man has added appreciable amounts of sediment to streams and reservoirs due to activities such as strip mining, construction, urban development, logging operations, and grazing and farming of agricultural lands (Vanoni, 1975).

Glymph (1957) states that "determination of sediment sources is one of the most difficult problems facing the watershed planning engineer; it is relatively much easier to estimate rates of sediment yield than it is to determine the source of the sediment." Thus, many studies have been conducted to determine rates of sediment yields (Gottschalk and Brune, 1950; Glymph, 1951; and Fleming, 1969); however, in all studies of sediment yield, the sediment source must be considered. Brune (1950) presented a dynamic concept of sediment sources in which the upland sources, sheet, rill, and gully erosion, diminish in importance with time. Conversely, the bottomland sources, streambed and bank erosion, floodplain scour and valley trenching, increase in importance as the watershed system tends to equilibrium.

Attempts have been made to quantify amounts of erosion from various sediment sources. Gottschalk and Brune (1950) found that in the Missouri Basin loess hills physiographic area, sheet erosion was by far the largest contributor to gross erosion. In a third of the watersheds studied, negligible gully erosion was taking place. The maximum amount of gully erosion occurring in any watershed was computed to be 24 percent of the total computed gross erosion.

Glymph (1957), in a study of 113 watersheds throughout the United States, found that in half of the watersheds sheet erosion accounted for 90 percent or more of the sediment at the point of measurement. In 73 of the watersheds, sheet erosion accounted for more than 75 percent of the sediment and in 89 watersheds sheet erosion accounted for 50 percent or more.

Empirical relationships have been developed by Musgrave (1947) and Wischmeier and Smith (1978) to calculate sheet and rill erosion. The relationships have been developed for small agricultural plots and are not generally applicable to large watersheds. Gully erosion has been quantified by a number of investigators (Thompson, 1964; Beer and Johnson, 1965; and Soil Conservation Service, 1966). These quantifications have been developed through empirical and statistical analyses of large data bases and are applicable to specific physiographic areas.

The volume of material eroded in an area does not necessarily equal the volume of sediment that will be produced from that area. Due to redeposition of eroded soil en route, the sediment yield of an area is generally much smaller than the amount of eroded soil. To analyze sediment yield, the factors which affect the sediment must be considered. Many studies have been conducted to analyze the variables affecting sediment yield from various physiographic areas (Brune and Allen, 1941; Gottschalk and Brune, 1950; Flaxman and Hobba, 1955; Glymph, 1954; and Maner, 1958). Glymph (1954) offers one of the more complete lists of factors affecting sediment yield. In outline form, he lists the following:

A. Soils

    1. Parent material
    2. Texture
    3. Organic content
    4. Chemical constituents

B. Cover

    1. Permanent vegetation -- type, age, density
    2. Impermanent vegetation -- kinds of crops, growth characteristics, age, density

C. Precipitation

    1. Form
    2. Seasonal occurrence
    3. Intensities
    4. Amount

D. Drainage area and topographic features

    1. Size
    2. Shape
    3. Drainage pattern and density
    4. Length of land slope
    5. Degree of land slope

E. Channel types

1. Shape, size, and cross section
2. Slope
3. Erodibility of bed and bank

F. Runoff

1. Rate
2. Duration
3. Amount

G. Soil and cover management practices

Kind and amount of soil and cover management practices, including crop rotations, fertility amendments, grazing rates, fire protection, etc.

H. Conservation practices and watershed treatment measures

Kind and amount of conservation practices and watershed treatment measures, including tillage methods, terracing, waterways, channel stabilization, detention reservoirs, etc.

A quantitative evaluation of these factors would be a monumental task. The Universal Soil Loss Equation (USLE) attempts to take into account many of these factors (Wischmeier and Smith, 1978). The drawback of the USLE is that it is generally applicable to small areas and agricultural lands.

The total sediment outflow from a watershed is defined as the sediment yield (in volume/unit area), and the ratio of sediment yield to gross erosion is termed the sediment delivery ratio (expressed as a fraction) (Glymph, 1954). Using reservoir survey records and suspended sediment-streamflow data, sediment yields from watersheds in various physiographic areas have been computed (Gottschalk and Brune, 1950; Maner, 1958; and Upper Mississippi River Basin Coordinating Committee, 1970). In most cases, the sediment yield is compared with the drainage area of a watershed and composite curves developed.

The general trend has been found to be that sediment yield rates decrease with increasing drainage area. Brune (1950) cites two reasons for this. First, decreasing stream gradients result in lower eroding and carrying capacity. Second, the decreasing frequency of basin-wide, high intensity storms results in deposition of sediment in colluvial areas, on floodplains, and in channels. Vanoni (1975) has produced composite curves relating the sediment yield and the sediment delivery ratio to the drainage area from a number of studies.

Measurement of Reservoir Sedimentation

The measurement of reservoir sedimentation entails the collection of field data, which are used to make computations to determine the amount of sediment deposited in the reservoir since it was impounded. The two principal methods of determining sediment accumulation are by reservoir sediment surveys and by streamflow sampling of the suspended sediment (Glymph, 1954).

Reservoir surveys are conducted at various times to update sedimentation volumes by comparing the present accumulation to a previous accumulation or to the original topography (Gottschalk, 1952). The primary purpose of a survey is to obtain accurate estimates of the sedimentation rate for the reservoir. In addition, the survey also acquires data on the sediment distribution in the reservoir, the sediment yield of the watershed, and density currents (Gottschalk, 1964).

The frequency of a survey depends upon many factors. Vanoni (1975) lists reasons for a new survey along with a set of guidelines indicating the necessity of a new survey. These include a check of sediment gaging records, field observations during drawdown, reconnaissance measurements on key ranges, and special problems or new uses of the reservoir.

There are two methods to survey the reservoir: the contour method and the range method (Gottschalk, 1952). The choice between the two depends upon the apparent amount and distribution of the sediment, the accuracy required, the purpose of the survey, the availability of previous maps, and the cost (S.C.S., 1973).

In the contour method, topographic mapping procedures are used to establish elevations for the present sediment surface and contours of equal elevation are drawn. The area between the contours is planimetered and the volume of sediment computed when compared with a previous contour map. The advantage of this method is that it supplies both the horizontal and vertical distribution of sediment and permits plotting of reservoir capacity curves. It is also more advantageous in areas where the sediment accumulations are large or irregularly deposited, since it provides better identification of the bottom profile. The big disadvantages of the contour method are its relatively high cost and the amount of time necessary to complete the survey (S.C.S., 1973).

Heinemann and Dvork (1965) describe four methods for computing sediment accumulations from contour surveys. These methods are: stage-area, modified prismoidal, Simpson's rule, and the average contour area. According to their study, the stage-area method of calculation provides the best results.

The range method is the second method of conducting a reservoir survey. This method is used where good original maps are not available (Gottschalk, 1952). Simultaneous soundings of water depth and of sediment thickness are made along ranges established at regular intervals. These data are plotted on cross sectional paper and the volume computed on the basis of the segment area between the ranges.

The computation of the volume can again be accomplished by several methods. Heinemann and Dvork (1965) describe four methods of computation: Eakin's range end formula, cross sectional area versus distance from dam curve method, Simpson's rule, and the average-end-area method. Gottschalk (1952) describes two methods, the Dobson prismoidal formula and the average-end-area method. According to Gottschalk (1952), the range method will provide results well within 10 percent of the true value on reservoirs with irregular shapes, many embayments, and/or long winding arms. Values within two percent can be expected on regularly shaped reservoirs.

The equipment needed for reservoir surveys has evolved from simple sounding weights and tag lines to sophisticated electronic fathometers and electronic distance measuring equipment. Gottschalk (1952) describes the necessary equipment as the boat and associated gear, range-cable equipment, sounding equipment, equipment for measuring sediment thickness, and equipment for sampling or determining the unit weight of the sediment. Vanoni (1975) provides a complete listing of the various types of equipment that are available for the collection of data. An account of the evolution of the equipment in the past 30 years is provided by Gilmore (1977). Pemberton and Blanton (1980) describe the recent advances by the Water and Power Resources Service in using an electronic positioning system for reservoir surveys. This system incorporates advanced technology to allow automatic data processing in the field.

Another method for determining the sedimentation rate for a reservoir is by monitoring the suspended sediment load above and below the reservoir. This is accomplished by any of a number of samplers available. Many sampling devices were developed in the landmark Interagency Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams during the 1940s. A recent discussion of these and other sampling devices is given by Vanoni (1975).

Using the suspended sediment and discharge data collected over a period of time, a sediment rating curve can be generated. Campbell and Bauder (1940) and Miller (1951) describe the methodology of developing a rating curve. From these curves, the weight of sediment deposited in the reservoir is computed. Using the unit weight of the sediment, the volume of space the sediment will occupy in the reservoir is computed.

In using a sediment rating curve to estimate the amount of sedimentation, correction must be made for the bed load of the stream. There are two methods to determine bed load (Lane and Borland, 1951): 1) assuming bed load is the difference between that determined by a reservoir survey and the suspended sediment rating curve, and 2) by the use of bed load equations. Lane and Borland (1951) discuss the factors affecting bed load and the criteria used to estimate the bed load. Vanoni (1975) offers a complete listing of bed load formulas and their use. In practice, bed load is difficult to determine and usually is estimated at between 5 and 25 percent of the suspended sediment load (Miller, 1951).

The sediment rating curve technique has been criticized because of the wide variability of the data and the reliance upon short time spans to predict long term conditions. Studies by Campbell and Bauder (1940), Miller (1951), and Walling (1977) assess the accuracy of the method. In all of the studies, the rating curve was found to be a poor predictor using short term records, but when long term data were available, long term predictions appeared to be within reason.

When using sediment rating curves, a trap efficiency must be determined. This is applied to the data to determine how much of the sediment is being retained in the reservoir.

Trap efficiency of a reservoir is defined as the ratio of sediment accumulation to sediment inflow (Brune, 1953). As implied, trap efficiency is the effectiveness of a reservoir in retaining the delivered sediment.

One of the earlier studies of trap efficiency was conducted by Brune and Allen (1941), who developed a curve relating the percent of eroded soil trapped in a reservoir to the original capacity of the reservoir. Values for the trap efficiency were low because gross erosion far exceeds the amount of sediment delivered to the reservoir.

Brown (1943) developed an equation relating true trap efficiency to the capacity-watershed ratio (the storage capacity of the lake in acre-feet to the drainage area of the watershed in square miles) and observed that considerable variation occurred between values predicted by the equation and values measured in the field. Moore et al. (1960) point out that this variation exists because reservoirs having the same capacity-watershed ratio may have a very different capacity-inflow ratio.

Brune (1953), in the most comprehensive study of trap efficiency, found that a number of factors affect trap efficiency. These include the ratio between storage capacity and inflow, age of the reservoir, shape of the reservoir basin, type of outlets and method of operation, the grain-size characteristics of the sediment, and the behavior of the finer sediment fractions under various conditions. Using data from 44 reservoirs across the U.S., Brune (1953) developed a curve relating trap efficiency to capacity-inflow for normally ponded reservoirs. The correlation between trap efficiency and capacity-inflow ratio was much better than that between trap efficiency and capacity-watershed ratio.

When sediment load measurements cannot be made at a site prior to construction of a structure, the probable sediment yield can be estimated on the basis of measurements from the general region of the watershed (Gottschalk, 1957). For this purpose, both sediment-load records and reservoir survey results can be utilized. Usually, the known data for the region are plotted against drainage areas and a design curve established (Vanoni, 1975).

The unit weight of sediment must be known to convert weight estimates to volume estimates. Studies began in the 1930s to estimate the unit weight of sediment deposits. Lane and Koelzer (1943), in a comprehensive literature review, found unit weights varying from 30 to 125 lb/ft^3 reported. A unit weight between 50 and 70 lb/ft^3 was normally used for design purposes. Trask, as cited by Lane and Koelzer (1943), found that the initial density increased as particle size increased. According to Lane and Koelzer (1943) three factors affect the unit weight: 1) reservoir operation, 2) sediment particle size, and 3) rate of compaction of the sediment. Koelzer and Lara (1958) further studied the effect of the rate of compaction upon density. From their research, the primary factors influencing rate of compaction are the weight of overlying sediment, the degree of exposure to drying, particle size, permeability, and time.

Because reservoir operation is considered to be the most influential of the factors affecting unit weight, Lane and Koelzer (1943) divided reservoir operation into four classes. Using all available data, equations were derived relating the unit weight to the percentage of sand, silt, and clay of the sediment.

Miller (1953), in applying Lane and Koelzer's relationships to measured values, found that for samples of predominantly sand, the values are usually satisfactory; however, for sediment in which clay-sized particles predominate, the results tend to be too high. He concluded that Trask's work, cited by Lane and Koelzer, seems more applicable for fine grained sediments.

Lara and Pemberton (1965) updated the study of Lane and Koelzer (1943) to produce equations based upon regression analysis. They include data used by Lane and Koelzer and the available data from the 20 years between the studies. The classification system used was slightly altered, but essentially the same.

Heinemann (1962) reports on a study which relates in-place unit weights determined by piston tube sampling and measured by gamma probe. The two measurements agree reasonably well, with unit weights determined by the gamma probe being slightly higher. In addition, Heinemann studied the effect upon unit weight of depth of sediment, percentage of clay, distance on range from thalweg, and distance from dam. Using multiple regression analysis, eight combinations of these independent variables were made. This study found that as the clay content increased, the unit weight decreased, and that the percentage of clay was such a dominant parameter that the other variables appeared to be of little value.

INVESTIGATION AND RESULTS

An investigation of the sediment problem of Lake Panorama has been conducted. The main emphasis of this study is the determination of the rate of sedimentation of the reservoir, with supporting studies of the sediment properties, shoreline erosion, and the expected levels of storage capacity.

Lake Morphometry

An important aspect concerning a reservoir is the watershed area draining into the impoundment. Using U.S. Geological Survey 1:250,000 scale topography maps, the watershed area was interpreted and determined to be 440 square miles. The runoff from this watershed contributes sediment to a lake having about 1120 acres of surface area at the normal operating elevation of 1045, National Geodetic Vertical Datum.

Lake Panorama is a long narrow impoundment, following a northwest-southeast orientation. The distance from the dam to the upper end of the reservoir stretches almost seven miles. In this distance, the width of the lake rarely exceeds 1000 feet, except for the southeast portion of the lake which forms an open area ½ mile wide by 1½ miles long. The shoreline length of the lake is just under 28 miles.

In order to determine the effect that sedimentation has on the storage capacity of a lake it is necessary to know the original storage capacity of the lake. The storage capacity has been found for Lake Panorama using topographic maps which were made for the design of the lake. The maps were planimetered using a Numonics Graphic Calculator and the areas found for each five foot contour interval above the dam to elevation 1045. The results of these measurements appear in Table 1. As indicated, the original capacity of Lake Panorama is 19,345 acre-ft. This figure is approximate due to possible mapping and planimetering errors, but can be assumed to be reasonably close to the actual storage capacity.

Geologic Setting

The watershed above Lake Panorama dam comprises about 440 square miles and is divided into two principal geologic areas. The northeastern two-thirds of the watershed is Wisconsin glacial till, whereas the remaining southwestern area is loess capped Kansan till. The Middle Raccoon River is the dividing line between these two areas throughout most of the watershed. The watershed and geology are shown in Figure 2.

The Wisconsin till area is a portion of the Des Moines lobe which was deposited by glaciers 14,000 to 13,000 years ago. The terminus of the lobe is the Bemis moraine; this marks the maximum advance of the glacier during the Wisconsin glacial period (Prior, 1976). The Middle Raccoon River flows along the western edge of the Bemis moraine.

The Clarion-Nicollet-Webster soil association predominates in the Wisconsin till area. The topography is nearly level to gently sloping in the central portions of the lobe, with more steeply sloping areas on the terminal moraines and nearer the Middle Raccoon River (Oschwald et al., 1965).

The loess capped Kansan till is part of the Southern Iowa Drift

Table 1. Original Lake Panorama storage capacity[a]

Elevation	Area acres	Capacity acre-ft
1005	13	0
1010	33	116
1015	189	671
1020	306	1907
1025	434	3756
1030	576	6280
1035	776	9658
1040	989	14068
1045	1122	19345

[a] Operating level of the lake is elevation 1045, National Geodetic Vertical Datum.

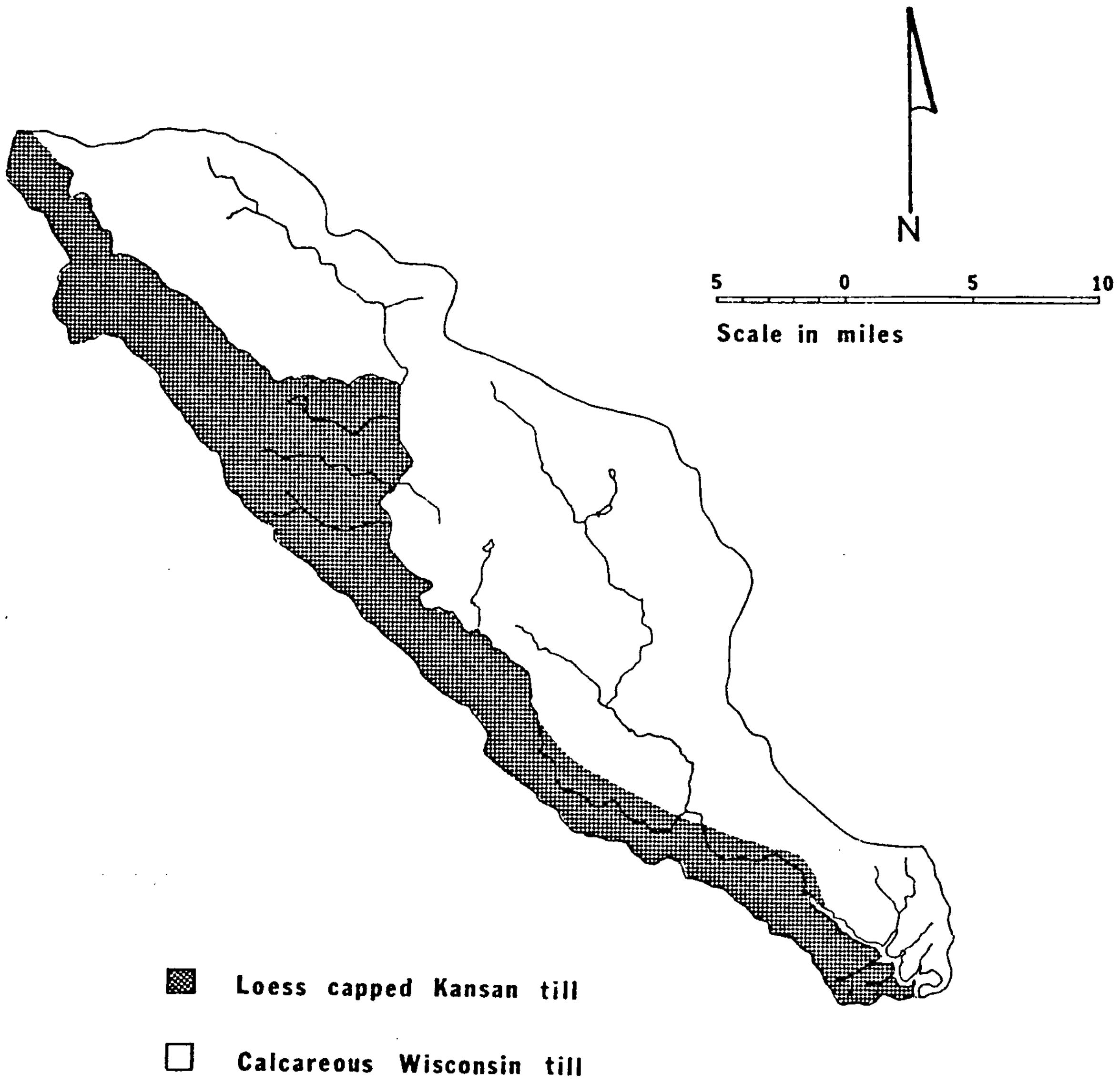


Figure 2. Geology of Lake Panorama watershed

Plain. The topography of this area differs from that of the Wisconsin till plain because it was subjected to subsequent loess deposition and to wind and water erosion for a much longer time. The most recent glacier in the Southern Drift Plain retreated about 600,000 years ago. This erosion has eliminated the characteristic morainal and bog features found in the Des Moines lobe (Prior, 1976).

At the surface of the Kansan till is an ancient soil profile, or paleosol, which developed during the Yarmouth and Sangamon interglacial stages. This paleosol is evidence of long exposure to weathering and deep soil development. The paleosol contains large amounts of clay which act as an effective barrier to the downward movement of water (Ruhe, 1969).

Loess (wind blown silt) deposition in the area took place during the Wisconsin glacial era and covered the Kansan till. This loess mantle is sufficiently thick in many places to alter slope angles and provide additional relief. Due to the stream erosion, a dendritic drainage pattern has developed. In some locations deep valleys have cut through the sequence of loess, paleosol, and glacial drift to the underlying bedrock, where the entire stratigraphic sequence can be found outcropping along the valley wall.

Two soil associations are present in the loess capped Kansan till portion of the watershed: the Marshall soil association in the northern half of this area and the Shelby-Sharpsburg-Macksburg soil association in the southern portion (Oschwald et al., 1965).

The native vegetation 80 to 100 years ago was a variety of prairie grasses, with trees found only in the areas bordering streams. Today, the area is under heavy row-crop cultivation, primarily corn and soybeans.

The climate of the area is characterized as humid, with about 31 to 32 inches of precipitation occurring annually. The normal precipitation during the growing season is 23 inches (Iowa Natural Resources Council, 1978) and the average seasonal snowfall is 30 inches per year (Waite, 1970). Average annual surface runoff from this area is five inches (Wiitala, 1970). The mean annual temperature is just under 50 degrees Fahrenheit (Iowa Natural Resources Council, 1978).

Reservoir Survey

Methodology of the survey

A survey of Lake Panorama was conducted to determine the amount of sediment present in the reservoir. This was accomplished using a range-survey technique whereby ranges were established perpendicular to the shore. The procedure followed closely that outlined by Gottschalk (1952). A tag line was used to measure the distance across the range and to provide stability to the boat. The location of each end of the range was noted and a picture taken showing the attachment of the tag line. This aids in future location of the range.

The depth of water along each range was recorded by two procedures. After the tag line was secured, a traverse across the range was made in the boat with an electronic depth fathometer equipped with a recording chart. This provided a continuous profile of the water depth across each range. Additionally, at each interval in which a sediment sounding was made, the water depth was measured using a 25 pound sounding weight.

A cross section of the sediment thickness was developed by probing the sediment at intervals across the range with a 3/4" diameter sounding pole marked at one foot intervals. The sounding pole was pushed into the sediment to a depth at which the resistance increased markedly. This increase was interpreted as resulting from the contact between the lake sediments and the underlying preimpoundment alluvium. Sediment depth was determined to the nearest tenth of a foot.

Sediment samples were obtained at each range. The location of sampling was dependent upon the profile, with samples collected from areas on the range where depositional conditions might differ, i.e. on the floodplain and in the old channel. The sampling process and analysis of the sediments is described in the section on sediment properties.

Data collected

Sixteen ranges were established across Lake Panorama, including three in adjoining coves. The locations of these ranges are shown in Figure 3. The ranges are numbered according to the distance in miles above the dam. The ranges in the coves are marked as to north cove or west cove. The depth of sediment and depth of water at intervals across each range and the distance across range were recorded.

These sediment depth data were plotted, with the aid of the original topographic maps, to develop cross sections from which the sediment volume calculations were made. The cross sections developed

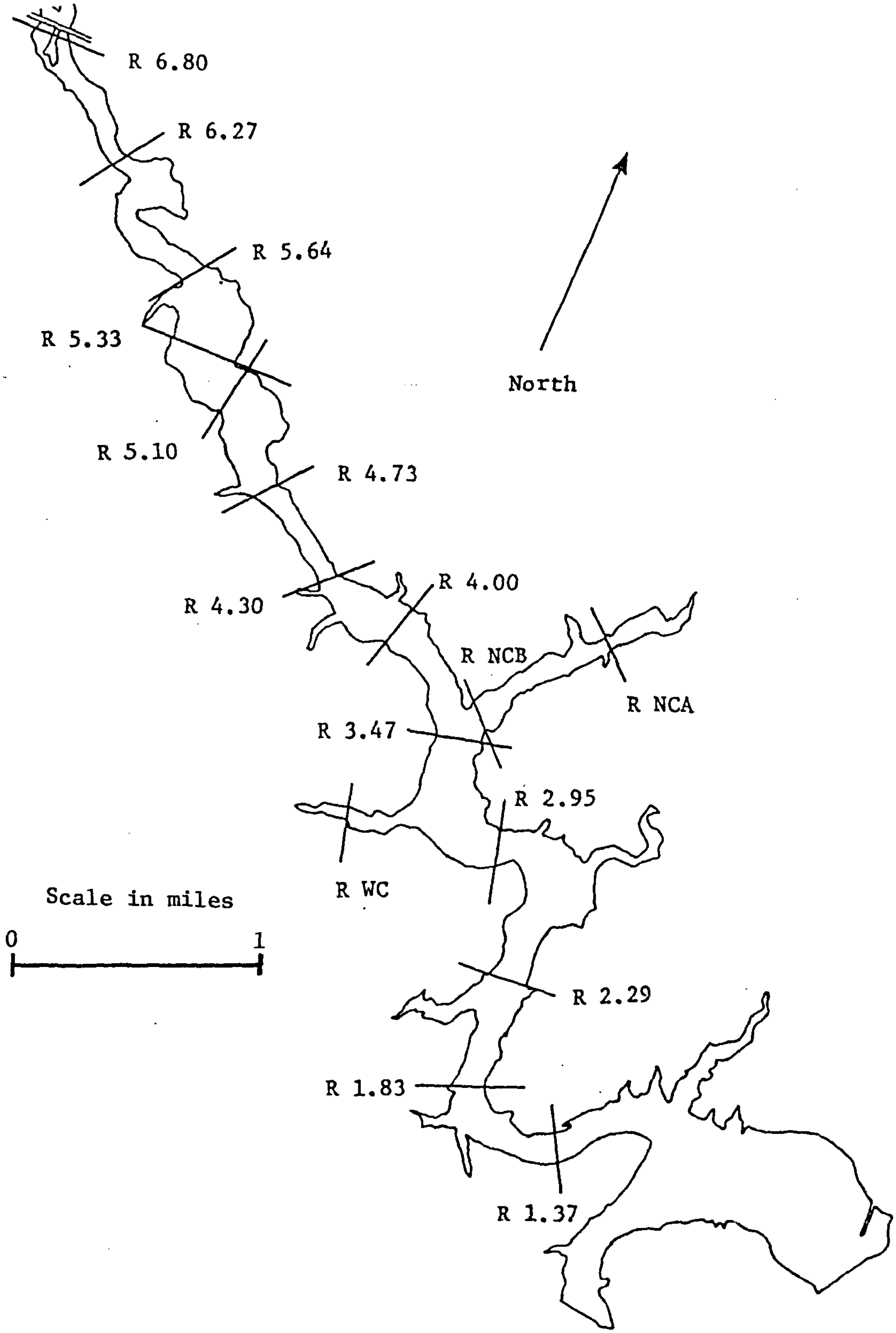


Figure 3. Location of sediment ranges

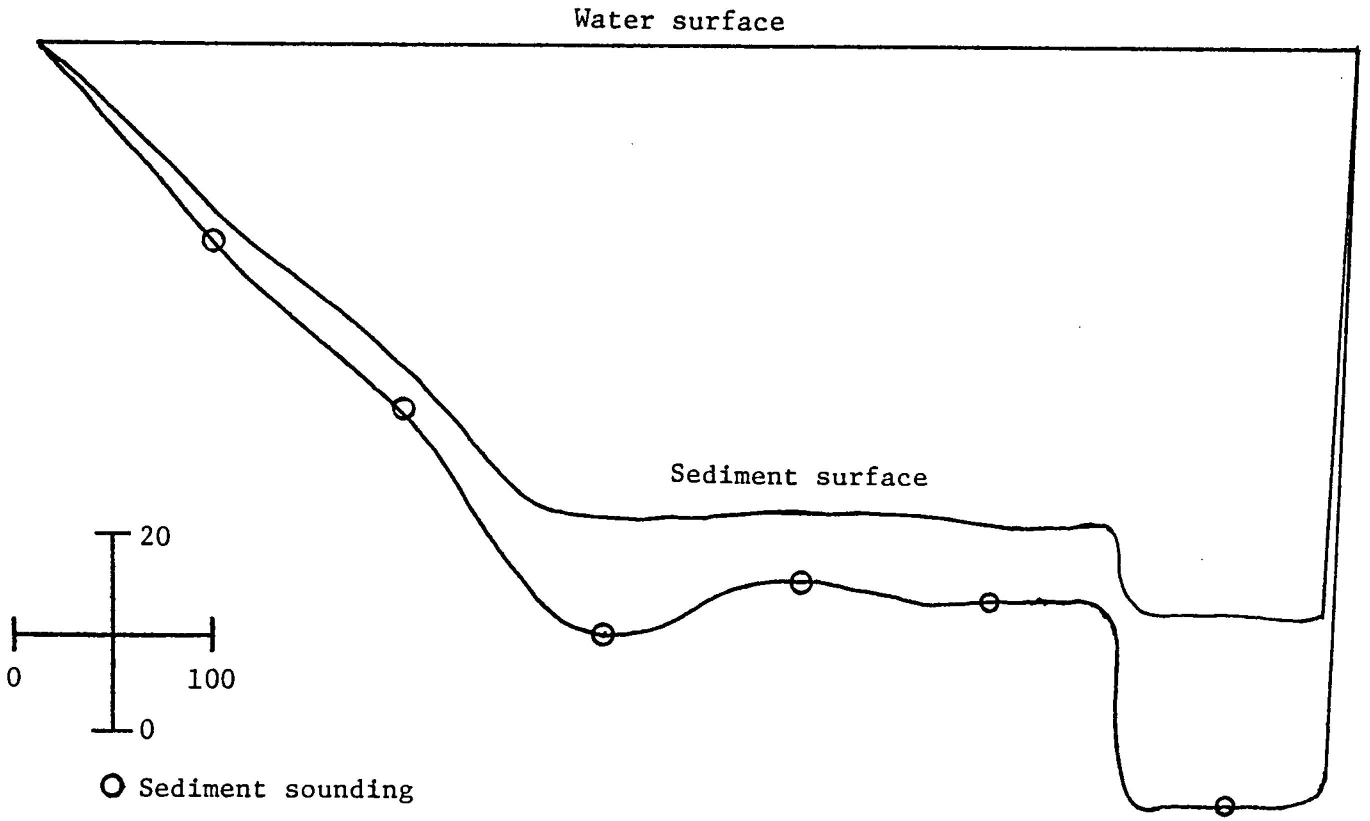


Figure 4. Cross section of range 1.37

for each range can be found in Appendix A. Figure 4 shows Range 1.37 as an example.

Methods of calculation

In order to calculate the amount of sediment accumulated from the range survey data, several bits of information must be obtained. First, the data collected in the survey must be analyzed, to produce usable numbers for sediment accumulation calculations. In this study, two methods were used to analyze the data. These consist of the average-end-area method described by Gottschalk (1952) and a variation of the average-end-area method used by Bechtel Assoc. (1977).

In both methods, the area between ranges must be determined in order to calculate the volume of sediment between ranges. For this purpose, the location of each range was plotted on a 1 inch = 500 feet scale map of the lake. This map was developed from aerial photography provided by CIECO. The area between each range was planimetered using a Numonics Graphic Calculator and the area converted to acres. Table 2 shows the area between ranges.

In the average-end-area method, the average depth across a range is determined by planimetering the area of the cross section of sediment thickness versus horizontal distance across the range and dividing this area by the distance across the range. The area of sediment from each plot was also measured with a Numonics Graphic Calculator. The distance across the range is the distance measured in the field. Table 3 summarizes the results of these measurements and calculations.

Table 2. Area between ranges

Range	Area between ranges acres
1.37	
	56.8
1.83	
	56.6
2.29	
	104.0
2.95	
	63.5
3.47	
	50.4
4.00	
	31.6
4.30	
	21.2
4.73	
	48.5
5.10	
	37.5
5.33	
	49.9
5.64	
	50.6
6.27	
	42.5
6.80	
	22.4
Upstream	
NCB	
	36.6
NCA	
	21.0
Upstream	
WC	
	18.6
Upstream	

Table 3. Area-length-depth relationships of ranges for use in average-end-area method

Range	Area of sediment ft^2	Length of range ft	Average depth of sediment ft
1.37	2870	670	4.28
1.83	1840	630	2.92
2.29	1815	695	2.61
2.95	4325	960	4.51
3.47	2890	1010	2.86
4.00	3825	840	4.55
4.30	2100	395	5.32
4.73	3845	630	6.26
5.10	7470	980	7.62
5.33	8240	1550	5.32
5.64	3620	640	5.66
6.27	1465	355	4.13
6.80	980	210	4.67
NCA	1030	300	3.43
NCB	965	610	1.58
WC	775	280	2.77

Using the information in Tables 2 and 3, the volume of sediment between ranges can be computed. The average sediment depth of two adjacent ranges is averaged and this average is multiplied times the area between the ranges. Table 4 summarizes the results of these calculations.

By adding the volumes found between adjacent ranges, the total volume of sediment above Range 1.37 was found. Using the average-end-area method, 2926 acre-feet of sediment has accumulated above Range 1.37.

The second method used to determine the sediment volume accumulation is a variation of the average-end-area method employed by Bechtel Assoc. (1977). This procedure, referred to here as the Bechtel method, involves averaging the individual sediment probe measurements for a range. Those probe measurements in the old river channel are deleted from the above average. This average is then used to calculate the sediment volume between adjacent ranges similar to the average-end-area method. A separate calculation for the amount of sediment in the channel is made. Original topographic maps are used to determine the length and width of the channel segments between adjacent ranges. The Bechtel method was used with the data collected in this study to allow comparisons between this study and the Bechtel Assoc. study.

For the Bechtel method, the length, width, and depth of the original channel were needed. The length and width were determined from 1965 topographic maps of the area, and the measurements are shown in Table 5. The depth of the channel was more difficult to ascertain.

Table 4. Sediment volume calculations by the average-end-area method

Range	Ave. sediment depth ft	Ave. of adjacent ranges ft	Area between adjacent ranges acres	Sediment volume acre-ft
1.37	4.28			
		3.60	56.8	204.5
1.83	2.92			
		2.77	56.6	156.8
2.29	2.61			
		3.56	104.0	370.2
2.95	4.51			
		3.69	63.5	234.3
3.47	2.86			
		3.71	50.4	187.0
4.00	4.55			
		4.94	31.6	156.1
4.30	5.32			
		5.79	21.2	122.7
4.73	6.26			
		6.94	48.5	336.6
5.10	7.62			
		6.47	37.5	242.6
5.33	5.32			
		5.49	49.9	274.0
5.64	5.66			
		4.90	50.6	247.9
6.27	4.13			
		4.40	42.5	187.0
6.80	4.67			
		2.34	22.4	52.4
Upstream	0			
NCB	1.58			
		2.51	36.6	91.9
NCA	3.43			
		1.72	21.0	36.1
Upstream	0			
WC	2.77			
		1.39	18.6	25.9
Upstream	0			
			Total	2926

Table 5. Length, width, and depth of channel sediments for use in Bechtel method

Range	Length feet	Width feet	Depth feet
1.37			
	3170	90	9.25
1.83			
	2450	90	9.25
2.29			
	4800	90	9.05
2.95			
	3020	90	8.20
3.47			
	3420	85	9.30
4.00			
	2020	90	9.75
4.30			
	2390	90	7.95
4.73			
	2900	90	9.70
5.10			
	1580	90	7.95
5.33			
	2380	90	7.05
5.64			
	4220	90	9.85
6.80			

The channel depth was interpreted from sediment sounding data obtained during the 1979-80 range survey. On those ranges where good data were not available, a channel depth of nine feet was assumed, as this is the channel depth shown on Iowa Department of Transportation cross section maps for bridges that once crossed the Middle Raccoon River where Lake Panorama is now. The channel depth used in the calculations was then found by averaging the channel depth of adjacent ranges. This depth is shown in Table 5. The sediment in the channel is found by multiplying the length, width, and depth of the channel together, and converting to acre-feet.

Table 6 shows the average sediment thickness calculated from the sediment depth probes for each range as used in the Bechtel method. The average sediment depth of each range is used to calculate the average depth between adjacent ranges. This average is used with the information on the area between ranges in Table 6 to calculate the volume of sediment between ranges. The sediment occurring in the channel is added to this volume. A summary of the computed volumes of sediment between ranges and in the channels is shown in Table 7. Using the Bechtel method, 3005 acre-feet of sediment have accumulated above Range 1.37, which is essentially the same volume as calculated by the average-end-area method. This shows that the method of calculation has very little effect upon the sediment volume.

These two methods account for the sedimentation occurring above Range 1.37. This area represents about half the original lake capacity. The area below Range 1.37 was not surveyed as part of this study,

Table 6. Average sediment depth of ranges, exclusive of channel measurements, average sediment depth of adjacent ranges, and area between ranges for use in the Bechtel method

Range	Ave. sediment depth (exclusive of channel measurements) feet	Ave. sediment depth of adjacent ranges feet	Area between ranges acres
1.37	3.0		
		2.7	50.3
1.83	2.4		
		2.25	37.1
2.29	2.1		
		3.2	81.2
2.95	4.3		
		3.0	57.3
3.47	1.7		
		2.9	43.7
4.00	4.1		
		4.25	31.0
4.30	4.4		
		4.7	16.3
4.73	5.0		
		6.6	42.5
5.10	8.2		
		6.9	32.6
5.33	5.6		
		5.8	45.0
5.64	6.0		
		5.05	41.9
6.27	4.1		
		4.0	36.0
6.80	3.9		
		1.95	7.8
Upstream	0		
NCB	2.4		
		2.65	31.5
NCA	2.9		
		1.95	21.0
Upstream	1.0		
WC	3.2		
		2.1	28.3
Upstream	1.0		

Table 7. Sediment volume computations by the Bechtel method

Range	Volume in channel acre-feet	Volume between ranges acre-feet	Total acre-feet
1.37			
	60.6	135.7	196.3
1.83			
	46.8	83.6	130.4
2.29			
	89.8	259.9	349.7
2.95			
	51.2	171.9	223.1
3.47			
	62.0	126.7	188.7
4.00			
	40.7	131.8	172.5
4.30			
	45.4	76.6	122.0
4.73			
	58.2	280.5	338.7
5.10			
	26.0	224.9	250.9
5.33			
	34.7	261.0	295.7
5.64			
	85.9	211.6	295.7
6.27			
	66.5	144.0	210.5
6.80			
	31.6	15.2	46.8
Upstream			
NCB			
		83.5	83.5
NCA			
		41.0	41.0
Upstream			
WC			
		59.5	59.5
Upstream			
			3004.8

because of the limitations of the equipment available.

In order to obtain the sediment accumulation for the entire lake, an estimate for the amount of sediment below Range 1.37 must be made. These estimates are made by prorating the data from the Bechtel Assoc. 1977 study, in which the whole lake was surveyed. The Bechtel data show that 1610 of the total 2002 acre-feet of sediment was above Range 1.37 in 1977. This indicates that 80.4% of the total lake sedimentation occurred above Range 1.37. Applying the percent of sediment found above Range 1.37 to the data of this study for the average-end-area method, gives a total estimate of 3638 acre-feet of sediment accumulation in the lake. The procedure outlined above is repeated to make an estimate of the sediment accumulation when the calculations are performed by the Bechtel method. This results in an estimate of 3737 acre-feet for the entire lake. Table 8 outlines the results of these calculations, and compares the estimates from this study with the results of the Bechtel Assoc. (1977) study, and shows that this study estimates 50% more sediment deposited per year than that estimated by Bechtel.

Stream-Sediment Gaging

Another method of determining the sediment accumulation in a reservoir is by measuring the suspended sediment upstream and downstream of the reservoir. As part of this study, suspended sediment samples from two gaging stations were collected. The U.S. Geological Survey collected and analyzed most of these data. One station is located 1.7 miles downstream of the Lake Panorama dam (Panora site)

Table 8. Estimates of reservoir sedimentation from reservoir studies by Bechtel, and Iowa State University in conjunction with U.S. Geological Survey

	Bechtel Assoc.	ISU-1 (average-end area method)	ISU-2 (Bechtel method)
Total sediment volume in acre-feet	2002	3638	3737
Age of lake, years	7	9	9
Average annual rate of sediment accumulation in acre-feet/year	286	404	415
Total loss in storage capacity to date, %[a]	10.3	18.8	19.3
Average annual loss in storage capacity, %[a]	1.47	2.09	2.14
Average annual sediment yield in acre-feet/mi^2	0.65	0.92	0.94

[a] Based upon an original lake capacity of 19,350 acre-feet.

and one 12.0 miles upstream of the dam near State Highway 25 bridge (Bayard site). The location of these gages is shown in Figure 5, and descriptions of the gaging stations can be obtained from the U.S. Geological Survey Office in Iowa City, Iowa.

Daily sediment sampling at these two stations began on March 24, 1979. The stations are equipped with a U.S. Geological Survey D-74 suspended sediment sampler installed in a permanent enclosure on the bridge at each site. At times when the D-74 sampler cannot be used, the sediment station observer has been furnished with a DH-59 hand line sampler, a DH-48 hand sampler, and a DH-75P ice sampler. Descriptions of these samplers can be found in Vanoni (1975).

In addition to the daily sediment stations, and the surface water gage at Panora, a stream flow gaging station was installed at the Bayard site and a lake level gage was installed at the dam. The stream flow gages are equipped with strip-chart recorders in addition to digital recorders. Telemetering equipment was installed at these two sites, as well as at the existing stream flow station at Panora. Continuous records are being obtained from the three sites. These data are being collected by the U.S. Geological Survey in Fort Dodge and Iowa City.

From the daily sediment samples, the concentration of sediment in the water is determined and translated into a sediment load. The short term records, from March 24, 1979 to the end of the water year, October 31, 1979, have been adjusted to long term representation by standard U.S. Geological Survey methods. This consists of developing a long term flow duration curve (Searcy, 1963) and a sediment rating

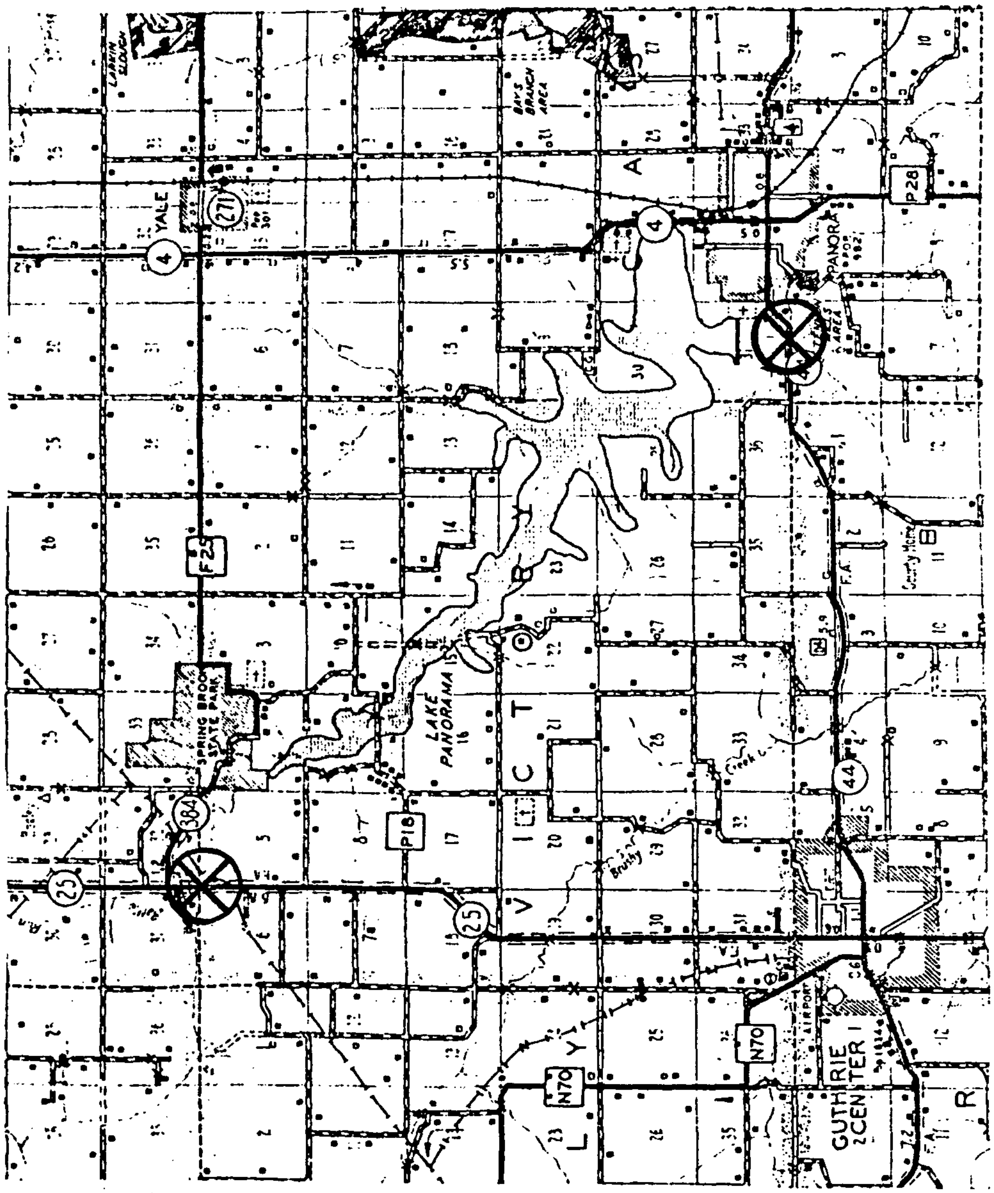


Figure 5. Location of sediment gaging stations

curve (Colby, 1956).

The sediment rating curve relates the sediment concentrations to the stream discharge. Using this in conjunction with a long term flow duration curve, it is possible to compute the sediment load a stream will carry. Due to the scatter of data during the year, seasonal duration curves and sediment discharge curves have been developed to minimize the variations. For this study, the data have been analyzed by the U.S. Geological Survey. Regression equations have been generated for four seasons of the year and an estimated long term sediment load has been computed, based upon a sediment unit weight of 60 lb/ft^3. For the March-May season, 250 acre-feet/year is expected; for June-August, 120 acre-feet/year; and for September-November, 26 acre-feet/year. Lack of data prevents computation of sediment loads for the December-February period; however, an estimate of 10 acre-feet/year is used to cover this period. The total long term sediment yield is the sum of these values, and is 406 acre-feet/year (O. G. Lara, U.S. Geological Survey, Iowa City, Iowa, personal communication, 1980).

It must be emphasized that the 406 acre-feet/year is the sediment load produced by 375 square miles of the watershed. An additional 65 square miles of the watershed drains into Lake Panorama. Assuming a uniform production of sediment over the entire watershed, the 65 square miles produces an additional 70 acre-feet/year of sediment not measured by the gaging station above the reservoir. This would result in a total of 476 acre-feet/year of incoming sediment to the reservoir.

This number must be adjusted to account for two additional facts: bed load and reservoir trap efficiency. A modest five percent (5%) allowance for bed load would further increase the sediment inflow rate to 500 acre-feet/year. The second consideration is the trap efficiency of the reservoir. Comparing the upstream sediment load with the downstream load for the period studied, the trap efficiency has been determined to be 91 percent (O. G. Lara, U.S. Geological Survey, Iowa City, Iowa, personal communication, 1980). Applying the trap efficiency to the 500 acre-feet/year of sediment inflow results in an estimate of 455 acre-feet/year of sediment deposited in Lake Panorama. This estimate agrees reasonably well with the sediment accumulation estimated by the range survey.

Regional Analysis

On a regional basis, sediment yields for the Lake Panorama drainage basin can be estimated from data obtained in other basins within the region. Two such studies give the sediment yields from three nearby basins. The Middle River watershed, directly south of the Middle Raccoon River watershed, is entirely in loess capped Kansan till. Springbrook Lake, a small recreational facility a few miles northwest of Lake Panorama, is situated in Wisconsin till. The Raccoon River is a large watershed, containing the Middle Raccoon River watershed, and consists of predominantly Wisconsin till, with a small portion of loess capped Kansan till. Tables 9 and 10 summarize the estimated long term sediment yields for these basins from two different studies.

Table 9. Annual sediment yields from nearby watersheds as compiled by Brune (1948)

	Drainage area mi^2	Measured yield $tons/mi^2$	Estimated long term yield $tons/mi^2$	Geology
Middle River	502	2646	2370	loess capped till
Springbrook Lake	2.1	695	860	Wisconsin till
Raccoon River at Van Meter	3410	1395	740	primarily Wisonsin till

Table 10. Annual sediment yields from nearby watersheds as compiled by Upper Mississippi River Basin Coordinating Committee (1970)

	Drainage area mi^2	Estimated long term yield $tons/mi^2$	Geology
Middle River	503	2300	loess capped till
Springbrook Lake	2.1	779	Wisconsin till
Raccoon River at Van Meter	3441	720	primarily Wisconsin till

These tables show that the estimated sediment yield from loess capped Kansan till is about 2300 tons per square mile per year, whereas for the Wisconsin till area about 800 tons per square mile per year can be expected. These values fall within the limits of the variation of sediment yields in the United States. For loess capped Kansan till, the range is 1000 to 7000 tons per square mile per year; and for calcareous Wisconsin till, the range is 40 to 4000 tons per square mile per year (Vanoni, 1975).

It is possible to estimate the sediment volume delivered into Lake Panorama by mutliplying the sediment yield figures from each geologic material times the area of the drainage basin containing that material, and then dividing the total weight of sediment produced by the average unit weight of the sediment, if deposited in the lake. The respective areas of geologic material in the watershed are 145 square miles for loess capped Kansan till and 295 square miles for Wisconsin till. Applying the estimated sediment yields to the appropriate areas results in a sediment yield for the watershed of 1295 tons/mi^2. Assuming a sediment unit weight of 60 lb/ft^3, the estimated annual sediment volume is 436 acre-feet. If the unit weight of sediment is estimated at 75 lb/ft^3, the sediment volume is 350 acre-feet/year.

Sediment Properties

Sediment sampling

Two different methods of obtaining samples from the lake were employed. The first method was used in conjunction with the reservoir survey. These samples were taken using a 1½ inch inside diameter by four feet long sampler. The sampler includes a plastic liner to retain the sediment. The device was pushed by hand into the sediment, the depth of penetration recorded, and the sampler pulled out by hand. The plastic tube was removed, capped, and marked to indicate the sampling site according to the range, and the station in feet from the east end of the range. In this sampling process, the length of sediment core recovered in the tube varied from 20 to 40 percent of the tube length. This observation, combined with an area ratio of the sampler at 17.4%, leads to the conclusion that undisturbed samples could not be obtained with this sampling process.

The second procedure to collect samples involved the use of 3 inch outside diameter Shelby tubes. These tubes, varying in length from 18 to 36 inches, were hydraulically pushed into and extracted from the sediment from a platform placed between two canoes. The tubes were pushed to a maximum of three-fourths of their length into the sediment to prevent accidental compaction during the sampling process. The samples were capped in their tubes, and marked as to location, and transported to the laboratory. Figure 6 shows the location of the sampling sites within the lake. The Shelby tubes have an area ratio of 8.9% and thus should provide relatively undisturbed samples.

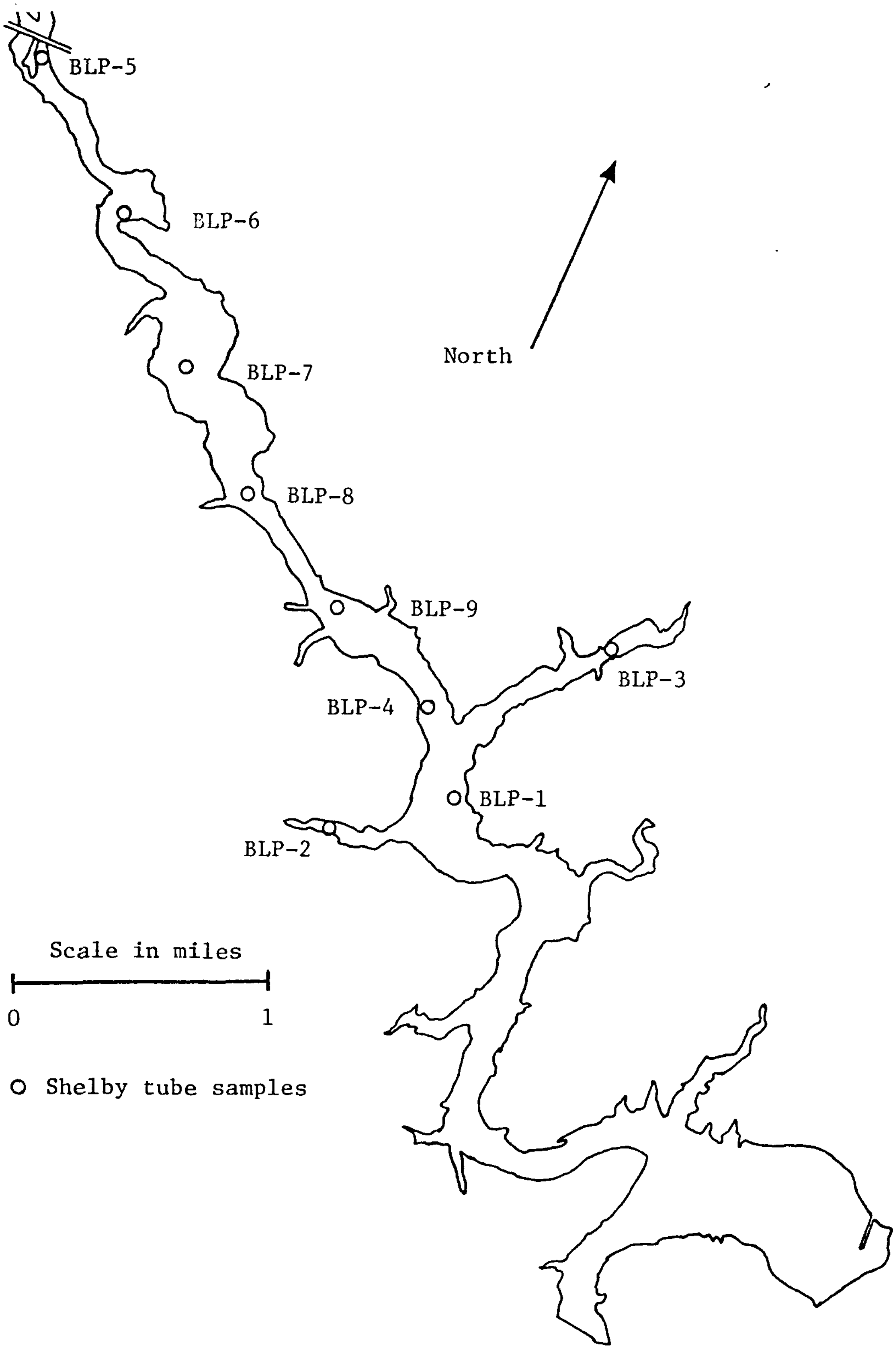


Figure 6. Location of sampling sites for unit weight determination

Laboratory procedures

Sediment samples were brought back to the laboratory to determine unit weights and particle size distributions. An attempt was made to determine the unit weight from the 1½ inch diameter samples, but due to disturbance and poor recovery ratios, it became apparent that good unit weight data would not be forthcoming. Thus, all measured unit weight data are based on measurements from the Shelby tube samples.

For the unit weight measurements, four-inch-long samples were cut from the extruded Shelby tube samples, measured to determine the volume, weighed, and placed in an oven to dry. The moisture content was determined and the dry unit weight calculated by dividing the dry weight by the volume.

Particle size analyses were run on the samples from the range survey using the pipette method, as recommended for sediment mechanical analysis by Vanoni (1975). A modification of the procedure presented by Walter et al. (1978) was used. The modification consisted of using the air jet dispersion apparatus described by Chu and Davidson (1953) for five minutes at 25 psi for dispersion, rather than shaking in a reciprocating shaker overnight. The following size fractions were classified: greater than 0.074 mm, 0.074 to 0.031 mm, 0.031 to 0.016 mm, 0.016 to 0.004 mm, and 0.004 to 0.002 mm. The sand fraction (greater than 0.074 mm) was collected following completion of the pipetting procedure by washing the remaining soil through a #200 sieve.

The organic content was found using a procedure recommended by the U.S. Geological Survey (Guy, 1969). The procedure was modified to use 30% hydrogen peroxide and a steam bath to drive off the excess hydrogen peroxide.

Standard engineering index properties: liquid limit, plastic limit, and plasticity index, were determined on selected samples in accordance with AASHTO designations T89-76I and T90-70 (Asphalt Institute, 1969). Summary tables of the particle size analysis, organic content, liquid limit, plastic limit, and plasticity index can be found in Appendix B.

Unit weight

The unit weight of sediment is perhaps the most important sediment property pertaining to sedimentation studies. The unit weight is used to calculate the volume which will deposit in a reservoir if incoming sediment concentrations by weight are known. Low unit weight indicates that the incoming sediment will require more of the lake volume for sediment storage. In this study, two procedures have been used to determine the unit weight of the sediment: a measurement of the unit weight using Shelby tubes, and estimation of unit weight using empirical relationships based upon particle size.

Twenty-nine 4 inch long samples were used for the measured unit weight determination. The average of all 29 samples is 80.0 lb/ft^3. When classified according to depth of sample, an increase of unit weight with depth is noted. From 7 to 15 inches, the average unit weight is 71.7 lb/ft^3; from 15 to 30 inches, the average is 79.9 lb/ft^3; and for samples at greater than 30 inches, the average is 85.0 lb/ft^3. Table 11 shows the results of the unit weight measurements. Table 11 also shows the depth of water at each boring location and indicates the likelihood of the sediment having been exposed during its history. The samples

Table 11. Measured unit weights from Shelby tube samples

Location	Depth in	Depth of water ft	Moisture content %	Possible sediment exposure	Dry unit weight lb/ft^3
BLP-1	10-14	6.7	24.1	not likely	113.4
BLP-2	8-12	3.2	44.9	likely	70.0
	14-16		45.5		72.6
	18-22		47.2		71.7
	24-28		31.2		90.1
	30-34		29.7		88.1
BLP-3	8-12	4.2	65.3	likely	59.4
	18-22		30.0		95.4
BLP-3A	11-15	4.3	58.7	likely	56.8
	16-20		30.0		90.4
	24-28		29.5		90.7
BLP-4	8-12	6.9	28.0	not likely	95.1
BLP-5	9-13	4.3	22.0	likely	111.1
BLP-6	7-11	3.6	79.4	likely	55.6
	13-17		59.8		60.0
	21-25		55.9		66.1
BLP-7	10-14	3.2	53.4	likely	67.2
	18-22		49.2		70.4
	27-31		44.0		74.1
	34-38		60.1		62.6
	39-43		49.3		73.4
BLP-8	8-12	6.7	45.1	not likely	75.1
	18-22		40.7		90.0
	24-28		47.6		73.1
	35-39		37.4		81.8
BLP-9	8-12	7.6	30.6	not likely	89.8
	14-18		29.4		90.8
	24-28		30.9		87.9
	34-38		26.7		96.6

from the cove areas and the upper reaches have probably been exposed at some time, while the others have not. Samples BLP-1 and BLP-5 show unusually high unit weight, probably due to the fact that these particular samples had very high sand contents.

Empirical equations have been developed which relate sediment unit weight to the percent fraction of sand, silt, and clay of the sediment. The equations of Lane and Koelzer (1943), and Lara and Pemberton (1965) were compared with the particle size data of the Lake Panorama sediments.

In using empirical equations to estimate sediment unit weight, reservoirs are divided into four groups according to reservoir operation, because the mode of operation has great influence upon the unit weight (Lane and Koelzer, 1943). In this study, two types of reservoir operation need consideration. Type I reservoirs are always submerged, and Type II reservoirs normally have a moderate amount of drawdown when sediment may be exposed to air. Lake Panorama would typically be classified as a Type I reservoir, except that during the winter months the water level has been dropped 4 to 7 feet, exposing sediments in coves and the upper reaches of the reservoir. Thus, the samples from coves and upper reaches should be estimated by the Type II equations, and the remainder by Type I.

An analysis of the unit weight was made on this basis. A listing of the equations used can be found in Appendix C. In these equations, the sand, silt, and clay fractions are multiplied by constants derived by regression analysis to estimate a unit weight. Samples from ranges in the coves and ranges above Range 4.73 were considered Type II, and all others Type I. The unit weight for each sample was calculated, and the average for each group of samples computed. Table 12 summarizes the averages.

The Lane and Koelzer equation estimates an initial unit weight of 42.4 lb/ft^3 for Type I samples. The Lara and Pemberton equation for the same samples is similar at 42.6 lb/ft^3. In analyzing the Type II samples, Lane and Koelzer's equation estimates an initial unit weight of 70.0 lb/ft^3, and Lara and Pemberton's 60.9 lb/ft^3. To obtain an average for the lake for each set of equations, the Type I and Type II estimates are averaged. This average is 56.2 lb/ft^3 for the Lane and Koelzer equations and 51.8 lb/ft^3 for Lara and Pemberton's equations. Although a significant difference does exist when individual unit weights from the Type I and Type II equations are computed, the averages show little difference exists between the two sets of equations.

It must be stressed that these equations yield an estimate of the initial unit weight, defined as the unit weight one year or less since deposition. To obtain an estimate applicable to the present time (10 years after impoudment), the procedure of Miller (1953) is applied to allow for consolidation of the sediment. In this procedure, the general equation for estimating the unit weight is $W = W_1 + k \ln T$, where W_1 is is the initial unit weight determined by the previously discussed equations, and $k \ln T$ relates the increase in unit weight due to consolidation for a period of T years. The k factors for each reservoir operation can be found in Appendix C.

Computing the consolidation effects results in Lane and Koelzer's Type I unit weight average increasing to 73.4 lb/ft^3. The average for

Table 12. Average estimated unit weight determined by empirical equations and delineated by type of reservoir operation

	Unit weight, lb/ft^3			
Equation	Initial	Ave.	10 year	Ave.
Lane and Koelzer				
Type I	42.4	56.2	50.8	62.1
Type II	70.0		73.4	
Lara and Pemberton				
Type I	42.7	51.8	50.9	57.6
Type II	60.9		64.3	

the lake becomes 62.1 lb/ft^3. Thus, for 10 years of consolidation, the Lane and Koelzer equations predict an increase in unit weight from 56.2 to 62.1 lb/ft^3. The Lara and Pemberton equations show a 10 year unit weight average of 50.9 lb/ft^3 for Type I and 64.3 lb/ft^3 for Type II reservoir operation. The average for the lake is 57.6 lb/ft^3, when consolidation is taken into account in the Lara and Pemberton equations, an increase of 5.8 lb/ft^3 over the initial unit weight average of 51.8 lb/ft^3.

The borings upon which the measured unit weights are based were made as close as possible to the ranges of the sediment survey. By pairing mechanical analysis and unit weight samples from nearby ranges and borings, a comparison may be made. Table 13 shows the data used in the comparison. The empirical unit weights are divided as Type I or Type II, and averaged across a range, whereas the measured unit weights are the average for a particular boring.

This comparison shows that the Lara and Pemberton Type I estimates are closer to the measured unit weights than the Lane and Koelzer Type I, but the difference is small. In the Type II unit weights, the Lane and Koelzer estimates are closer, the difference in the two empirical equations being greater for Type II than Type I.

Figure 7 is a graph of the data of Table 13. As can be seen, in all but one instance, the measured unit weight is greater than that estimated by the equations. The figure also shows that the Type II equations tend to more closely model the measured unit weight than the Type I equations. It is interesting that the Type I areas have, in three

Table 13. Measured unit weights and estimated unit weights from empirical equations for matched ranges and borings

Boring and range		Measured unit weight lb/ft^3	Ten year estimated unit weights, lb/ft^3			
			Lane and Koelzer		Lara and Pemberton	
			Type I	Type II	Type I	Type II
BLP-1	R3.47	113.4	53.5		57.5	
BLP-2	RWC	78.5		73.0		67.1
BLP-3,3A	RNCA	78.5		73.4		66.9
BLP-4	R4.00	95.1	48.6		49.9	
BLP-5	R6.80	111.1		81.6		77.3
BLP-6	R6.27	60.6		74.7		72.5
BLP-7	R5.33	69.5		68.4		60.9
BLP-8	R4.73	80.0	58.9		59.5	
BLP-9	R4.30	91.3	52.6		52.8	

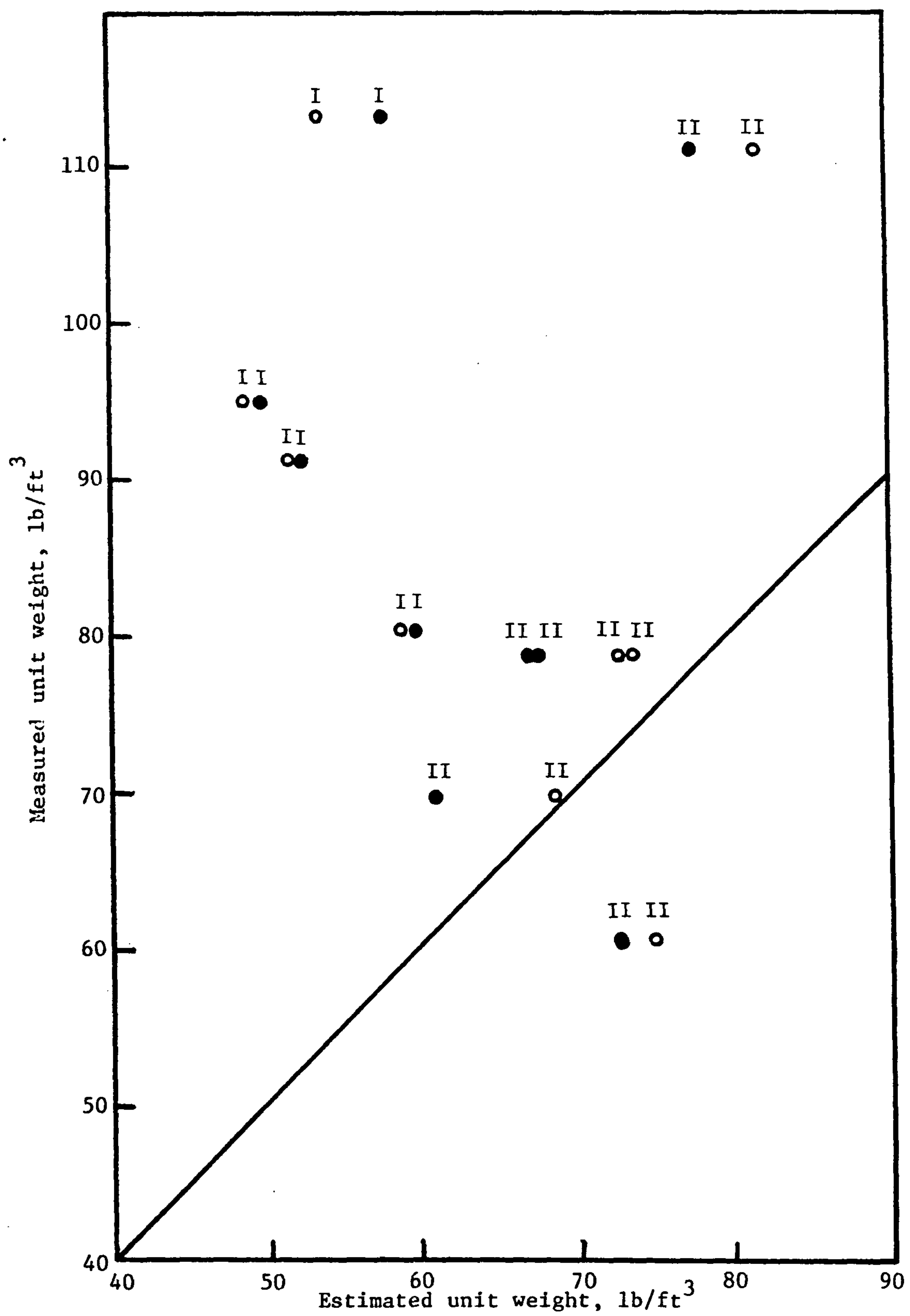
Figure 7. Measured unit weight versus estimated unit weight from empirical equations

○ Lane and Koelzer equation

● Lara and Pemberton equation

I Type I reservoir

II Type II reservoir


Measured unit weight, lb/ft^3
Estimated unit weight, lb/ft^3
40
50
60
70
80
90
100
110
I
I
II
II
II
II
II
II
II
II
II
II
II
II
II
II

instances, unit weights predicted by the equations that are only about half the measured unit weight.

Shoreline Inventory

An inventory of the lake shoreline erosion was undertaken. The shoreline profile is classified into five categories. Riprap and fieldstone refer to shoreline segments which have had remedial work performed on them, either in the form of riprap or rock placement, or wooden or concrete retaining wall structures. The "no erosion" category defines shoreline segments which have no apparent erosion, are covered with vegetation, and have gentle slopes into the water. Three categories of erosion are defined based upon height of wave cut cliff: 0 to 2 feet, 2 to 5 feet, and greater than 5 feet. Table 14 summarizes the results of the inventory.

This survey shows that 48% of the lake shoreline is currently being eroded and 27% is being protected from the threat of erosion by riprap and fieldstone bank protection. This indicates the possibility of substantial amounts of sediment production from shoreline erosion. The problem is more acute downstream of the narrows where the larger distances across the water (i.e. longer fetch) enhance wave action. Of the nearly seven miles of shoreline exhibiting no erosion, over four miles are in the area above the upper end of the narrows where shoreline slopes are more gradual and fetches smaller.

Relatively steep slopes usually show more shoreline erosion. The soil type does not appear to have an influence upon the height of the

Table 14. Shoreline inventory

	Miles	% of total
Riprap and fieldstone	7.56	27.2
No erosion	6.92	24.9
0 to 2 ft cliffs	7.20	25.9
2 to 5 ft cliffs	3.74	13.4
Greater than 5 ft cliffs	2.40	8.6
(Perimeter surveyed)	27.82	100.0

cut. Loess and limestone account for the majority of cliffs that are over five feet in height. The cliffs that ranged from zero to five feet in height are generally till at the base of gently sloping inclines.

Following a procedure used by Berg (1980), an estimate of the amount of sediment derived from shoreline erosion can be computed in terms of a volume of eroded soil per foot of shoreline for each of the three categories of cliff erosion defined: 15 ft^3/ft for 0 - 2 ft cliffs, 55 ft^3/ft for 2 - 5 ft cliffs, and 130 ft^3/ft for cliffs greater than 5 ft in height. These volumes are from measurements Berg (1980) made at Big Creek Lake, and so should be considered as only approximations when applied to Lake Panorama. If these volumes are multiplied by the respective lengths of eroded shoreline, and a unit weight of 110 lb/ft^3 is assumed for the shoreline material, an estimated 181,700 tons of material have eroded from Lake Panorama's shoreline. At a sediment unit weight of 60 lb/ft^3, this translates to 139 acre-ft of sediment deposition in the lake, or 13.9 acre-ft/year. If the unit weight of the sediment is 75 lb/ft^3, the sediment volume deposited in the lake is 111 acre-ft, or 11.1 acre-ft/year.

DISCUSSION

Sedimentation Rates

The sedimentation rate for Lake Panorama has been calculated by three independent methods: reservoir survey, streamflow sampling of suspended sediment, and regional analysis. Of these methods, the regional analysis is the least reliable, because actual watershed conditions may not be similar to the regional averages.

The lake survey and sediment gaging data should provide more reliable estimates. However, the survey is limited by excluding a portion of the lake south of Range 1.37, and relying upon an estimate for this area. This fact points to the need for obtaining a complete reservoir survey to overcome this limitation of the 1979-80 survey. From the reservoir survey, a sedimentation rate of 405 acre-ft/year is estimated. Although the streamflow data have been corrected to long term estimates by standard methods, the data are from a short period of record, and may not be representative of long term concentration levels. The sediment gaging estimate is 455 acre-ft/year, based upon a sediment unit weight of 60 lb/ft^3. If the unit weight of the sediment is 75 lb/ft^3, the gaging data estimate is 364 acre-ft/year. The unit weight of the sediment plays an important role in determining rates from gaging data. Whereas the sediment gaging estimate is less reliable than the reservoir survey, the estimates of 364 and 455 acre-ft/year are close to the result of the reservoir survey, and lend independent support to the estimate from the reservoir survey.

The regional analysis method provides estimates that indicate the general trend of the area. The results of the regional analysis indicate sedimentation rates varying from 350 acre-ft/year to 436 acre-ft/year, depending upon the unit weight of the sediment. This range closely approximates the results of the previous two methods, and provides support for those estimates.

The estimates generated in this study show a marked increase in the sedimentation rate of Lake Panorama over the 286 acre-ft/year reported by Bechtel Assoc. (1977). Several reasons can be advanced for the differences in the two studies. The Bechtel study was a rapid, two day study, in which the survey was conducted without the benefit of a tag line to locate horizontal positions accurately. Using a spud probe, the sediment was probed across the range from a boat. In the current study, it was found that without the use of a tag line, the boat was not stable enough to permit probing of the sediment accurately. The current study consistently found greater depths of sediment at corresponding ranges than the Bechtel study. This difference may be due to actual sediment accumulations, or to the method of measurement of the sediment depth. By using the tag line to stabilize the boat while making the probes, it is believed that better data were obtained in this study. By calculating the sediment accumulation in the same manner as Bechtel, and by the standard average-end-area method, it was determined that either procedure produces essentially the same results.

In the years immediately preceding the Bechtel study, severe drought conditions prevailed over this area, which may have reduced the incoming sediment loads to below normal levels. On the other hand, the period from 1977 to 1979 was one of greater than normal streamflow, which may have resulted in greater than normal sediment loads being deposited in the reservoir. It seems unlikely, however, that the difference in the rates can be reflected in the amount of sediment deposited between studies. For the difference between the two studies to be attributed to actual differences in amounts of sediment deposited, requires that 2000 acre-ft of sediment was deposited between 1970 and 1977, as Bechtel found, and that the additional 1600 acre-ft found in this study was deposited between 1977 and 1979, the period between the two studies. This enormous increase seems unlikely, since the largest flows occurred during the 1973-1974 period of record (U.S. Geological Survey, 1970 - 79). Thus, it becomes apparent that one of the studies is in error. As the current study has three independent methods to determine the sedimentation rate, and these agree reasonably well, the current study seems to be more reliable.

Taking into consideration the short time period of obtaining the sediment gaging data, and the above normal flow record during that period (U.S. Geological Survey, 1970 - 79), the author believes that the reservoir survey coupled with continued stream-sediment gaging produces the more consistent and reliable estimate. This estimate would be made even more precise with a complete reservoir survey, coupled with continued stream-sediment gaging. Taking into account the accuracy of the measuring procedures and calculating procedures, it is thought that a round figure of 400 acre-ft/year for the sedimentation rate provides a good estimate for Lake Panorama.

Unit Weight

The unit weight of the sediment has been determined in this study by two different means. One method utilized empirical equations related to particle size data of the sediment to estimate the unit weight. The second method made use of the Shelby tube samples to obtain direct measurement of the unit weight.

In the empirical analysis, several equations were analyzed, the result being that a combination of reservoir operations was necessary to correctly evaluate the sediment unit weights. Due to the geometry of the lake, during its history portions of the lake have been exposed during drawdown, and portions have remained submerged. Since the empirical equations are based upon reservoir operation, it became necessary to use a combination of Type I and Type II reservoir operation. In the Type I modelling, the Lara and Pemberton equations are slightly closer to the measured values, but in general both Type I equation estimates were far under the measured values. In the Type II analysis, the Lane and Koelzer equation gives results closer to measured values than the Lara and Pemberton equation. However, the estimate from the equations still varies from the measured value by 10 to 25 percent.

The average unit weight values estimated by the empirical equations for the entire lake run between 50 and 60 lb/ft^3 for initial estimates, and slightly above and below 60 lb/ft^3 for the 10 year unit weight. These values fall in line with the normally assumed values of 55 or 60 lb/ft^3, used in sedimentation studies.

In the unit weights measured from the Shelby tube samples, an average unit weight of 80.0 lb/ft^3 was found. The areas sampled were in relatively shallow water, because the sampling platform was able to be steadied only in shallow water. Because of this, the measured samples are probably biased towards high unit weights, because the possibility exists that these samples were exposed at one time or another. Countering this is the fact that the samples with the least possibility of exposure also exhibit some of the highest unit weights, as shown in Table 11. The measured unit weights were taken from the best undisturbed samples that could be obtained. This does not preclude the fact that disturbance, both in sampling and transport back to the lab, has increased the unit weight. Although it is impossible to quantify the effect of disturbance, it is important to recognize its existence. A unit weight value of 75 lb/ft^3 seems representative of the measured unit weights. This recognizes the sampling bias and disturbance possibilities, and is a slight downward adjustment from the average measured unit weight from the Shelby tube samples.

The failure of the empirical equations to correlate with the measured values of the unit weight can be attributed to the general nature of the equations. The equations are based upon very large data bases, encompassing studies from around the world. In Lake Panorama. the equations consistently underestimate the unit weight when compared with the measured values. Better data are provided by the measured unit weights, and thus the 75 lb/ft^3 unit weight is considered the most reliable estimate. It is not possible to determine what the initial unit weight was some 10 years ago, but it is entirely possible that it was near 60 lb/ft^3, and at that time the sediment would not have been subjected to exposure. This is supported by the observation that samples from more shallow sediment depths have lower unit weights.

Sediment Source Areas

Although quantitative evaluation of the amount of sediment arriving from specific sources has not been undertaken, some comments are in order. The geology of the watershed above the dam is divided into two distinct areas: loess capped Kansan till and Wisconsin till. Data from regional analysis of sediment yield indicate that loess capped Kansan till produces 2 to 3 times as much sediment per unit area as Wisconsin till. With one-third of the watershed in loess capped Kansan till, it it probable that this area of the watershed produces roughly half of the sediment. This indicates that sediment management and soil conservation programs should concentrate efforts in the western third of the watershed for maximum benefit.

Based upon previous studies in other watersheds (Gottschalk and Brune, 1950; Glymph, 1957) sheet erosion is probably the largest contributor of sediment to Lake Panorama. The Lake Panorama watershed is under heavy cultivation, thus enhancing the amount of sediment produced by sheet erosion. Qualitative field observations noted gully erosion to be significant in the loess capped Kansan till areas of the watershed

A quantitative evaluation becomes important should efforts be directed to stopping the erosion of material at its source.

While the shoreline erosion has produced a somewhat inaccessible and unsightly border to the lake, the amount of sediment contributed by shoreline erosion is small. Sediment from shoreline erosion is only 2.8 percent of the annual total, and shoreline protection is thus more important from an aesthetic point of view.

Reservoir Longevity

An important aspect of a reservoir is its useful life. The life can vary depending upon the use of the reservoir, i.e. recreational use versus consumptive use. From a power company's viewpoint, the amount of actual storage and the amount of makeup water available are the two critical factors. The life of Lake Panorama can be evaluated in terms of actual storage available, using 400 acre-ft/year of sediment accumulation, assuming no remedial measures are taken. Based upon this assumed linear relationship of sediment accumulation, Lake Panorama would be 90% filled with sediment by the year 2014. Figure 8 shows when levels of active storage will be available, assuming the linear rate of sedimentation. From this figure, approximately 15,350 acre-ft of storage capacity is available at the present (1980) time.

The linear relationship may not be an appropriate model for reservoir sedimentation. A study by Brune (1953) suggests a declining trap efficiency as the age of the reservoir increases. If this is the case, less incoming sediment will be trapped each year, and the longevity of

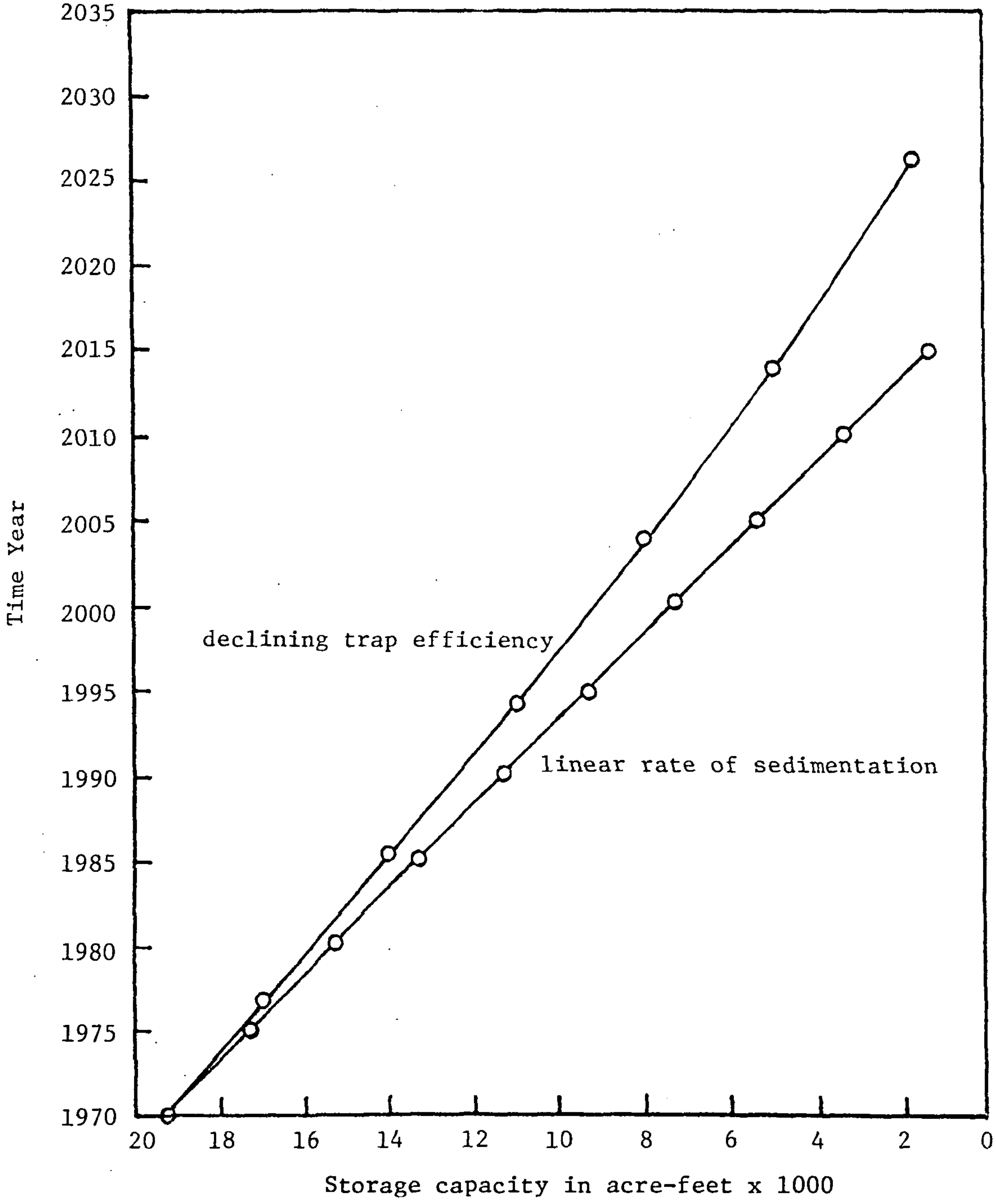


Figure 8. Effect upon storage capacity of a linear rate of sedimentation and a declining trap efficiency

the reservoir will be greater. Brune's graph of trap efficiency versus capacity inflow of the watershed was used to calculate the time to reach various levels of storage capacity (Table 15). If Lake Panorama is analyzed according to this criterion, it is calculated that sediment will fill 90% of the original capacity by the year 2026. As shown in Figure 8, the declining trap efficiency with time increases the actual storage available at a given time.

Table 15. Sediment accumulation and reservoir life, time to fill 90% full of sediment with declining trap efficiency[a]

Storage capacity acre-feet	ΔV acre-feet	C/I ratio	Ave. C/I	Trap eff. %	Time to fill ΔV	ΣTime years
19350		0.125				
	2350		0.118	88	6.7	6.7
17000		0.110				
	3000		0.101	87	8.6	15.3
14000		0.091				
	3000		0.081	84	8.9	24.2
11000		0.071				
	3000		0.062	79	9.5	33.7
8000		0.052				
	3000		0.042	74	10.1	43.8
5000		0.032				
	3065		0.022	62	12.4	56.2
1935		0.012				

[a] Average annual inflow is 154,300 acre-ft/year. Average annual sediment inflow assumed 400 acre-ft/year. Does not account for sediment deposition above the operating level of the reservoir.

CONCLUSIONS AND RECOMMENDATIONS

It is evident from this study that a serious sediment problem exists at Lake Panorama. The sediment problem is most acute in the area above the narrows and in the tributary cove areas. These areas have been virtually closed to recreational users. Specific conclusions drawn from this study are:

1) An average annual sedimentation rate of above 400 acre-ft/year exists for Lake Panorama.
2) The unit weight of the sediment as determined with measurements of relatively undisturbed samples is an average of 75 lb/ft^3.
3) Although a shoreline erosion problem exists at the lake, which contributes an estimated 11.1 acre-ft/year of sediment to the lake, it represents only 2.8% of the total sedimentation.
4) The sedimentation rates are having a drastic effect upon the storage capacity of the lake. The storage capacity has been reduced to around 15,000 acre-ft at present, a drop of 22.5% in 10 years.
5) At the present rate of sedimentation, if no remedial measures are employed, the reservoir's capacity will be depleted in about 40 to 50 years. More important, the capacity will be reduced to a fourth of the original capacity in 30 years. Dredging the lake could recover lost storage capacity. A rough cost analysis, assuming $1.50/$\text{yd}^3$ for the removal of the sediment, indicates it would require nearly $1 million to

remove the annual sediment inflow of 400 acre-ft to maintain the present capacity. To increase the capacity of the lake would cost proportionately more.

As a result of this study, the following recommendations are made:

1) The sediment gaging should be continued in order to build the data base from which to obtain more reliable estimates from this method.

2) An extensive survey should be undertaken to map the entire lake bottom to determine the present capacity.

3) Permanent monuments should be established to clearly mark the sediment ranges. A few index ranges should be chosen and monitored yearly to provide a key to the need for additional complete surveys. Major flood events or extended droughts should be evaluated to determine their effect upon the rate of sedimentation.

4) An independent determination of the unit weight of sediment should be made using a gamma probe, and compared with measured values from sampling tubes. An empirical equation unique to Lake Panorama could be established from particle size analysis of the sediment samples used for the measured unit weights.

5) Sediment traps should be established for the cove areas of the lake, particularly on the west side, to reduce the incoming sediment from the loess-capped Kansas till areas.

6) A study should be conducted to determine the feasibility of dredging portions of the lake, and of establishing a sediment

trap upstream of the reservoir to reduce the incoming sediment from the Middle Raccoon River watershed. A cost-benefit analysis to determine the feasibility of reducing erosion in the watershed, i.e. through terracing, against the continued necessity of dredging should be investigated.

7) The effectiveness of a sediment management plan to reduce the sedimentation of the lake should be evaluated by subsequent studies, to determine its effectiveness and the cost-benefit ratio.

BIBLIOGRAPHY

Asphalt Institute. 1969. Soil manual for design of asphalt pavement structures. 3rd edition. Manual Series No. 10 (MS-10). Asphalt Institute, College Park, Maryland.

Bechtel Assoc. 1977. Preliminary evaluation of water resource Lake Panorama Iowa. Bechtel Associates Professional Corp., Ann Arbor, Michigan.

Beer, C. E. and H. P. Johnson. 1965. Factors related to gully growth in the deep loess area of Western Iowa. Proc. 1963 Federal Interagency Conference on Sedimentation. U.S.D.A. Misc. Publ. 970.

Berg, B. M. 1980. Shoreline erosion on selected artificial lakes in Iowa. Unpublished M.S. Thesis, Iowa State University Library, Ames.

Brown, C. B. 1943. Discussion of "Sedimentation in reservoirs" by B. J. Witzig. Proc. Am. Soc. Civil Engr. 69:1493-1499.

Brune, G. M. 1948. Rates of sediment production in the Midwestern United States. TP-65. S.C.S., Milwaukee, Wisconsin.

Brune, G. M. 1950. Dynamic concept of sediment sources. Trans. Am. Geophys. Union 31:587-594.

Brune, G. M. 1953. Trap efficiency of reservoirs. Trans. Am. Geophys. Union 34:407-418.

Brune, G. M. and R. E. Allen. 1941. Consideration of factors influencing reservoir sedimentation in the Ohio Valley region. Trans. Am. Geophys. Union 22:649-655.

Campbell, F. B. and H. A. Bauder. 1940. A rating-curve method for determining silt-discharge of streams. Trans. Am. Geophys. Union 21: 603-607.

Chu, T. Y. and D. T. Davidson. 1953. Simplified air-jet dispersion apparatus for mechanical analysis of soils. Highway Research Board 32:541-547.

Colby, B. R. 1956. Relationship of sediment discharge to streamflow. Open file report. U.S. Geol. Survey, Washington, D.C.

Flaxman, E. M. and R. L. Hobba. 1955. Some factors affecting rates of sedimentation in the Columbia River basin. Trans. Am. Geophys. Union 36:293-303.

Fleming, G. 1969. Design curves for suspended load estimation. Proc. Institution of Civil Engr., Paper 7183, No. 43, London England.

Foster, G. R. and L. D. Meyer. 1977. Soil erosion and sedimentation by water - an overview. Proc. of the National Symposium on Soil Erosion and Sedimentation by Water. Am. Soc. Agr. Engr., St. Joseph, Michigan.

Fruhling, L. 1979. Panorama: The lake's still there. Des Moines (Iowa) Sunday Register, June 10, I-1.

Gilmore, M. 1977. Recording river and reservoir water depths. Civil Engineering (New York): 47(4):64-66.

Glymph, L. M., Jr. 1951. Relation of sedimentation to accelerated erosion in the Missouri Basin loess hills. TP-102. S.C.S., Lincoln, Nebraska.

Glymph, L. M., Jr. 1954. Studies of sediment yield from watershed. Internat. Union of Geodesy and Geophysics Publ. No. 36.

Glymph, L. M., Jr. 1957. Importance of sheet erosion as a source of sediment. Trans. Am. Geophys. Union 38:903-907.

Gottschalk, L. C. 1946. Silting of stock ponds in land utilization project area SD-LU-2, Pierre, S.D. Special Report No. 9. S.C.S., Washington, D.C.

Gottschalk, L. C. 1952. Measurement of sedimentation in small reservoirs. Trans. Am. Soc. Civil Engr. 117:59-71.

Gottschalk, L. C. 1957. Problems of predicting sediment yields from watersheds. Trans. Am. Geophys. Union 38:885-888.

Gottschalk, L. C. 1964. Reservoir sedimentation. Ch. 17 in V. T. Chow, ed. Handbook of Hydrology. McGraw-Hill, New York, New York.

Gottschalk, L. C. and G. M. Brune. 1950. Sediment design criteria for the Missouri Basin loess hills. TP-97. S.C.S., Milwaukee, Wisconsin.

Guy, H. P. 1969. Laboratory theory and methods for sediment analysis. Techniques of Water-Resources Investigations of the U.S. Geological Survey. U.S. Govt. Printing Office, Washington, D.C.

Heinemann, H. G. 1962. Volume-weight of reservoir sediment. Proc. Am. Soc. Civil Engr. HY88:181-197.

Heinemann, H. G. and V. I. Dvork. 1965. Improved volumetric survey and computation procedures for small reservoirs. Proc. 1963 Federal Interagency Conference on Sedimentation. U.S.D.A. Misc. Publ. 970.

Iowa Natural Resources Council. 1978. Iowa Water Plan '78. State of Iowa, Des Moines, Iowa.

Koelzer, V. A. and J. M. Lara. 1958. Densities and compaction rates of deposited sediment. Proc. Am. Soc. Civil Engr. HY84:1603-1 - 1603-15.

Lane, E. W. and W. M. Borland. 1951. Estimating bed load. Trans. Am. Geophys. Union 32:121-123.

Lane, E. W. and V. A. Koelzer. 1943. Density of sediments deposited in reservoirs. Report No. 9. in A Study of Methods used in Measurement and Analysis of Sediment Loads in Streams. U.S. Army Engineer District, St. Paul, Minnesota.

Lara, J. M. and E. L. Pemberton. 1965. Initial unit weight of deposited sediment. Proc. 1963 Federal Interagency Conference on Sedimentation. U.S.D.A. Misc. Publ. 970.

Maner, S. B. 1958. Factors affecting sediment delivery rates in the Red Hills physiographic area. Trans. Am. Geophys. Union 39:669-675.

Miller, C. R. 1951. Analysis of flow duration sediment-rating curve method of computing sediment yield. U.S. Bureau of Reclamation, Denver, Colorado.

Miller, C. R. 1953. Determination of the unit weight of sediment for use in sediment volume computations. Bureau of Reclamation, Denver, Colorado.

Moore, C. M., W. J. Wood, and G. W. Renfo. 1960. Trap efficiency of reservoirs, debris basins, and debris dams. Proc. Am. Soc. Civil Engr. HY86:69-87.

Musgrave, G. W. 1947. The quantitative evaluation of factors in water erosion - a first approximation. J. Soil Water Conserv. 2:133-148.

Oschwald, W. R., F. F. Riecken, R. I. Dideriksen, W. H. Scholtes, and F. W. Schaller. 1965. Principal soils of Iowa. Iowa State Univ. Coop. Extension Service, Ames, Iowa.

Pemberton, E. L. and J. O. Blanton, III. 1980. Procedures for monitoring reservoir sedimentation. Paper presented at Symposium on Surface Water Impoundments, Minneapolis, Minnesota, June 2-5, 1980.

Prior, J. C. 1976. A regional guide to Iowa landforms. Iowa Geol. Survey, Educational Series 3, Iowa City, Iowa.

Ruhe, R. V. 1969. Quaternary landscapes in Iowa. Iowa State University Press, Ames.

Searcy, J. K. 1963. Flow-duration curves. Water Supply Paper 1542A. U.S. Geol. Survey, Washington, D.C.

Soil Conservation Service. 1966. Procedures for determining rates of land damage, land deposition and volume of sediment produced by gully erosion. Tech. Release No. 32. S.C.S., U.S.D.A., Washington, D.C.

Soil Conservation Service. 1973. Sedimentation. Section 3 of S.C.S. National Engineering Handbook. S.C.S., U.S.D.A., Washington, D.C.

Thompson, J. R. 1964. Quantitative effect of watershed variables on the rate of gully head development. Trans. Am. Soc. Agr. Engr. 7: 54-55.

U.S. Geological Survey. 1970-1979. Water resources data for Iowa - annual report. Part 1. Surface water records. U.S. Geological Survey, Iowa City, Iowa.

Upper Mississippi River Basin Coordinating Committee. 1970. Upper Mississippi River Comprehensive Basin Study, Appendix G: Fluvial Sediment. U.S. Army Engineer District, Rock Island, Illinois.

Vanoni, V. A. (ed.) 1975. Sedimentation Engineering. Manual of Engr. Practice No. 54. Am. Soc. Civil Engr., New York, New York.

Waite, P. J. 1970. Iowa Precipitation. Water Resources of Iowa, University Printing Service, Iowa City, Iowa.

Walling, D. E. 1977. Assessing the accuracy of suspended sediment rating curves for a small basin. Waster Resour. Res. 13:531-538.

Walter, N. F., G. R. Hallberg, and T. E. Fenton. 1978. Particle-size analysis by the Iowa State University Soil Survey Laboratory. In G. R. Hallberg (ed.). Standard Procedures for Evaluation of Quaternary Materials in Iowa. Iowa Geol. Survey, Tech. Info. Series No. 8.

Wiitala, S. W. 1970. Surface water resources of Iowa. Water Resources of Iowa, University Printing Service, Iowa City, Iowa.

Wischmeier, W. H. and D. D. Smith. 1978. Predicting rainfall erosion losses: a guide to conservation planning. Agricultural Handbook No. 537. U.S.D.A., Washington, D.C.

ACKNOWLEDGEMENTS

The author wishes to thank Central Iowa Energy Cooperative, and the Iowa State University Graduate College for the financial support to carry out this study.

Dr. Robert Lohnes is gratefully acknowledged for his guidance and counsel in serving as major professor.

Special thanks are due Oscar Lara, Al Heinitz, and Bill Matthes, of the U.S. Geological Survey in Iowa City, for data acquisition and interpretation of much of the data.

Thanks are due to Bryant Berg and Pete Julstrom, fellow graduate students, who helped with many portions of the field work. Bob Carson's help in the laboratory analysis of the sediment is greatly appreciated.

To my wife, Ruth, whose love, patience, encouragement, and continual support made this possible, the greatest of appreciation is extended.

APPENDIX A:

PLOTS OF CROSS SECTIONS OF RANGES

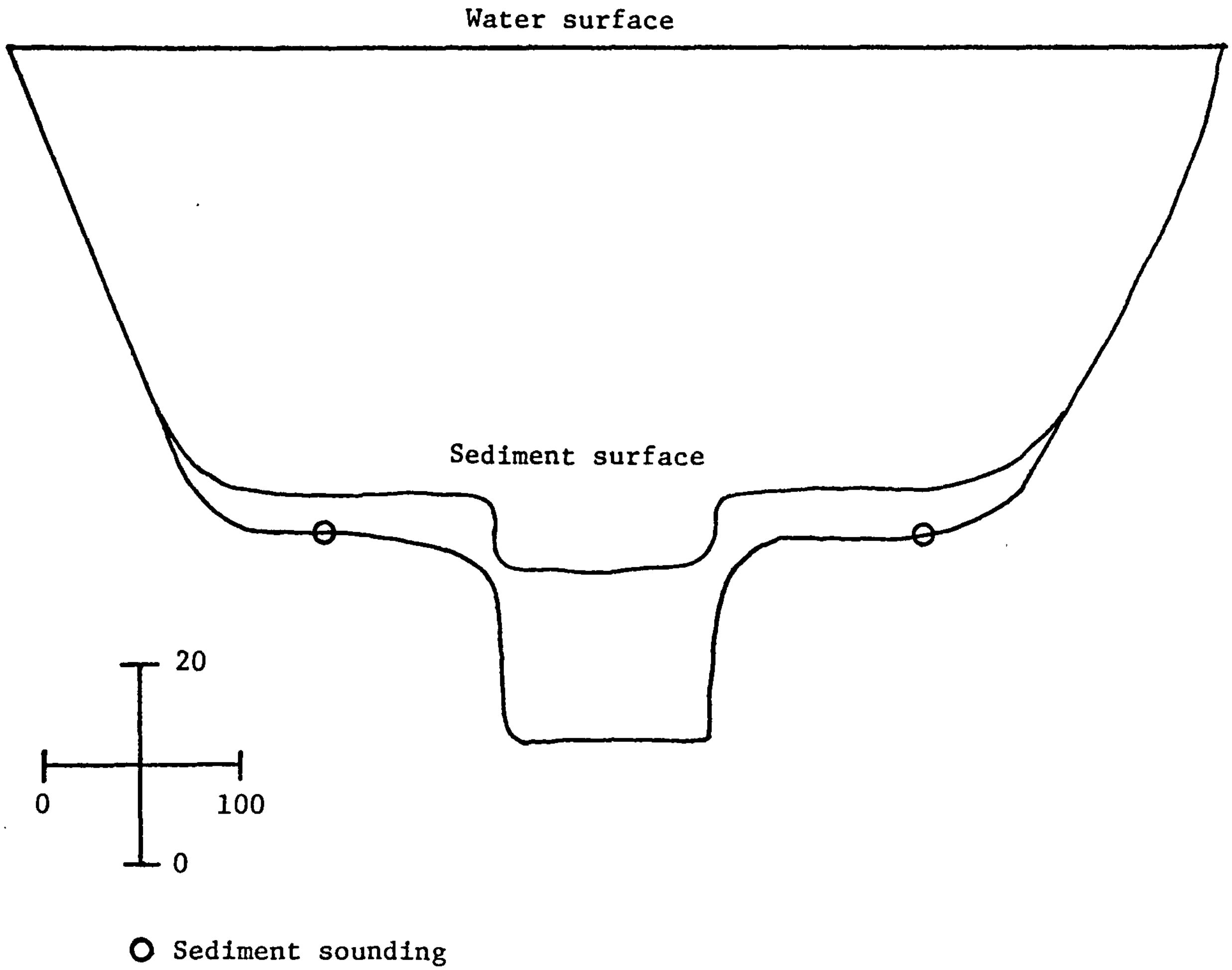


Figure 9. Cross section of range 1.83

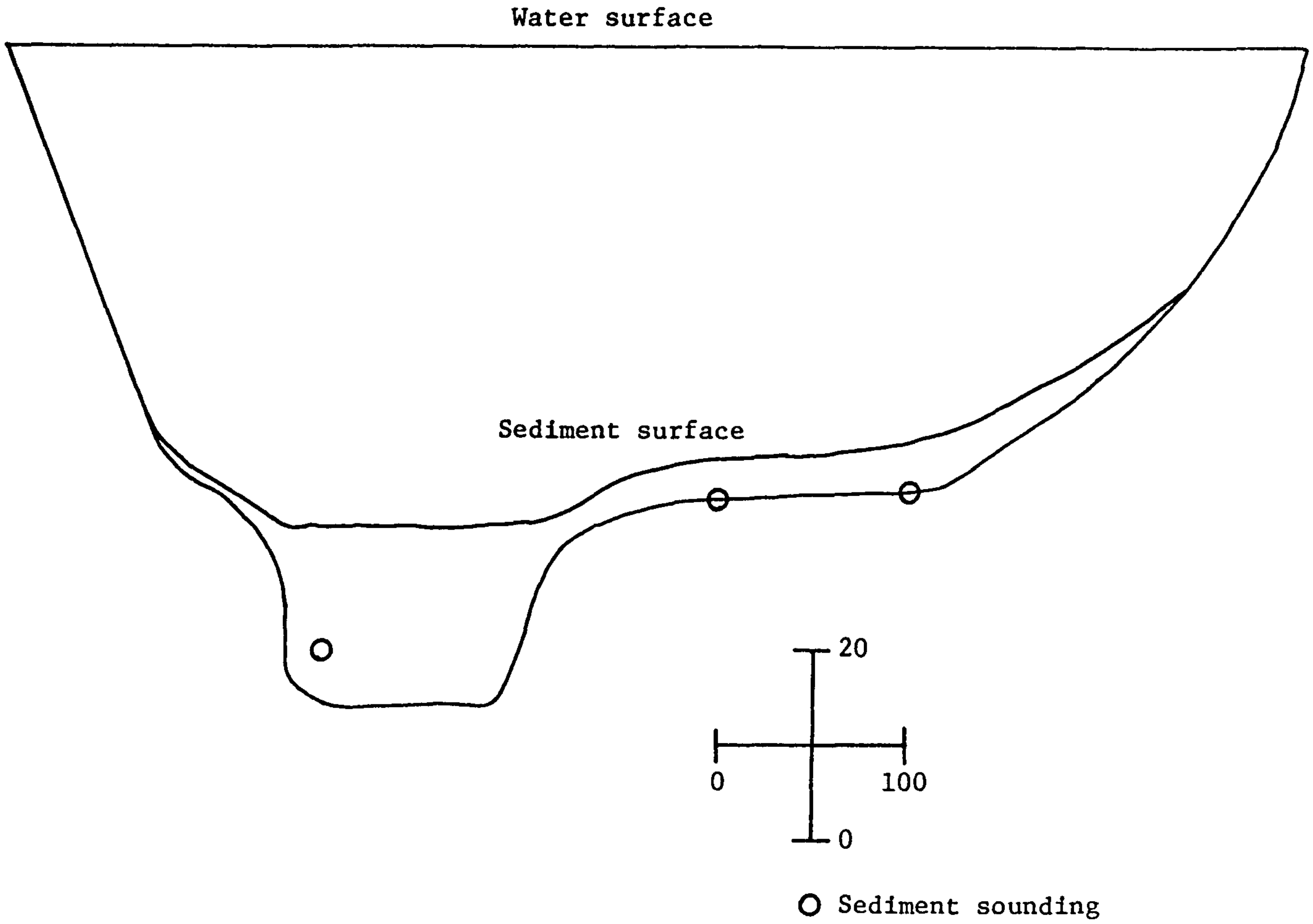


Figure 10. Cross section of range 2.29

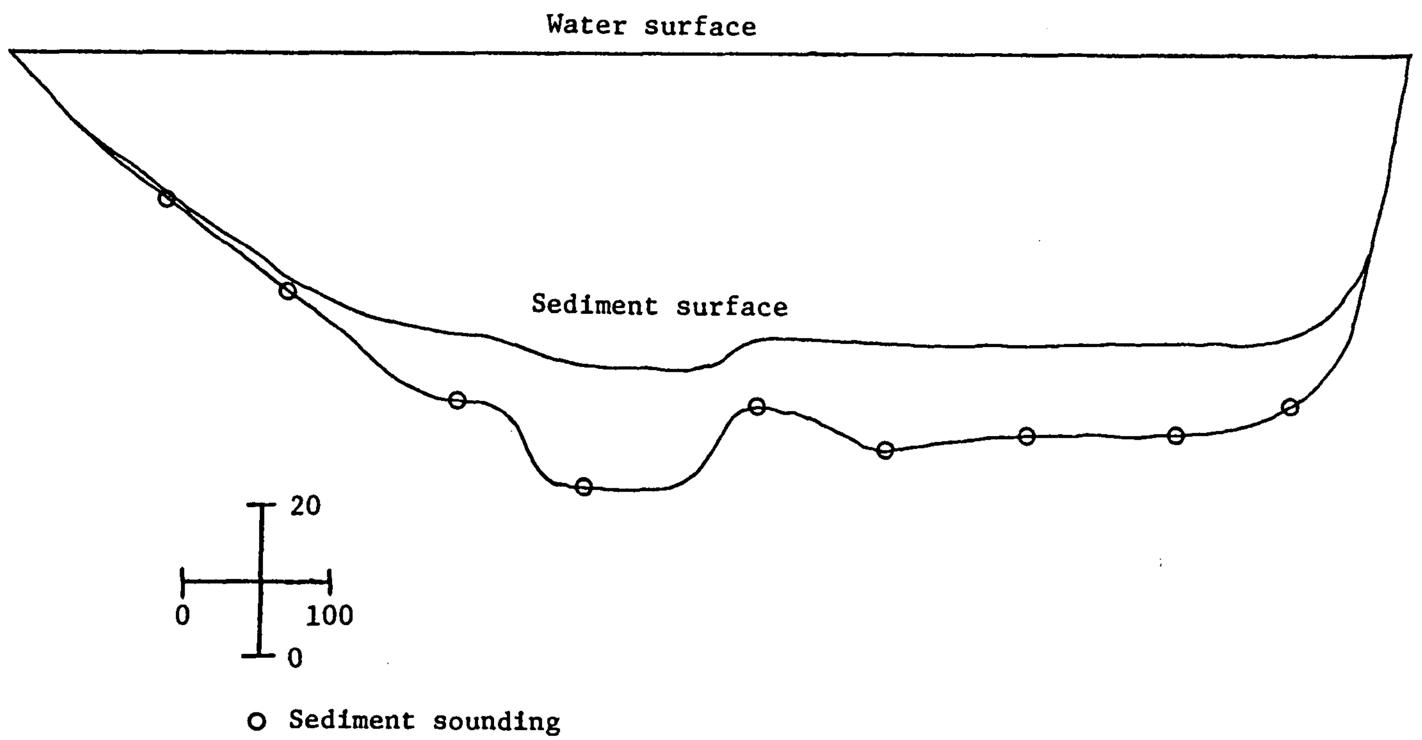


Figure 11. Cross section of range 2.95

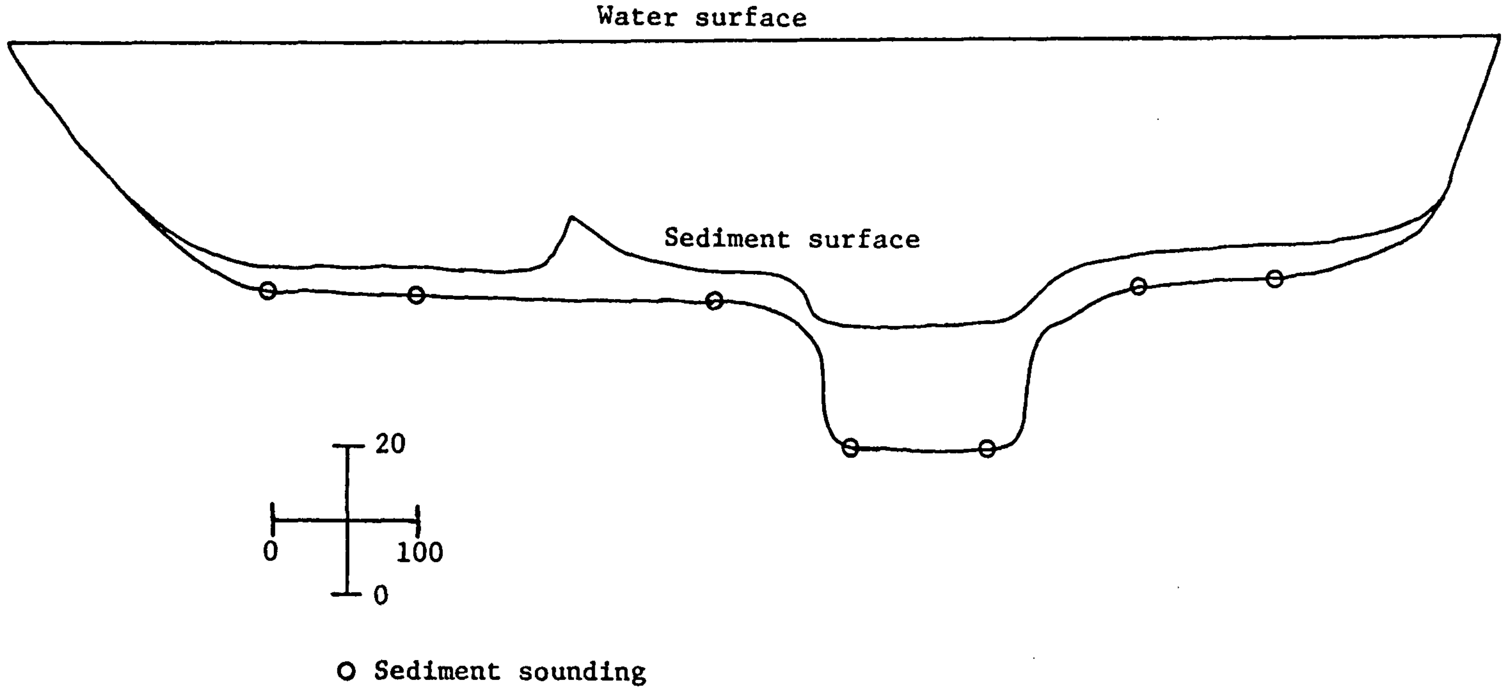


Figure 12. Cross section of range 3.47

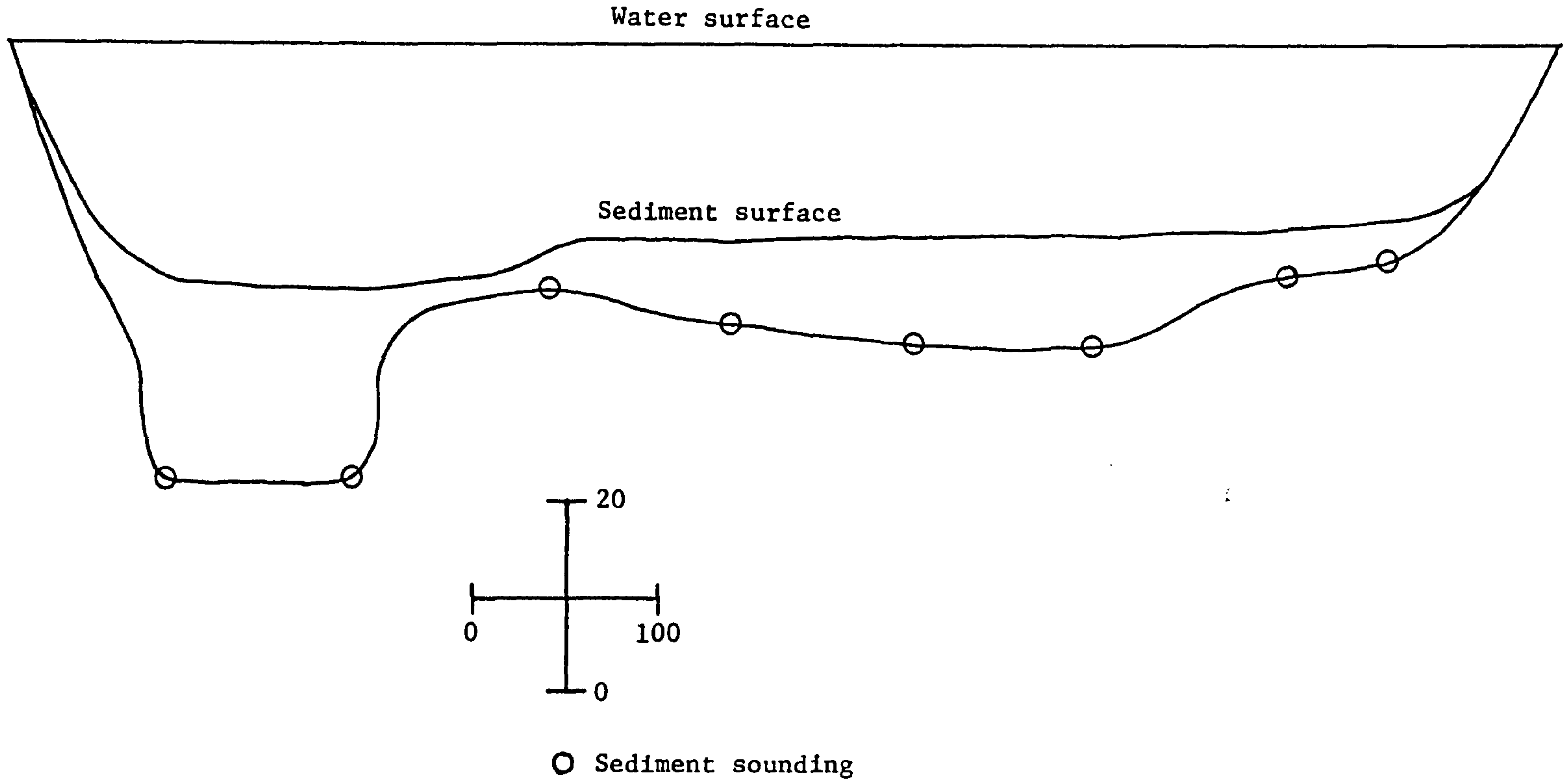


Figure 13. Cross section of range 4.00

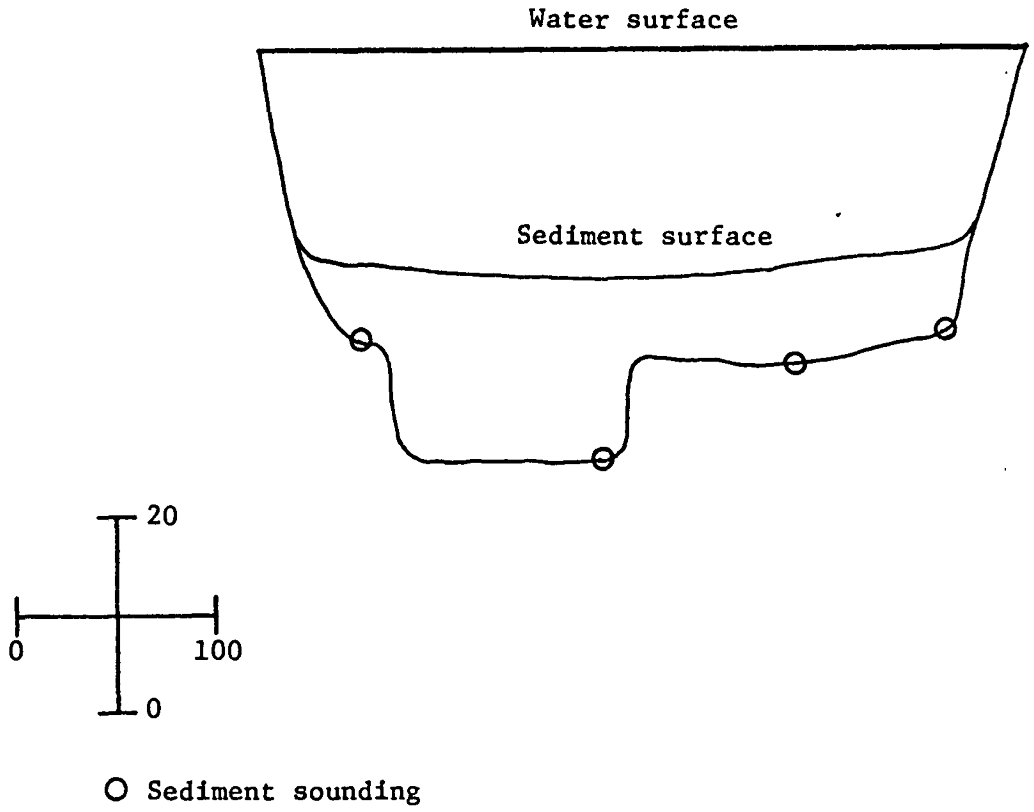


Figure 14. Cross section of range 4.30

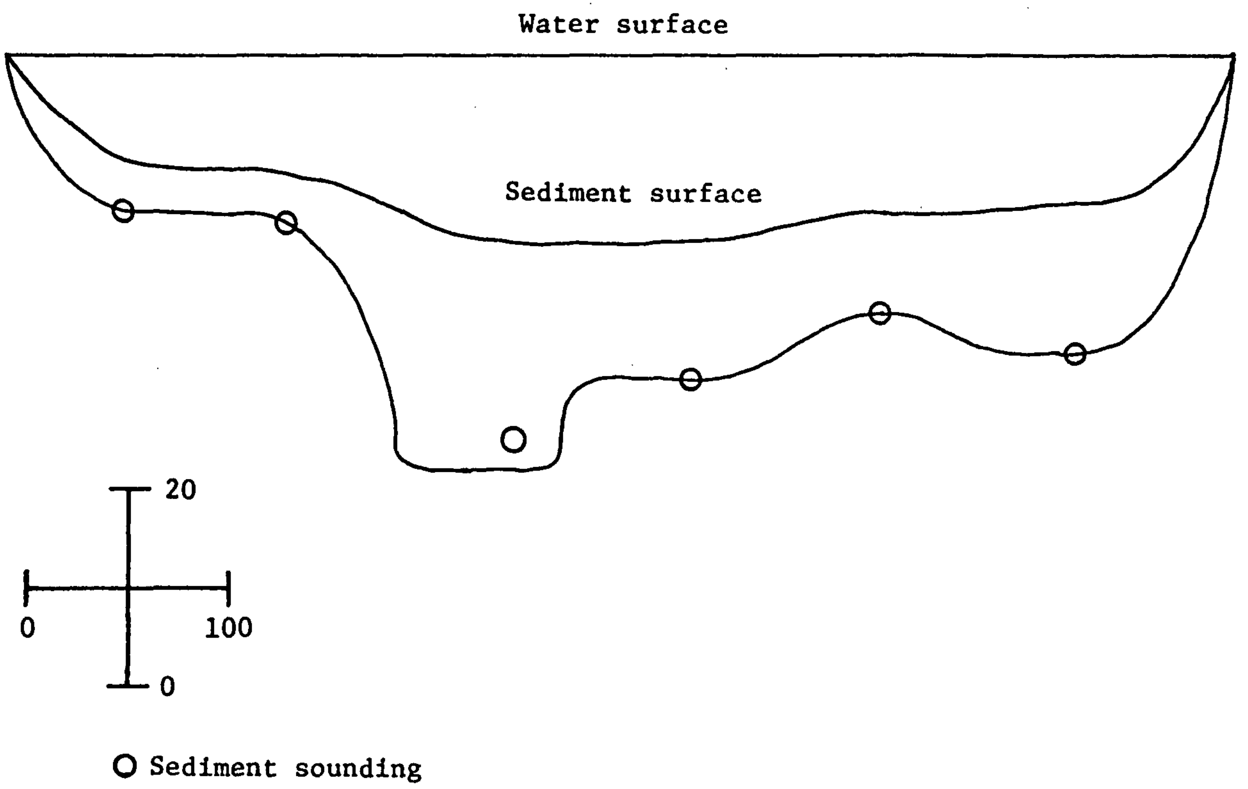


Figure 15. Cross section of range 4.73

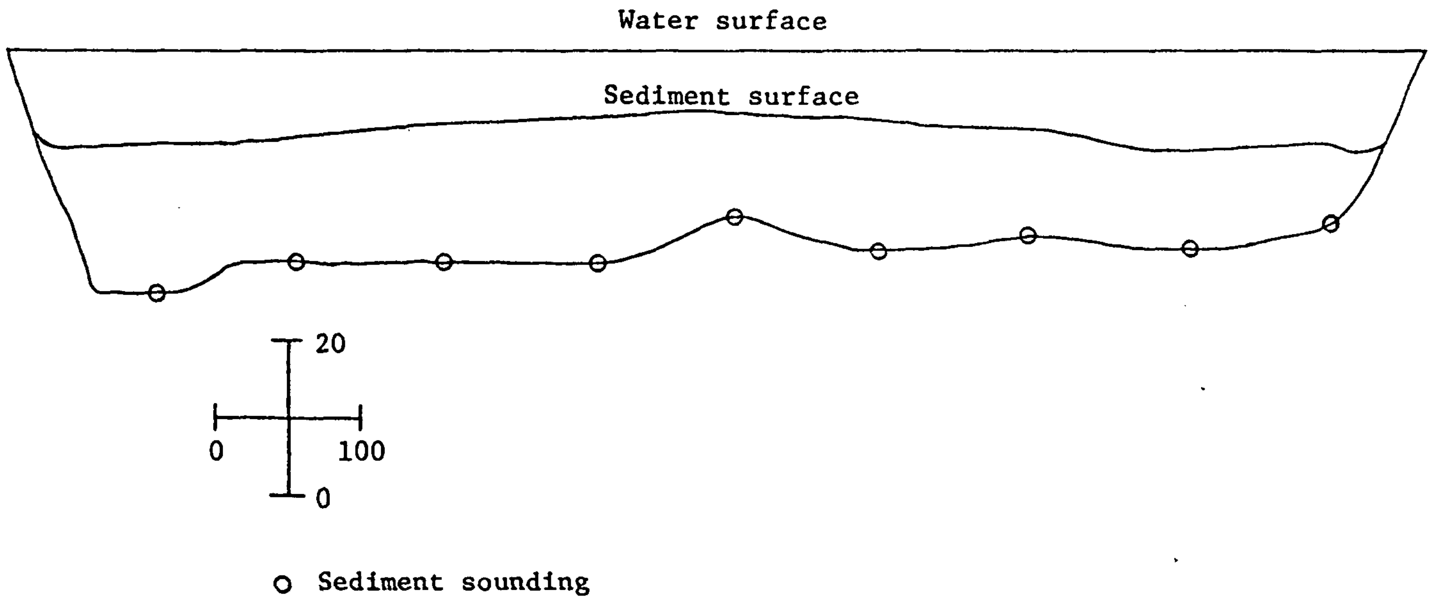


Figure 16. Cross section of range 5.10

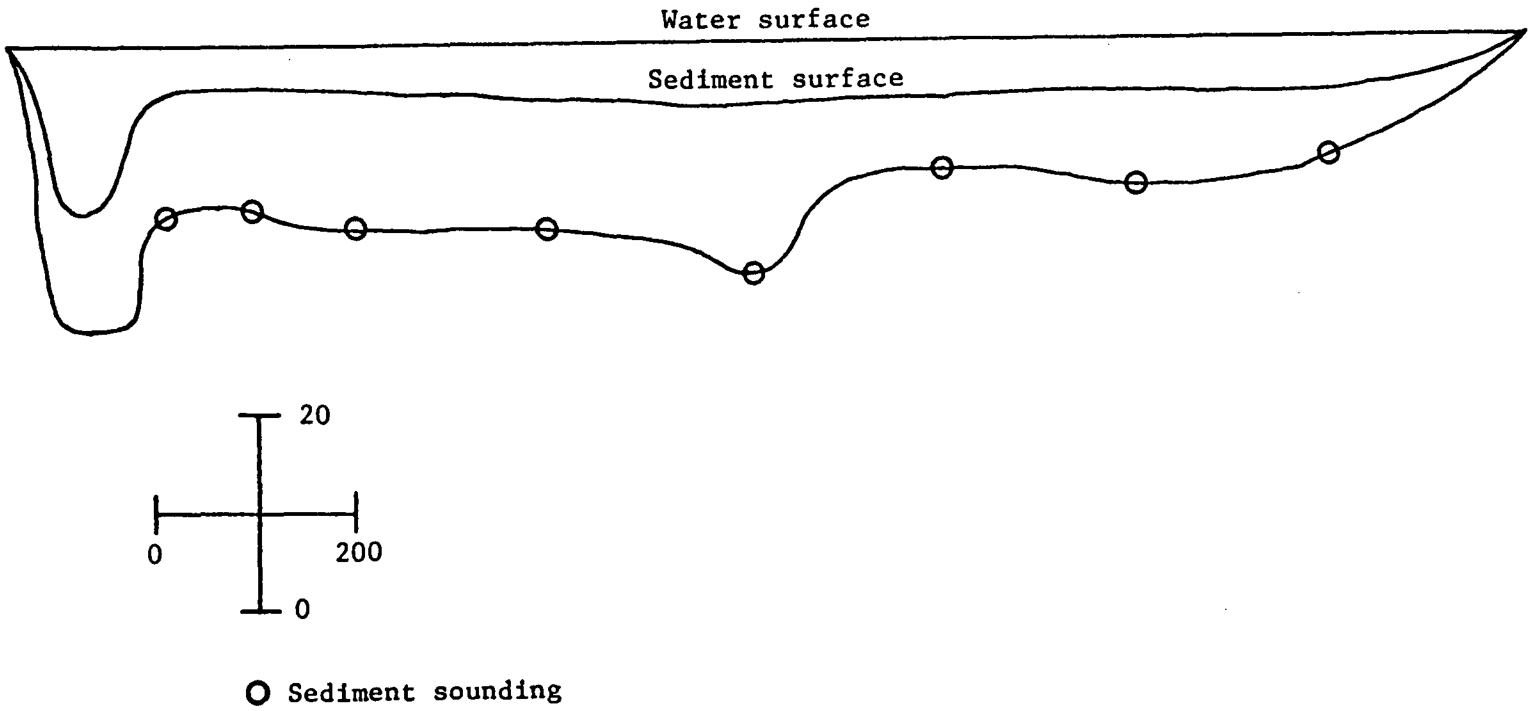


Figure 17. Cross section of range 5.33

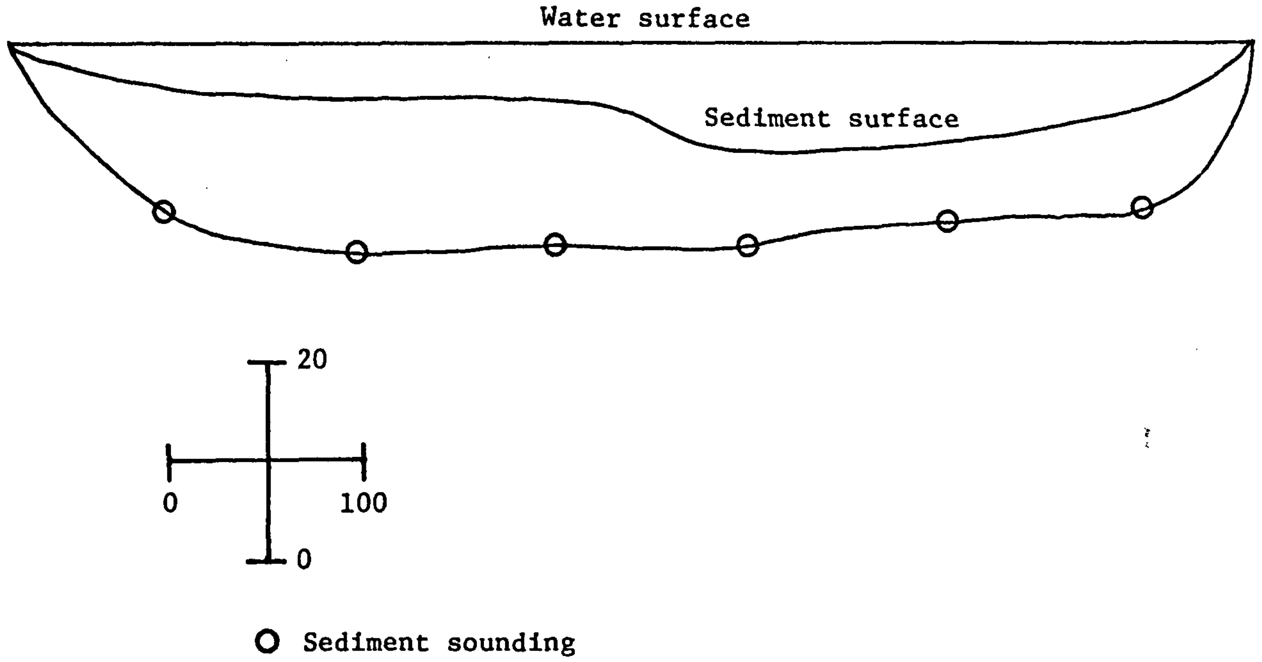


Figure 18. Cross section of range 5.64

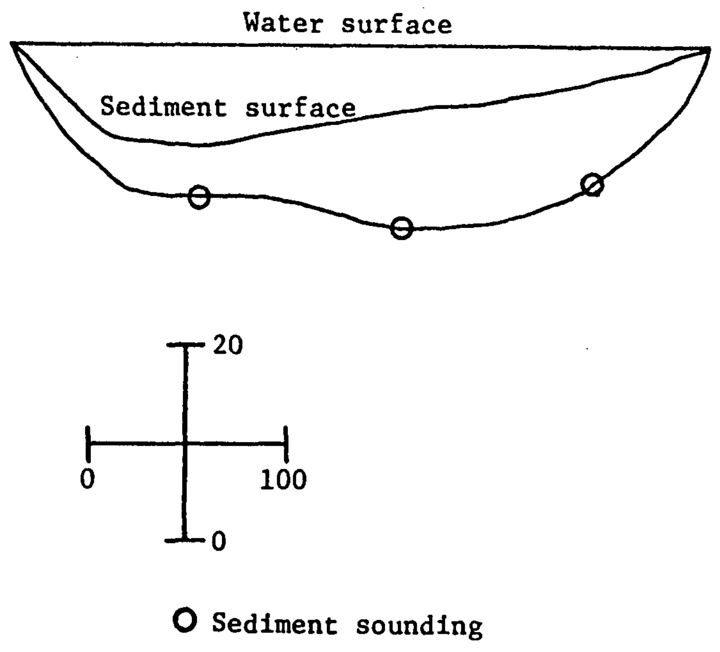


Figure 19. Cross section of range 6.27

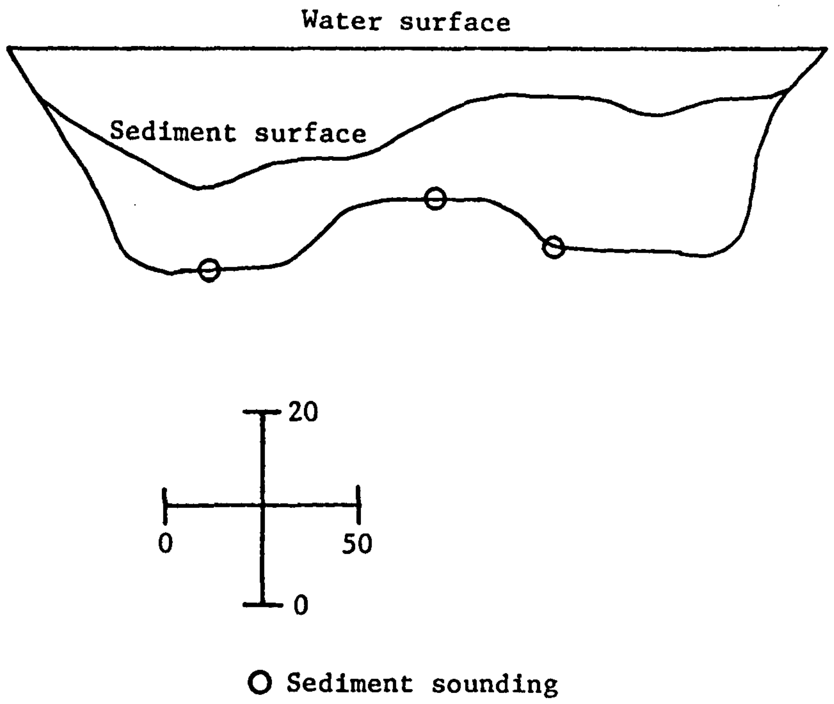


Figure 20. Cross section of range 6.80

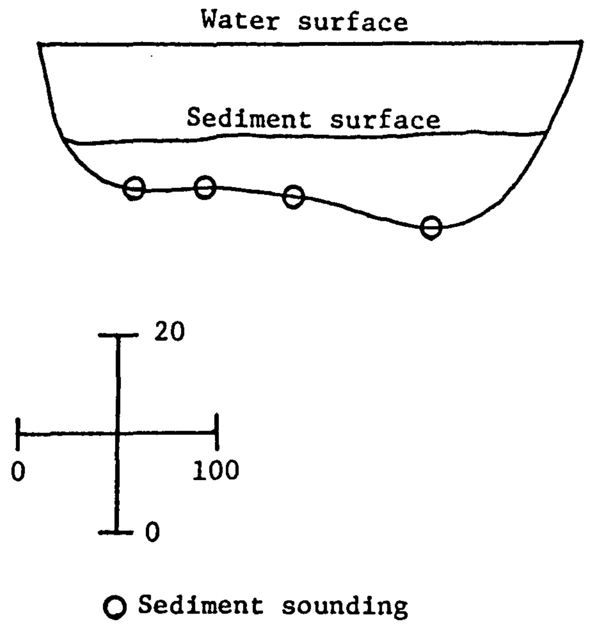


Figure 21. Cross section of range WC

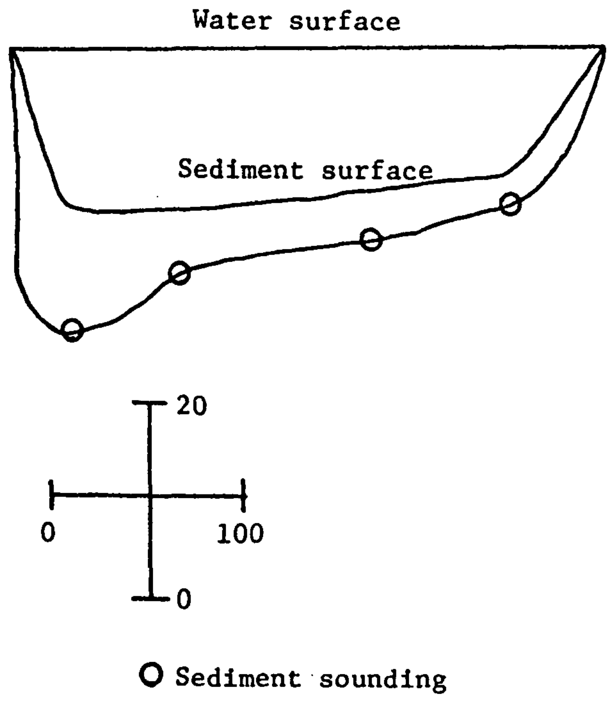


Figure 22. Cross section of range NCA

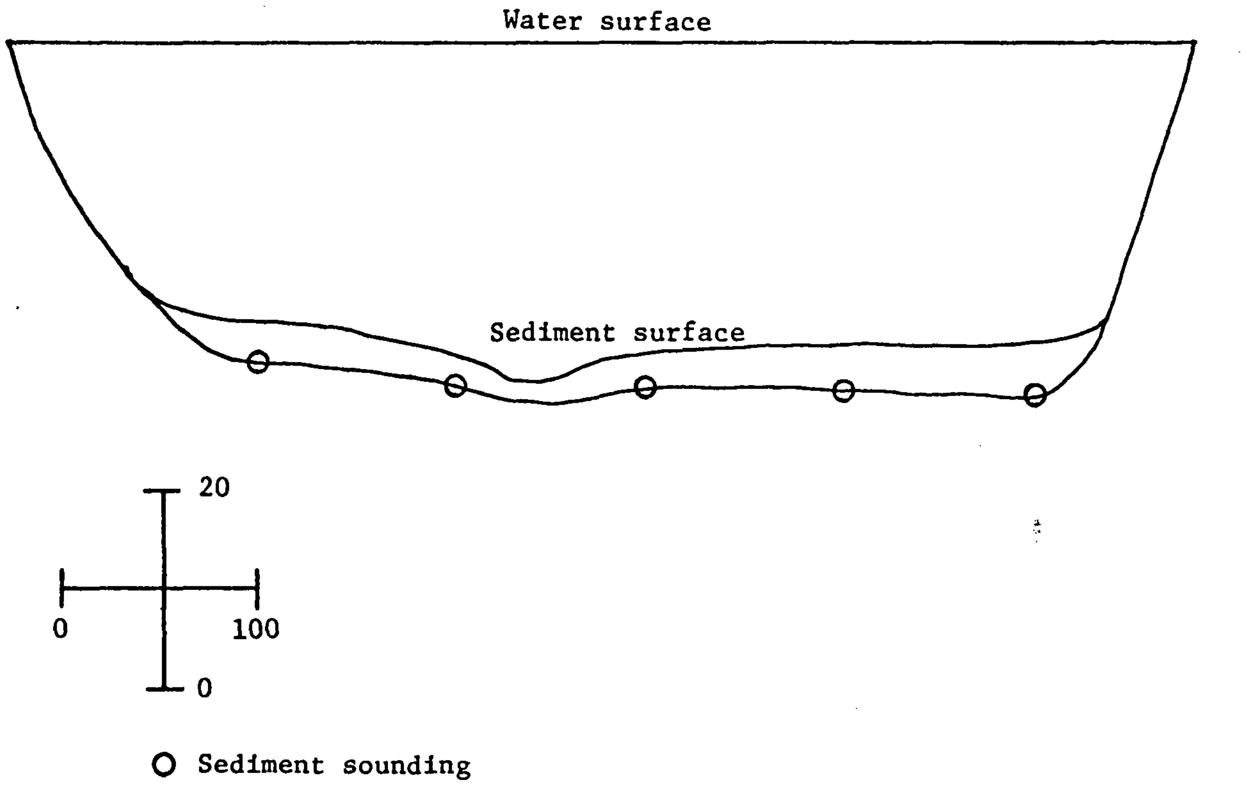


Figure 23. Cross section of range NCB

APPENDIX B:

SEDIMENT PROPERTY DATA

Range	Sample station	Particle size, percent passing					LL	PL	PI	Organic content %
		# 200 sieve	31μ	16μ	4μ	2μ				
R1.37	300	99.9	97.0	90.7	72.5	61.0	76.2	42.1	34.1	
	400	99.9	96.8	92.1	77.8	68.2	76.4	43.8	32.6	
R1.83	500	98.8	92.3	81.7	63.2	56.0	66.7	33.2	33.5	13.1
	200	99.7	98.5	93.6	74.9	67.9	76.2	50.7	25.5	
R2.29	400	99.3	89.8	74.4	54.3	47.6	63.4	34.0	29.4	10.0
R2.95	400	99.9	99.7	94.1	76.2	66.4	77.0	45.2	31.8	
	700	99.9		97.6	84.5	73.0	76.6	56.2	20.4	
R3.47	200	94.3	85.8	69.0	52.7	35.3	52.5	42.4	10.3	7.0
	900						57.0	29.0	28.0	6.5
R4.00	200	99.9	97.6	88.2	64.6	56.6	28.8	42.6	36.2	
	500						49.5	32.1	17.4	
R4.30	300	99.3	89.8	74.0	52.3	45.5	59.8	38.9	20.9	
	200	99.9	98.3	85.4	63.1	54.9	68.7	46.0	22.7	
R4.73	200	94.0	79.6	56.2	44.9	31.7	44.8	34.8	10.0	7.5
R5.10	70	36.0	28.2	18.5	12.0	11.2		too sandy		1.7
	400	93.1	77.7	57.7	38.1	33.9	49.3	28.3	21.0	7.95
R5.33	600	98.7	81.4	60.0	32.4	23.6	52.0	33.3	18.7	
R5.64	200	99.7	94.9	78.3	52.9	43.9	57.7	34.2	23.5	7.01
	400	99.2	88.5	67.6	44.8	37.7	48.3	27.6	20.7	9.7
	600	98.3	86.0	68.1	45.4	39.7	51.0	33.3	17.7	8.8
R6.27	100	37.3	31.5		28.4	22.2	24.0	20.3	3.7	
	200	97.8	85.3	66.6	43.6	34.2	48.5	34.5	14.0	8.1

Range	Sample station	# 200 sieve	Particle size, percent passing 31µ	16µ	4µ	2µ	LL	PL	PI	Organic content %
R6.80	110	18.8	9.6	7.0	5.0	4.2		too sandy		
	150	52.2	43.1	31.9	21.1	18.4	26.2	19.7	6.5	3.2
NCA	100	74.9	62.9	48.9	29.2	25.1	41.6	25.4	16.2	4.7
	200	95.6	79.4	57.2	31.7	24.0	44.4	29.0	15.4	10.8
	275	68.6	55.7	39.4	25.6	20.8	38.8	31.8	7.0	
NCB	200	96.6	85.4	76.8	55.0	47.4	63.3	36.0	27.3	10.4
	300	92.5	81.5	69.8	48.0	41.0	56.0	33.2	22.8	
	400	99.9	93.8	83.7	60.5	52.1	64.3	39.0	25.3	9.6
	500	97.6	89.7	79.9	58.2	49.3	66.3	35.6	30.7	7.6
WC	70	90.5	68.6	47.6	30.5	20.9	34.0	36.6	7.4	
	110	93.3	73.7	44.3	30.3	23.6	35.8	29.4	6.4	
	160	76.4	63.5	42.5	27.8	21.0				3.6
	220	89.2	74.4	48.3	29.9	21.7	38.5	29.4	9.1	4.1

APPENDIX C:

EQUATIONS AND RESULTS OF EMPIRICAL UNIT WEIGHT ANALYSES

Equations used to estimate the initial unit weight of sediment:

Source	Equation
Lane and Koelzer Type I reservoir	$W_1 = 30\ pc + 65\ pm + 93\ ps$
Lane and Koelzer Type II reservoir	$W_1 = 46\ pc + 74\ pm + 93\ ps$
Trask Type I reservoir	$W_1 = 13\ pc + 67\ pm + 88\ ps$
Lara and Pemberton Type I reservoir	$W_1 = 26.1\ pc + 70.2\ pm + 105.8\ ps$
Lara and Pemberton Type II reservoir	$W_1 = 27.3\ pc + 71.4\ pm + 95.8\ ps$

where pc = percent clay

pm = percent silt

ps = percent sand

Equation and k factors for use in calculating consolidation effects:

General equation: $W_{ave} = W_1 + 0.4343k[\frac{T}{T-1}(\ln T) - 1]$

where W_{ave} = average unit weight after T years

W_1 = initial unit weight

T = number of years since impoundment

k = factor relating consolidation

For Type I reservoir:

$k = 16.0\ (pc) + 5.7\ (pm)$

For Type II reservoir:

$k = 10.7\ (pc) + 2.7\ (pm)$

Unit weights by Lane and Koelzer Type I equation

Range	Station	γ_{initial}	$\gamma_{\text{10 years}}$
1.37	300	39.0	48.1
	400	37.2	46.6
1.83	200	37.7	47.0
	500	43.1	51.4
2.29	400	45.9	53.6
2.95	400	39.8	49.2
	700	34.2	44.2
3.47	200	43.5	50.8
	500	49.0	56.2
4.00	200	39.7	48.6
4.30	200	42.3	50.7
	300	46.9	54.4
4.73	200	52.3	58.9

Unit weights by Lane and Koelzer Type II equation

Range	Station	γ_{initial}	$\gamma_{10 \text{ years}}$
5.10	70	82.9	84.2
	400	64.8	68.6
5.33	600	64.7	68.4
5.64	200	58.4	63.3
	400	61.8	66.1
	600	61.9	66.2
6.27	100	79.3	81.3
	200	64.2	68.0
6.80	100	81.7	83.3
	150	77.7	79.8
NCA	100	70.9	73.9
	200	66.6	70.1
	275	73.6	76.2
NCB	200	68.6	73.4
	300	72.4	76.7
	400	69.6	74.7
	500	69.8	74.8
WC	70	69.8	72.7
	110	69.6	72.5
	160	72.4	75.3
	220	68.6	71.5

Unit weights by Lara and Pemberton Type I equation

Range	Station	$\gamma_{initial}$	$\gamma_{10\ years}$
1.37	300	38.4	47.3
	400	36.2	45.4
1.83	200	37.1	46.2
	500	42.8	51.0
2.29	400	46.7	54.3
2.95	400	36.2	45.4
	700	32.7	42.5
3.47	200	49.4	56.6
	500	51.4	58.3
4.00	200	41.5	49.9
4.30	200	42.4	50.6
	300	47.5	55.0
4.73	200	52.8	59.5

Unit weights by Lara and Pemberton Type II equation

Range	Station	$\gamma_{initial}$	$\gamma_{10\ years}$
5.10	70	81.7	83.0
	400	56.6	60.3
5.33	600	57.3	60.9
5.64	200	47.8	52.5
	400	52.0	56.2
	600	52.3	56.5
6.27	100	76.2	78.2
	200	62.8	66.8
6.80	110	76.9	78.6
	150	73.9	76.0
NCA	100	65.2	68.1
	200	59.0	62.4
	275	67.7	70.3
NCB	200	48.4	53.1
	300	52.2	56.5
	400	45.2	50.2
	500	46.4	51.3
WC	70	63.7	66.6
	110	62.3	65.3
	160	67.4	70.0
	220	63.7	66.6